LOUIS PASTEUR
Founder of Bacteriology

Cyclopedia
of
Heating, Plumbing and Sanitation

A Complete Reference Work

ON PLUMBING, GAS FITTING, SEWERS AND DRAINS, HEATING AND VENTILATING, STEAM FITTING, CHEMISTRY, BACTERIOLOGY AND SANITATION, HYDRAULICS, WATER SUPPLY, ELECTRIC WIRING, MECHANICAL DRAWING, SHEET METAL WORK, ETC.

Prepared by a Corps of

SANITARY EXPERTS, CONSULTING ENGINEERS, AND SPECIALISTS OF THE HIGHEST PROFESSIONAL STANDING

Illustrated with over One Thousand Engravings

FOUR VOLUMES

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THE editors have freely consulted the standard technical literature of America and Europe in the preparation of these volumes. They desire to express their indebtedness, particularly, to the following eminent authorities, whose well-known treatises should be in the library of everyone interested in Sanitary Engineering.

Grateful acknowledgment is here made also for the invaluable co-operation of the foremost Engineering Firms and Manufacturers in making these volumes thoroughly representative of the latest and best practice in every branch of the broad field of Heating, Plumbing, and Sanitation; also for the valuable drawings, data, suggestions, criticisms, and other courtesies.

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LAKEVIEW INTAKE CRIB OF THE WATERWORKS SYSTEM OF CHICAGO, ILLINOIS

Foreword

THE widespread need for a more scientific knowledge of the principles of Sanitation on the part of thousands of practical men of limited education, calls for an authoritative work of general reference embodying the results of modern experience and the latest approved practice. The Cyclopedia of Heating, Plumbing, and Sanitation is designed to fill this acknowledged need.

¶ The Cyclopedia of Heating, Plumbing, and Sanitation is based upon the method which the American School of Correspondence has developed and successfully used for many years in teaching the principles and practice of engineering in its different branches. It is a compilation of representative Instruction Books of the School, and forms a simple, practical, concise, and convenient reference work for the shop, the library, the school, and the home.

¶ The success which the American School of Correspondence has attained as a factor in the machinery of modern technical and scientific education, is in itself the best possible guarantee for the present work. Therefore, while these volumes are a marked innovation in technical literature—representing, as they do, the best ideas and methods of a large number of *different* authors, each an acknowledged authority in his work—they are by no means an experiment, but are in fact based on what has proved itself to be the most successful method yet devised for the education of the busy workingman. They have been prepared only after the most careful study of modern needs as developed under the conditions of actual practice.

¶ Neither pains nor expense have been spared to make the present work the most comprehensive and authoritative in its field. The aim has been, not merely to create a work which will appeal to the trained expert, but one that will commend itself also to the beginner and the self-taught, practical man by giving him a working knowledge of the principles and methods, not only of his own particular trade, but of all allied branches of it as well. The various sections have been prepared especially for home study, each written by an acknowledged authority on the subject. The arrangement of matter is such as to carry the student forward by easy stages. Series of review questions are inserted in each volume, enabling the reader to test his knowledge and make it a permanent possession. The illustrations have been selected with unusual care to elucidate the text.

¶ Grateful acknowledgment is due the corps of authors and collaborators—men of wide practical experience, and teachers of well-recognized ability—without whose hearty co-operation this work would have been impossible.

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† For professional standing of authors, see list of Authors and Collaborators at front of volume.

ILLUSTRATING WEIR METHOD OF MEASURING FLOW OF WATER IN SMALL STREAMS

HYDRAULICS.

1. Hydraulics is that branch of Mechanics which treats of the laws governing the pressure and motion of water. *Hydrostatics* is that particular branch of hydraulics which treats of water at rest, and *hydrodynamics* is that branch which treats of water in motion.

2. Units of Measure. The unit of length most frequently used in hydraulics is the foot. The unit of volume is the cubic foot or the United States gallon. The unit of time usually employed in hydraulic formulas is the second, but in many water-supply problems the minute, the hour, and the day are also often used. The unit of weight is the pound, and that of energy the foot-pound.

1 U. S. gallon = 231 cubic inches = 0.1337 cubic foot;

1 cubic foot = 7.481 U. S. gallons;

1.2 U. S. gallons = 1 Imperial gallon.

3. Weight of Water. The weight of distilled water at different temperatures is given in Table No. 1.

The weight of ordinary water is greater than that of distilled water on account of the impurities contained. For ordinary purposes the weight of a cubic foot of fresh water may be taken equal to 62.5 pounds. Sea water will weigh about 64 pounds per cubic foot.

TABLE NO. 1.

Weight of Distilled Water.

Temperature, Fahrenheit.	Weight, Pounds per Cubic Foot.	Temperature, Fahrenheit.	Weight, Pounds per Cubic Foot.
32	62.42	140°	61.39
39.3	62.424	160	61.01
60	62.37	180	60.59
80	62.22	200	60.14
100	62.00	212	59.84
120	61.72		

As will be seen from this table, water is heaviest at a temperature of about 39.3° F., or as is commonly stated, about 40° F.

If a is the area of the piston P and A that of the piston W, then the pressure per square inch produced by the weight P will be $\frac{P}{a}$. This will also be the pressure per square inch on W, and

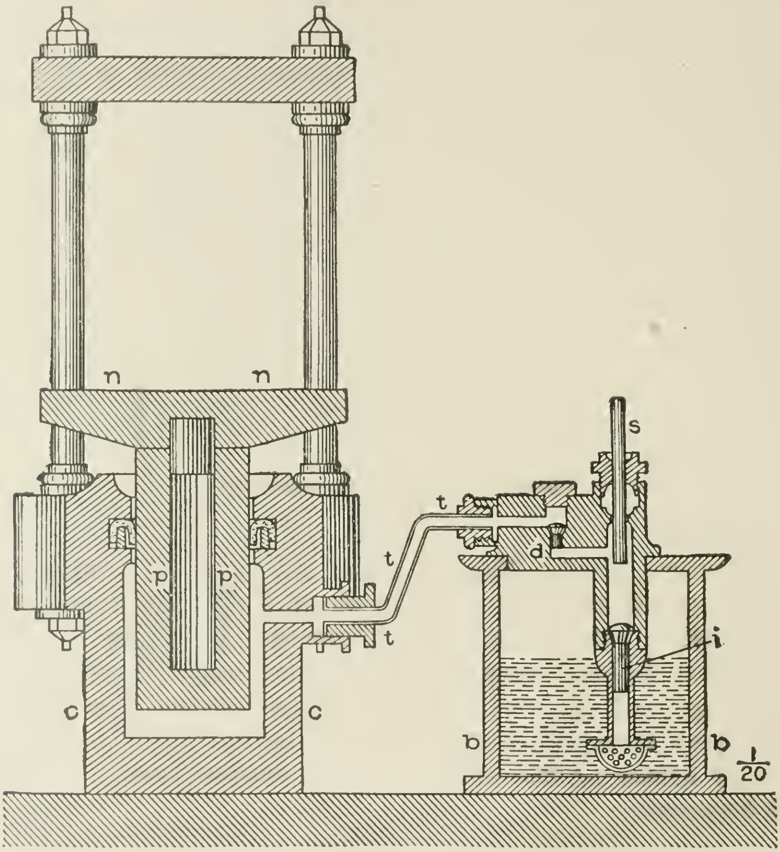


Fig. 3.

hence the weight W which will be sustained will be equal to the area A multiplied by the pressure per square inch, $\frac{P}{a}$, or

$$W = A\frac{P}{a}. \qquad (1)$$

The principle above stated is utilized in the hydraulic press shown in Fig. 3. In this apparatus a pump on the right with small plunger feeds a large plunger p underneath the movable plate of the press on the left. The pump plunger corresponds to the piston P in Fig. 2, and the press to the piston W. By making the pump very small and the plunger under the press very large, enormous pressures can be exerted even by means of a hand pump. The pressure produced is given by formula (1) above. It is to be noted that the pressure per square inch on the interior of the apparatus, the pump, piping and press, is the same at all points.

Examples. 1. If the area of the pump plunger be 2 sq. in. and that of the press 1 sq. ft., what pressure will be exerted by the press when the load on the pump is 100 lb.?

Using equation 1 we have $a = 2$ sq. in., $A = 144$ sq. in., and $P = 100$ lb., whence $W = 144 \times \frac{100}{2} = 7{,}200$ lb. Ans.

2. If a pressure of 10 tons be desired and the area of the press plunger be 200 sq. in., and the available pressure on the pump plunger be 150 lb., what area must be given to the pump plunger?

Here $W = 10 \times 2{,}000 = 20{,}000$ lb., $A = 200$ and $P = 150$. Using equation 1 and letting x = desired area, we have $20{,}000 = \frac{200 \times 150}{x}$. Solving for x we have $x = \frac{200 \times 150}{20{,}000}$
$= 1.5$ sq. in. Ans.

6. Pressure Due to the Weight of Water. Let Fig. 4 represent a vessel of water. Consider a vertical column of the water of height h and a cross-section of one square foot. Its volume will be h cubic feet and it will weigh $62.5 \times h$ pounds. As it is supported entirely by the water underneath, it therefore exerts a pressure upon that water of $62.5 \times h$ pounds. Likewise the pressure at any other point in the vessel at a distance h below the surface is $62.5 \times h$ pounds per square foot. Furthermore, since the water exerts equal pressures in all directions it follows that the pressure against the sides of the vessel at this depth, or against any object immersed in the water, will also be $62.5 \times h$ pounds per square foot.

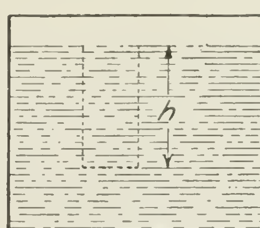


Fig. 4.

Consider now the pressure on one of the sides, as BC. In this case the pressure per square inch is not uniform, varying from nothing at B to a maximum at C where it is equal to $h_1 \times .434$ pounds per square inch, the same as on the bottom. At any depth h the pressure is $h \times .434$ pounds per square inch. This variation in pressure is represented in Fig. 6 by the variation in length of the arrows acting against BC. From an inspection of the figure it is evident that the average length of these arrows is equal to one-half the length of the one at the bottom, or in other words, the *average* pressure per square inch against BC is equal to one-half the maximum, or $\frac{1}{2} h_1 \times .434$, which is the same as the pressure at the center of BC. The *total* pressure on the entire surface is then equal to this average pressure multiplied by the total area, or equal to $\frac{1}{2} h_1 \times .434 \times h_1 d$.

If the area in question be a plate B′C′ immersed in the water to a depth h_2 the result is the same, except in this case there is an equal pressure on each side. As before, the pressure on either side of the plate is equal to $\frac{1}{2} h_2 \times .434 \times$ (area of submerged portion of plate).

If the plate be wholly submerged, as BC, Fig. 7, the pressure per square inch at B will be $h_1 \times .434$, and that at C will be $h_2 \times .434$, and the variation in pressure will be represented by a trapezoid of arrows instead of a triangle. The average pressure will now be $\frac{h_1 + h_2}{2}$ which is again the same as the pressure at the center of BC. The total pressure will be this average pressure multiplied by the area of the plate.

In all the above cases it will be seen that the average pressure found is the same as the pressure at the center of the plate. In a similar way it can be shown that for plates of *any shape* the average pressure is equal to the pressure at the *center of gravity* of the area, hence the following:

Rule. *The total pressure on a submerged vertical plane surface is equal to the pressure per unit area at its center of gravity multiplied by its area.* (3)

Suppose now the plate BC, Fig. 8, be an inclined plate immersed in water. From the principles already explained the pressure per square inch will be the same at any given depth as if the plate were vertical. Hence at B the pressure is $h_1 \times .434$ and that at C is $h_2 \times .434$. The average pressure is again $\frac{h_1 + h_2}{2}$ $\times .434$, or the pressure at its center, and the total is equal to this pressure multiplied by the area of the plate. Whence the more general rule,—

Rule. *The total pressure on any submerged plane surface is equal to the pressure per unit area at its center of gravity multiplied by its area. Such pressure always acts at right angles to the surface.* (4)

8. Pressure in a Given Direction. In the above discussion we have considered only the total pressure of the water, which always acts perpendicular to the surface of the body. In Fig. 9 let P represent this total pressure on the surface BC, which has a

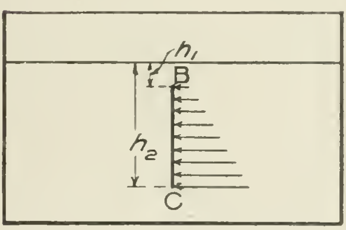


Fig. 7.

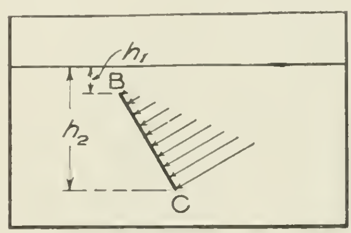


Fig. 8.

length l and a width d (its area equals ld). Suppose it is desired to find the horizontal and vertical components P_h and P_v of this pressure. Since P is perpendicular to BC the inclination of P from the horizontal is the same as that of BC from the vertical. Call this angle θ. From Mechanics we have at once, $P_h = P \cos \theta$ and $P_v = P \sin \theta$ From the foregoing articles we also have $P = h \times .434 \times ld$, in which h is the depth of the center of gravity of BC. Hence we have $P_h = P \cos \theta = .434\, h \times \cos \theta \times ld$, and $P_v = P \sin \theta = .434\, h \times \sin \theta \times ld$. From the figure we see that the area of the vertical projection of the plate BC $= m \times d = l \cos \theta \times d$, and the horizontal projection $= n \times d = l \sin \theta \times d$. Whence we have $P_h = .434\, h \times md$ and $P_v = .434$

10. Bursting Pressure in Pipes and Cylinders. Let BECD, Fig. 12, be the cross-section of any pipe of diameter d and length l and containing water under a head h. The figure shows the pipe connected to an open vessel with water standing at a height h above the center. This free surface of water may represent a reservoir at a height h above the pipe, or the pipe may be entirely closed and the pressure head h exerted upon the water by means of a force pump or a pumping engine. The pressure per square inch at the center of the pipe will be $h \times .434$ pounds. The pressure against the pipe BEDC will be perpendicular to the surface at all points, and if the diameter is small compared to the height h, this pressure will be practically the same at all points and equal to $h \times .434$ pounds per square inch.

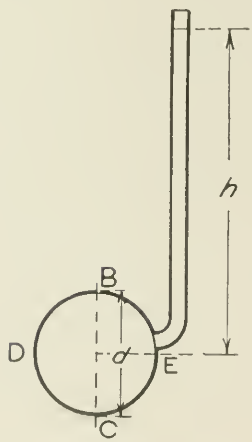


Fig. 12.

Suppose we wish to find the total horizontal force acting against the half BDC. By the foregoing article we may consider the pressure on its vertical projection BC. The center of gravity of this vertical projection will be at the center of the pipe and the pressure per square inch at that point will be $h \times .434$. The area of the projection BC is equal to $d \times l$. Hence the total horizontal pressure against BDC will equal $h \times .434 \times dl$. The pressure against the side BEC will be the same, but opposite in direction.

The action of the pressures on BDC and BEC tends to burst the pipe at points B and C. This is resisted by the stress in the pipe, the amount of which at each of these points is one-half the total horizontal pressure on BDC or BEC, or equal to $\frac{1}{2} h \times .434 \times dl$. If we consider a length of pipe of only one inch then $l = 1$ and we have the important formula for the bursting stress in a pipe:

$$S = \frac{1}{2} h \times .434 \times d \qquad (6)$$

in which S = stress per lineal inch of pipe

h = head of water in feet

and d = diameter of pipe in inches.

By expressing the pressure-head in pounds per square inch instead of feet head we have

$$S = \frac{pd}{2} \qquad (7)$$

in which p = pressure per square inch at center of pipe.

If t = thickness of pipe in inches and s = stress on the metal per square inch then

$$s = \frac{pd}{2t} \qquad (8)$$

For large pipes and low heads the stress at C will be a little larger than at B.

11. Longitudinal Stress in Closed Pipes and Cylinders. Let Fig. 13 represent a side view of a short pipe or cylinder, closed at

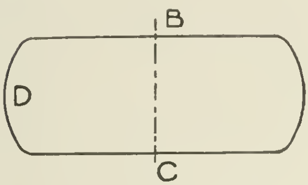


Fig. 13.

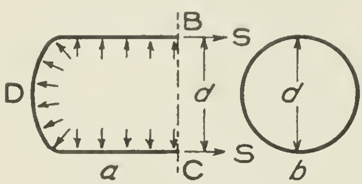


Fig. 14.

the ends like a steam boiler and containing water under a pressure p per square inch. Consider the portion to the left of a section BC. (See Fig. 14a.) The cross-section of the cylinder at BC will be a circle of diameter d on which there will be a stress S due to the horizontal water pressure on the end of the cylinder at D. This total horizontal pressure may be found as in the preceding article. It is equal to the average pressure p multiplied by the vertical projection of the area of the end. This projection, Fig. 14b, is equal to the area of the circle of diameter d, or to $\frac{1}{4}\pi d^2$. Hence the total horizontal force is $p \times \frac{1}{4}\pi d^2$, and hence

$$\text{Total stress} = p \times \tfrac{1}{4}\pi d^2.$$

This stress is distributed entirely around the circumference of the cylinder, or over a distance equal to πd. The stress per inch of circumference is then equal to

$$x = \frac{2}{3} l \frac{\frac{AB}{2} + AC}{AB + AC} \qquad (13)$$

13. Center of Pressure on Plane Areas of Any Form. The center of pressure of irregular plane areas can be found by the following rule, the demonstration of which is here omitted. Let BC, Fig. 15, represent a plane area of any form, then

The distance AF from the surface to the center of pressure is equal to the moment of inertia of the given area about an axis at A divided by the product of the area times the distance from A to its center of gravity. (14)

Examples. 1. What force S will be required to lift a sluice gate BC, Fig. 16, placed on the sloping face of a dam and hinged at B? The gate is 3 feet wide, 4 feet long from B to C, and has such a slope that the vertical projection BD = 3.5 ft., and the

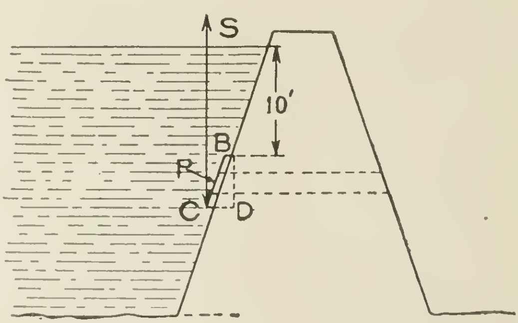


Fig. 16.

horizontal projection CD = 1.93 ft. The depth of B below the surface is 10 ft.

We will first find the total pressure P against the gate. By Art. 7 this will be the pressure per sq. in. at the center multiplied by the area. The depth of the center is $10 + \frac{1}{2}$ BD $= 10 + \frac{3.5}{2}$ = 11.75 feet. The pressure per sq. ft. = 11.75 × 62.5 = 734 lb. The total pressure = 734 × 3 × 4 = 8,808 lb.

AN ARTESIAN WELL SPOUTING

View taken in Australia, showing a typical example of the spouting bores which are transforming vast areas of that continent from parched desert into the richest and most fertile of pastoral and agricultural regions. Australia has long been known as the driest of all the continents; but it has recently been discovered that the rock strata underlying the greater part of the country are storage reservoirs of inexhaustible water supply. Strangely enough, Victoria, which is itself watered by fine rivers, is devoid of these sources of underground supply.

The center of pressure will be found next. This is at a distance from B given by formula 12, in which $h_1 = 10$ and $h_2 = 13.5$. We have then $x = \frac{2}{3} \times 4 \times \frac{\frac{10}{2} + 13.5}{10 + 13.5} = 2.1$ feet.

Now taking moments about B we have $S \times 1.93 = P \times 2.1$ or $S = 8{,}808 \times \frac{2.1}{1.93} = 9{,}590$ lb. Ans.

2. Find the water pressure on a gate AB, Fig. 17, one foot long, when the heads on the two sides are different; also find the reactions R_1 and R_2 of the gate against sills at A and B.

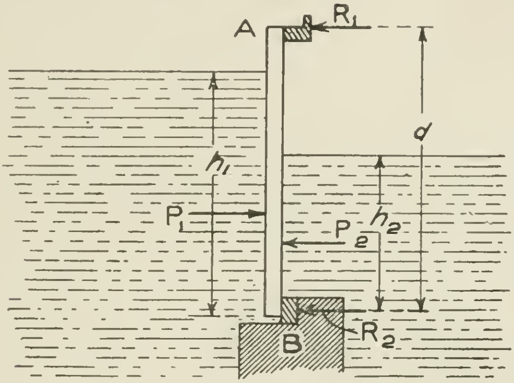


Fig. 17.

By Art. 7 the total pressure P_1 of the water on the left side of the gate is equal to the pressure at the half depth $\frac{h_1}{2}$ multiplied by its submerged area. Taking here the square foot as the unit and letting w = weight of a cubic foot of water, the pressure at a depth $\frac{h_1}{2}$ is $\frac{h_1}{2} \times w$ pounds per square foot, and as the exposed area is $h_1 \times 1$ the total pressure $P_1 = \frac{h_1}{2} \times w \times h_1 = \frac{1}{2} h_1^2 \times w$. The center of pressure, or point of application of P_1, is $\frac{2}{3} h_1$ below the surface (Art. 12).

In like manner the pressure $P_2 = \frac{1}{2} h_2^2 w$, and its point of application is $\frac{2}{3} h_2$ below the water surface on that side.

The forces P_1 and P_2 being known, the reaction R_1 may be found by taking moments about B as explained in Mechanics.

There results the equation

$$R_1 \times d - P_1 \frac{h_1}{3} + P_2 \frac{h_2}{3} = 0$$

whence

$$R_1 = \frac{1}{3} \frac{P_1 h_1 + P_2 h_2}{d}$$

Substituting the values of P_1 and P_2 above given, we have

$$R_1 = \frac{1}{3} \times w \times \frac{1}{2} \frac{h^3_1 + h^3_2}{d}$$

$$= \frac{1}{6} w \frac{h^3_1 + h^3_2}{d} \qquad (15)$$

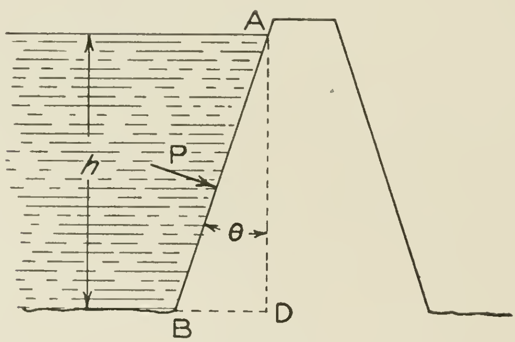


Fig. 18.

in which all dimensions are to be expressed in feet, and the result will be for a gate one foot long. For other lengths the value of R_1 will be proportional to the length.

3. Find the pressure P on a dam AB, Fig. 18. Let h = depth of water against the dam. Consider a length of dam of one foot. By Art. 7 the total pressure P is equal to the pressure at the half depth multiplied by the area of AB or

$$P = \frac{h}{2} \times w \times (\text{length of AB}) \times 1.$$

The center of pressure, by Art. 12, is two-thirds of the distance from A to B.

The horizontal component of the pressure is, by Art. 8, equal to the pressure per square foot at mid-depth multiplied by the vertical projection of the face AB, or

$$P_h = \frac{h}{2} \times w \times h \times 1 = \frac{1}{2} wh^2 \qquad (16)$$

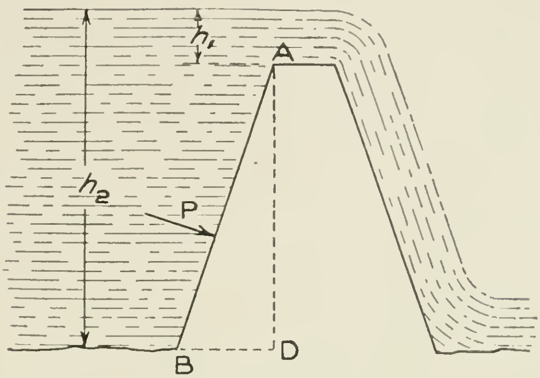


Fig. 19.

The vertical component is likewise

$$P_v = \frac{h}{2} \times w \times (\text{length BD}),$$

but we can write BD $= h \tan \theta$. Hence

$$P_v = \frac{1}{2} wh^2 \tan \theta. \qquad (17)$$

If the dam is submerged, as shown in Fig. 19, then the method employed in example 1 of this Article must be used.

EXAMPLES FOR PRACTICE.

1. What is the horizontal pressure on a dam one foot long on which the water has a depth of 80 feet ; and where is the center of pressure ? 200,000 lb., and 26 ft. 8 in. from the bottom. Ans.

2. What is the vertical component of the pressure in example 1 if the face of the dam slopes 1 inch horizontally to 1 foot vertically ? (The horizontal projection $= \frac{1}{12} \times 80 = 6\frac{2}{3}$ ft.) 16,670 lb. Ans.

3. In Fig. 19 if $h_1 = 10$ ft., $h_2 = 40$ ft., AD $= 30$ ft., and BD $= 10$ ft., wh^t will be the horizontal and vertical components

of the pressure P? The center of gravity of the area is 30 ft. deep. Use rule 5.

Hor. comp. = 46,875 lb.; Vert. comp. = 15,625 lb. Ans.

4. How far from A is the center of pressure in example 3? The length of AB = 31.62 ft. Use equation (12). 18.97 ft. Ans.

14. Buoyant Effect of Water on Submerged Bodies. If a body AB, Fig 20, be submerged, the water exerts an uplift upon it owing to the fact that the pressure upwards on the bottom of the body is greater than the pressure downwards on the top. The net upward force, or buoyant effect, is exactly equal to the weight

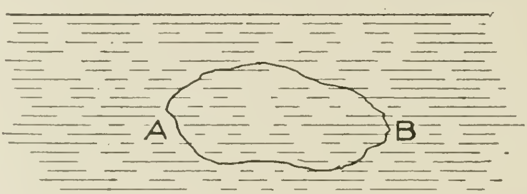


Fig. 20.

of a volume of water equal to that of the body AB. It is plain that this must be so, for if AB be replaced by water, the water would tend neither to rise nor fall, that is, it would be just supported by the surrounding pressures. Hence the following well-known law:

The weight of a body in water is less than its weight in air by an amount equal to the weight of an equal volume of water.

15. *The Specific Gravity* of a substance is the ratio of its weight to that of an equal volume of water. The specific gravity is found by weighing a body in air and then in water. The difference is the weight of an equal volume of water. Then if W equals weight in air; and W′ equals weight in water, then W − W′ = weight of water displaced, and

$$\text{Specific gravity} = \frac{W}{W - W'} \qquad (18)$$

as explained in Elementary Mechanics.

EXAMPLES FOR PRACTICE.

1. If a body weighs 100 lb. in air and 40 lb. in water, what is its specific gravity? 1.67. Ans.

2. If a body of .6 cu. ft. in volume weighs 75 lb., what is its specific gravity, the weight of water being 62.5 lb. per cu. ft.? 2.0. Ans.

3. If a body of 3 cu. ft. in volume has a specific gravity of .75, what force is necessary to submerge it? Here the buoyant effect is greater than the weight of the body. 46.9 lb. Ans.

FLOW OF WATER THROUGH ORIFICES.

16. Velocity of Flow Through Orifices. If AB, Fig. 21, be a vessel containing water of depth h, and C and D are any open tubes connected therewith, the water will stand in these tubes at

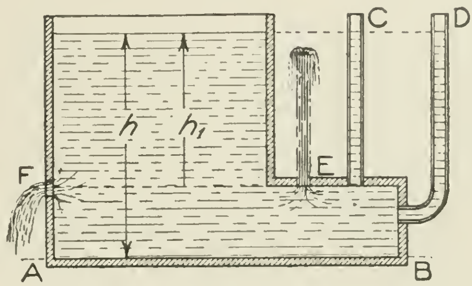


Fig. 21.

the same height h above the base level AB as in the large vessel, and the pressure in the tubes at any given depth is the same as in the large vessel at the same depth. If we now make an opening at E so that the water will issue in a vertical direction it has been experimentally demonstrated that the water will rise very nearly to the same level as it will in the tubes. The discrepancy is due to the air resistance and a slight friction at the opening. Neglecting this discrepancy the velocity of the water at E can be determined on the principle that it must be sufficient to cause the water to rise the distance h_1. In Mechanics it was shown that, neglecting air resistance, the velocity a body must have to cause it to rise against gravity a distance h_1 is the same as the velocity acquired by a body falling through the same distance. This velocity is given by formula

$$v = \sqrt{2gh}$$

in which v = velocity in feet per second
g = acceleration of gravity
= 32.2 feet per second
and h = height of fall, or the height a body will rise when started with a velocity v.

Applying this to the jet issuing from E we find that the theoretical velocity of efflux is

$$v = \sqrt{2gh_1}$$

If the orifice be in the side of the vessel, as at F, on the same level as E, it is plain that the water will issue with the same force as at E, since the pressure is the same. Hence in general:

The theoretical velocity of efflux from an orifice in any direction is

$$v = \sqrt{2gh} \qquad (19)$$

where h is the pressure head in feet at the orifice.

In practice the velocity is a little less than that given by the formula, the actual velocity being from 97% to 99% of the theoretical. This ratio of .97 to .99 is called the *coefficient of velocity.*

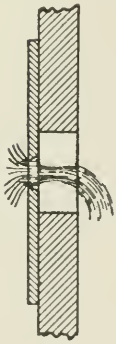


Fig. 22.

17. Use of Orifices for Measuring Water. In making use of an orifice for measuring water it is desirable, for the sake of accuracy, that the orifice be constructed in such a way that the water in passing out will touch the inner edge only. This may be done by making the orifice of a very thin plate, or cutting it on a bevel so that the water will not come in contact with the side, as shown in Fig. 22. To get accurate results an orifice should be made of metal, such as brass, and fastened to the inside of the tank as in Fig. 22, but in many cases sufficiently accurate results can be obtained by cutting a beveled hole in the side of a tank.

To give reliable results the orifice should be located a distance from the nearest side or the bottom of the tank not less than three times the width of the orifice. The tank or channel should also have a cross-section much larger than that of the orifice so that the velocity of the water as it approaches the orifice will be small, otherwise the discharge will be affected by this "velocity of approach". If the cross-section of the tank is as much as twenty times that of the orifice this effect is of no consequence.

18. Discharge Through Small Orifices. When water flows through an orifice, such as shown in Fig. 22, the direction of the flow at the edges is such as to cause the water vein to contract as it issues from the orifice. The area of the contracted vein at its smallest section is only 60 to 70 per cent of the full area of the orifice, the exact value depending upon the size of the orifice, and the pressure. Now the discharge through any orifice, pipe, or channel is equal to the area of the cross-section of the stream of water multiplied by its velocity at that point. If we measure the cross-section in square feet and the velocity in feet per second, then the discharge will be expressed in cubic feet per second. In the case of the orifice, then, to determine the discharge per second we would need to multiply the area of the cross-section of the vein of water by its velocity. In Art. 16 it was shown that the actual velocity of the jet was about 97 to 99 per cent of the theoretical velocity v, which refers to the velocity of the vein at the contracted section where the velocity is a maximum. The discharge will then be found by multiplying this actual velocity by the actual area at the point of contraction. Thus if we take the coefficient of velocity as .98 and the coefficient of contraction as .65, the discharge would be

$$Q = .98\, v \times .65\, A$$

where Q = discharge in cubic feet per second
v = theoretical velocity in feet per second by equation 19, and A = area of orifice in square feet.

If we substitute for v its value $\sqrt{2gh}$ we have

$$Q = .98 \times .65\, A \sqrt{2gh}$$
$$= .637\, A \sqrt{2gh},$$

The coefficient .637 in this case is called the *coefficient of discharge*, and as it varies with different conditions, it is desirable to use the more general formula

$$Q = c\, A \sqrt{2gh}. \qquad \textbf{(20)}$$

in which c = coefficient of discharge, which varies in value from about .66 to .60. This coefficient is the product of the "coefficient of velocity" and the "coefficient of contraction."

TABLE NO. 3.

Coefficients for Circular Vertical Orifices.

Head, *h*, in Feet.	Diameter of Orifice in Feet.						
	0.02	0.04	0.07	0.10	0.2	0.6	1.0
0.4	....	0.637	0.624	0.618			
0.6	0.655	.630	.618	.613	0.601	0.593	
0.8	.648	.626	.615	.610	.601	.594	0.590
1.0	.744	.623	.612	.608	.600	.595	.591
1.5	.637	.618	.608	.605	.600	.596	.593
2.0	.632	.614	.607	.604	.599	.597	.595
2.5	.629	.612	.605	.603	.599	.598	.596
3	.627	.611	.604	.603	.599	.598	.597
4	.623	.609	.603	.602	.599	.597	.596
6	.618	.607	.602	.600	.598	.597	.596
8	.614	.605	.601	.600	.598	.596	.596
10	.611	.603	.599	.598	.597	.596	.595
20	.601	.599	.597	.596	.596	.596	.594
50	.596	.595	.594	.594	.594	.594	.593
100	.593	.592	.592	.592	.592	.592	.592

TABLE NO. 4.

Coefficients for Square Vertical Orifices.

Head, *h*, in Feet.	Side of the Square in Feet.						
	0.02	0.04	0.07	0.1	0.2	0.6	1.0
0.4	....	0.643	0.628	0.621			
0.6	0.660	.636	.623	.617	0.605	0.598	
0.8	.652	.631	.620	.615	.605	.600	0.597
1.0	.648	.628	.618	.613	.605	.601	.599
1.5	.641	.622	.614	.610	.605	.602	.601
2.0	.637	.619	.612	.608	.605	.604	.602
2.5	.634	.617	.610	.607	.605	.604	.602
3	.632	616	.609	.607	.605	.604	.603
4	.628	.614	.608	.606	.605	.603	.602
6	.623	.612	.607	.605	.604	.603	.602
8	.619	.610	.606	.605	.604	.603	.602
10	.616	.608	.605	.604	.603	.602	.601
20	.606	.604	.602	.602	.602	.601	.600
50	.602	.601	.601	.600	.600	.599	.599
100	.599	.598	.598	.598	.598	.598	.598

TABLE NO. 5.

Coefficients for Rectangular Orifices 1 Foot Wide.

Head, h, in Feet.	Depth of Orifice in Feet.						
	.125	.25	.50	.75	1.0	1.5	2.0
.4	.634	.633	.622				
.6	.633	.633	.619	.614			
.8	.633	.633	.618	.612	.608		
1.	.632	.632	.618	.612	.606	.626	
1.5	.630	.631	.618	.611	.605	.626	.628
2.	.629	.630	.617	.611	.605	.624	.630
2.5	.628	.628	.616	.611	.605	.616	.627
3.	.627	.627	.615	.610	.605	.614	.619
4.	.624	.624	.614	.609	.605	.612	.616
6.	.615	.615	.609	.604	.602	.606	.610
8.	.609	.607	.603	.602	.601	.602	.604
10.	.606	.603	.601	.601	.601	.601	.602
20.				.601	.601	.601	.602

19. Experimental Coefficients of Discharge. Many experiments have been made on different kinds of orifices to determine the value of c, equation 20, so that by means of this formula and a table of coefficients, orifices could readily be used for measuring water. The accompanying tables give these coefficients for circular, square, and rectangular orifices in vertical planes, the rectangular orifices all being one foot wide.

Example 1. What is the discharge from a circular orifice 3 in. in diameter under a pressure head of 10 feet?

By Table No. 3 the coefficient of discharge for an orifice of a diameter of .25 ft. and under a head of 10 feet is .597. The area of the orifice $= \frac{1}{4} \times 3.14 \times .25^2 = .049$ sq. ft. Then by equation 20 the discharge will be $.597 \times .049 \times \sqrt{2 \times 32.2 \times 10} = .743$ cu. ft. per sec. Ans.

2. What will be the velocity of flow in example 1, the coefficient of velocity being taken equal to .97?

By equation 19 the velocity $= .97 \sqrt{2 \times 32.2 \times 10} = 24.6$ ft. per sec. Ans.

EXAMPLES FOR PRACTICE.

1. What will be the discharge from an orifice 4 in. square under a head of 16 feet? 2.14 cu. ft. per sec. Ans.

2. What must be the diameter of a circular orifice acting under a head of 25 feet to discharge 1 cu. ft. per sec.? (Assume $c = .6$ for a trial solution.) 2.76 in. Ans.

3. A pipe discharges 1.5 cu. ft. per sec. into a tank from which the water escapes through an orifice 6 in. square. How

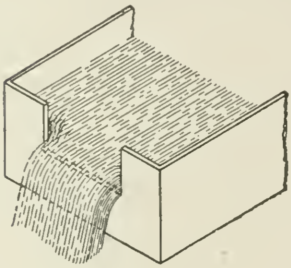


Fig. 23*a*.

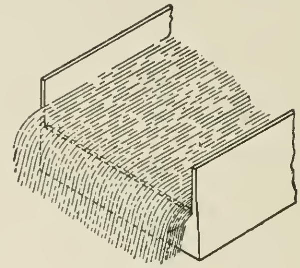


Fig. 23*b*.

deep will the tank be filled above the orifice when the outflow is just equal to the inflow? 1.53 ft. Ans.

FLOW OF WATER OVER WEIRS.

20. General Explanation. The term weir is usually given to a notch cut in the side of a tank or reservoir through which water may flow and be measured. The notch is usually rectangular and may have a width less than that of the tank, as shown in Fig. 23*a*, or equal to that of the tank, as in Fig. 23*b*. Such weirs are often used for measuring the flow of a small stream by building a small dam and leading all the water through a notched plank or timber wall. For accurate work weirs should be sharp-crested (the "crest" is the lower edge over which the water passes) so that the water will touch the inner corner only as in the case of the standard orifice described in Art. 18. The back side of the weir should be smooth and vertical for a considerable distance downwards from the crest.

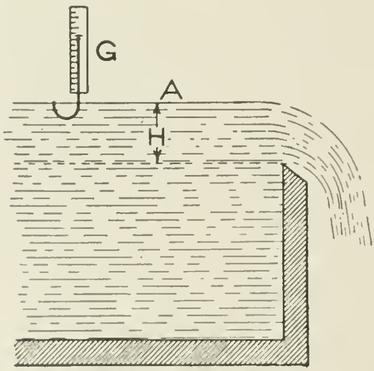


Fig. 24.

If the weir is made as in Fig. 23*a* the water in passing out will cause a contraction of the stream laterally, but if made as in Fig. 23*b* the water will pass out parallel to the sides of the tank and there will be no lateral, or, as it is called, "end contraction". In either case reliable results may be obtained by the use of the proper coefficients, but if the form of Fig. 23*a* be used, the distance of the notch from the side of the tank or channel should be at least three times the depth of the water on the weir in order that the contraction may be complete.

The measurement of water flowing over a weir is accomplished by merely measuring the depth of the water flowing over it. Then knowing this and the length of the weir the discharge can be calculated. In measuring this depth of water, or "height" of water on the weir, as it is commonly called, it is necessary to take the level of the water some distance back from the weir, as at A, Fig. 24, in order to avoid the effect of the curvature of the water surface. The difference between the level of the water and that of the weir is then the desired height H. The necessary distance back from the weir may be taken as 2 or 3 feet for small weirs to 8 or 10 feet for large ones.

A common and accurate way of determining the level of the water at A is by means of a submerged hook, shown at G, Fig. 24, called a *hook gauge*, arranged to be easily moved vertically along a scale. Fig. 25 shows such a gauge in detail. The gauge is set by moving it until the hook comes to the surface of the water. The scale is then read and the level of the water determined.

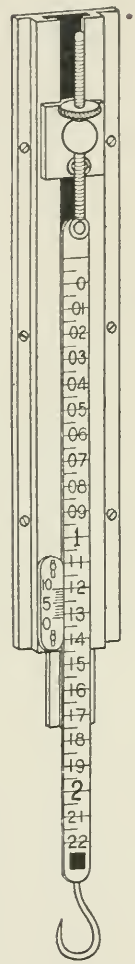


Fig. 25.

21. Formulas for Discharge. If the weir were a rectangular orifice at a considerable depth below the surface its discharge would be given by the formula

$$Q = c \times b \times d \sqrt{2gh} \qquad \textbf{(21)}$$

as in equation 20 of Art. 18. In this expression b = breadth and d = height of orifice, and h = average depth of orifice below the surface, or the average pressure head. In the case of the weir the depth d is the height H, and the average pressure head, h, is something less than H, varying from nothing for the water at the surface to the full value H for the water at the crest. For a case like this where the square root of a quantity, h, is taken, that varies from zero to a given value H, the *average* value of this square root is two-thirds the square root of the maximum limit H. That is, for h in equation 20 we may substitute $\frac{2}{3}\sqrt{H}$, giving for the discharge

$$Q = cb \times \frac{2}{3} H \sqrt{2gH}$$

$$= c \times \frac{2}{3} b \sqrt{2g} \times H^{\frac{3}{2}} \qquad (22)$$

in which c is the coefficient of discharge and equal to about .60 to .65 as for orifices.

If the channel is small the "velocity of approach" will have an appreciable effect upon the discharge, increasing it somewhat above what it otherwise would be. This is taken account of by calculating approximately the velocity of the water in the channel of approach at the place where the level of the water is measured, and determining the head h corresponding to this velocity by the formula

$$h = \frac{v^2}{2g}.$$

Then the discharge will be, for weirs with end contractions,

$$Q = c \times \frac{2}{3} b \sqrt{2g} (H + 1.4h)^{\frac{3}{2}} \qquad (23)$$

and for weirs without end contractions

$$Q = c \times \frac{2}{3} \sqrt{2g} \; (H + 1\frac{1}{3} h)^{\frac{3}{2}} \qquad (24)$$

The coefficient c should, in all cases, be selected according to the character of the weir.

In calculating "velocity of approach", it is necessary first to get an approximate value for the discharge Q by omitting the term h. The resulting discharge, divided by the cross-section of the tank or channel will be, with sufficient accuracy, the desired velocity of approach.

22. Coefficients of Discharge. Tables Nos. 6 and 7 give values of the coefficient *c* for the above formulas for rectangular sharp-crested weirs.

TABLE NO. 6.

Coefficients for Contracted Weirs.

Effective Head in Feet, *h*.	Length of Weir in Feet, *b*.						
	0.66	1	2	3	5	10	19
0.1	0.632	0.639	0.646	0.652	0.653	0.655	0.656
0.15	.619	.625	.634	.638	.640	.641	.642
0.2	.611	.618	.626	.630	.631	.633	.634
0.25	.605	.612	.621	.624	.626	.628	.629
0.3	.601	.608	.616	.619	.621	.624	.625
0.4	.595	.601	.609	.613	.615	.618	.620
0.5	.590	.596	.605	.608	.611	.615	.617
0.6	.587	.593	.601	.605	.608	.613	.615
0.7	....	.590	.598	.603	.606	.612	.614
0.8	....	....	.595	.600	.604	.611	.613
0.9	....	....	.592	.598	.603	.609	.612
1.0	....	....	.590	.595	.601	.608	.611
1.2	....	....	.585	.591	.597	.605	.610
1.4	....	....	.580	.587	.594	.602	.609
1.6	....	....	....	.582	.591	.600	.607

TABLE NO. 7.

Coefficients for Weirs without Contractions.

Effective Head in Feet, *h*.	Length of Weir in Feet, *b*.						
	19	10	7	5	4	3	2
0.1	0.657	0.658	0.658	0.659			
0.15	.643	.644	.645	.645	0.647	0.649	0.652
0.2	.635	.637	.637	.638	.641	.642	.645
0.25	.630	.632	.633	.634	.636	.638	.641
0.3	.626	.628	.629	.631	.633	.636	.639
0.4	.621	.623	.625	.628	.630	.633	.636
0.5	.619	.621	.624	.627	.630	.633	.637
0.6	.618	.620	.623	.627	.630	.634	.638
0.7	.618	.620	.624	.628	.631	.635	.640
0.8	.618	.621	.625	.629	.633	.637	.643
0.9	.619	.622	.627	.631	.635	.639	.645
1.0	.619	.624	.628	.633	.637	.641	.648
1.2	.620	.626	.632	.636	.641	.646	
1.4	.622	.629	.634	.640	.644		
1.6	.623	.631	.637	.642	.647		

23. The Francis Formula. The most widely used weir formula for large weirs without end contractions is that derived by Mr. James B. Francis from an extensive series of experiments on weirs 10 feet long. His formula is

$$Q = 3.33\, bH^{\frac{3}{2}}, \qquad (25)$$

in which the unit of length must be the foot. This is equivalent to the use of a constant value of the coefficient c of equation 22, equal to .623. It gives results sufficiently close for most purposes. With end contractions the length b is to be reduced by .1 H for

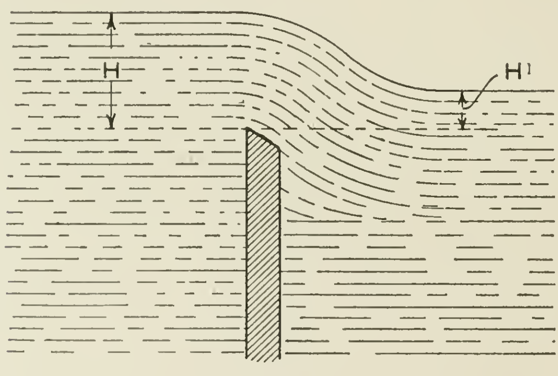


Fig. 26.

one end contracted and by .2 H for both ends contracted. The formula is further modified to allow for velocity of approach, but where this element enters, use may be made of the other formula.

24. Submerged Weirs. Where the water on the downstream side of a weir is higher than the crest, as in Fig. 26, the discharge is closely given by the formula

$$Q = 3.33\, b\, (n\mathrm{H})^{\frac{3}{2}}, \qquad (26)$$

where H is the height of the water on the upper side and n is a coefficient depending on the ratio of the head on the lower side, H^1, to the head H. The values of n are as follows:

TABLE NO. 8.

Values of n for Submerged Weirs.

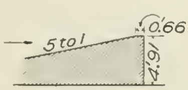
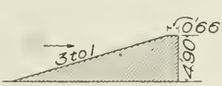
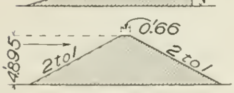
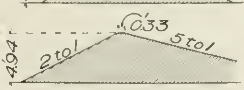
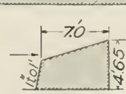
$\frac{H'}{H}$	n	$\frac{H'}{H}$	n	$\frac{H'}{H}$	n	$\frac{H'}{H}$	n
.00	1.000	.20	0.985	.45	0.912	.70	0.787
.02	1.006	.25	0.973	.50	0.892	.75	0.750
.05	1.007	.30	0.959	.55	0.871	.80	0.703
.10	1.005	.35	0.944	.60	0.846	.90	0.574
.15	0.996	.40	0.929	.65	0.819	1.00	0.000

25. Weirs of Irregular Section. In many cases it is desirable to determine the flow of a stream by measurements taken of the height of water flowing over some dam or weir; and, on the other hand, in the design of waste-weirs some method of estimating their capacity is essential. The law of flow over such weirs

TABLE NO. 9.

Values of the Coefficient C in the Formula

$$Q = CbH^{\frac{3}{2}} \text{ for irregular weirs.}$$

	Form of Weir.	Height on Weir in Feet.							
		1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
1		3.51	3.37	3.33	3.31	3.29	3.23	3.16	3.14
2		.....	3.76	3.68	3.68	3.70	3.75	3.83	
3		.....	3.68	3.71	3.81	3.90	4.00	4.06	
4		3.81	3.61	3.68	3.65	3.72	3.80	3.93	
5		3.81	3.61	3.57	3.63	3.62	3.67	3.71	3.80

is very complicated, and the only accurate way of determining the constants for any particular case is by means of experiments on a section of the same form as the one in question. If this is impossible, the best substitute for it is to use constants which have been determined for a weir agreeing as closely in form as may be to the one under consideration.

In Table No. 9 are given several sets of coefficients for five forms of dams, as determined by experiment. This coefficient is to be used in place of the value 3.33 in equation 25.

It will be noted by comparing Nos. 1 and 3 that the discharge falls off considerably by using a flat slope for the back of the dam.

Examples. 1. What will be the discharge of a sharp-crested weir 4 ft. long with H = 6 inches, there being contraction at both ends?

By Table No. 6 the coefficient may be taken at .610. Then by equation 22, $Q = .61 \times \frac{2}{3} \times 4 \times \sqrt{64.4} \times \left(\frac{1}{2}\right)^{\frac{3}{2}} = 4.6$ cu. ft. per sec. Ans.

2. If the channel of approach in example 1 be 6 feet wide by $2\frac{1}{2}$ feet deep, what will be the effect of the "velocity of approach"?

Assuming the same discharge as above, the velocity of flow in this channel will be $\frac{4.6}{6 \times 2\frac{1}{2}} = .11$ ft. per sec. The head h corresponding to this velocity $= \frac{v^2}{2g} = \frac{.11^2}{64.4} = .0002$ ft. Introducing this value for h in equation 23, it is seen that the additional term 1.4 h is too small to be of any practical consequence.

FLOW OF WATER THROUGH PIPES.

26. Discharge Through Pipes for Different Velocities. The rate of discharge through a pipe is equal to the average velocity of the flowing water multiplied by the cross-section of pipe. Velocities are usually expressed in feet per second and discharge in cubic feet per second or gallons per minute. The diameter of a pipe is always given in inches. These differences in units make it desirable to have a table at hand giving for a velocity of one foot per second the discharge of pipes of various diameters expressed both in cubic feet per second and in gallons per minute. Such a table is given below:

PIPE-ARCH BRIDGE OVER SUDBURY RIVER, NEAR SAXONVILLE, MASS.

Part of the waterworks system of Boston. Width of span 80 feet, central part of arch rising 5½ feet above horizontal. Arch consists of double-riveted sections of steel pipe, ⅝ inch thick and 7½ feet in diameter, sustaining both its own weight and that of the water it contains. Stone abutment reinforced with a backing of 40 feet of solid concrete. A larger bridge built on same principle, supported by two arched mains, spans Rock Creek, between Washington and Georgetown, D. C.

TABLE NO. 10.

Discharge of Pipes in Cubic Feet Per Second and in Gallons Per Minute for a Velocity of One Foot Per Second.

(For other velocities multiply the discharge here given by the velocity expressed in feet per second.)

Diameter of Pipe in Inches.	Discharge.	
	Cubic Feet Per Second.	Gallons Per Minute.
1	.0055	2.4
2	.0218	9.8
3	.0491	22.0
4	.0873	39.1
6	.1964	88.1
8	.3491	157
10	.5454	245
12	.7854	352
14	1.069	480
16	1.396	627
20	2.182	978
24	3.142	1410
30	4.909	2200
36	7.069	3155
42	9.624	4317
48	12.568	5639

EXAMPLES FOR PRACTICE.

1. What will be the discharge in gallons per minute of a 6-inch pipe for a velocity of 4.5 feet per sec.? 396 gallons per min. Ans.

2. What velocity will be required to discharge 1,000,000 gallons per day through an 8-inch pipe? 4.4 ft. per sec. Ans.

3. What diameter of pipe will be required to discharge 1,000 gals. per min. at a velocity of 5 feet per sec.?

An 8-inch pipe will discharge 785 gals. per min. and a 10-inch pipe will discharge 1,225 gals. per min. A 10-inch pipe would therefore be necessary if no intermediate size is available. Ans.

27. General Principles Governing the Flow of Water Through Pipes. Let ABCD, Fig. 27, be any pipe leading from a reservoir and having a stop valve at D. Also suppose B*b* and C*c* are tubes connected with the pipe at B and C and open at the top.

From the laws of pressure explained in Art. 6 we know that if the valve D be closed so that there will be no motion of the water the water will rise in the tubes B*b* and C*c* to the same level as that in the reservoir. The pressure at A will be represented by the head h_1 and that at B and C by the heads h_2 and h_3 respectively, which heads may be greater or less than the head at A according as the pipe slopes downwards or upwards from A.

Now let the valve at D be opened partly so as to permit the water to escape slowly. It will be found that the pressures at B and C will immediately decrease and that the water in the tubes will fall to some lower levels b' and c'. This decrease in pressure

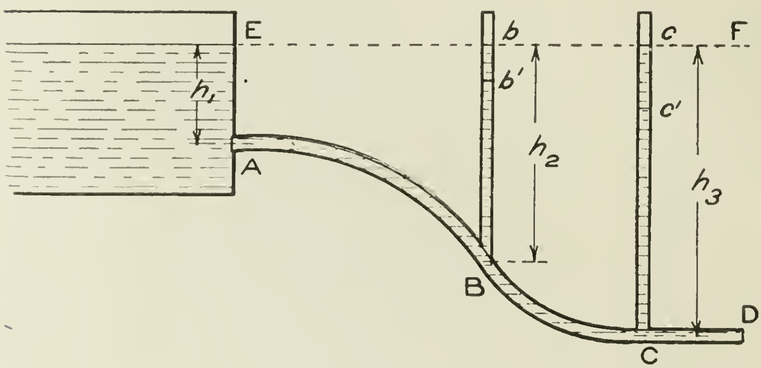


Fig. 27.

is due to two causes. First, a part of the pressure head has been used to give the water some velocity in the pipe, and second, a part has been consumed in the friction of the water in passing from A to B and C. The portion used in giving the water its velocity is the same as the head required to produce a given velocity of efflux, v, from an orifice, and is found from the formula $v = \sqrt{2gh}$. Solving for h we have

$$h = \frac{v^2}{2g} \qquad (27)$$

in which v is the actual velocity of flow in the pipe.

The pressure head lost in friction is usually much greater than that used in velocity and is the most important as well as the most difficult part of the problem of determining the flow in pipes.

If H represents the total loss of pressure head between the reservoir and any point B, h_v the head necessary to produce the given velocity at B ("velocity head") and h_f the pressure lost by friction between A and B we then have in general

$$H = h_v + h_f \qquad (28)$$

or from equation 27

$$H = \frac{v^2}{2g} + h_f \qquad (29)$$

In the figure, *bb'* represents the head H for point B and *cc'* that for point C. Between B and C the loss in head is the *difference* between *bb'* and *cc'* and is all due to friction, since the velocity is the same at the two points, the pipe being of uniform size.

If now we open the valve D farther so as to give the water a higher velocity the level of the water in the tubes *b*B and *c*C will fall still more, that is, there will be a greater loss of pressure head, H, than before. This increase in loss of pressure is due mainly to the increased friction loss h_f caused by the higher velocity, but to a small extent also to the increased energy transformed into velocity head.

In any case that part of the head H needed to produce the velocity v, which is equal to $\frac{v^2}{2g}$, can readily be calculated or can be obtained from the following table:

TABLE NO. 11.

Velocity Heads

$$h = \frac{v^2}{2g}$$

Corresponding to Various Values of v.

v feet per sec.	h ft.	v ft. per sec.	h ft.	v ft. per sec.	h ft.	v ft. per sec.	h ft.
2.0	0.06	4.0	0.25	6.0	0.56	8.0	0.99
2.2	0.08	4.2	0.28	6.2	0.60	8.2	1.04
2.4	0.09	4.4	0.30	6.4	0.64	8.4	1.10
2.6	0.10	4.6	0.33	6.6	0.68	8.6	1.15
2.8	0.12	4.8	0.36	6.8	0.72	8.8	1.20
3.0	0.14	5.0	0.39	7.0	0.76	9.0	1.26
3.2	0.16	5.2	0.42	7.2	0.80	9.2	1.31
3.4	0.18	5.4	0.45	7.4	0.85	9.4	1.37
3.6	0.20	5.6	0.49	7.6	0.90	9.6	1.43
3.8	0.22	5.8	0.52	7.8	0.94	9.8	1.49

The usual problem in practice consists in calculating the friction loss h_f between any two given points in a pipe for a given velocity v; or, conversely, to determine the velocity which will occur with a given loss of head h_f.

28. Formulas for Friction Loss in Pipes. A great number of experiments have been made to determine the friction loss in the flow of water through pipes. The results show great variations due to many causes, chief of which is the variation in the character of the pipe as to material, degree of roughness of the interior, diameter, etc. Consequently much less accuracy is possible in the estimation of the flow of water through pipes than through orifices or over weirs. Theory is of very little assistance here, and the only practicable method of calculation is to express by some formula the approximate law of variation in friction, and then use coefficients as determined from experiments.

Results of experiments show that the friction loss in a pipe is approximately proportional to the length of the pipe and to the square of the velocity of the water, and is inversely proportional to the cross-section of the pipe divided by its circumference. If we let

h_f = loss by friction between any two points;
l = length of pipe between same two points;
v = velocity of water in pipe;
r = ratio of cross-section to circumference of pipe, called the "hydraulic mean radius",

we then have, according to the above law,

$$h_f = \frac{v^2 l}{r} \times k$$

where k is some coefficient.

It is usual to write this formula so as to express directly the value of v. By solving for v we have

$$v = \sqrt{r \frac{h_f}{l}} \times \frac{1}{\sqrt{k}}$$

Putting C for $\frac{1}{\sqrt{k}}$, we may write

$$v = C \sqrt{r \frac{h}{l}} \qquad (30)$$

which is known as the Chezy formula. The values of r, h, and l are to be expressed in feet, and the result will give v in feet per second.

The above formula may be used for all kinds of pipe by using a suitable value of C as determined by experiments on similar pipe. For ordinary cast iron pipe the value of C varies from about 100 for pipes 1 or 2 inches in diameter to 140 or 150 for pipes 4 or 5 feet in diameter. Various diagrams and formulas for C have been devised for cast iron pipe, all of which are more or less unsatisfactory. Mr. Hamilton Smith has constructed a diagram which is probably as satisfactory as any now in use. This diagram is not entirely convenient in form, and instead of it we give below an extended table giving the actual velocities of flow v for various diameters of pipe and various losses of head for a length of 100 feet for pipes from $\frac{3}{4}$ in. to 3 in. in diameter, and for a length of 1,000 feet for larger pipes. This table is very convenient to use in calculations, as the desired velocity or loss of head can be seen at a glance.

TABLE NO. 12.

Discharge, Friction Head, and Velocity of Flow Through Smooth Pipes such as Cast Iron.

Discharge. Gals. per Minute.	¾-inch Pipe.		1-inch Pipe.		1½-inch Pipe.	
	Loss of Head, Feet per 100 Feet.	Velocity, Feet per Second.	Loss of Head, Feet per 100 Feet.	Velocity, Feet per Second.	Loss of Head, Feet per 100 Feet.	Velocity, Feet per Second.
1	0.5	0.72	0.02	0.41		
2	2.0	1.4	0.6	0.82		
3	4.0	2.2	1.1	1.2		
4	7.2	2.9	1.8	1.6		
5	11.0	3.6	2.6	2.0		
6	15.0	4.3	3.6	2.4		
7	20.4	5.1	4.8	2.9		
8	25.5	5.8	6.2	3.3		
9	32.0	6.5	7.7	3.7		
10	39.0	7.2	9.4	4.1	1.1	1.8
12			13.0	4.9	1.6	2.2
14			17.1	5.7	2.2	2.5
16			21.8	6.5	2.8	2.9
18			27.1	7.3	3.5	3.3
20			33.0	8.2	4.3	3.6
30					9.5	5.4
40					16.0	7.2
50					24.0	9.1
60					34.0	10.9
70					45.0	12.7

TABLE NO. 12.—Continued.

Dicharge. Gals. per Minute.	2-inch Pipe.		2½-inch Pipe.		3-inch Pipe.	
	Loss of Head, Feet per 100 Feet.	Velocity, Feet per Second.	Loss of Head, Feet per 100 Feet.	Velocity, Feet per Second.	Loss of Head, Feet per 100 Feet.	Velocity, Feet per Second.
10	.4	1.0	0.1	0.65	0.05	0.45
20	1.2	2.0	0.4	1.3	0.2	0.90
30	2.4	3.1	0.8	1.9	0.4	1.4
40	4.0	4.1	1.4	2.6	0.7	1.8
50	6.1	5.1	2.1	3.3	1.0	2.3
60	8.6	6.1	2.9	3.9	1.4	2.7
70	11.5	7.1	3.9	4.6	1.8	3.2
80	14.8	8.2	5.0	5.2	2.3	3.6
90	18.4	9.2	6.3	5.9	2.8	4.1
100	22.2	10.2	7.7	6.5	3.4	4.5
120			10.8	7.8	4.8	5.4
140			14.3	9.1	6.3	6.3
160			18.3	10.4	8.0	7.2
180			22.7	11.8	9.9	8.1
200			27.5	13.1	12.0	9.0
250					18.0	11.3
300					25.0	13.6

TABLE NO. 12.—Continued.

Discharge, Gals. per Minute.	4-inch Pipe.		6-inch Pipe.		8-inch Pipe.	
	Loss of Head, Feet per 1,000 Feet.	Velocity, Feet per Second.	Loss of Head, Feet per 1,000 Feet.	Velocity, Feet per Second.	Loss of Head, Feet per 1,000 Feet.	Velocity, Feet per Second.
50	2.3	1.3				
75	5.2	1.9				
100	8.7	2.5	1.2	1.1		
125	13.1	3.2	1.8	1.4		
150	18.3	3.8	2.5	1.7		
175	24.3	4.5	3.3	2.0		
200	31.0	5.1	4.2	2.3	1.1	1.3
250	46.5	6.4	6.3	2.8	1.6	1.6
300	65.0	7.7	8.9	3.4	2.2	1.9
350			11.9	4.0	2.9	2.2
400			15.1	4.5	3.7	2.6
450			18.7	5.1	4.6	3.9
500			22.7	5.7	5.6	3.2
600			31.8	6.8	7.9	3.8
700			42.2	7.9	10.5	4.5
800			54.0	9.1	13.4	5.1
900					16.6	5.8
1000					20.2	6.4
1100					24.1	7.0

TABLE NO 12.—Continued.

Discharge, Gals. per Minute.	10-inch Pipe.		12-inch Pipe.		16-inch Pipe.	
	Loss of Head, Feet per 1,000 Feet.	Velocity, Feet per Second.	Loss of Head, Feet per 1,000 Feet.	Velocity, Feet per Second.	Loss of Head, Feet per 1,000 Feet.	Velocity, Feet per Second.
200	.35	.82	.14	.57		
300	.73	1.2	.30	.85		
400	1.24	1.6	.51	1.1		
500	1.87	2.0	.78	1.4	.18	.80
600	2.6	2.4	1.10	1.7	.26	.96
700	3.5	2.9	1.45	2.0	.34	1.1
800	4.4	3.3	1.82	2.3	.43	1.3
900	5.5	3.7	2.3	2.6	.54	1.4
1000	6.7	4.1	2.8	2.8	.66	1.6
1100	8.0	4.5	3.3	3.1	.78	1.8
1200	9.4	4.9	3.9	3.4	.92	1.9
1300	10.9	5.3	4.5	3.7	1.06	2.1
1400	12.6	5.7	5.1	4.0	1.22	2.2
1500			5.8	4.2	1.38	2.4
1600			6.5	4.5	1.55	2.6
1700			7.3	4.8	1.74	2.7
1800			8.1	5.1	1.93	2.9
1900			9.0	5.4	2.1	3.0
2000			9.9	5.7	2.3	3.2
2200			11.7	6.2	2.8	3.5
2400					3.3	3.8
2600					3.8	4.2
2800					4.4	4.5
3000					5.0	4.8
3500					6.6	5.6

Examples. 1. What is the head lost in friction due to the flow of 800 gallons per minute in a 6-inch pipe?

From Table No. 12 we see that the friction head in a 6-inch pipe for a flow of 800 gals. per min. is 54.0 ft. for each 1,000 ft. of pipe. Ans.

2. What size of pipe will be required to convey 700 gallons of water per minute a distance of 8,000 feet with a total loss of head of 40 feet?

The loss of head per 1,000 ft. is $40 \div 8 = 5$ ft. From the table we find that for a discharge of 700 gallons per min. the loss of head in an 8-in. pipe is 10.5 ft. per 1,000, and in a 10-in. pipe it is 3.5 ft. A 10-in. pipe would then be required if the assumed loss is not to be exceeded. Ans.

3. If a town is supplied with water from an elevated reservoir through a pipe line 15,000 feet long, how high must the

TABLE NO. 12. Continued.

Discharge, Gals. per Minute.	20-inch Pipe.		24-inch Pipe.		30-inch Pipe.	
	Loss of Head, Feet per 1,000 Feet.	Velocity, Feet per Second.	Loss of Head, Feet per 1,000 Feet.	Velocity, Feet per Second.	Loss of Head, Feet per 1,000 Feet.	Velocity, Feet per Second.
1000	.23	1.0	.08	.71		
1200	.32	1.2	.12	.85		
1400	.42	1.4	.16	.99		
1600	.52	1.6	.20	1.1		
1800	.64	1.8	.25	1.3		
2000	.77	2.0	.31	1.4	.10	.91
2200	.92	2.2	.37	1.6	.12	1.00
2400	1.08	2.5	.43	1.7	.14	1.09
2600	1.25	2.7	.50	1.8	.17	1.18
2800	1.43	2.9	.58	2.0	.19	1.27
3000	1.62	3.1	.66	2.1	.22	1.36
3200	1.82	3.3	.74	2.3	.24	1.45
3400	2.04	3.5	.83	2.4	.27	1.55
3600	2.27	3.7	.92	2.5	.30	1.64
3800	2.51	3.9	1.02	2.7	.33	1.73
4000	2.76	4.1	1.12	2.8	.36	1.82
4500	3.43	4.6	1.39	3.2	.46	2.05
5000	4.16	5.1	1.68	3.5	.56	2.27
5500	4.96	5.6	2.00	3.9	.67	2.50
6000	5.80	6.1	2.35	4.3	.78	2.73
6500					.90	2.96
7000					1.03	3.18
7500					1.17	3.41
8000					1.32	3.64
9000					1.64	4.09
10000					2.00	4.55

reservoir be above the town and what must be the size of the pipe line so that the pressure of water in the distributing pipes be not less than 60 pounds per sq. in., equivalent to 60 × 2.3 = 138 ft. head. The amount of water required is 1,800 gals. per min.

This problem has several solutions since various sizes of pipe may be assumed and the reservoir placed at the elevation to furnish the necessary pressure. An examination of Table No. 12 shows that to deliver 1,800 gals. per min. a 12-in. pipe would consume in friction 8.1 ft. of head per 1,000 ft., a 16-in. pipe would consume only 1.93 ft. per 1,000 ft., and a 20-in. pipe only .64 ft. No value is given for a 10-in. pipe, but it would evidently be 20 feet or more per 1,000, which would give a total loss for 15,000 ft. of 300 feet, a loss which would ordinarily be impracticable.

If we use a 12-in. pipe the total loss in friction will be 8.1 × 15 = 121.5 ft. The velocity of flow will be 5.1 ft. per sec. and the necessary velocity head, h_v, will be, by Table No. 11, .4 ft. The total head = 121.5 + .4 = 121.9 ft., and the necessary elevation of the reservoir = 138 + 121.9 = 259.9 ft. above the town.

If a 16-inch pipe be assumed, the friction loss = 1.93 × 15 = 28.9 ft., the velocity head = .1 ft., and the total head = 29 ft. Elevation of reservoir = 29.0 + 138 = 167 ft.

If a 20-inch pipe be used, the friction head = .64 × 15 = 9.6 ft., the velocity head is less than .1 ft. and may be neglected. The required height of reservoir = 147.6 ft.

Still larger sizes will give still lower elevations for the reservoir, but it is evident that the reservoir in any case must have an elevation somewhat greater than 138 ft.

From the above results we see that a 12-in. pipe requires the reservoir to be at an elevation of 259.9 ft., a 16-in. pipe requires an elevation of 167 ft., and a 20-in. pipe an elevation of 147.6 ft. The proper size to use would be that size which would give the cheaper construction for the pipe and reservoir combined.

29. The Hydraulic Grade Line. Referring again to Fig. 27, it will be seen that the drop in pressure between B and C will be proportional to the length of the pipe from B to C, and if we have a long pipe with several open tubes attached to it like *b*B and *c*C, the level of the water in them would be lower and lower as we proceed along the pipe, the drop being uniform so long as the pipe is of the same size and kind, the amount of the drop per 1,000 feet being given in Table No. 12. If now a line were drawn from E through the points *b*, *c*, etc., so that the height of this line above the pipe would represent the pressures in it, this line would be called the "hydraulic grade line" for the pipe under the given conditions. It is convenient in various problems to construct such a grade line. Its position will evidently vary with the velocity of the flow and will be a horizontal line when the water is still, and always a straight line for a pipe of uniform conditions.

30. Siphons. If in any case a pipe line rise above this hydraulic grade line, as shown in Fig. 28, the pressure in such portion of the pipe will be less than atmospheric, the pressure measured by the grade line as described above referring in all cases to the pressure in excess of the usual atmospheric pressure. That portion of the pipe BC lying above the grade line is called a *siphon*. The greatest height above the grade line which it is practicable to operate a siphon is considerably less than the height of the water barometer given in Art. 4. Evidently since the velocity of flow, and hence the hydraulic grade line, can be varied by varying the opening at D, a pipe which may act as a siphon at one time may not so act at another. Thus in the figure, if valve D be nearly closed so that the flow is reduced and hence also the frictional loss,

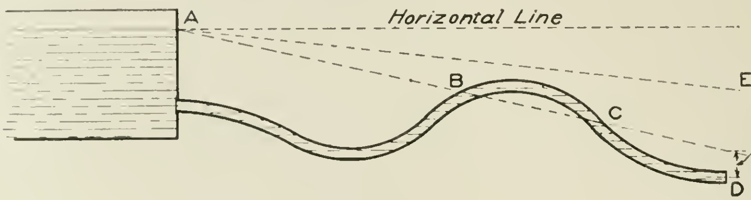


Fig. 28.

the grade line will rise to some position such as AE and there will be pressure in excess of atmospheric at all points.

31. Flow Through Special Forms of Pipes. *Riveted Pipe.* The friction loss in riveted pipes depends upon the thickness of the plates and the manner of making the joints. Experiments on this class of pipes are not sufficiently numerous to enable any general expression to be formulated, so that in the design of such pipes the selection of coefficients must be made by reference to the experimental data. In general it is found that the coefficient C, of equation 30, changes little with change in diameter or velocity, and in this respect exhibits considerable difference from its variation in cast-iron pipe. For ordinary velocities the value of C, for new pipe appears to range between 100 and 115. A value of 100 is as great as it is well to use.

32. Wood Stave Pipe. Few experiments have been made on this class of pipe although it has been used quite extensively in the West. The pipe is usually quite smooth and not subject to deterioration on the interior, so that its discharging capacity is high. For ordinary velocities the value of C, equation 30, may be taken at 110.

33. Fire Hose. In making provisions for fire protection it becomes necessary to estimate the effectiveness of a stream of water when led through a given length of hose for a given pressure at the hydrant, or to find what pressure is required to throw a stream a given height or a given distance. The usual size of fire hose is $2\frac{1}{2}$ inches. At the end of the hose is attached a nozzle of a diameter usually of 1 in., $1\frac{1}{8}$ in., or $1\frac{1}{4}$ in., which partly controls the amount and pressure of the water discharged. If there were no friction in the hose the water could be thrown nearly to a height corresponding to the pressure head at the hydrant, but the hose friction is very great, and two or three hundred feet of hose will cut down the effective pressure often more than one-half. Evidently the more rapid the flow through the hose the greater the friction loss, hence if the nozzle is small so that the discharge will be small, the effective pressure near the nozzle will be greater than with a large nozzle and large discharge. Hence a higher stream can be thrown through a small nozzle with a given hydrant pressure and length of hose than through a large nozzle, although the stream is not so effective in quenching a fire as the larger stream.

In Table No. 13 are given the necessary data for estimating the loss of head and effectiveness of fire streams for various pressures and for three sizes of nozzles

In the table, page 44, the pressure given is that at the nozzle instead of at the hydrant. To get the latter, it is necessary to add to the nozzle pressure the head lost in the hose. The result will be the hydrant pressure, providing nozzle and hydrant are at same level. If not, then a correction would need to be made for this difference in elevation. The vertical height and horizontal distances are to be measured from the nozzle. The heads are given in pounds per square inch, which is the customary unit in this class of work. To reduce to feet of head multiply pounds pressure by 2.3.

Examples. 1. What hydrant pressure will be required to throw a stream of water 75 feet vertically through a $1\frac{1}{8}$-in. nozzle and 300 feet of hose.

In the table for the $1\frac{1}{8}$-in. nozzle we see that for a height of 75 feet the loss of head per 100 feet of hose is 20 pounds, and the pressure at the nozzle is (in first column of table) 50 pounds. The

TABLE NO. 13.

Hose and Fire-Stream Data.

Pressure at Nozzle (Base of Play-pipe).	1-inch Smooth Nozzle.					$1\frac{1}{8}$-inch Smooth Nozzle.					$1\frac{1}{4}$-inch Smooth Nozzle.				
	Discharge in Gallons per Minute.	Loss of Head per 100 Feet of Ordinary Hose.	Vertical Height of Jet for Good Fire-streams.	Maximum Horizontal Distance for Good Fire-streams.	Extreme Drops at Level of Nozzle.	Discharge in Gallons per Minute.	Loss of Head per 100 Feet of Ordinary Hose.	Vertical Height of Jet for Good Fire-streams.	Maximum Horizontal Distance for Good Fire-streams.	Extreme Drops at Level of Nozzle.	Discharge in Gallons per Minute.	Loss of Head per 100 Feet of Ordinary Hose.	Vertical Height of Jet for Good Fire-streams.	Maximum Horizontal Distance for Good Fire-streams.	Extreme Drops at Level of Nozzle.
lb.		lb.	ft.	ft.	ft.		lb.	ft.	ft.	ft.		lb.	ft.	ft.	ft.
20	132	5	35	37	77	168	8	36	38	80	209	12	37	40	83
30	161	7	51	47	109	206	12	52	50	115	256	19	53	54	119
40	186	10	64	55	133	238	16	65	59	142	296	25	67	63	148
50	208	12	73	61	152	266	20	75	66	162	331	31	77	70	169
60	228	15	79	67	167	291	24	83	72	178	363	37	85	76	186
70	246	17	85	72	179	314	28	88	77	191	392	43	91	81	200
80	263	20	89	76	189	336	32	92	81	203	419	49	95	85	213
90	279	22	92	80	197	356	36	96	85	214	444	55	99	90	225
100	295	25	96	83	205	376	40	99	89	224	468	62	101	93	236

hydrant pressure will then be $50 + (20 \times 3) = 110$ pounds per square inch. The discharge will be about 266 gallons per minute.

2. With a hydrant pressure of 100 pounds, what will be the discharge through 250 feet of hose with a $1\frac{1}{4}$-in. nozzle, and how high can such a stream be thrown with effectiveness?

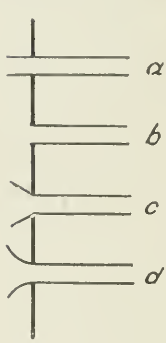


Fig. 29.

This problem must be solved by trial. In the table for $1\frac{1}{4}$-in. nozzles, we see that for a discharge of 269 gallons the nozzle pressure is 40 pounds, and the loss of head per 100 feet of hose is 25 pounds; for a discharge of 331 gallons the nozzle pressure is 50 pounds, and the loss of head per 100 feet is 31 pounds, etc. We have given the head of 100 pounds, which must equal the sum of the nozzle pressure and the loss in the hose. If we try the first value for discharge, we have a nozzle pressure of 40 pounds and a total loss in the hose of $25 \times 2.5 = 62.5$ pounds, or a total of $40 + 62.5 = 102.5$ pounds. This being a little more than the total available head, it is evident that we have assumed too high a discharge. The next lower value is 256 gallons, giving a nozzle pressure of 30 pounds and a total hose loss of 19 × 2.5 or 47.5 pounds, giving a total of 30 + 47.5 = 77.5 pounds. Evidently the correct value is somewhere between 296 and 256, and further that it is but very little below the former value. For a total change in discharge of 40 gallons we have a change in total head of 102.5 – 77.5 or 25 pounds. Hence for a change of 2.5 pounds the discharge will vary about $\frac{1}{10}$ of 40 gallons, or 4 gallons. The discharge may then be taken as 292 gallons per minute. The effective height will be between 67 feet and 53 feet, but only a little less than the former value, say 65 feet. This is as close an estimate as the conditions of the problem will warrant, since the hose friction is a factor that varies greatly according to the character of the hose.

34. Minor Losses of Head in Pipes. In most of the following formulas the quantity $\frac{v^2}{2g}$ occurs. For given values of v this quantity can readily be taken from Table No. 11.

Loss of Head at Entrance. This is expressed by the formula

$$h = \left(\frac{1}{c^2} - 1\right)\frac{v^2}{2g}. \qquad (31)$$

where v = velocity in the pipe, and c is the coefficient of discharge. For various forms at entrance, as shown in Fig. 29, we have the following values:

	$c.$	$\frac{1}{c^2} - 1.$
Pipe projecting into reservoir, Fig. (a)	.72	.93
End of pipe flush with reservoir, Fig. (b)	.82	.49
Conical or bell-shaped mouth, Fig. (c) or (d)	.93 to .98	.15 to .04

Loss of Head at Bends. For 90° bends this is equal to

$$h = n\frac{v^2}{2g} \qquad (32)$$

in which n has the following values according to the ratio of the radius of the pipe r to the radius of curvature R:

$\frac{r}{R}$	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
n	.13	.14	.16	.21	.29	.44	.66	.98	1.41	1.98

Loss of Head in Valves. Weisbach's experiments on small gate-valves gave values for n in the expression $h = n\frac{v^2}{2g}$ as follows:

Ratio of height of opening to diameter.	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{1}{8}$
Values of n	.07	.26	.81	2.1	5.5	17	98

In applying the above formula v is the velocity in the pipe.

For a throttle-valve placed at various angles θ with the axis of the pipe, Weisbach found the following values of n:

θ..	5	10	20	30	40	50	60°	65°	70°
n..	.24	.52	1.5	3.9	11	33	118	256	750

Experiments on large gate-valves have been made by Kuichling and by J. W. Smith. The following table gives values of the coefficient c in the expression $Q = cA\sqrt{2gh}$. In this expression A is the area of the opening, h is the head lost in the valve, Q is the rate of discharge.

TABLE NO. 14.

Coefficients for Large Gate-Valves.

Ratio of height of opening to diameter	.05	.1	.2	.3	.4	.5	.6	.7	.8
Ratio of area of opening to total area	.05	.10	.23	.36	.48	.60	.71	.81	.89
Coefficient c for 24-in. valve	1.7	1.0	.72	.70	.77	.92	1.2	1.6	
Coefficient c for 30-in .valve	1.2	.9	.83	.82	.84	.90	1.05	1.35	2.1

Example. If a pump draws water from a pipe projecting into a reservoir what will be the loss of head at entrance, the velocity of water in the pipe being 6 feet per second

Using equation 31 of Art. 34 the value of $(\frac{1}{c^2} - 1)$ is, for this case, about .93. The loss of head is then $.93 \times \frac{v^2}{2g}$ which by Table No. 11 $= .93 \times .56$ or .52 feet. Ans.

If the pipe is flush with the reservoir the loss of head will be only $.49 \times .56$, or .27 feet.

Finally, if the pipe is enlarged to a bell-mouth or conical form the loss of head will be very small, say $.10 \times .56$ or .056 feet.

FLOW OF WATER IN OPEN CHANNELS.

35. General Formula. Where water flows in an open channel like a ditch, or a concrete, brick or tile sewer flowing less than full, the inclination of such channel is what furnishes the necessary fall or head to the water for overcoming friction. In this case there is no pressure at any point, and the loss of head from point to point will be the difference in level of the water surface between the given points. This difference in level, or head, after the flow has become steady is equal to the loss of head due to friction in the same distance.

The frictional loss in open channels is expressed by the same general formula as that used for pipes in Art. 28. It is

$$v = c\sqrt{rs} \qquad (33)$$

in which as before

v = velocity in feet per second,
c = a coefficient,
r = hydraulic mean radius = the cross-section of the actual stream of water divided by that part of the perimeter that is under water ("wetted perimeter").
s = slope of channel, or ratio of fall to length = $\frac{h}{l}$.

For open channels the value of c varies much more than for pipes, as the nature of the channel varies more. Thus the channel may be a smooth tile sewer where c may be 100 or more, which is about the same as for iron pipe; or the channel may be a rough natural water-course for which the value of c will be only 30 or 40. Estimates of flow in very rough channels are obviously subject to great uncertainties, but for sewers and open masonry drains or conduits, estimates may be quite closely made, as the values of c have been quite well determined.

For convenience the value of c has been expressed in a formula, called Kutter's formula, in which the condition of the channel is taken account of by a special coefficient n, called the coefficient of roughness. This formula for ordinary cases is

$$c = \frac{\frac{1.8}{n} + 45}{1 + \frac{45n}{\sqrt{r}}} \qquad (34)$$

in which r = hydraulic mean radius in feet, and n = coefficient of roughness, varying from a value of about .009 for smooth plank to .030 for natural channels full of stone, etc.

The following are the values of n usually assumed for the various surfaces mentioned:

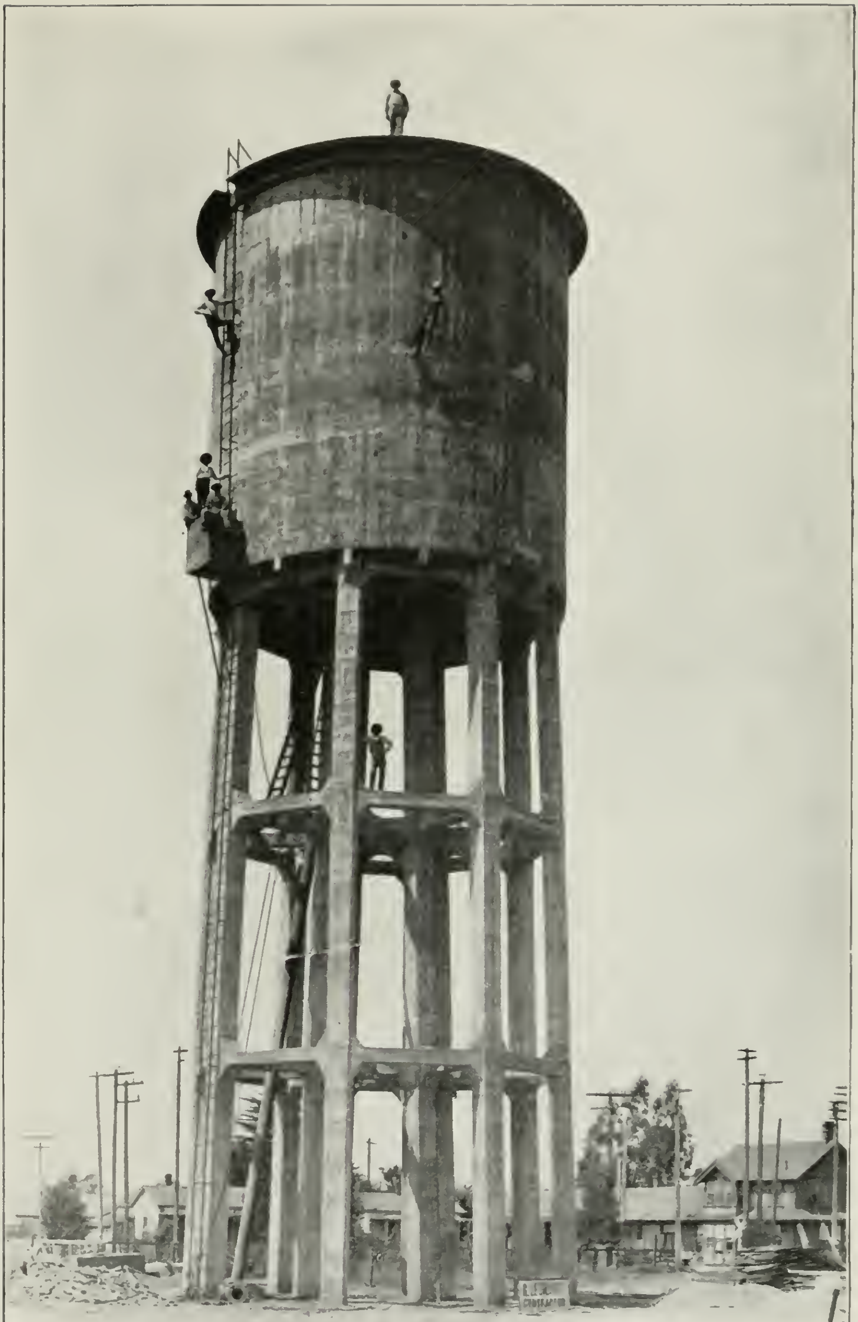
	n
Channels of well-planed timber	.009
" " neat cement or of very smooth pipe	.010
" " unplaned timber or ordinary pipe	.012
" " smooth ashlar masonry or brickwork	.013
" " ordinary brickwork	.015
" " rubble masonry	.017
" in earth free from obstructions	.020 to .025
" with detritus or aquatic plants	.030

After selecting the value of n, the value of c can readily be obtained from Table No. 15.

TABLE NO. 15.

Values of c in Kutter's Formula, for Various Values of n.

r in Feet.	Values of n.									
	.009	.010	.011	.012	.013	.015	.017	.020	.025	.030
.1	108	94	82	73	65	53	45	35	26	20
.2	129	113	100	89	80	66	56	45	34	26
.3	142	124	111	99	90	75	63	52	38	30
.4	150	132	118	106	96	80	69	56	42	34
.5	157	139	124	111	101	85	73	60	45	36
.6	162	143	128	116	105	89	76	63	48	38
.7	166	147	132	119	109	92	79	65	50	40
.8	170	151	135	122	112	95	82	68	52	42
.9	173	154	138	125	114	97	84	70	54	43
1.0	175	156	140	127	116	99	86	71	55	45
1.2	180	160	145	131	120	103	89	74	58	47
1.4	184	164	148	135	124	106	92	77	60	49
1.6	187	167	151	137	126	108	94	79	62	51
1.8	189	169	153	140	129	110	97	81	64	53
2.0	191	172	155	142	130	112	98	83	65	54
2.5	196	176	160	146	135	116	102	86	69	57
3.0	199	179	163	149	138	119	105	89	71	59
3.5	202	182	166	152	140	122	107	91	73	61
4.0	204	184	168	154	143	124	110	93	75	63
4.5	206	186	170	156	144	126	111	95	77	64
5.0	208	188	172	158	146	127	113	97	78	66



REINFORCED-CONCRETE WATER TANK, ANAHEIM, CALIFORNIA

Total height, 113 ft.; supporting frame, 75 ft. high; tank, 38 ft. high, 32 ft. in diameter, with walls 5 in. thick at bottom, tapering to 3 in. thick at top. Capacity, 200,000 gallons. Cost, $11,400, or 75 per cent of lowest estimate on a steel tank and tower of like dimensions.

36. The Hydraulic Mean Radius r. As before explained, this is a name given to the quotient found by dividing the actual cross-section of a stream of water by the "wetted perimeter," or that part of the perimeter of the cross-section of the channel that is under water. In the case of a pipe flowing full, of diameter d, the cross-section is $\frac{1}{4}\pi d^2$ and the perimeter is πd, hence the value of r is $\frac{1}{4}\pi d^2 \div \pi d = \frac{1}{4}d$. For a pipe flowing half full it is, similarly, $\frac{1}{8}\pi d^2 \div \frac{1}{2}\pi d$ or $\frac{1}{4}d$, the same as when flowing full. When less than half full the cross-section of the stream falls off more rapidly than the wetted perimeter, so that the value of r decreases. Hence we see from equation 33 that the velocity also falls off.

For any given form of channel filled to a given point the value of r can readily be found by plotting the cross-section to a large scale and measuring the area and the wetted perimeter.

Example. What will be the velocity and discharge of water flowing in a concrete channel 4 ft. wide and 3 ft. deep and having a slope of 1 ft. per 1,000 ft.?

Equation 33 must be used. We will first get the values of r and s. The value of r is equal to the cross-section of the stream of water divided by the wetted perimeter $= \dfrac{3 \times 4}{4 + 3 + 3} = 1.2$ ft.

The slope $s = \dfrac{1}{1{,}000} = .001$. The value of c is to be obtained from Table No. 15, n being taken at .013, say, the same as for brickwork. For $n = .013$ and $r = 1.2$ Table No. 15 gives $c = 120$. Substituting then in equation 33 we have $v = 120 \times \sqrt{1.2 \times .001} = 4.16$ ft. per sec. The discharge will be $4.16 \times 4 \times 3 = 49.92$ cu. ft. per sec. Ans.

37. Flow Through Ordinary Sewers. Sewers are usually constructed of vitrified earthen pipe or of brick or concrete. For the former material the value of n in equation 34 is usually taken at .013, and for brick and concrete about .015. If the concrete is smoothly finished n may be taken at .013.

The following Table No. 16 gives the velocities and discharges for circular sewers flowing full. For sewers flowing half full the velocity will be the same and the discharge one-half of the given values.

TABLE NO. 16.

Velocity and Discharge for Pipe Sewers (n = .013);

Velocity in Feet per Second (V); Discharge in Cubic Feet Per Second (Q).

(For n = .011 add 20 per cent.)
(For n = .015 subtract 16 per cent.)

Fall of Sewer, in Feet per 100 ft.	4-inch.		6-inch.		8-inch.		10-inch.		12-inch.		15-inch.		18-inch.	
	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
10.	5.75	.50	7.99	1.57	10.01	3.50	11.94	6.51	13.73	10.78	16.24	19.93	18.59	32.86
5.	4.06	.35	5.64	1.11	7.09	2.48	8.43	4.60	9.70	7.62	11.48	14.08	13.13	23.22
4.	3.63	.32	5.05	.99	6.31	2.21	7.54	4.11	8.65	6.80	10.26	12.59	11.74	20.73
3.	3.15	.27	4.25	.83	5.49	1.92	6.53	3.56	7.51	5.90	8.89	10.91	10.17	17.97
2.	2.57	.22	3.56	.70	4.48	1.56	5.33	2.91	6.13	4.82	7.25	8.90	8.30	14.67
1.	1.82	.16	2.52	.49	3.17	1.11	3.77	2.06	4.33	3.40	5.13	6.30	5.87	10.38
.8	1.61	.14	2.25	.44	2.83	.99	3.37	1.84	3.87	3.04	4.59	5.63	5.25	9.28
.6	1.38	.12	1.95	.38	2.45	.86	2.92	1.59	3.35	2.64	3.97	4.89	4.55	8.04
.4			1.59	.31	2.00	.69	2.38	1.30	2.74	2.15	3.24	3.97	3.70	6.55
.2					1.40	.49	1.67	.91	1.91	1.51	2.27	2.79	2.60	4.60
.1							1.17	.64	1.35	1.06	1.60	1.96	1.83	3.24
.09											1.51	1.86	1.73	3.06
.08													1.63	2.88
.07													1.52	2.69

TABLE NO. 16.—Continued.

Fall of Sewer, in Feet per 100 ft.	20-inch.		22-inch.		24-inch.		30-inch.		33-inch.		36-inch,	
	V	Q	V	Q	V	Q	V	O	V	Q	V	Q
10.	20.08	43.8	21.51	56.8	22.91	72.0	26.84	131.7	28.69	170.3	30.46	215.3
5.	[illegible]	30.9	15.20	40.1	16.19	50.9	18.97	93.1	20.27	120.4	21.54	152.3
4.	12.69	27.7	13.59	35.9	14.47	45.5	16.96	83.3	18.13	107.7	19.26	136.5
3.	10.98	24.0	11.77	31.1	12.53	39.4	14.69	72.1	15.70	93.6	16.68	118.0
2.	8.97	19.6	9.61	25.4	10.23	32.2	11.99	58.9	12.82	76.1	13.62	96.3
1.	6.34	13.8	6.79	17.9	7.21	23.3	8.48	41.6	9.06	53.8	9.63	68.1
.8	5.67	12.4	6.07	16.0	6.47	20.3	7.58	37.2	8.11	48.1	8.61	60.9
.6	4.91	10.7	5.26	13.9	5.60	19.6	6.57	32.2	7.02	41.7	7.46	52.7
.4	4.00	8.7	4.29	11.3	4.56	14.3	5.35	26.3	5.72	31.0	6.08	43.0
.2	2.81	6.1	3.01	7.9	3.21	10.1	3.76	18.5	4.02	23.9	4.28	30.2
.1	1.98	4.3	2.12	5.6	2.26	7.1	2.66	13.0	2.84	16.9	3.02	21.3
.09	1.87	4.1	2.01	5.3	2.14	6.7	2.51	12.3	2.69	16.0	2.86	20.2
.08	1.76	3.8	1.89	5.0	2.02	6.3	2.37	11.6	2.53	15.0	2.69	19.0
.07	1.64	3.6	1.76	4.6	1.88	5.9	2.20	10.8	2.36	14.0	2.51	17.7
.06	1.51	3.3	1.63	4.3	1.73	5.4	2.04	10.0	2.18	12.9	2.32	16.4
.05			1.48	3.9	1.58	5.0	1.86	9.1	1.99	11.8	2.11	14.9
.04			1.32	3.5	1.40	4.4	1.65	8.1	1.77	10.5	1.88	13.3
.03					1.20	3.8	1.40	6.9	1.52	9.0	1.62	11.4
.02					0.96	3.1	1.13	5.6	1.22	7.2	1.30	9.2

TABLE NO. 17.

Velocity and Discharge for Brick and Concrete Sewers (*n* = .015); Velocity in Feet per Second (*V*); Discharge in Cubic Feet Per Second (*Q*).

(For *n* = .013 add 19 per cent.)
(For *n* = .017 subtract 13 per cent.)

Fall of Sewer in Feet per 100 ft.	33-inch.		36-inch.		42-inch.		4-foot.	
	V	Q	V	Q	V	Q	V	Q
.5	17.17	102.0	18.27	129.2	20.37	196.1	22.36	281.1
.4	15.36	91.2	16.34	115.5	18.21	175.3	20.00	251.3
.3	13.30	79.0	14.15	100.0	15.77	151.8	13.31	217.6
.2	10.85	61.5	11.55	81.7	12.88	123.9	14.13	177.6
.1	7.68	45.6	8.16	57.7	8.90	87.6	9.99	125.6
.8	6.86	40.7	7.30	51.6	8.14	78.3	8.93	112.3
.6	5.94	35.2	6.32	44.6	7.04	67.8	7.73	97.2
.4	4.81	28.8	5.15	36.4	5.75	54.0	6.31	79.3
.2	3.41	20.3	3.63	25.7	4.05	39.0	4.15	55.9
.1	2.40	14.3	2.52	18.1	2.85	27.5	3.13	39.1
.09	2.27	13.5	2.42	17.1	2.70	26.0	2.97	37.3
.08	2.14	12.7	2.28	16.1	2.55	24.5	2.80	35.2
.07	2.00	11.9	2.13	15.0	2.38	22.9	2.61	32.9
.06	1.85	11.0	1.97	13.9	2.20	21.1	2.42	30.4
.05	1.68	10.0	1.79	12.6	1.95	18.8	2.20	27.6
.04	1.49	8.9	1.59	11.3	1.78	17.1	1.96	24.6
.03	1.28	7.6	1.37	9.7	1.53	14.7	1.68	21.2
.02					1.23	11.9	1.36	17.1
.15							1.16	14.6

TABLE NO. 17.—Continued.

Fall of Sewer. in Feet per 100 ft.	5-foot.		6-foot.		8-foot.		10-foot.	
	V	Q	V	Q	V	Q	V	Q
5.	26.05	512						
4.	23.30	457	26.34	745				
3.	20.17	396	22.81	645				
2.	16.47	323	18.62	527	22.53	1133	26.03	2045
1.	11.61	228	13.17	372	15.93	801	18.41	1446
.6	10.41	204	11.78	333	14.25	716	16.46	1293
.8	9.01	177	10.19	288	12.33	620	14.25	1119
.4	7.36	144	8.32	235	10.07	506	11.63	914
.2	5.19	102	5.87	166	7.10	357	8.21	645
.1	3.66	72	4.14	117	5.02	252	5.81	456
.09	3.47	68	3.92	111	4.76	239	5.51	433
.08	3.27	64	3.70	105	4.49	226	5.19	408
.07	3.05	60	3.46	98	4.20	211	4.86	382
.06	2.82	55	3.20	90	3.88	195	4.50	353
.05	2.57	50	2.92	82	3.54	178	4.10	322
.04	2.29	45	2.60	74	3.16	159	3.66	288
.03	1.97	39	2.24	63	2.73	137	3.17	249
.02	1.60	31	1.82	51	2.22	112	2.58	203
.015	1.37	27	1.56	44	1.93	97	2.23	175
.012			1.39	39	1.70	86	1.99	156
.010					1.55	78	1.81	143
.0095					1.25	63	1.77	139
.0090							1.72	135

MEASUREMENT OF THE FLOW OF STREAMS.

38. General Methods. For measuring the flow of a small stream the best method is by the use of a weir constructed of plank and built into a temporary dam of earth. Such weirs can readily be used for streams up to 3 or 4 feet in depth and 40 or 50 feet wide, although streams normally of such size would have flood flows many times greater and which could not be so measured. Where a dam already exists in a stream, observations of the flow over such a dam will give fairly good results when the coefficient of discharge is carefully selected as noted in Art. 25.

Where a weir cannot be used, then the flow must be measured by actually determining the mean velocity of the flow at a given

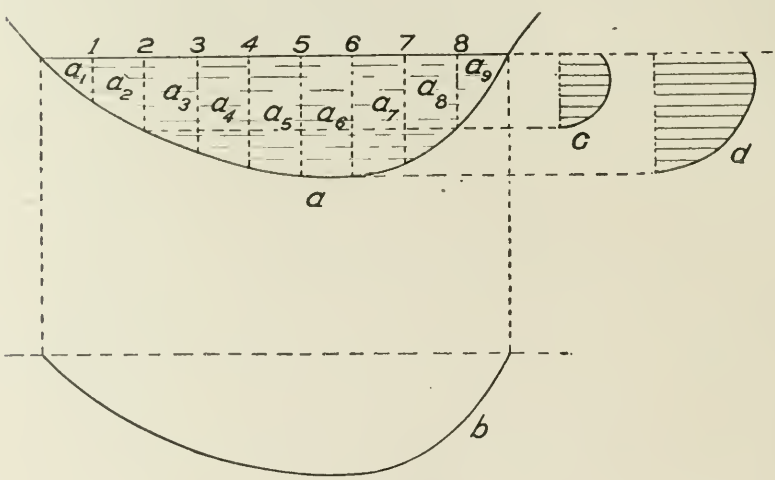


Fig. 30.

section and the area of such cross-section, then the discharge will be equal to the product of these quantities.

39. Variations in Velocity. Owing to the disturbing effect of the bottom and sides of a channel, the velocity of the water will not be the same at all points in a given cross-section. In general the velocity will be greater near the center of a stream than near the edges, and will be greater where the water is deep than where it is shallow. Thus if Fig. 30*a* represents the cross-section of a stream, the velocity of flow along the surface will vary in some such way as is represented in Fig. *b*, being greatest near the deepest parts and very small near the banks. Likewise if we consider the velocities along the vertical section 2 they will vary somewhat as shown in Fig. *c*, and at section 6 they will be as shown in Fig. *d*. In both Figs. *d* and *c* the maximum velocity is shown to be a little below the surface. This is usually the case, although it depends somewhat on the effect of the wind.

From these statements it will be seen that there are great variations in the velocity throughout the cross-section, and therefore the determination of the average velocity is not readily accomplished.

Instead of trying to get the average velocity through the entire cross-section, it is usual to divide the section of the stream into several vertical strips as shown in Fig. *a*. Then get the average velocity and discharge of each strip separately. In doing this a place should be selected where the flow is as uniform and the channel as regular as possible. In case floats are used to get velocities, as described later, it is necessary to establish two sections 100 feet apart or more, between which points the velocities are measured. In either case careful soundings must be taken and an accurate plot made of the cross-section, and the area of each division a_1, a_2, etc., determined. The divisions of the section may be marked by knots or tags on a rope stretched across the channel. The sections having been divided off, it remains to determine the average velocity in each.

40. **Use of the Current Meter.** The most accurate method of finding the velocity is by means of the current meter, one form of which is illustrated in Fig. 31.

The essential part of the current meter consists in the series of cups mounted on a wheel with vertical axis shown at the left of the vertical rod. This wheel being submerged, is rotated by the current, and the number of revolutions is recorded by an electrical device which may be held in a boat or on shore. The long vane attached to the wheel is to keep the meter always parallel with the current. A heavy weight is attached to the bottom of the rod to keep the meter steady, the whole apparatus being suspended by means of a rope from a boat or bridge. The number of revolutions per minute of the wheel being known, the velocity of the water at the wheel is calculated by multiplying by a coefficient determined by previous experiments with the meter.

The average velocity for any given strip is determined either by getting the velocity along the center of the strip at several different depths and taking the average, or by moving the meter slowly from top to bottom and then back to the top and taking a single reading. Whichever way determined the resulting velocity multiplied by the area of the strip in question equals the discharge of that strip. Then the total discharge equals the sum of the discharges of all the strips.

The coefficient to use in calculating actual water velocities

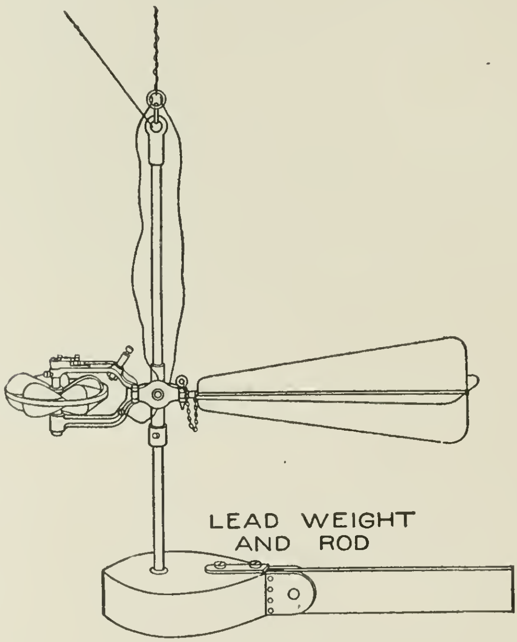


Fig. 31.

from meter readings is determined by a "rating" of the meter. This rating is done by moving the meter at various known velocities through still water in a reservoir, pond, or canal. Then knowing the velocity of the meter through the water and its readings, a rating curve or table of coefficients can be worked out.

41. Use of Floats. Very often a meter is not at hand, and a less accurate method must be employed. That most often used is by means of floats. These are of three kinds—*surface floats*, *subsurface floats*, and *rod floats*. The best form is the rod float.

The *rod float* is a rod of wood, or a tube of tin, which is weighted at one end so that it will float in an upright position and as near to the bottom of the stream as practicable. The float is then placed in the stream at the desired point, and far enough up stream from the upper of two measured cross-sections so that it will acquire the same velocity as the water by the time it reaches such section. The time of its passage from the upper to the lower section is then observed and its velocity deduced therefrom. In this way observations are made for each of the vertical strips in which the stream section is divided. The average velocity of each strip is taken equal to that of the rod itself.

The *surface float* may be made of any convenient form which will be readily seen from the point of observation. Its use will give only the surface velocities of the several strips and not the desired average velocities. To get the average velocity, we may use the approximate formula,

$$\text{Average velocity} = .9 \times \text{surface velocity} \qquad \textbf{(35)}$$

whence the discharge of the several strips can be calculated as before. This method is not so accurate as the use of rod floats and is not to be recommended except for very rough determinations. It is much influenced by the wind, and observations should, if possible, be made on still days.

Sometimes a very rough determination is desired from one or two measurements of velocity. If the surface velocity is measured at a point where it is a maximum (near the center of the stream), then the average velocity for the entire stream may be taken at about $\frac{8}{10}$ of the measured velocity, although the exact value of this coefficient will vary between quite wide limits. The discharge then equals the total cross-section multiplied by the average velocity.

The *sub-surface float* consists of a submerged body a little heavier than water that is attached by means of a fine cord to a surface float of much smaller size. The sub-surface float can be adjusted to float at any desired depth. By setting it at mean depth the observed velocity will be approximately the average velocity of the vertical strip. The use of such floats is not looked upon with much confidence. Rod floats are much better.

WATERWORKS PUMPING STATION AT ANDERSON, INDIANA

Here, in February, 1905, were carried out tests which finally demonstrated the possibility of the absolute removal from water of all disease germs of animal or vegetable origin, by means of a process using lime and sulphate of iron, with a small proportion of sulphate of copper. Over 40 cities in the United States have adopted this process for the purification of their water supply.

WATER SUPPLY.

PART I.

INTRODUCTION.

1. Historical. The earliest method of artificially obtaining a water supply was by the digging of wells. These were at first mere shallow cavities scooped out of the ground in low places; but it is interesting to know that the sinking of deep wells through rock dates from a very early period, the Chinese having been familiar with such work from very early times. Besides wells, other works for water-supply purposes were constructed by the Ancients, such as reservoirs, cisterns, aqueducts, etc.

The greatest development of waterworks construction in ancient times took place during the prosperous period of the Roman Empire, some of the finest works having been built at this time. To supply the chief cities of the empire great aqueducts were constructed, many miles in length, and there were in some cases several such aqueducts supplying a single city. Rome was at one time supplied from fourteen different aqueducts some of which had a length of 40 miles. The first of these was built about 312 B.C. and the last about 305 A.D. Some of the other cities which were well supplied with water at this time were Paris and Lyons in France, Metz in Germany, and Segovia and Seville in Spain.

The distribution of water in this age was by no means general. From the aqueducts the water first passed into large cisterns, and from these it was distributed through lead pipes to the fountains, baths and various public buildings, and to a few private consumers. The masses of the people were obliged to get their supply from public fountains. While the actual amount of water used by private consumers was not great the liberality of the supply for public purposes was so great that the total consumption was in many cases very high, some estimates making the consumption of water in Rome as high as 300 gallons per capita daily.

After the fall of Rome the entire subject of water supply was neglected for many centuries, and as one result, Europe was ravaged many times by terrible pestilences, due to polluted water. In some cases even the purpose for which the ancient aqueducts had been built was forgotten by the inhabitants.

The development of modern waterworks began in Paris and London as early as the beginning of the 17th century, but little progress was made until the application of steam to pumping engines, first made in London in 1761. Since 1800 the development has been very rapid, both in Europe and America.

The first works in America for the supply of water to towns were those of Boston, built in 1652. Machinery was first used for pumping water at Bethlehem, Pennsylvania, where the works were put into operation in 1754. The first use of the steam engine was at Philadelphia in 1800, and in New York steam was applied in 1804. The principal development in this country has taken place since 1850, about ninety-eight per cent of all existing works having been constructed since that time. Nearly all towns of 2,000 inhabitants or more now have a public water supply, and the construction of works is progressing rapidly in many smaller towns and villages. While there is more work yet to be done in this direction, the chief work of the future will be in providing increased supplies for the rapidly growing cities and towns of this country, in developing new and better sources of supply and in the improvement of the quality of the existing supplies. There is also much opportunity for the engineer in the management of waterworks, in the direction of reducing cost of operation, prevention of waste and in the improvement of service in many other ways.

2. Value and Importance of a Public Water Supply. The most important use of a public water supply is that of furnishing a suitable water for domestic purposes. For such use the prime requisite is that the water should be pure. The transmission of certain diseases such as cholera and typhoid fever by polluted water is now universally recognized, and the value to a city of a pure supply when compared to one constantly polluted by sewage can scarcely be overestimated.

Another highly important function of a water supply is that of furnishing the necessary flushing water for a sanitary system of drainage. The most satisfactory and economical method yet found for disposing of the organic wastes of a community is by the water-carriage system. Such a sewerage system is manifestly of but slight value to the public at large without the coexistence of a public water supply, as otherwise the necessary water for the flushing of closets—the most important function of a sewerage system—can be afforded by but few.

Besides furnishing an improved supply from the sanitary standpoint, a public works may often be made to furnish a water which for other reasons will be of greatly increased value to the domestic consumer; such as a soft water in place of a hard well water,—a point of very considerable importance to both domestic and commercial users.

A good water supply is also of great value to the manufacturing interests of a town. Many establishments, such as sugar refineries, starch factories, cleaning and dyeing houses, chemical works, etc., require an abundant water supply, and in some cases water of a high degree of purity. The question of water supply indeed often determines the location of factories. Large quantities are also used for operating elevators, for boiler purposes, and for many other uses that may be classed as commercial.

The most important public use of water supply is in extinguishing fires. The economic value of a good fire-protection system is directly shown in the reduced rates of insurance which follow its introduction or improvement. Instead of distributing a heavy fire loss among the people of a community through high rates of insurance it is assuredly much better economy to contribute to the maintenance of a public waterworks, which at the same time provides a suitable water for other purposes. To permit of the establishment of a certain class of factories it is absolutely essential that an efficient fire protection be furnished.

Other important public uses of a water supply are in street sprinkling and sewer flushing, in furnishing water for public buildings, and for drinking and ornamental fountains. A real value exists in the improved appearance which may be given a city by the use of water in fountains and for lawns and public parks; and, indeed, all the benefits accruing from a good water supply act indirectly to increase the desirability of a town for many purposes and to enhance the value of the property therein.

CONSUMPTION OF WATER.

3. **General Considerations.** When a new or enlarged water supply is under consideration one of the first questions to be answered is that relating to the quantity of water which will be required in the near future. The knowledge which is required includes not only the average daily quantity which will be needed, but also the monthly, daily, and hourly variation in the rate of consumption. In designing certain parts of the works the average consumption for the year is sufficient, but in certain other parts, such as pumps and distributing pipes, we need to know the greatest rate of consumption for a very short period of time.

There are many influences which affect the rate of consumption per capita of any given town or city. One of these is the actual population of the town. Thus in large cities the use of the public supply is almost a necessity, while in small towns and villages the private supplies may remain in use to a large extent long after the introduction of the public water supply.

The nature of the industries of a town is a large factor in determining the amount of water used; also the wealth and habits of the people, and the extent to which water is used for fountains, watering of lawns, street sprinkling, and other public purposes. Climate has also a very considerable influence, especially as to the amount used for sprinkling purposes and that which is wasted in winter to prevent freezing. It is probable, however, that the most important factors in determining the consumption is the degree of care taken to detect leakage or waste, and the fact as to whether the water is sold by measure or otherwise. Good quality, abundant quantity, and high pressure tend to increase the consumption by encouraging a more liberal use and often, at the same time, greater wastefulness.

4. **The Average Daily Consumption Per Capita.** In Table No. 1 are given the rates of consumption per capita for several American cities and towns in 1895.

It will be noted from Table No. 1 that a great variation exists in the rate of consumption in different cities and that the consumption in some of the cities is very high. For example, it is 271 gallons in Buffalo, New York, and 247 gallons in Allegheny, Pennsylvania. It will also be noted from a comparison of Tables No. 1 and 2 that the consumption is, on the average, much less in European than in

TABLE I.

Consumption of Water in American Cities and Towns.

City.	Population. 1900.	Daily consumption per inhabitant, 1895.
New York	3,437,202	100
Chicago	1,698,575	139
Philadelphia	1,293,697	162
Brooklyn	....	89
St. Louis	575,238	98
Boston	560,892	100
Cincinnati	325,902	135
San Francisco	342,782	63
Cleveland	381,768	142
Buffalo	352,387	271
New Orleans	287,104	35
Washington	278,718	200
Montreal	....	83
Detroit	285,704	152
Milwaukee	285,315	101
Toronto	....	100
Minneapolis	202,718	88
Louisville	204,731	97
Rochester	162,608	71
St. Paul	163,065	60
Providence	175,597	57
Indianapolis	169,164	74
Allegheny	129,896	247
Columbus	125,560	127
Worcester	118,421	66
Toledo	131,822	70
Lowell	94,969	82
Nashville	80,865	139
Fall River	104,863	35
Atlanta	89,872	42
Memphis	102,195	100

In Table No. 2 are given the rates of consumption for several European cities.

TABLE 2.

Consumption of Water in European Cities.

City.	Estimated population.	Daily consumption per capita, gallons.
London	5,700,000	42
Manchester	849,093	40
Liverpool	790,000	34
Birmingham	680,140	28
Bradford	436,260	31
Leeds	420,000	43
Sheffield	415,000	21
Berlin	1,427,200	18
Breslau	330,000	20
Cologne	281,700	34
Dresden	276,500	21
Paris	2,500,000	53
Marseilles	406,919	202
Lyons	401,930	31
Naples	481,500	53
Rome	437,419	264
Florence	192,000	21
Venice	130,000	11
Zurich	80,000	60

American cities. Both of these variations are due largely to the variation in practice in the use of meters to measure the water used and to charge accordingly. In some American cities meters are quite generally used, and without exception the consumption of water in those places is comparatively low. Meters are also generally used in European cities with the results as indicated in the table. It is true, however, that there is a greater general use of water for proper purposes in this country than in foreign countries.

5. Consumption of Water for Different Purposes. In studying the subject of the consumption of water it is desirable to consider the different uses of water under the following heads: (1) Domestic use; (2) Commercial use; (3) Public use; (4) Loss and waste.

(1) *Domestic Use.* Statistics collected from many sources where the supply has been actually measured by meter show that the amount of water used for domestic purposes will vary from about 15 to 40 gallons per capita; usually from 20 to 30 gallons. Where the supply is not metered, but is paid for according to the number and kind of fixtures in use, or the number of rooms in the house, the consumption may be several times the above figures. It has been known in some cases to go as high as 175 and 200 gallons per capita. Under these conditions it is difficult to predict what the consumption will be.

(2) *Commercial Use.* Under this head are included all uses for mechanical, trade, and manufacturing purposes. Large users of water for such purposes are office buildings and stores, hotels, factories, elevators, railroads, breweries, sugar refineries, and a few other industries. In large cities the use for commercial purposes is likely to be more than in small cities. Various statistics show a consumption for these purposes of 10 to 40 gallons per capita. The nature of the industries will determine very largely this item.

(3) *Public Use.* This includes the water used for schools and other public buildings, street sprinkling, water troughs and fountains, sewer flushing and the flushing of water mains, fire extinguishment, and a few other occasional uses. Water for such purposes is seldom measured, but the amount is not likely to exceed on the average a few gallons per capita, although the rate of consumption is far from being uniform. The water used for street-sprinkling purposes is likely to be quite a large proportion of the total, as much as 10 gal-

lons per capita being used in some places. The average is, however, not more than one or two gallons per capita. For fire purposes the total consumption is relatively small, but during fires the rate of consumption is very high for a short time. The total consumption for public purposes may be estimated from 3 to 10 gallons per capita.

(4) *Loss of Water.* The chief cause of waste is bad plumbing and carelessness on the part of the private consumer, but this source of waste has already been mentioned under the first item. There is in addition considerable waste due to leakage of mains and reservoirs and minor uses of water, not included under the foregoing. It is estimated that at least 15 gallons per capita should be allowed for this item.

From the foregoing analysis it may be concluded that a reasonable estimate of the consumption of water where meters are largely used will be about 40 gallons as a minimum and 120 gallons as a maximum; 75 or 80 gallons may be taken as a fair allowance under average conditions. Where meters are not used extensively the statistics in Table No. 1 show that 200 gallons per capita would not be an excessive figure, but it is impossible under such circumstances to make a very close estimate.

6. Variations in Consumption. The foregoing sections have discussed only the average consumption throughout the year. There will now be considered the variations which occur in the consumption from time to time.

Monthly Variations. In nearly all cases the rate of consumption reaches a maximum in the summer owing to the use of water for street and lawn sprinkling. This high rate usually extends over two or three months. A secondary maximum often occurs in the winter, due to the waste of water to prevent freezing, but the use of meters will largely prevent excessive variations from this cause. In extreme cases, however, the winter consumption may be very high. The monthly variations in consumption for several places are illustrated by the data given in Table No. 3.

From the table it may be concluded that the maximum monthly rate will seldom exceed 125 per cent of the average, it being in fact much below this figure for most places represented. Excessive consumption is likely to continue for two or three consecutive months, averaging for this longer period a rate of 110 to 115 per cent of the yearly average.

Daily Variations.—The maximum daily rate is usually estimated at about 150 per cent of the average. In Table No. 3 very considerable differences are to be noted in the ratios for different places, these being caused by a variety of conditions, some accidental and some constant.

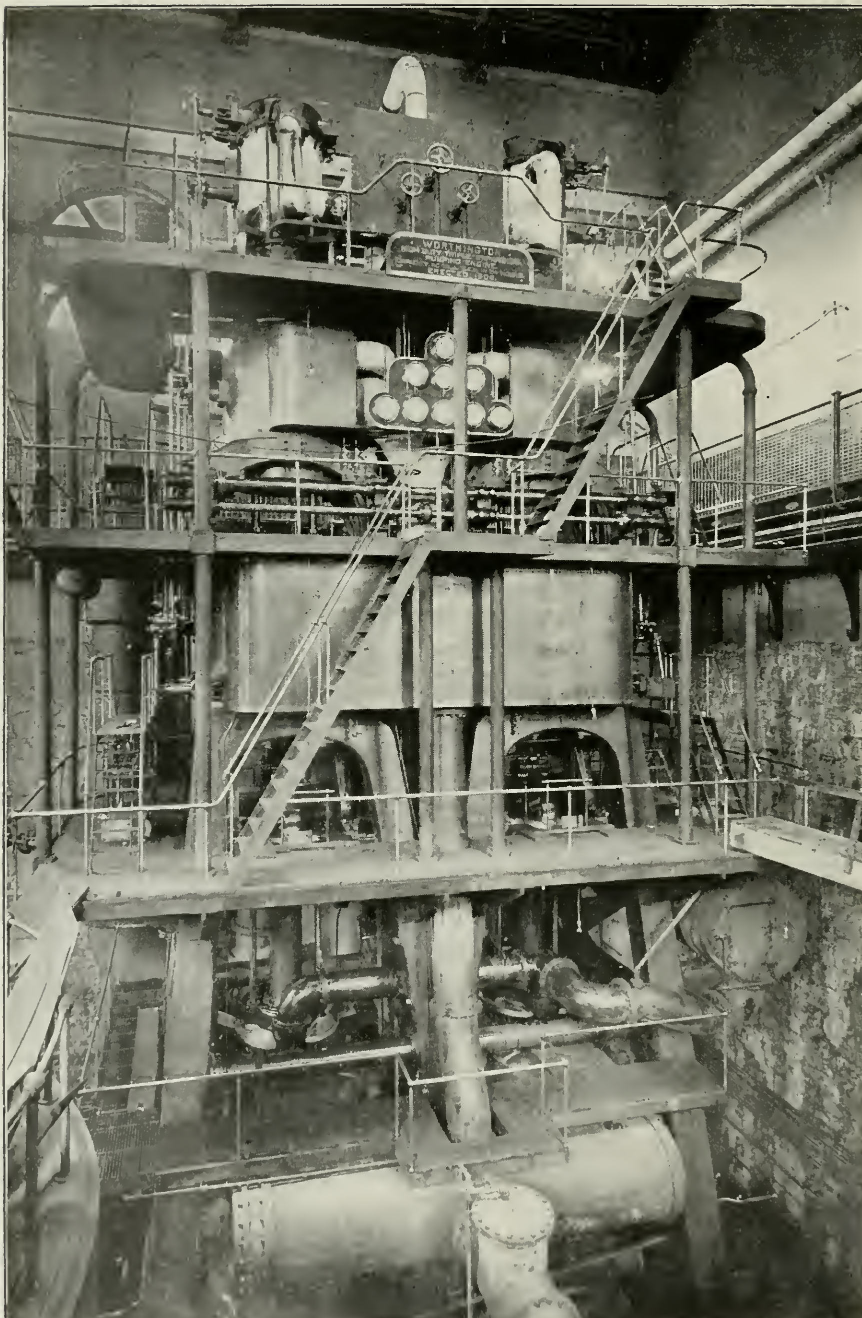
TABLE 3.

Maximum Monthly and Daily Ratios Expressed as Percentages of Average Consumption.

City.	Ratio of maximum monthly to average consumption.	Ratio of maximum daily to average consumption.	City.	Ratio of maximum monthly to average consumption.	Ratio of maximum daily to average consumption.
Chicago	108	116	Louisville	127	135
Philadelphia	110	122	Columbus	107	157
Boston	114	119	Fall River	115	......
Cincinnati	124	153	Dayton	118	178
Cleveland	111	146	Newton	125	143
Buffalo	......	168	Pawtucket	111	153
Detroit	117	150	Woonsocket, R. I.	122	155
Milwaukee	113	......	Marquette, Mich	139	194

The maximum daily rate will usually occur in the month of maximum consumption, and a rate considerably above the average for the month will occur for several consecutive days. Thus where the maximum daily consumption is 150 per cent of the average, the maximum weekly consumption is likely to be from 130 per cent to 140 per cent of the average, but for longer periods of time the rate will approach the monthly maximum.

Ordinary Hourly Variations. If there were no waste or leakage, the consumption during several hours of the night would be almost nothing and the consumption during several hours of the day would be two or three times the average for the twenty-four hours. It is a fact, however, that the rate of consumption at night is usually as much as 60 per cent of the average, and during the hours of maximum consumption it is not often more than one and a half times the average. Where waste is carefully prevented, and the consumption therefore low, the variation during the twenty-four hours will be relatively greater than where the waste is great and the total con-



WATERWORKS PUMPING ENGINE AT CENTRAL PARK AVENUE PUMPING STATION, CHICAGO, ILL.

Worthington pump; capacity, 40,000,000 gallons daily.

sumption great. Fig. 1 shows typical curves representing the hourly variation in consumption throughout the day. The curve for New York illustrates what occurs in a city where waste is fairly large, while that for Des Moines represents a case where consumption is small and the waste largely prevented. The average daily consumption per capita for New York was 100 gallons and for Des Moines 43 gallons.

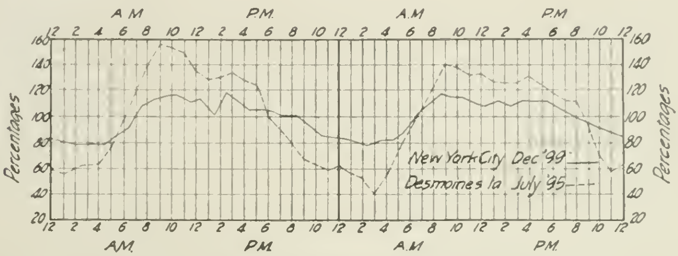


Fig. 1. Typical Curves Showing Hourly Variations of Water Consumption.

Consumption for Large Fires. The consumption for large fires must be considered in addition to the rates given above, The maximum rate of fire consumption in gallons per capita per day for a town or city of average character may be taken equal to $\frac{1000}{\sqrt{x}}$, where x = population in thousands. This is based on Mr. Kuichling's estimate of the required number of fire streams.

If, for example, the average consumption is 100 gallons per capita, then tne fire rate in per cent of the average will be as follows for different size cities:

Population.	Rate of fire consumption in percentage of average, when average equals 100 gallons per day.
1,000	1000 per cent.
5,000	447 "
10,000	316 "
50,000	141 "
100,000	100 "
200,000	71 "
300,000	58 "
500,000	45 "

For other values of the daily consumption the percentages would vary accordingly, being greater foi smaller consumptions. In the case of small cities the fire rate is evidently the principal factor to be considered; in large cities it is of much less relative importance. The duration of the above rate of fire consumption may be several hours; it has been estimated by Freeman at about six hours as a maximum.

The Combined Maximum Hourly Rate. In obtaining the total maximum rate of consumption at times of fires it is not necessary to assume that a great fire will occur coincident with the maximum use for other purposes. In fact, at times of great fires the use of water for many purposes would be interrupted. For average conditions the following may be taken as a reasonable allowance:

If the average daily rate is 100 per cent, then the maximum daily rate equals 150 per cent, and adding 20 per cent for increased consumption during day gives a total of 180 per cent. To this the fire consumption should be added by the use of the formula of the preceding paragraph.

Example. If the average daily consumption of a city of 20,000 inhabitants equals 80 gallons per capita, what will be the approximate maximum rate of consumption (a) for the day of greatest consumption, and (b), at the occurrence of a large fire?

From the foregoing discussion the maximum daily consumption may be estimated at 80×150 per cent $= 120$ gallons per capita.

From the above estimate the rate for ordinary use may be taken at 180 per cent of 80 gallons or $80 \times 180 = 144$ gallons. The fire rate $= \frac{1000}{\sqrt{20}} = 224$ gallons per capita. The total rate is therefore $144 + 224 = 368$ gallons per capita per 24 hours.

7. Growth of Cities. A necessary factor in any estimate of future consumption is that of future population. The rate of growth of different cities is exceedingly various, but of any one city it is likely to be fairly constant for several years, or at least will vary but slowly. The older and the larger the city the more uniform the rate of growth, and, barring national disasters, a fairly close estimate can be made for two or three decades in the future.

Probably the best way to estimate the population of a city for several years in the future is to take as a basis its growth in past years. If conditions do not change the per cent added each year or decade is apt to remain about the same. No one can predict closely the growth of a city, and in water-supply problems a close estimate is unnecessary.

Example. If the population of a city be 5,250 in 1880, 7,670 in 1890 and 11,400 in 1900, estimate the population in 1910.

The growth from 1880 to 1890 was 2,420; equal to 46 per cent, and from 1890 to 1900 it was 3,730, equal to about 49 per cent of the population in 1890. These figures show a steady growth, and it may be assumed that for the next decade the growth will be about the same, say 48 per cent. Then, 48 per cent of 11,400 = 5,472, and the estimated population in 1910 = 11,400 + 5,472 = 16,872.

The population for 1920 may be estimated in the same way, but the result will be much more uncertain than for 1910.

SOURCES OF SUPPLY.

8. Classification. The sources of water supply may be divided into the following classes, according to the general source and the method of collection:

A. Surface waters:
   1. Rain water collected from roofs, etc.
   2. Water from rivers.
   3. Water from natural lakes.
   4. Water collected in impounding reservoirs.

B. Ground waters:
   5. Water from springs.
   6. Water from shallow wells.
   7. Water from deep and artesian wells.
   8. Water from horizontal galleries.

Each of the above sources except the first and last is at present furnishing many cities in the United States with a more or less satisfactory water.

The following table gives the number of waterworks in 1896 obtaining their supply from the various sources indicated.

Region.	Surface waters.	Ground waters.	Total.
Northeastern States	615	511	1,238
Southeastern States	143	180	340
North Central States	193	469	715
Western States	329	662	1,063
Total	1,280	1,822	3,356

SURFACE WATER SUPPLIES.

9. Rainfall is the source of all water supply, whether it be caught as it flows over the surface or is first allowed to percolate into the ground to furnish water for wells and springs. The amount of rainfall is expressed in inches of depth upon a horizontal surface, snowfall being reduced to its equivalent amount of rainfall. With the ordinary rain gauge it is impracticable to determine rates of rainfall for short periods of time, the records usually obtained from these gauges being merely the total amounts of rainfall for each twenty-four hours. For estimating flood volumes from small areas, however, it is important to know the rate of rainfall for much shorter periods than one day. For this purpose self-recording gauges are essential, that is, gauges which give a continuous record of the rainfall or a record taken at such short intervals as to be for all practical purposes continuous. Various forms have been devised, some weighing the water, others recording by volume.

Rainfall statistics for a large number of stations can now be readily obtained from the monthly reports of the Weather Bureau. The data of importance in connection with water-supply questions are the mean yearly rainfall, the deviation from this in dry years, the monthly rainfall, and finally the maximum depth of rain falling in a single day or less.

10. **Mean Annual Rainfall.** The mean annual rainfall for a number of stations in the United States is shown in Table No. 4. The table also gives the ratio of the rainfall in the driest year, covered by the statistics, to the average.

The maximum rainfall is along a narrow belt of the North Pacific coast, where it considerably exceeds 60 inches. Towards the interior the amount rapidly falls off, and between the Sierras and the Rocky Mountains it ranges from 5 to 15 inches. East of the Rockies there is a gradual increase eastward and southward to a maximum along the Gulf of 60 inches, and from 40 to 50 inches on the Atlantic coast. The table also shows that in the driest years the rainfall is in most places only 50 to 60 per cent of the average. In the central and Western States the variation is greater than in the Eastern States.

The monthly distribution of the rainfall is of great importance in all questions relating to the utilization of water for power purposes or for the supply of cities. The rain falling in the summer months, when vegetation is using a maximum of water and evaporation is rapid, is of but little value for supplying water to the streams. It is the winter and spring rains which must largely be relied upon to fill reservoirs and to raise the low ground water to its normal level.

TABLE 4.

General Rainfall Statistics for the United States.

Station.	Mean yearly rainfall, Inches.	Per cent rainfall, driest year to mean rainfall.
Boston	45.1	60
New York	44.7	62
Philadelphia	42.3	70
Charleston	49.4	48
Jacksonville	54.1	71
Shreveport	48.2	67
Mobile	62.6	68
New Orleans	60.3	64
Vicksburg	52.7	70
Louisville	47.2	74
Cairo	42.6	62
Cincinnati	42.1	60
Cleveland	36.6	71
Marquette	32.3	69
Chicago	34.0	66
Milwaukee	31.0	66
St. Louis	40.8	55
St. Paul	28.2	53
Duluth	30.7	65
Omaha	31.4	57
North Platte	18.1	56
Denver	14.3	59
Salt Lake City	18.8	55
Spokane	18.6	73
Santa Fe	14.6	53
Yuma	2.8	25
San Diego	9.7	30
Los Angeles	17.2	33
San Francisco	23.4	51
Portland	46.2	67

11. Maximum Rates of Rainfall. In estimating the maximum flood discharges of small streams—a matter of very great importance in the design of dams and reservoir embankments—it is desirable to know the maximum rates of rainfall for periods of a few hours or a single day. Great rainstorms occur but rarely, but in hydraulic works where a failure would mean not only the destruction of property but often a great loss of life, it is necessary to provide against the greatest flood ever likely to occur. Accurate data of such floods must be based on many years of observation, but extraordinary rainfalls are likely to occur almost anywhere, and it may be assumed that what has happened in one locality may happen at any place in the same region. Examination of the data contained in the United States Weather Bureau Reports shows that in the Northern and Central States a rainfall at the rate of 4 inches for one hour and 8 inches for 24 hours represents the greatest rain likely to occur; in the South Atlantic and Gulf States these figures should be about 4 inches for one hour and 10 inches for 24 hours.

That excessive rainfalls are of sufficient extent to cover areas of such size as are ordinarily considered in water-supply problems is shown by the statistics of great storms. In October, 1869, a great storm occurred in the eastern part of the United States, with its maximum intensity in Connecticut. A careful analysis of the records made by Mr. James B. Francis shows the areas covered by different depths of rain to have been as follows:

Depth of rain.	Area covered.
6 inches or more	24,431 square miles.
7 " " "	9,602 " "
8 " " "	1,824 " "
9 " " "	1,016 " "
10 " " "	519 " "
11 " " "	179 " "

The following are some of the maximum rates observed in this storm:

4.00	inches in	2	hours.
4.27	"	3	"
5.86	"	18.5	"
7.15	"	24	"
8.90	"	30	"
8.44	"	42	"

FLOW OF STREAMS.

12. When a stream is under consideration as a source of water supply, the peculiarities of its flow—the minimum, maximum, and total flow for various periods of time—are among the first things to be determined. The most accurate as well as the most direct method of determining these is by means of a series of gaugings extending over several years, but, where gaugings are not to be had, or where they are very limited in extent, as close an estimate as possible must be made from a comparison with other streams whose flows are known, taking into account as far as may be the differences in rainfall, climate, and in the various characteristics of the different watersheds.

Rainfall is expressed in inches in depth, and the rate in inches per hour or per twenty-four hours; and for comparative purposes stream flow is often likewise expressed, meaning thereby inches in depth over the entire watershed. For other purposes the flow is usually expressed in cubic feet, or cubic feet per square mile of watershed, and the rate of flow in cubic feet per second, or cubic feet per second per square mile. The foot and second units are also convenient to use in all hydraulic formulas, but in matters pertaining to storage and distribution the gallon unit is in common use, and rates are expressed in gallons per minute and gallons per twenty-four hours.

For convenience in computations relative to rainfall and flow of streams, the following table is inserted:

TABLE 5.

Volumes and Rates of Flow in Feet and Seconds Corresponding to Given Volumes and Rates of Rainfall in Inches and Hours.

Depth in inches.	Cubic feet per square mile.	Inches per hour.	Cubic feet per second per square mile.	Inches per 24 hours.	Cubic feet per second per square mile.
0.1	232,320	0.1	64.5	1	26.9
0.2	464,640	0.2	129.0	2	53.8
0.3	696,960	0.3	193.5	3	80.7
0.4	929,280	0.4	258.1	4	107.5
0.5	1,161,600	0.5	322.6	5	134.4
0.6	1,393,920	0.6	387.1	6	161.3
0.7	1,626,240	0.7	451.7	7	188.2
0.8	1,858,560	0.8	516.2	8	215.1
0.9	2,090,880	0.9	580.7	9	242.0
1.0	2,323,200	1.0	645.3	10	268.9

One inch of rain = 2,323,200 cu. ft. per sq. mile.
One inch per hour = 645.33 cu. ft. per sec. per sq. mile.
One inch per 24 hours = 26.89 cu. ft. per sec. per sq. mile.
One cubic foot = 7.4805 U. S. gallons.
One cubic foot per sec. = 646,300 gallons per day.

The question of the flow of streams naturally divides itself into three parts:

First, the minimum flow of the stream.

Second, the maximum or flood flow.

Third, variations in the flow through successive months and years.

The first information is necessary in case a stream is under consideration for which but little storage is obtainable, or in answer to the question whether it is practicable to draw directly from the stream without storage. The second is of great importance in the design and execution of all river work, and especially in determining the size of waste weirs. The third determines the supplying capacity of the watershed and the size of impounding reservoirs.

EXAMPLES FOR PRACTICE.

1. If a rain is falling at the rate of $\frac{1}{2}$ inch per hour, how many cu. ft. per sec. will this amount to over an area of 10 sq. mi.? 3,226 cu. ft. per sec. Ans.

2. If 1 inch of water is collected from an area of 20 sq. mi., how many days will this supply a town of 15,000 inhabitants using 100 gallons per capita daily?

The total amount of water collected = 2,323,200 × 20 = 46,-464,000 cu. ft. = 347,500,000 gal. This will last 231 days. Ans.

13. The Dry-Weather Flow. The dry-weather flow of streams is maintained entirely from ground and surface storage; and as facilities for such storage vary in different watersheds, so will the minimum flow vary.

In Table No. 6 are given the minimum flows of several streams in different localities. It will be seen that the minimum varies greatly with the size of the stream and locality, and that streams of several hundred square miles of drainage area may have a minimum of zero.

TABLE 6.

Minimum and Maximum Flow of Streams.

Stream.	Place.	Drainage area. square miles.	Minimum flow. cubic feet per sec. per sq. mile.	Maxim'm flow. cubic feet per sec. per sq. mile.
	New England.			
Merrimack	Lawrence	4,599	0.31	20.87
Connecticut	Hartford	10,234	0.51	20.27
Nashua	Massachusetts	109		104.5
Sudbury	Massachusetts	78	0.036	44.2
	New York.			
Chemung	Elmira	2,055		67.1
Croton West Br.		20.37	0.016	54.43
	New Jersey.			
Delaware	Stockton	6,790	0.17	37.5
Pequannock		48		115
	Pennsylvania.			31.9
Perkiomen	Frederick	152	0.39	
South Fork	Dam in Creole Township	48.6		215
	Maryland.			131
Potomac	Cumberland	1,361	0.018	
	Illinois.			
Rock	Rockford	6,500	0.0158	
Des Plaines	Riverside	630	0	21.4

14. Flood Flow. The maximum rate at which the waters from great storms will pass down a stream is affected largely by the steepness of the slopes, by the size and shape of the drainage area, and by the distribution of the branches. Small areas will have larger maximum rates of flow than large areas, other things being equal, as the former are affected by short rainfalls of high rates, while in the latter case the maximum flows are caused by rains of longer duration but of less intensity. For a like reason streams with steep slopes will have a higher maximum rate than those with flat slopes.

Of great importance in distributing the run-off over a long interval of time, and so reducing the maximum rate, is the surface storage of natural lakes and ponds and of those created by the inundation of large flats bordering the stream. The effect of this last factor may be sufficient to reduce the flood flow to one-half or one-fourth that of a stream with a narrow valley.

In Table No. 6 great variation in the maximum flow is observable, due partly to the varying rates of rainfall, but largely to the different characteristics of the streams. Various formulas have been proposed for expressing the maximum flow of a stream, some involving only the rainfall and area, while others attempt to take account also of the slope and shape of the watershed.

Among the most widely known of this class of formulas is that given by Fanning and recommended by him as applicable to average New England and Middle-State basins. It is

$$Q = \frac{200}{\sqrt[6]{M}} \qquad (1)$$

in which Q = discharge in cubic feet per second per square mile and M = area in square miles. It gives results probably somewhat too low for small areas.

Example. What will be the flood flow according to formula 1 for a drainage area of 10 square miles?

The flow will equal $\frac{200}{\sqrt[6]{10}}$ = 136 cu. ft. per sec. per sq. mi.

TABLE 7.

Statistics of the Yearly Flow of Streams.

Stream.	Area drained, square miles.	Average yearly flow.		Dry year flow.	
		Rain, inches.	Flow, per cent of rainfall.	Rain, inches.	Flow, per cent of rainfall.
Cochituate	18.87	47.08	43.2	31.20	31.3
Croton	338.0	48.38	50.8	38.52	37.8
Genesee	1,060	39.82	32.5	31.00	21.5
Perkiomen	152	47.98	49.2	38.67	40.4
Potomac	11,043	45.47	52.7	37.03	39.2
Savannah	7,294	45.41	48.9	43.10	37.7
Upper Mississippi	3,265	26.57	18.4	22.86	7.1

15. Annual Discharge. Table 7 gives some statistics of the annual flow of streams as compared to rainfall. It will be seen that in the dry years the percentage running off is much less than in the average year. From these data and other statistics it is estimated that for a stream of average conditions east of the Missouri and Mississippi Rivers the percentage of rainfall flowing off for different annual rainfalls is about as follows:

Rainfall, inches.	Per cent running off.
20	25 to 35
30	30 to 40
40	35 to 45
50	40 to 50

In the nature of the problem there is a wide variation in percentage due to variations in the conditions of the watershed, climate, etc. Whatever tends to promote evaporation from the watershed decreases the run-off. Thus a watershed with a large percentage in grass will yield a less amount than one with rocky and barren hillsides; one with a large percentage of water surface, less than one with a small percentage. Again, the higher the temperature the greater the evaporation and the less the stream flow. Steep, rocky hillsides will give a large per cent of the rainfall to the streams, but the flow will be very irregular; flat grass lands will give little or nothing to the streams during the season of growth. All these things must be considered in estimating the flow of a stream from rainfall data and from statistics of the flow of other streams.

Examples. Estimate the flow of a stream during dry years where the average annual rainfall is known to be 40 inches.

The rainfall for a very dry year may be taken from Table No. 4 at say 60 per cent of the average or 40 × .60 = 24 in. For a rainfall of this amount the per cent running off will probably be between 25 and 35. If this is an average watershed we may put it at about 32 per cent. The run-off will then be estimated at $24 \times .32 = 7.7$ inches.

Note. The wide variation in percentage indicates that such estimates as this are very uncertain. Actual stream measurements are the only safe guide.

2. How much water can probably be collected in a dry year from an average watershed where the rainfall in very dry years is 30 inches?

By the estimates of section 15 it is probable that at least 33 per cent will run off or can be caught in a reservoir. This amounts to $30 \times .33 = 9.9$ inches.

By Table No. 5 this amounts in gallons per sq. mi. to $9.9 \times 2{,}323{,}200 \times 7.48 = 172{,}000{,}000$ gallons.

16. Monthly Variation in Stream Flow. During dry years very little water can be collected from summer rains. Dependence must be had on winter snows and spring rains for filling storage reservoirs and nearly all the yearly supply will be caught in the months from December to May inclusive. During average seasons a large proportion of the stream flow occurs in the summer months. Generally about three-fourths of the yearly flow occurs in the months from December to May and only one-fourth from June to November, whereas in very dry years the summer flow may be considered as practically nothing.

17. Quality of Surface Waters. Surface water supplies are drawn from two general sources—rivers and lakes. River supplies may be divided into those obtained directly from large rivers and those obtained from impounding the flow of small streams in reservoirs. The quality of surface waters may be considered with reference to: (1) appearance, (2) mineral content, (3) the presence of disease-producing organisms.

(1) The appearance of a water is affected by the presence of clay and sand in suspension, rendering the water turbid, and by certain vegetable material giving the water a distinct color. Turbidity varies according to the nature of a watershed. While a turbid water is very objectionable for household use it cannot be said to be actually dangerous. Turbidity is removed by allowing the water to rest in

reservoirs, thus permitting the clay to settle, or by passing the water through filters. Surface waters flowing through swampy regions are usually colored, due mainly to the extraction of soluble coloring matter from vegetable material. Such peaty waters, while perhaps unsightly in appearance, may be, however, perfectly wholesome in spite of this physical defect.

(2) While flowing surface waters do not dissolve so much mineral matter as ground waters, yet they take up an appreciable amount, depending considerably on the character of the soil over which they pass. A large part of the mineral content is usually carbonate of lime. In general surface waters are preferable to ground waters as regards their mineral content, a hard water (one containing lime) being less desirable for culinary and manufacturing purposes.

(3) The most important question relating to the quality of a water is whether it is dangerous to the health. It has been well demonstrated that certain diseases, particularly cholera and typhoid, are caused by certain minute organisms called bacteria. These inhabit the intestinal tract of persons sick with the disease and are present in enormous numbers in the sewage wherever these diseases exist. Whenever such sewage or drainage gets into the water supply of any town an outbreak of the same epidemic is sure to appear. Many cases are on record of whole villages being affected through the contamination of the water supply by a single diseased person. From such facts it is seen that the quality of a water supply from this point of view is exceedingly important.

A surface water supply can be absolutely safe only when it is drawn from an uninhabited area. A few scattered farm houses, if not located too near a water course, are not likely to cause serious pollution. But where the watershed is quite populous, and especially where villages are located in the valleys, the danger of the transmission of disease through the water supply is very great.

The danger in the use of water from a large stream depends on the amount and nearness of the pollution. All large streams receive more or less drainage from towns and cities, but if such pollution is relatively small and remote the danger is small. As a rule a surface water supply is not free from danger unless the water is artificially purified by some adequate means, but many large cities in the United States continue to use water supplies which are badly contaminated.

The result of such use is shown in the relatively high death rate from typhoid fever in such places.

The quality of lake supplies is likely to be better than that of rivers. Such water is usually quite free from turbidity, as the sediment brought into it by the tributary streams soon settles; and unless polluted by sewage in the immediate neighborhood, it is likely to be relatively safe from a sanitary point of view. Experiments show that in the settling of the clay and sand particles, the bacteria settle to a great extent, and a marked purification takes place in a polluted water. For the same reason that lake water is better than river water, it is true that a supply from a small stream is usually improved by storage in a large storage reservoir. Sometimes, however, vegetable growths occur in reservoirs which give to the water a disagreeable odor.

GROUND WATER SUPPLIES.

18. Occurrence of Ground Water. The rain which falls upon the ground is disposed of in three ways: A part flows off immediately in the streams, a part is evaporated from the ground and vegetation, and a part percolates into the soil.

Percolating water that escapes beyond the reach of vegetation must, in obedience to the law of gravitation, pass on downward until it reaches an impervious layer of some sort. The immediate impervious stratum is the surface of the water which has preceded it and which has in past ages filled every pore and crevice of the earth's crust up to a certain level at which the escape of the water laterally becomes equal to the addition from percolation. The accumulation of water which thus exists in the ground is called *ground water,* and its surface the *ground-water level* or the *water table.*

In limestone regions it is sometimes the case that quite large streams are found flowing underground, and large cavernous spaces may be converted into underground lakes of considerable size, as in the great caverns of Indiana and Kentucky. Such bodies of water are, however, rarely available for a water supply, and it may be taken as a safe rule for ground-water supplies dependence must be placed upon the water which percolates into and flows through the pore-spaces in soils and rocks, the amount of which is strictly dependent upon the rainfall and the laws of hydraulics that govern the flow.

19. General Form of the Water Table. Under the action of gravity the surface of the ground water always tends to become a level surface, and as long as a supply is maintained through percolation there will be a continual downward and lateral flow which will on the average be equal to the percolation. In surface streams a very light inclination is sufficient to cause a rapid movement of water, but in the ground the resistance to movement is so great that a steep gradient is necessary to maintain even a very low velocity.

If we imagine the ground to be throughout of uniform porosity, the ground-water surface will conform in general outline to the ground surface, but with less variations. Such an ideal condition is represented in Fig. 2. At the margin of streams as at A and B the level

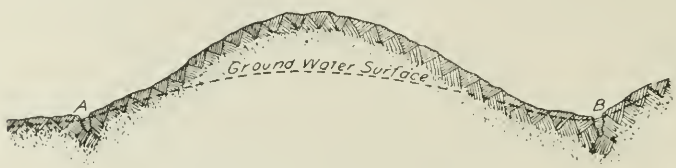


Fig. 2. Relation of Ground Water to Surface Water.

of ground and surface waters will coincide. Passing back from the stream the ground-water level will gradually rise, but at a less rate than the ground surface, then descend again into another depression, etc. In the valley there is also a fall parallel to the stream, corresponding to that of the surface water, and the direction of flow will be towards and slightly down the stream in the line of greatest slope.

Variations in ground-water level take place comparatively slowly, following gradually the variations in yearly, seasonal, and briefer periods of rainfall. Near streams and in lowlands the level varies little, being fixed largely by the level of the adjacent surface water. At higher points in the water table the level is subject to correspondingly great fluctuations, often many feet in extent. In porous material where slopes are small the variations are small.

20. Porosity of Soils. All soils and rocks near the surface of the earth are capable of absorbing more or less water. In sand of a fairly uniform size the porous space is commonly from 35 to 40 per cent of the entire volume. Mixed sand and gravel will have a smaller percentage of voids, the decrease depending on the variation in size of particles, but it will seldom be less than 25 per cent. Rocks will vary in porosity from a very small fraction of 1 per cent in the case of some granites to 25 or even 30 per cent for some loose textured sandstones.

The amount of moisture which a soil or rock will absorb is, however, not of so much importance to the water-works engineer as is the carrying capacity and the amount which can readily be drawn from such material when previously saturated. In fine soils the movement of the water is so slow and such a large part of the water is retained by capillary action that such soils are of little value as carriers of water; and to obtain economically the large quantities required for public supplies it is necessary that the water-bearing material be of a very open, porous character. Adequate supplies are rarely obtained from anything but sand and gravel deposits, or from very porous rock. The most favorable formations for furnishing large quantities of water, are the various sandstones, conglomerates, and gravel deposits. Sandstones are found which vary in texture from a very compact rock having a very small degree of porosity to a material almost as porous as sand. Uncemented sands and gravels are of course the most favorable as regards porosity, but they are apt to be rather limited in extent.

21. The Flow of Ground Water. It has been explained in the previous section that the water in the ground has in general a slow rate of flow through the ground. Where a supply of ground water of considerable amount is to be obtained this rate of flow is of much importance. To get water from a ground-water "stream" is exactly similar to the taking of water from a surface stream; in both cases the flow of water in the stream must be at least equal to the proposed draught or the supply will be inadequate. The notion is quite common that in many places the water in the ground is inexhaustible. This is an entirely mistaken idea as is well illustrated by the gradual failure of many ground-water supplies.

Ground water in large quantities is usually obtained either from large gravel deposits of comparatively small depth, forming broad underground streams, or from extensive deposits of porous rock like sandstone, the latter source being tapped by deep wells many of which are the well known "artesian" wells. In the case of a gravel deposit near the surface it is often possible to estimate the quantity of water actually flowing through a given section of the deposit.

The best method of estimating capacity of a ground-water source is by means of actual pumping tests carried on for a sufficient length of time to bring about an approximate state of equilibrium between the supply and the demand which will be shown when the level of the water in the trial well ceases to lower. It will rarely be practicable to continue such tests until perfect equilibrium is reached, for in many cases several years of operation would be required to determine the ultimate capacity of a source. Pumping tests of short duration are apt to be very deceptive, as the ground water may exist in the form of a large basin or reservoir with very little movement, corresponding to a surface pond with small watershed, and brief tests would give but little more information than similar tests on a pond.

Where it can be done it is very desirable to get an approximate idea of the amount of water actually flowing per unit of time through the area in question.

To do this we must estimate the velocity of flow, the cross-section of the porous stratum containing the water, and the percentage of porous space.

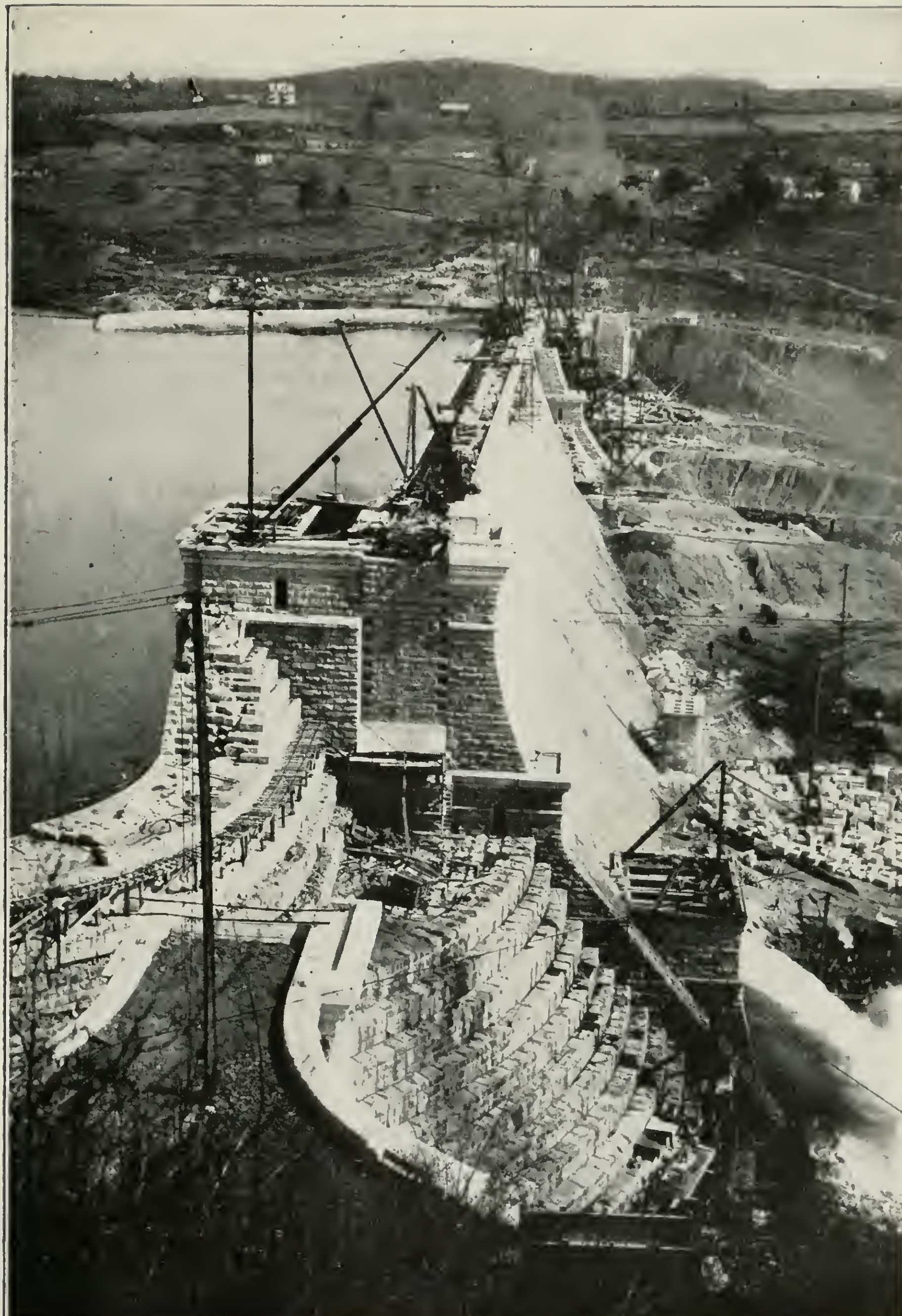
The rate of flow of ground water streams is very small compared to that of surface streams. It depends on the slope or inclination of the ground and upon the size of the grains of sand or gravel through which it passes. The following table shows about what the velocities are likely to be for various slopes and conditions of soil.

TABLE 8.

Velocities of Flow of Ground Water in Feet Per Day.

Material.	Slope of ground, feet per mile.					
	10	20	30	40	50	100
Fine Sand	0.2	0.4	0.6	0.8	1.0	2.0
Medium Sand	1.5	3.0	4.5	6.0	7.5	15.
Coarse Sand	4.0	8.0	12.0	16.0	20.	40.
Fine Gravel, free from sand . . .	20–40	40–80	60–120	80–160	100–200	200–400

The velocity of flow having been determined it remains to estimate the actual quantity of water flowing through a given territory. Of the total volume of a body of sand or gravel, the water will occupy only about 25 to 30 per cent. The actual volume of



NEW CROTON DAM UNDER CONSTRUCTION

Largest masonry dam in the world, part of the waterworks system of New York City. Took 14 years to build, requiring about 850,000 cu. yds. of masonry. Completed in 1906. Cost, $7,700,000. Length, 2,400 feet; height, 301 feet; thickness, 216 feet at base, tapering to ten feet at top of spillway (at left) and 21 feet at top of main dam. Capacity, 30,000,000,000 gals., and with auxiliary dams, 100,000,000,000 gals. Water at dam, 160 feet deep, the impounded river forming a lake 20 miles long and 2 miles in extreme width, burying under 30 feet of water the old dam 3 miles upstream.

water, therefore, which will pass through a given section will be only 25 or 30 per cent of the amount were it solid water. If v = velocity of flow in feet per day, A = area of cross-section of the porous bed at right angles to the direction of flow, then assuming a porosity of 25 per cent or $\frac{1}{4}$th, the actual volume of flow per day will be in cubic feet

$$Q = \tfrac{1}{4}\,vA \qquad (2)$$

Thus suppose we have a porous bed of coarse sand in which the water is 10 feet deep, the bed is 500 feet wide and slopes 20 feet per mile. The velocity of flow by Table 8 may be taken at about 8 feet per day. The cross-section A = 10 × 500 = 5,000 square feet. Hence the volume of flow will be approximately $\frac{1}{4} \times 8 \times 5{,}000 = 10{,}000$ cubic feet per day, or about 75,000 gallons. This being the total rate of flow through the sand it is evidently the greatest amount of water that could be extracted from this sand deposit by means of any system of wells or other devices. To give the above results the bed must be of considerable length and the water in it must be about the same depth throughout and have the same slope as the surface.

SPRINGS.

22. Formation of Springs. Springs are formed where, for any reason, the ground water is caused to overflow upon the surface. The conditions causing their formation are varied and should be carefully studied in connection with the design of collecting-works, as upon them depend largely such questions as the constancy of flow, the possibility of increasing the yield by suitable works, and the probable success of a search for additional springs. According to differences in these conditions springs may be divided into three general classes, each of which will be discussed separately.

First Class. The most important class of springs is that in which the water, in its lateral movement, is brought to the surface at the outcrop of a porous stratum where it is underlain by a relatively impervious one. Fig. 3 represents such conditions, the ground water escaping at the outcrop of the impervious material thus forming a spring. The porous stratum may be sand or gravel, or a porous rock; while the impervious layer is usually clay, or rock of an argillaceous character.

There are many cases of large springs of this class, the supplies for some of the largest cities of Europe being obtained from such sources. The city of Vienna is supplied from springs 60 miles distant that occur at the outcrop of a fractured dolomitic limestone underlaid by slate. The largest spring, the Kaiserbrunnen, has an average flow of about 150 gallons per second, varying from 60 to about 250.

Second Class. Under this class are considered those springs where the water-bearing stratum is covered to a greater or less extent by an impervious one, and which are therefore more or less artesian in character. In this case the water finds its way to the surface

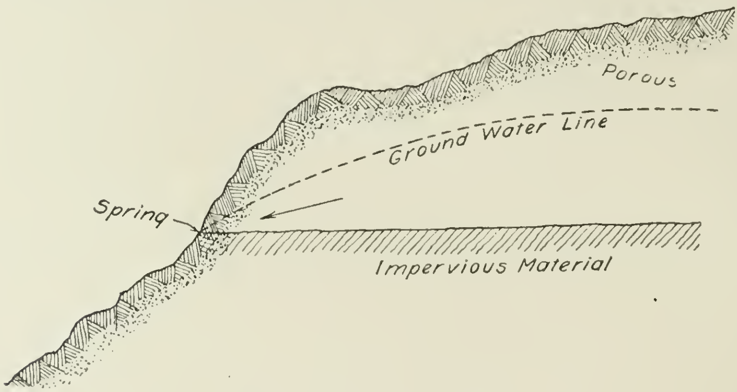


Fig. 3. Formation of Springs.

where the overlying impervious material is broken, or through a fault, or it breaks through at places where it is not sufficiently strong or compact to resist the upward pressure.

In some cases springs of this character are fed by water coming long distances through extensive formations which at other points offer conditions favorable for artesian wells. Conditions of this sort give rise to the peculiar phenomenon of large fresh water springs which boil up in the ocean several miles out from the Florida coast, and it is supposed that the great springs in northern Florida are from a similar cause.

Third Class. The third class of springs are mere overflows of the ground water, and occur whenever the carrying capacity of the porous material is insufficient to convey the entire tributary flow. Such conditions also give rise to marshy places at the foot of hills and even on side hills.

23. The Yield of Springs. The yield of any particular spring can readily be determined by weir measurements, and if these are carried out through a period of drought they will give all needed information regarding the supplying capacity of the existing spring.

Springs of the first class will vary in yield with the variations in ground-water level and, therefore, will vary with the rainfall, but will not wholly cease to flow if the water is intercepted by suitable constructions.

Springs of the second class are apt to be much less affected by variations in rainfall than either the first or the third class.

Where a spring of this class exists, investigation may show that the ground-water stream from which it is fed is of considerable size and that the water of the spring is but a small portion of the entire flow. In such a case the yield may be increased by simply enlarging the opening, or by sinking wells and pumping therefrom, as in the case of an ordinary ground-water supply.

Springs of the third class are liable to very great fluctuations, the flow often ceasing entirely.

ARTESIAN WATER.

24. General Conditions. Whenever a water-bearing stratum dips below a relatively impervious one the former becomes in a sense a closed conduit or pipe, and if the flow out of this conduit at the lower end be impeded from any cause, the water will accumulate and exert more or less pressure against the impervious cover The amount of this pressure will depend on the extent to which the flow is obstructed and on the elevation of the upper end of the conduit, that is, of the outcrop of the porous stratum. If a well be sunk through this impervious stratum at any point, the water will rise in it in accordance with the pressure; and if the surface topography and pressure are favorable, the water may rise to the surface, or considerably above, in which case the well becomes a true artesian, or flowing, well.

Fig. 4 shows an ideal condition for artesian or flowing wells. If A B is a porous stratum outcropping at A and B and covered by an impervious stratum of clay or impervious rock, water entering at A could escape at the lower end B, but at intermediate points would exert a pressure on the covering. If the resistance to flow were uniform, and no water could escape except at B, the decrease of head from A to B would be uniform, or in other words the hydraulic grade line would be a straight line A B. Water would rise to this line in a tube sunk to the porous stratum, and a flowing well would be possible wherever the surface of the ground lies below this line.

Actual conditions may be much modified from those represented in Fig. 4, as where the water is prevented from flowing out at B by reason of an increased density of the stratum or by the stratum becoming thinner. The effect in causing the water to exert an

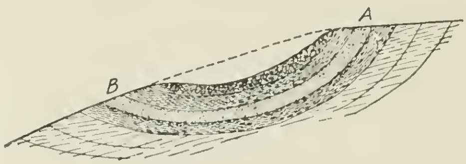


Fig. 4. Dip in Water-Bearing Stratum.

upward pressure is, however, the same. The water-bearing stratum is most often a porous sandstone, although artesian water is also obtained from limestone and in many places from extensive strata of loose uncemented material.

The overlying impervious strata usually consist of clays and shales, these being practically impervious except where fissured. Probably some leakage always takes place through such strata; and many instances are known of large springs which occur at points where the overlying stratum is broken as noted in the preceding section. Except in the case of very limited areas, the capacity of an artesian source as a whole is a question of little importance where it is to be used only for water-supply purposes in towns widely separated; for the total amount of water capable of being drawn from porous rock strata, often hundreds of feet thick and having an outcrop of hundreds or thousands of square miles, is ordinarily very great as compared to any possible demands for such purposes. But wells sunk to tap an artesian stratum must not be placed too close together else they will interfere with one another and the yield per well will be reduced.

25. Predictions Concerning Artesian Wells. The question of the existence of water-bearing strata at any point, their character and depth, and the location of outcrops, is a geological one;

and where full information on this point has not been gained by the sinking of wells or by borings, a geologist familiar with the region in question should be consulted. Much money has often been wasted in fruitless attempts to obtain water in areas and at depths where none could be expected, and frequently such work has been carried on contrary to the advice of experts.

In the construction of wells it is important to preserve samples of the borings, as it is largely through these that a knowledge of the geology of the region is acquired. Chemical analyses of the water are also a valuable aid in identifying strata.

QUALITY OF GROUND WATER SUPPLIES.

26. The quality of ground waters is, in general, quite different from that of surface waters. By percolating through the ground, practically all suspended matter is filtered out, and ground waters are usually clear and sparkling. At the same time this very filtration process causes the water to dissolve more of mineral substances, and the result is that ground waters usually contain much more mineral matter than surface waters. In a limestone country the ground water will be hard, as it will contain lime, and where the soil contains alkali the water will be changed with it. Water that contains little beside lime is not especially objectionable for drinking purposes, but for most other purposes it is more or less expensive and troublesome. An alkali water may be quite unusable.

As regards disease organisms a ground water is likely to be quite free on account of the filtering action of the soil. In the case of private wells, often located near outhouses, pollution is much more likely to occur than in public supplies where any source of pollution must be quite remote.

The temperature, odor and taste of ground waters are generally much more satisfactory than of surface waters. Ground waters constitute a most valuable source of supply for small cities and towns, and where such a supply can be had it should almost always be chosen in preference to a surface water.

CONSTRUCTION OF WORKS.

Before passing on to the details of waterworks construction it will be of assistance to obtain a general view of the subject, and to that end we will here briefly outline the various general features which go to make up a waterworks system.

27. Classification. The various constructive features of a water supply system may be divided into three groups—works for the collection of water; works for the conveyance and distribution of water; works for the purification of water.

28. Works for the Collection of Water. These are divided according to the nature of the source into: (A) Works for taking water from large streams or natural lakes; (B) Works for the collection of ground water; (C) Works for the collection of water from small streams by means of impounding reservoirs.

(A). Works for taking water from large streams or lakes vary in character from a simple cast-iron pipe extending a short distance from shore, to the expensive tunnels and cribs of some of the large cities on the Great Lakes. The location of these works is determined very largely with respect to the quality of the water obtainable. Wherever, as is often the case, it is desired to draw a supply from a lake which at the same time receives sewage from the city, the question is one involving difficulties.

(B). Works for the collection of ground water consist of various forms of shallow wells, artesian wells, filter galleries, etc. The location of works of this class is determined, primarily, by the location of the water-bearing strata. If these are extensive, it will usually be convenient and economical to place the wells at relatively low elevations in order that the water may readily be reached by pumps, or perhaps in order that a flowing well may be secured. In the case of shallow wells the location is often affected by the possibility of local contamination, an element usually absent in the case of deep wells.

(C). Water collected in impounding reservoirs from streams of comparatively small watersheds depends for its good quality chiefly upon the scarcity of population upon the watershed. Suitable areas are therefore more likely to be found in the more rugged parts of the country and at the higher elevations, and usually at considerable distances, sometimes as great as 50 or 75 miles, from the population to be served. The location of such impounding reservoirs is also largely dependent upon questions of construction, such as the location of the dam, length and cost of aqueduct or conduit, and, what is of great economic importance, whether the water can be conveyed and distributed entirely or partly by gravity.

29. Works for the Distribution of Water. These include aqueducts and conduits for conveying water from a distant source, pumps and pumping stations, local reservoirs for equalizing the flow or for storage, and the pipes for distributing to the consumers. Conduits may be open channels, masonry conduits, or pressure conduits, such as pipes of wood, iron, or steel, and sometimes tunnels. The form is determined chiefly by considerations of cost. Pumps are used in a great variety of forms and situations, and may be operated by steam, gas, electricity, wind, or by hydraulic power. There are deep-well pumps for drawing water from depths not reached by suction, low-lift pumps for raising water from a river into settling basins or on to filters, or from wells into a low reservoir; and high-lift pumps for forcing the main supply into the distributing pipes or into an elevated distributing reservoir. Local reservoirs are used for receiving water from long conduits and regulating the flow in the distributing system, for equalizing the flow and pressure in pumping systems, and as settling reservoirs. The pipe system includes distributing mains, fire hydrants, service pipes, shut-off valves, regulating valves, etc.

30. Works for the Purification of Water. These vary in kind according to the nature of the impurities to be removed. Thus in the case of surface waters the sediment, bacteria, etc., are removed more or less completely by settling basins and various forms of filters. In the case of ground waters iron may be removed by aeration and filtration; hardness by chemical precipitation, etc. In these ways waters otherwise very undesirable can be greatly improved or made entirely satisfactory, but of course at a considerable expenditure of money. It will often happen, therefore, that a source of good quality but expensive will need to be compared with another poor in quality but capable of being made fairly comparable with the other at no greater total cost. Not infrequently the possibility of the future deterioration of a surface supply and the consequent necessity for artificial purification must also be considered.

RIVER AND LAKE INTAKES.

In drawing a water supply from a large river or lake a pipe or tunnel must extend from the pumping works out some distance from shore and the construction of such pipe line or tunnel often involves some very difficult work.

31. River Intakes. The location of the point of intake must be selected with reference to (1) the quality of water, and (2) the cost of construction and maintenance of the works connected therewith. The point of intake should be free from local sources of pollution and should therefore be located above all sewer outfalls of the town in question. In the case of tidal streams, sewage-polluted water may be carried long distances above the respective outfalls at flood tide, and before selecting the location careful study should be made of this question by means of floats and by examinations of the water at various seasons of the year. The location of the intake must also be determined with special reference to the lowest water stage.

The form of construction to be used depends upon the character of the stream in question, especially whether the difference between low and high water level is small or great.

If the water level vary only a small amount, as in the case of streams near dams or near a lake or ocean, the water may usually be taken from near the shore, the end of the intake pipe being supported on a small foundation of concrete, or on a wooden crib, or by a masonry retaining wall.

The intake pipes, usually of cast iron, may lead directly to the pumps, thus acting as suction pipes, or to a gate chamber and pump well. In the latter case the suction pipes of the pumps lead from this pump well. Gratings of cast iron or wood, with large openings, are usually placed at the entrance to the intake to prevent the admission of large objects, while fish screens of copper are inserted in the gate house or placed over the ends of the suction pipes.

If there is a large fluctuation of water level considerably more work is involved. It is usually necessary to extend the intake pipe a considerable distance from the banks of the stream in order to reach a suitable location at low water. Furthermore, pumps cannot lift by suction more than about 20 feet in practice, hence in order to enable the pumps to reach the water at the lowest stage, it is often necessary to place them in a deep pump pit much below high water level. The construction of a water-tight pit for this purpose is then an important feature of the works.

Another form of construction at the end of the intake is a masonry tower extending above high water and containing ports and sluice-gate similar in form to those used in reservoirs. To provide stability against ice and drift the tower is built similar to a bridge pier in form, the inlet ports being placed along the sides. The outer end of the intake pipe is usually protected by a simple timber crib supporting the end of the pipe 2 or 3 feet above the river bottom, and held in place and protected from scour by broken stone. A coarse screen or grating is ordinarily placed over that compartment of the crib containing the intake pipe. It is desirable to have the total area of the openings of this grating 2 or 3 times that of the pipe itself in order to keep the entrance velocity low. Sometimes in order to strain out the sediment the crib is entirely filled with broken stone and sand to form a filter crib. Such intake towers are used at St. Louis and at Cincinnati and tunnels connect with the tower through which the water is conveyed to the pumps.

The tower has the advantage over the crib construction in permanence and reliability. For these reasons this form of construction is to be commended, but it is much more expensive than the crib construction and is therefore suited only for the larger and more important works.

From the crib or inlet tower the intake pipe or tunnel usually runs to a screening chamber or pump well and from this chamber suction pipes lead direct to the pumps.

Fig. 5 illustrates a good design for small works. Here the water flows by gravity to the wet well made of boiler steel and con-

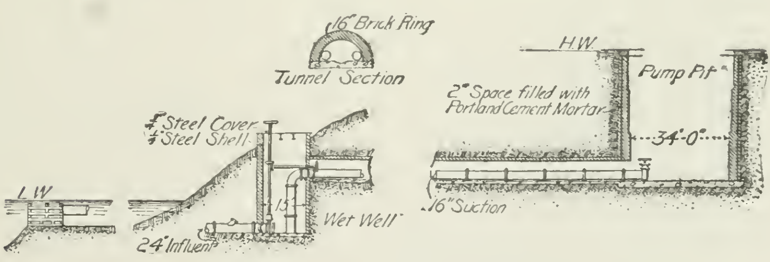


Fig. 5. Intake on the Ohio River.

structed below high water line. From this well the water is drawn by suction pipes attached directly to pumps in the pump pit. The suction pipe is placed in a tunnel through which access may be had in time of high water to the valves in the wet well. The size of intake pipe and suction pipe should be such that the velocity of the water in them will not exceed 1½ to 2 feet per second.

32. Lake Intakes. The location of a lake intake in such a position as to obtain at all times water of the best quality, and to fulfill the requirements of safety against interruption, is a question requiring very careful study. In a lake unpolluted by sewage some of the things to be investigated are—the location of the mouths of streams and the sediment carried by them; the character of the lake bottom; the direction of wind and currents and their effects in stirring up the mud on the lake bottom and in conveying sediment from point to point.

The intake should if practicable be located at a sufficient depth to be free from any considerable wave action, both to secure a greater stability and to avoid the effect of the disturbance of the sediment by the waves. Even in small ponds the wind stirs up the water to a depth of 15 or 20 feet, so that this may be taken as about the minimum depth. A greater depth is desirable if the water is not too stagnant, since the water becomes rapidly cooler below this point. In large lakes the wave action extends to much greater depths and the intake should be extended accordingly to depths of 40 or 50 feet.

Most of the cities along the Great Lakes dispose of their sewage by running it directly into the lake at the most convenient point; and for those places that draw their water supply from the same body of water the most difficult part of the intake problem is to exclude their own sewage. As the cities grow, the intakes are pushed farther and farther out, but usually not until the necessity of the step is brought home by increased mortality from typhoid fever; and, however carefully this matter is followed up, the quality of the water taken from such sources must always be looked upon with suspicion. In Chicago the length of intake has gradually increased to 4 miles. In Milwaukee it is 1½ miles, while the new intake at Cleveland is about 5 miles long.

Whether the conduit should be a pipe line or a tunnel depends upon the cost of construction and the relative reliability of the two forms. In small works the cost of a tunnel would be prohibitory, while in the case of a very large intake a tunnel may be the cheaper. Again, a pipe-line, unless sunk very deep, is subject to disturbances near the shore end by ice action, wreckage, and scour from storms.

Submerged-pipe intakes are usually laid by the aid of divers, although other methods have been used. The pipe is preferably laid in a dredged trench, at least as far out as wave-action is to be feared, and should be covered generally to a depth of 3 or 4 feet. Near the shore end the covering should be considerably deeper than this. Various methods of laying submerged pipe are described later.

Most lake intakes are protected at their ends by submerged crib work of timber partly filled with stone, the end of the pipe being raised 6 or 8 feet above the lake bottom to prevent the entrance of sand. At some of the larger ones, as at Chicago and Cleveland, large inlet cribs or towers built above the water surface are used, similar to river inlet towers.

The greatest difficulty met with in operating lake intakes is due to the clogging of the ports by anchor ice. This consists of needles and thin scales of ice which form in moving water and which are of such small size that they are readily carried below the surface by comparatively weak currents. They cease to form after the body of water has become frozen over. On coming in contact with submerged objects these particles of ice adhere and soon form large masses difficult to dislodge. Anchor ice has given much trouble at lake intakes both at the exposed cribs and at the shallower submerged ones. It is removed in various ways. Compressed air discharged near the port has been effective in some submerged intakes. Steam, water from hose, chains drawn back and forth through the ports, and pike poles, are some of the other means used. As tending to obviate difficulty with anchor ice all crib openings or port holes should have a large area so that the velocity of flow through them will not be more than 3 or 4 inches per second.

WORKS FOR THE COLLECTION OF GROUND WATER.

33. Collection of Water from Springs. The chief objects to be accomplished in the construction of works of the kind here considered are the protection of the water from pollution and the spring from injury through clogging or otherwise, the furnishing of a convenient chamber from which the conduit pipes may lead, and, in some cases, the enlargement of the yield by suitable forms of construction.

If a supply sufficient at all times for the demand can be obtained from one or more large springs, each one should have its separate basin from which the water may be conducted to a common main. The simplest form of works consists of a small masonry well or basin surrounding the spring and from which the conduit pipe leads. To prevent a growth of vegetable organisms and consequent deterioration of the water, such basin should always be covered so as to exclude the light. For a small spring, a circular well covered with a stone cap cemented in place and provided with a manhole is a simple and effective arrangement. For larger springs a masonry vault covered with 2 or 3 feet of earth is preferable. If the spring is located on a steep hillside, the collecting chamber is conveniently constructed in the form of a horizontal gallery built into the hill, access to which is had through a door or manhole.

Mineral and other springs occurring in public places usually have open basins, and opportunities are offered in the walls and parapets for ornamentation.

If the natural yield of a spring is insufficient, it will sometimes be possible to increase it. The proper form of collecting works to accomplish this depends upon the character of the spring. If the water appears at the upper surface of a stratum of impervious material overlaid by the water-bearing deposit, frequently in the form of several small springs, instead of dealing with each one individually it will often be better to construct a long collecting gallery running parallel to the outcrop and leading to a central collecting chamber which can be made similar in form to that for a large spring. This gallery, which may be made similar to that shown in Fig. 12, should be built deep enough to rest upon the impervious material, and thus to collect all the underground flowage as well as that appearing as springs. The total yield may be thus much increased, the increase being relatively greatest during dry weather.

The gallery may be simply a line of drain tile or vitrified pipe laid with open joints at the upper part of the pipe. If large quantities are collected the gallery may be made of brick or stone and large enough to permit of the passage of a man.

Where springs originate in a deep porous stratum such stratum may usually be tapped by wells without much reference to the spring. Use of such wells will generally reduce or entirely stop the flow of the spring.

THE CONSTRUCTION OF WELLS.

34. Principles Governing the Yield of Wells. If a well, either large or small, be sunk into a body of water-bearing material the water will run into such well, and if no pumping is done the water will, after a time, reach a level in the well the same as the level of the water in the surrounding soil. Fig. 6 represents a section through such a well. The dotted line A B represents the level of the water in the ground and in the well. Now if water is pumped from this well the level of the water therein will be lowered and as a consequence water will tend to flow into it from the surrounding ground and the surface of the ground water will assume some such shape as shown by the full line C D E F. The amount which the water surface is lowered decreases rapidly as we get farther from the well, until at some point more or less remote there is no sensible effect. The area within which the level is appreciably lowered is called the *circle of influence.* If the pumping is continued the level will be more and more lowered until it is so low that water will run into the well as rapidly as it is pumped out, after which no further change will take place. If the pumping ceases the well will gradually fill up to the original level.

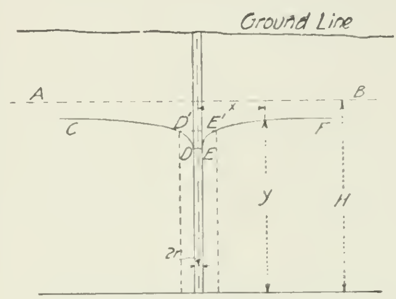


Fig. 6. Well Sunk in Ground Water.

Where the water flows under pressure, as in a porous stratum overlaid by an impervious one, the flow into a well is not accompanied by a change of *level* in the surface water, but the curve of *pressures* is of a form similar to the water surface in the case already treated.

The principles underlying the yield of wells have been investigated both theoretically and practically, but the subject is too difficult to be discussed in detail here. There are certain general principles, however, that are very important and which aid greatly to a clear understanding of the behavior of a set of wells under varying conditions. These may be stated as follows:

Having given a sand or gravel stratum of at least several feet in thickness in which water is flowing at some appreciable slope, such as 5 or 10 feet per mile, and a well is sunk into this stratum to a considerable depth, the yield of such a well when pumped from continually will follow approximately the following laws:

(1) The yield will be proportional to the distance the water level is lowered in the well below its normal level.

(2) The yield will be proportional to the thickness of the water-bearing stratum.

(3) For the same amount of lowering of the water the yield will be a little greater the larger the well, but the difference is not great except in case of very deep wells of small diameter in which the upward velocity of flow through the well is greater than 2 or 3 feet per second. A 10-foot well will yield only about 50 per cent more than a 6-inch well.

(4) For the same amount of lowering of the water the yield will be much greater in coarse material than in fine.

The following table will serve to give a rough idea of what may be expected from a single well sunk at least half way through a water-bearing stratum of various grades of material.

TABLE 9.

Approximate Yield of a 6-Inch Well When Sunk Into Water-Bearing Material 10 Feet Thick and When the Water Level Is Lowered One Foot by Continuous Pumping.

Material.	Yield in gallons per day.
Fine Sand	4,000
Medium Sand	30,000
Coarse Sand	80,000
Fine Gravel, free of Sand	500,000 or more.

For other thicknesses of material and other amounts of lowering the yield can be obtained by the law of proportion as stated above. The great increase in yield due to increasing coarseness of material is very marked and shows that for this very reason it is very difficult to make close predictions as to yield. Larger wells will give slightly better results.

Example. A well is sunk into a water-bearing stratum consisting of medium size sand to a depth of 30 feet below water level. What will be the yield if the water therein is pumped down 5 feet below its normal level?

By Table 9 the yield would be about 30,000 gallons per day for a 10-foot stratum and one foot of lowering. Hence for a 30-foot stratum and 5 feet of lowering the yield will be about 3 × 5 = 15 times as much, or 15 × 30,000 = 450,000 gallons per day.

If two or more wells penetrating to the same stratum are placed near together and simultaneously operated, the total yield will be relatively much less than the yield of a single well pumped to the same level. This mutual interference of wells depends in amount upon the size and spacing of the wells, upon the radius of the circle of influence of the wells when operated singly, and upon the depth to which the water is lowered by pumping.

The amount of this interference depends mainly upon the distance the wells are apart. It also depends upon the amount the water is lowered by pumping, and upon the general capacity of the stratum. If the water is lowered a considerable amount, such as 10 feet, the wells should be placed 200 to 400 feet apart in order that the interference be not too great. A small spacing like 25 to 50 feet will give an interference of a large amount,—often as great as 50 per cent in the case of 3 or more wells. That is to say, if 4 wells are placed 50 feet apart the total yield is not likely to be more than 50 per cent of the yield if these 4 wells were placed 300 or 400 feet apart.

Where it can be done, the best way to determine the capacity of wells is by actual tests conducted for a sufficient length of time to bring about a condition of equilibrium in the flow, but unless this condition is approximately fulfilled such tests are apt to be very deceptive. With a flat slope to the ground water a test may be carried on for weeks and even months, and the circle of influence will still continue to widen, resulting in a gradually decreasing yield. It may thus require years of operation to bring the conditions to a final state of equilibrium.

In the case of deep wells sunk into rock strata it is impossible to make an analysis of the conditions so as to be able to predict the yield. A pumping test is a necessity, but in this case also a very useful principle to remember is that of proportionality of flow to the lowering of the water level in the well. Thus if by pumping the level down 10 feet we get 200,000 gallons per day we may say with great certainty that the yield will be about 400,000 gallons if the water is pumped down 20 feet. In all cases this lowering of the water is to be measured from the level to which it rises when no water is pumped. In a flowing artesian well to get this level it is necessary to extend the casing above the ground as far as the water will rise, or to cap the well and determine this level by a pressure gauge.

35. Large Open Wells. As already explained, the yield of a well that is constantly pumped from is not much affected by its size. For other reasons, however, large wells are often advantageous.

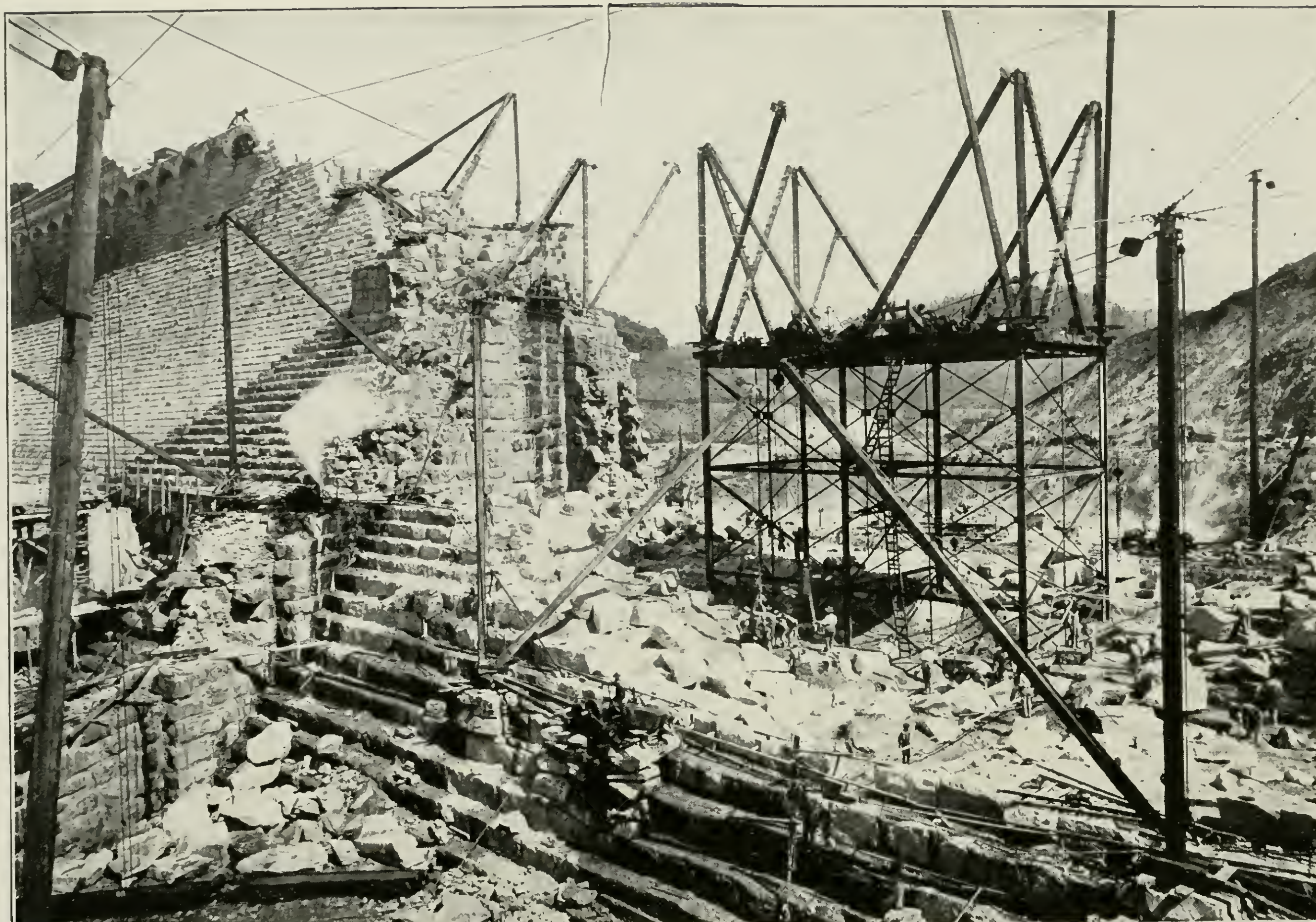
The large well possesses a great advantage over the small well in its storage capacity. If the pumping is carried on at a variable rate, it thus acts to increase greatly the real capacity of the large well over that of a series of small tube wells. Furthermore, in the operation of the pumps there are many advantages in being able to get the entire supply from a single well, or from two or three large wells close together, chief among which is the avoidance of long suction pipes. The large well is also of great advantage where it becomes necessary to lower the pumps, as it permits the use of a more economical form of pumping machinery.

Trouble is often experienced in the small wells through clogging and the entrance of fine sand. This is largely avoided in the large well, as the entrance velocity of the water is very small. Opportunity is also given for the settling of fine material.

The chief disadvantage of the large well is in its great cost compared to the tube well for like yields. This disadvantage increases rapidly as the depth increases, and where it may be economy to construct a large well to a certain depth to serve as a pump pit it will usually be cheaper to develop the yield by sinking tube wells from the bottom, or by driving galleries therefrom, than by further sinking.

Large wells for waterworks are constructed of diameters of 10 feet or less to as great as 100 feet, 30 to 50 feet being the most common size. The minimum depth of a well is determined by the depth necessary to reach and penetrate for a short distance the water-bearing stratum, allowing a margin for dry seasons.

In the construction of a large well large quantities of water will be met with, and adequate means of handling it must be provided. As the water level must be kept at the lowest level of the excavation, the maximum pumpage will be considerably more than the future capacity of the well. For moderate depths the excavation can be carried on with no other aid than sheet piling. If the well



CONSTRUCTION WORK IN PROGRESS ON NEW CROTON DAM, PART OF WATERWORKS SYSTEM OF NEW YORK CITY

View showing steel towers used in the work and afterwards sealed into the reservoir wall.

is of large diameter, an annular trench is usually first excavated and the curb or lining built therein, after which the interior core is removed. This method enables the sheet piling to be readily braced. A method adapted to smaller wells is to drive the sheet

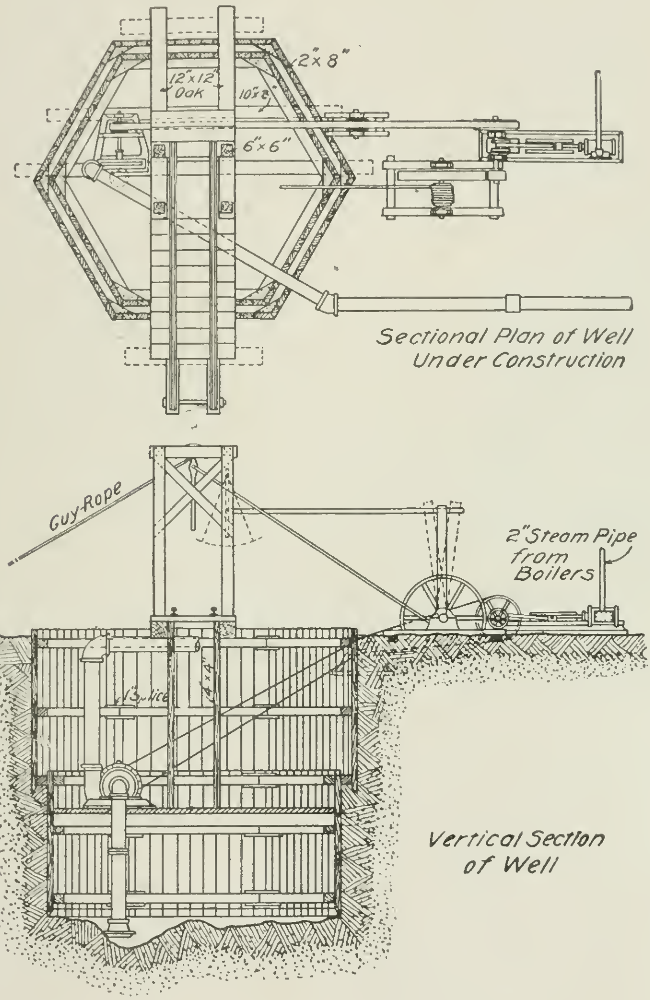


Fig. 7. Large Well under Construction.

piling outside of a series of wooden frames or ribs, and to excavate the entire well at once. The ribs are built in place as the excavation proceeds. This method is illustrated in Fig. 7.

For wells of considerable depth sunk in soft material, the curb may be started on a shoe of iron or wood, and the excavation and the construction of the curb carried on simultaneously, the curb sinking from its own weight. The material may be either excavated in the ordinary way, or by the use of compressed air, or dredged out without attempting to keep out the water, the method used depending upon depth of well, quantity of water, and character of the material. Where the friction becomes too great to sink the first curb the desired distance, a second curb with shoe may be sunk inside the former. In Fig. 8 are illustrated two forms of shoes used in sinking wells. These are both constructed mainly of wood. To strengthen such curbs iron rods should extend from the shoe well up into the masonry. For large wells, pump pits, etc., heavy iron shoes are often employed, and occasionally a pneumatic caisson is found necessary.

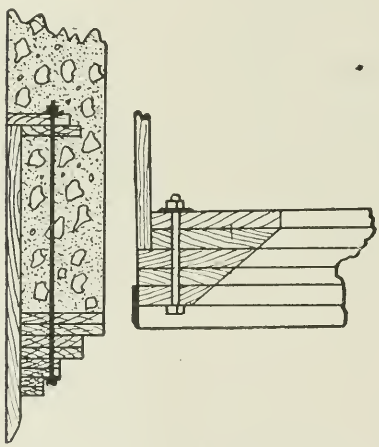


Fig. 8. Shoes for Sinking Well Curbs.

The lining or curb usually consists of a circular wall of brick or concrete masonry of a thickness varying with diameter and depth of the well, but ranging ordinarily from 2 to 5 feet. Dry rubble may be used for the lower portion, but the upper portion should be of concrete.

All wells should be covered to exclude the light and to prevent pollution of the water. The cover is usually made of wood, which for large wells may be conveniently made of a conical form and supported by a light wooden truss, or by rafters resting against the wall.

36. Shallow Tubular or Driven Wells. Shallow tubular wells, or wells of small diameter, also called *driven* wells, are sunk in various ways, depending upon the size and depth of well and nature of the material encountered. To furnish large quantities of water it usually requires a number of wells, and in addition to the question of sinking, questions of arrangement, spacing, connecting and operation are important. We will here consider only the methods of sinking wells in earth or soft strata.

As regards methods of sinking there are two principal kinds of wells—the closed-end well or driven well proper, and the open-end well.

The Closed-end or Driven Well. In this form the well tube consists of a wrought-iron tube from 1 to 4 inches in diameter, closed and pointed at one end, and perforated for some distance therefrom. The tube thus prepared is driven into the ground by a wooden maul or block until it penetrates the water-bearing stratum. The upper end is then connected to a pump and the well is complete. Where the material penetrated is sand the perforated portion is covered with wire gauze of a fineness depending upon the fineness of the sand. To prevent injuring the gauze and clogging the perforations, the pointed end is usually made larger than the tube, or the gauze may be covered by a perforated jacket.

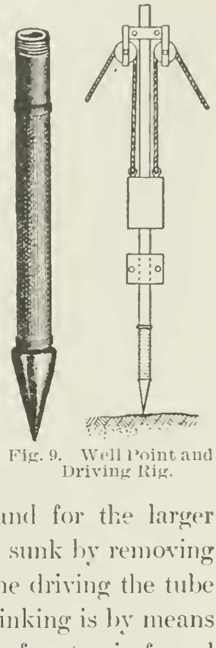


Fig. 9. Well Point and Driving Rig.

Fig. 9 shows a common form of well point and the method of driving wells by means of a weight operated by two men. The tube may also be driven by a wooden block operated by a pile driver or other convenient means. Such a well is adapted for use in soft ground or sand up to a depth of about 75 feet, and in places where the water is thinly distributed.

Open-end Wells. For use in hard ground and for the larger sizes the open-end tube is better adapted. This is sunk by removing the material from the interior, and at the same time driving the tube as in the other case. A very common method of sinking is by means of the water jet. In this process a strong stream of water is forced through a small pipe inserted in the well tube, the water escaping in one or more jets near the end of the pipe. At the same time the pipe, which is provided with a chisel edge, is churned up and down to loosen the material, which is then carried to the surface by the water in the annular space between the pipe and tube. If the material is hard or the well deep, a steel cutting edge may be screwed on to the end of the well tube.

With the open-end well the lower portion may be merely perforated with small holes in case the material is coarse or gravelly, or if sand is met with, the holes may be covered with brass gauze. Instead, however, of using a gauze it is common with this style of well to sink a solid tube, insert a special strainer of suitable length, and then withdraw the tube nearly to the top of the strainer.

Fig. 10. Cook Well Strainer.

Fig. 10 illustrates a commonly used form of strainer known as the Cook strainer. It is made of brass tubing and provided with very narrow, slotted holes, which are much wider on the interior than on the exterior, an arrangement intended to prevent clogging.

Small tubular wells are usually arranged in one or two rows alongside a suction pipe and connected thereto by short branches. The smaller sizes are connected directly to the branch, the well tube acting also as a suction pipe, but with the larger sizes a separate suction pipe is ordinarily employed. In the former case, to avoid the entrance of air, it is necessary that the perforated portion of the pipe be always under water, and to insure this being the case it should be kept below the limit of suction. With the latter arrangement there are no such limitations to the position of the perforated well casing.

In order to enable the pumps to draw as much water as possible from the wells the pumps and suction main should be placed as

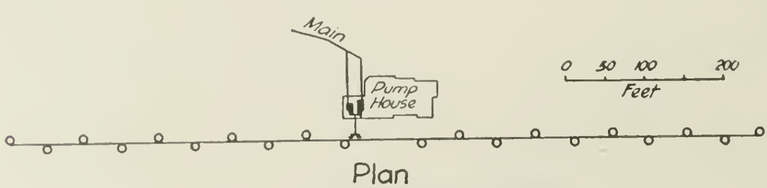


Fig. 11. Typical Arrangement of Wells.

deeply in the ground as practicable. A typical arrangement of wells is shown in Fig 11. In this plan the wells are 6-inch wells and are spaced 50 feet apart and are 35 to 50 feet deep.

The maximum amount of water obtainable from a given number of wells would be when they are spaced far enough apart so that their circles of influence will not overlap, but on account of cost of piping, and loss of head by friction, this would not be the most economical spacing. While it is impossible to give figures which would be of general application, it may be stated that from 25 to 100 feet is about the range for economical spacing of shallow wells. With very deep or artesian wells the spacing becomes still greater. Spacing less than 25 feet has quite often been used, but with doubtful economy.

Each well should be connected to the suction main by means of a short branch in which should be placed a gate valve, so that any well can be shut off at any time. The main suction pipe is usually made of flanged pipe, as this enables air-tight joints to be more readily made, although ordinary bell-and-spigot pipe with lead joints has been successfully used.

The greatest care must be taken in every part to make the work air tight, and to secure this it should be thoroughly tested in sections by means of compressed air. All valves should be carefully tested for air tightness, and all screw connections thoroughly fitted. In spite of the most careful construction, air will usually accumulate to some extent, and to eliminate it many plants are provided with air separators placed on the suction main near the pump. The simplest form consists of a large drum of steel placed on the suction pipe near the pumps through which the water passes at a slow velocity. A vacuum pump is attached to this drum.

Where sand is drawn up with the water it may be got rid of by passing the water at a slow velocity through a large drum or box inserted in the suction pipe and provided with suitable handholes for cleaning.

37. Deep and Artesian Wells. Where the depth exceeds 75 to 100 feet the small driven well is no longer practicable. Methods of sinking deep wells are in many respects different from those already described, and matters of spacing, pipe friction, arrangement of connections, etc., are much more important than in the shallow-well plant. Well boring is an art by itself, and the execution of any deep-well project should usually be put into the hands of some reliable well-drilling concern. The variety of ingenious tools and appliances in use for overcoming all kinds of difficulties and for penetrating all sorts of strata is very great, and it is possible to give here but a very general description of some of the methods of sinking in use.

In soft material it is necessary to case the well the entire depth, and on account of the difficulty of getting the casing down to great depths this operation becomes the chief feature of the construction. For depths up to 200 or 300 feet the ordinary well-drilling outfit can be used, and the casing driven close after the drill. When the casing can be driven no farther a smaller size is inserted and the sinking continued with a smaller drill, and so on until the well is sunk as far as desirable or possible. The material excavated is brought to the surface by means of a sand bucket, or by the water jet as previously described, the water being conducted to the end of the drill through hollow drill rods. By the latter method the hole is kept clean and a more rapid progress made.

The friction against the casing is greatly lessened, and the depth attainable much increased by the use of the revolving process. In this the lower end of the casing is provided with a toothed cutting shoe of hard steel of slightly greater diameter than the pipe, and the upper end is connected by means of a swivel to a water pipe through which water is forced by suitable pumps. The well is bored by turning the pipe, and the loosened material is carried to the surface by the water which passes down inside the casing and up on the outside between casing and soil. This process is very common in sinking artesian wells in the alluvial basins of California. It is very rapid, a rate of sinking as high as 20 or 30 feet per hour for depths of 1,000 feet having been attained.

It is essential to have a good length of strainer in the porous stratum. This is usually inserted after the desired depth has been reached, and the casing is then pulled up to the top of the strainer. By special devices it can, however, be attached to the end of the well casing and sunk with it.

A drilling outfit for deep wells is very similar to the ordinary familiar outfit for shallow wells worked by horse-power. A string of tools consists essentially of a steel bit, an auger-stem into which the bit is screwed, a pair of links or "jars" connecting the auger stem with another bar, called a sinker bar, and finally the rope cable which supports the apparatus and which passes over a pulley at the top of a derrick and then down to a winding drum. Just above the drum the cable is attached, by means of an adjusting or "temper" screw, to a large walking beam operated by a steam engine. As the work progresses the drill is lowerd by the temper screw. By means of the jars an upward blow may be struck to dislodge a jammed drill. Many ingenious tools are employed for recovering lost tools, cutting up and removing pipe, and carrying on the various operations involved.

Wells in soft material must be cased throughout. When bored in rock it is necessary to case the well at least through the soft upper strata to prevent caving. Casing is also desirable for the purpose of excluding surface water, to which end it should extend well into the solid stratum below. Where artesian conditions exist and the water will eventually stand higher in the well than the adjacent ground water, the casing must extend into and make a tight joint with the impervious stratum, otherwise water will escape into the ground above.

Ordinary artesian well casing is made of light-weight wrought-iron lap-welded pipe. For pipe which is to be driven the standard wrought-iron pipe is ordinarily used, but for heavy driving extra strong pipe is necessary. Joints of drive pipe should be made so that the ends of the tubing are in contact when screwed up. The life of a good heavy pipe is ordinarily very great, but cases have occurred where the pipe has been rapidly corroded, due to the presence of excessive amounts of carbonic acid.

The cost of sinking wells will of course vary greatly according to locality, nature of strata, and depth and size of well. For wells 6 to 8 inches in diameter and sunk in ordinary rock the cost per foot, not including casing, will usually range from $2.00 to $3.00 for depths of 500 feet, up to $3.00 to $5.00 for depths of 2,000 feet. For smaller sizes the cost will be somewhat less, especially for the shallow depths.

38. Connections for Deep Wells. The economical spacing for deep wells will be much greater than for shallow wells. It will likewise pay to spend more money in lowering the flow line by making deep connections, thus decreasing the number of wells and increasing the spacing. Generally speaking a spacing of from 400 to 800 feet will be found desirable.

On account of the relatively great cost of deep wells it will often be found economical to so arrange the pumps and connections that a considerable lowering of the water level below the ground surface may be obtained. This is generally accomplished by connecting all the wells to a single pump or set of pumps, placed at a considerable depth below the surface. Where the connections are very deep tunneling may have to be resorted to. Another common method of drawing water from deep wells in the case of small plants is by the use of a separate deep-well pump for each well. This method is applicable to any depth, but involves the use of uneconomical types of machinery. The air lift is another form suited to this work.

39. Yield of Artesian Wells. In making estimates regarding flow it is important to bear in mind that it requires a considerable length of time to determine with certainty the adequacy of the supply, and furthermore that the sinking of wells by other interests, even though at considerable distances, may very seriously affect the yield. Where conditions are sufficiently favorable for works of some magnitude the yield per well under a moderate head ranges from about 150,000 gallons per day to 800,000 gallons, or even more. With yields of less than 100,000 gallons per day, works for developing large quantities become very expensive, relatively more expensive than for small quantities, since with a large number of wells there is much greater interference. Often a well or set of wells will show a gradual falling off in capacity. The chief cause of a decrease in the yield of a well is the influence of other wells sunk in the vicinity. Where large numbers of wells are sunk in the same region this effect may be very serious, as in some cases where it has reduced the pressure of flowing wells from 75 or 100 feet down to nothing.

40. Galleries and Horizontal Wells. Where ground water can be reached at moderate depths it is sometimes intercepted by galleries constructed across the line of flow. If these are placed at a sufficient depth they will enable the entire flow of the ground water to be intercepted. In form a gallery may consist merely of an open ditch which leads the water away, or it may be a closed conduit of masonry, wood, iron, or vitrified clay pipe, provided with numerous small openings to allow the entrance of the water. Unless constantly submerged, wood should not be used. Masonry and vitrified pipe are preferable to iron, as these materials are uninjured by exposure to water. If galleries are not covered, excessive vegetable growth is apt to occur which may injure the quality of the water. Fig. 12 illustrates a form of gallery of concrete built in a water-bearing gravel.

Galleries for collecting ground water are occasionally tunneled in solid rock. This may happen along a side hill where an outcropping porous stratum overlies an impervious one and it is desired to develop the flow by running a tunnel along the hill near the bottom of the porous stratum; or it may occur where a steeply inclined artesian stratum can be more readily reached in this way than by vertical wells. Tunnels or galleries are also sometimes run from the bottom of large wells for the purpose of increasing the yield. This method of increasing the flow is advantageous where it is necessary to lower the pumps and to concentrate the flow in a single well.

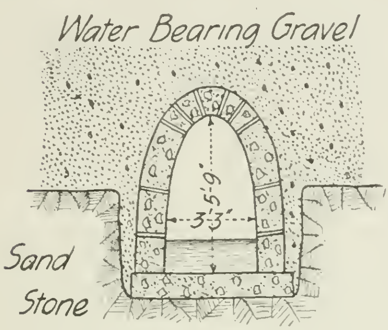


Fig. 12. Concrete Gallery.

Horizontal or push wells are tubular wells pushed approximately horizontally into a water-bearing stratum, or under the bed of a lake or stream. They are forced into the ground from a trench by means of jacks braced against the opposite side. These wells have been most successful when extended out under a lake or river.

Another method of utilizing a river bottom as a natural filter is to construct a wooden crib in an excavation in the bed of the stream, fill it with gravel and then cover the structure with 3 or 4 feet of sand up even with the river bottom. The suction pipe then leads from the crib to the pumps. This form of construction is well adapted to sandy-bottom streams with swift currents and has proved a very efficient way of clarifying muddy river waters.

Wells and galleries are often constructed near streams for the purpose of getting all or a portion of the supply therefrom. The success of such works depends much upon the character of the river bottom. Even when the lower strata are porous, the river, if a silt bearing one, may have a nearly impervious bottom and the natural filter will only become more clogged by use, necessitating perhaps the abandonment of the collecting works. Such failures have occurred in some instances. With a sandy river bottom kept clean by the scouring action of the floods, and with a porous substratum, works of this kind will give good results. To secure good filtration the works should be located at least 50 feet and preferably a greater distance from the stream.

The yield of a series of wells or of a gallery collecting filtered surface water will be, as in the case previously discussed, proportional to the lowering of the water level, and will be nearly proportional to the length of the line of works. In gallons per day per 100 feet of gallery, the yield from various successful works varies from 30,000 to 1,000,000 or more, which is about the same as is obtained from lines of wells.

RESERVOIRS AND DAMS.

Impounding Reservoirs.

41. Capacity. When the minimum flow of a stream is less than the daily demand of water it is necessary to store up the excess flow during the rainy season in large reservoirs called *impounding reservoirs*. The deficiency in the supply can then be made up by drawing from the reservoir. In this way the entire flow of a stream for a year or more may be stored and drawn off as wanted and streams that run dry at certain times may be made to supply quite a large population. Impounding reservoirs are made by constructing a dam across the valley in question, but natural lakes or ponds can often be utilized as reservoirs by building suitable works at this outlet.

In calculating the proper size of a reservoir we must consider (1) the yield of the source for successive intervals of time; and (2) the demand for all purposes for like intervals of time. The yield of the source of supply has been previously discussed. The demand to be considered includes not only the consumption for the city in question, but also the loss of water by evaporation from the area of the reservoir itself, also loss from leakage and percolation, and often the necessary withdrawals to satisfy the demands of riparian owners below.

The amount of leakage through the dam will usually be very small, but with certain forms of construction may be large. The quantity of water necessary to satisfy the demands of the riparian owners below the reservoir is often an exceedingly difficult matter to determine, and usually becomes a question for the courts to settle.

Practice differs greatly in different States, and in many of the Western States the water belongs to the State to dispose of as it sees fit. It is often expedient to buy up all rights and to utilize whenever necessary the entire flow of a stream, or to fix by contract the amount which will be allowed to flow.

The capacity of the reservoir must be based on the supplying capacity of the stream during the dryest year. The probable yield of the stream for each month of such a year should be estimated and recorded. Then likewise the monthly demand for the city in question and whatever allowance, if any, should be made for the use of riparian owners below.

Then for all months in which the demand is greater than the flow subtract the latter from the former; this will give the deficiency for each month. Add all deficiencies together and the result will be the total deficiency which must be made up from the reservoir and therefore is the required capacity of the reservoir, provided, however, that the total surplus for the remaining months is at least equal to the deficiency. If not, then the total yearly flow of the stream is not equal to the total demand and additional water must be obtained from some other source.

42. Location. In determining upon the location of a reservoir several elements must be kept in mind. In the first place it is very desirable that it shall be at such an elevation that at least a part of the consumers may be served by gravity alone, and it will be economy to spend a relatively large sum of money for conduits, or otherwise, to secure this advantage. The necessary elevation for this purpose depends upon the required pressure at, and elevation of, the various points of distribution, and the head lost in conducting thence the water.

The most favorable location for a reservoir as regards topography is a point where the valley forms a comparatively broad level area bounded by steep slopes at the sides, and below which the hills approach close together so as to form a good site for a dam. To prevent the escape of water the floor of the reservoir should contain no outcrop of porous strata of any extent which may lead the water away underground, and in the vicinity of the dam or embankment it should be underlain by an impervious stratum at a depth that can be reached by that structure.

After a tentative location has been decided upon, accurate levels must be run to connect the town with the reservoir site, also surveys for conduit lines, and an accurate topographical survey of the area to be flooded and all that may be affected by the reservoir. This survey should include information as to all buildings upon and adjacent to the area in question, nature of the vegetation, location of roads, property lines, etc. At the site proposed for the dam numerous borings must be made extending to a considerable distance above and below the dam as well as on the flanks, and these must be supplemented by test pits so that the nature of the supposed firm stratum can be accurately determined. If a suitable foundation cannot be reached at a reasonable cost, the site may have to be abandoned.

Calculations of storage volumes for different depths can readily be made from the contour map. The areas enclosed by each contour can be measured by a planimeter and the volume between any two successive contours taken as equal to the average of the areas enclosed by the contours, multiplied by the contour interval. The volume up to any given contour having been determined, the necessary height of dam to hold any given quantity of water becomes known.

All vegetation and perishable matter should be removed from the reservoir site, as the decay of such material injures the quality of the water. It is also desirable and of great benefit to the water to remove the top soil to a sufficient depth to include most of the organic matter therein.

As a further protection to the quality of the stored water it is desirable that there be as little area alternately flooded and exposed as possible, in order to limit the growth of vegetation. Shallow places should either be excavated to give a depth of 6 or 8 feet, or partly excavated and partly filled, the slopes being formed at about 3 to 1 and covered with sand or gravel.

43. Maintenance. In maintaining a reservoir so as to preserve the quality of the water and to supply the necessary quantity regularly and certainly requires a considerable degree of care and attention. To keep the quality as good as possible requires first of all that the watershed and reservoir be kept free from organic pollution. To insure that this is the case the city should have sanitary supervision over the area in question, and inspection should be regularly made to see that all sanitary requirements are complied with. During seasons of low water, opportunity is offered for removing the vegetation from around the borders of the reservoir.

Careful records should be kept at the reservoir of all matters which may be of any value in subsequent designs for enlargement or for new works. These should include records of rainfall, temperature, height of water in reservoir, amount passing over waste weir, and data pertaining to the quality of the water at different seasons of the year. The maintenance of dams and embankments should call for very little labor. Earthen embankments should be kept neat in appearance with slopes well sodded, or covered with large gravel so as to be permanent. The top of the embankment should of course be maintained at its full height, and the waste weir and the channel below it kept clear and of the designed capacity at all times. Gates and other apparatus should be frequently inspected and kept in thorough repair.

EARTHEN DAMS OR EMBANKMENTS.

44. Kinds of Dams. Dams may be divided according to the material used into five classes; earthen dams, masonry dams, loose-rock dams, wooden dams, and iron or steel dams. These materials are also used in various combinations. The form of dam suitable for a given case depends upon the character of the foundation, the topography of the site, the size and importance of the structure, the degree of imperviousness required, and the cost. Of the above kinds of dams those of masonry and of earth are the ones usually considered.

The earthen embankment is the most common form of dam. It can be built on a variety of foundations; it is commonly the cheapest form, and when well designed and executed is an entirely safe and reliable structure. Where flood waters have to be passed over a dam some other material than earth must be used for at least the portion of the structure subjected to water action. Water flowing over an earthen embankment is inadmissible, many failures having been caused by such occurrence, due to faulty construction. For dams higher than 100 feet or thereabouts few engineers would recommend an earthen structure. If the foundations are suitable, a masonry dam is in such cases greatly to be preferred. It is more reliable, and with the great pressures occurring it is desirable to have all outlet arrangements built in masonry.

The general requirements of a good foundation for an earthen dam are that an impervious stratum can be reached at a moderate depth, and that the material near the surface is sufficiently compact to support the load. A compact clay or hardpan makes the best foundation. Solid rock is also good if not fissured. Embankments of earth have been successfully constructed on foundations of sand; but in such a case it is important that the sand be fine and of a uniform character, containing no streaks of coarse material which will offer little resistance to the flow of water.

Earthen dams are of a trapezoidal form with top width, side slopes, etc., proportioned according to the material used. Where good material is at hand in sufficient quantities the entire embankment may be made of uniform consistency and all as nearly water tight as possible. Usually, however, it will be more economical and give as good results to put the best material near the upper side of the embankment, changing gradually to the more porous materials towards the lower face. Where good material is scarce, imperviousness is usually obtained by means of a wall or "core" of impervious earth or masonry placed near the centre of the dam. If impervious foundation is reached only at a considerable depth, this portion only of the embankment is carried to the extreme depth.

Various kinds of material can be used to make an embankment. Loam, sand, gravel, and clay, mixed in various proportions, are common. For the first three to be impervious they must contain a certain proportion of clay, the amount required depending upon the variation in size of the coarser particles. The suitability of a material for embankment construction can to some extent be determined by experiments. It should be strongly cohesive and plastic when mixed with water, and should be impervious; but the correct valuation of natural mixtures requires much experience in their actual use in construction.

If good material does not exist already mixed, artificial mixtures of gravel, sand, and clay may be used. A fairly uniform sand or gravel contains about 40 per cent of porous space. If then a mixture be made of coarse gravel, fine gravel, and sand, in each case just enough of the finer material being used to fill the interstices of the next coarser, there will be in the mixture a porous space equal to $.40 \times .40 \times .40 = 6.4$ per cent, which will represent the proportion of clay necessary to make the mixture impervious. In practice it will take considerably more to insure the filling of all the interstices, as much as 15 or 20 per cent, depending upon the nature of the gravel mixture. In any case the percentage of voids in an artificial mixture can be readily determined by tests with water.

45. Core Walls. For a puddle wall of clay the minimum thickness ordinarily used is 4 to 8 feet at the top and about one-third the depth of water at the bottom, with a uniform batter on both faces. The trench is also usually made with a batter, the width at the bottom being one-third to one-half that at the ground level, with a minimum of 4 or 5 feet.

Instead of a core of puddle, many engineers prefer a core of rubble masonry or of concrete, made as impervious as possible. The advantages of this over a core of puddle are its safety against attack by burrowing animals, safety against wash in case minute leaks occur, and the greater certainty with which a concrete wall can be made impervious, especially where it joins the foundation.

Masonry core walls are made of various widths. Sometimes in case of embankments made of good material, they are made only a foot or two thick, their purpose being mainly to prevent the passage of burrowing animals. Ordinarily, however, a core wall is made 2 to 4 feet thick at the top, with a batter of $\frac{1}{2}$ to $\frac{3}{4}$ inch per foot on each side down to the trench and then with vertical faces below. The height of a core wall should be equal to that of the highest water level.

Figs. 13, 14 and 15 show cross sections of several forms of embankments. Fig. 13 is without core wall except in the trench, Fig. 14 has a core wall of puddle and Fig. 15 one of concrete.

46. Dimensions of Embankments. On the water side the slope is usually protected from wave action and should only be sufficient to prevent slips. With coarse material this need not be flatter than 2 horizontal to 1 vertical. With finer material it may need to be $2\frac{1}{2}$ or 3 to 1, or in some cases even 4 to 1, since earth in a saturated condition has a comparatively small angle of repose. On the lower side a slope of 2 to 1 is to be recommended, although $1\frac{1}{2}$

to 1 has frequently been used. If the material will stand at 1 to 1, as broken stone, for example, then a slope of $1\frac{1}{2}$ to 1 would be suitable. On high embankments, bermes placed 30 to 40 feet apart vertically are a desirable feature.

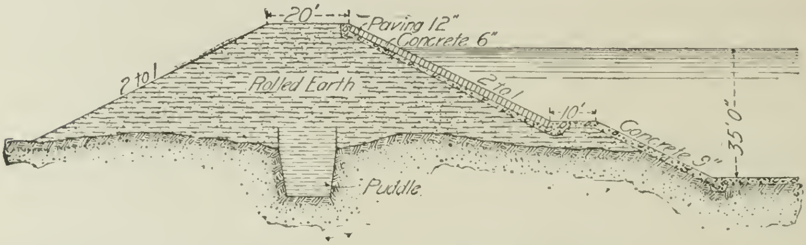


Fig. 13. Reservoir Embankment, Syracuse, N. Y.

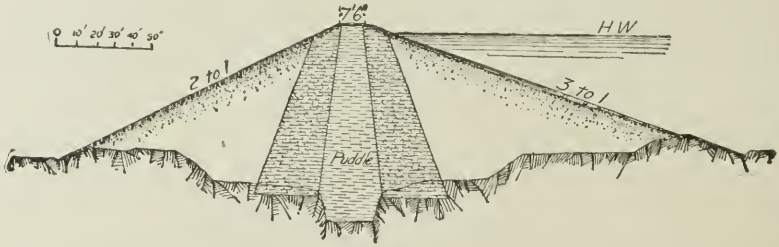


Fig. 14. Reservoir Embankment, Glasgow Waterworks.

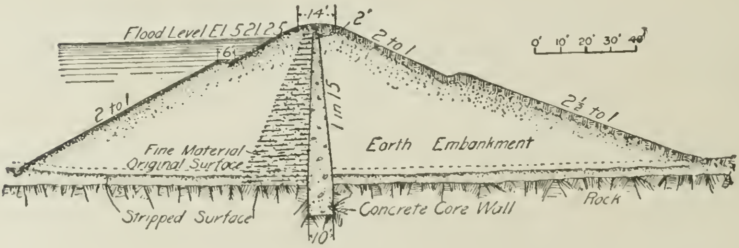
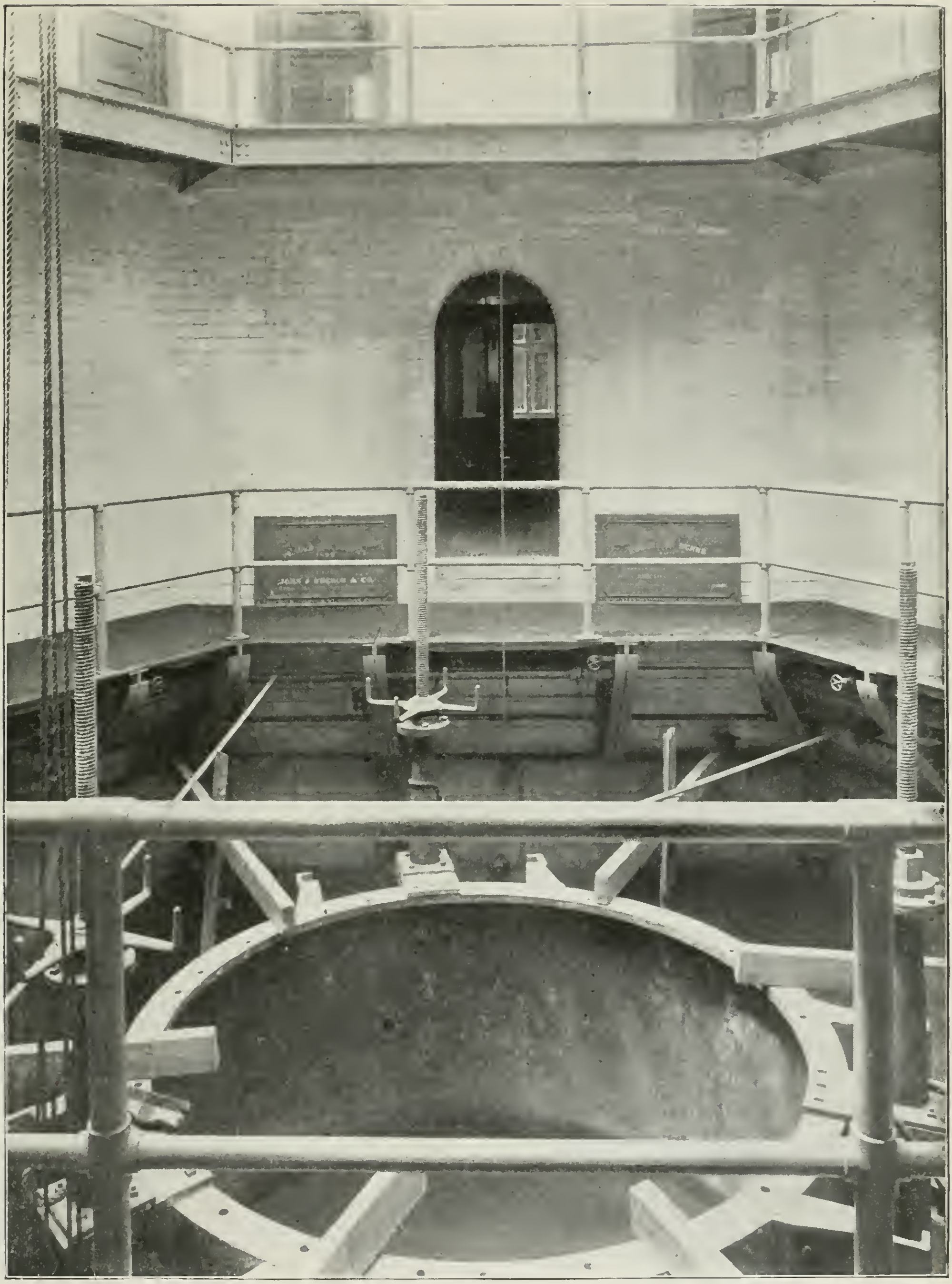


Fig. 15. Reservoir Embankment, Boston Waterworks.

The top of the dam should extend sufficiently above the high-water line to protect the material exposed to water action from frost and to give a safe margin against overflowing. This will be equal to the depth reached by frost plus an allowance of 2 to 5 feet for wave action, depending on the exposure to winds and the depth of the water.



INTERIOR OF LAKEVIEW CRIB, CHICAGO WATERWORKS SYSTEM
Showing intake shaft.

The width of top is frequently fixed by the requirements for a roadway. Where not so fixed it is made to vary with the height—from 6 to 8 feet for very low embankments to 20 or 25 feet for embankments 80 to 100 feet high, or, approximately, width = $\frac{1}{5} h + 5$ feet, where h = height of dam.

47. **Construction.** In preparing the foundation the surface soil must be removed over the entire site of the embankment to a depth sufficient to reach good sound material. All roots, stumps, and other perishable material must be removed, as any such material by decaying offers a passage for water. For the portion to be occupied by the core wall, if one is used, and a certain width in any case, the foundation must be excavated to an impervious stratum of solid rock or clay, and penetrate for a short distance such stratum. A sound bottom having been reached the surface should be roughened in order to give a better bond with the earth filling; and if the material is solid rock, all holes and crevices must be thoroughly cleaned and filled with cement or concrete.

After the foundation has been prepared the trench is first filled with the material selected. If puddle, it should be placed in 4- to 6-inch layers well rammed, or cut and cross cut with thin spades reaching well into the layer below, just enough water being used to render the material plastic. Where puddle is used in a narrow wall it is advisable to prepare it before placing by thoroughly pulverizing and tempering it with water, no more water being used than absolutely necessary. Puddle should be thoroughly worked and homogeneous. If concrete is used, special care must be taken to secure thoroughly good work in mixing and ramming, and in filling all irregular spaces in the excavation.

After the core is built to the surface, or a little above in the case of concrete, the main embankment is started. If the material used varies in quality, the finer and better should be placed above and adjoining the core wall, and the coarser placed on the down stream side and near the faces. If no core wall is used, the better material should still be placed in the up stream portion of the embankment. Stones exceeding 3 or 4 inches in diameter should not be allowed in the embankment except along the faces. The embankment is compacted usually by placing the material in layers 6 to 12 inches thick, wetting, and rolling with a heavy grooved roller weighing 200 to 300 pounds per lineal inch.

Much importance is attached to the work of compacting, and only by the best of supervision can work be secured. The use of water should be just sufficient to render the material plastic and capable of being packed, and no more. An excess of water makes rolling more difficult and increases subsequent settlement.

The up-stream slope must be protected from wave and ice action. This protection is usually afforded by a closely laid pavement about 18 inches thick laid on 6 to 12 inches of broken stone or gravel. Below low-water line a good layer of riprap is frequently substituted, the paving ending at a berme. The foot of the paving should be well supported by large blocks of stone or concrete. The down-stream face is usually sodded for sake of appearance and as a protection from rain, but may be protected by gravel and coarse material if more convenient.

48. Outlet Pipes. The design and construction of the outlet arrangements is one of the most important and at the same time most difficult features of the work. This is chiefly because of the difficulty of laying pipes or building masonry conduits through earth embankments in such a manner as to secure a perfect and reliable connection between the two materials. Poor work at this point is one of the chief causes of the many failures of earth embankments.

The outlet pipes are usually of cast iron and may either be laid underneath the embankment and surrounded thereby, or a culvert of masonry may be constructed in the embankment and the pipes laid therein, or they may be laid in a tunnel constructed in the natural ground at the end of the embankment or at some more remote point in the reservoir. A gate chamber containing the necessary valves is located at some point along the outlet pipe or conduit.

In the case of reservoirs with comparatively low embankments the outlet pipes are usually laid beneath the embankment at or near the lowest point. They should be laid on a good firm foundation in the natural ground, and should preferably rest upon and be surrounded by a bed of 8 to 12 inches of rich concrete, well rammed into the trench and left rough on the outside. To enable the earth to be more thoroughly bonded with the concrete, cut-off walls should be built projecting out from the main body of the concrete, $1\frac{1}{2}$ to 2 feet, as shown in Fig. 16.

For some reasons an open culvert is much to be preferred to a simple pipe. Once constructed, additional pipes may be laid therein at any time; the pipes may also be readily inspected, and any leaks that occur in them do not endanger the structure, a matter of especial importance where the pipes are under heavy pressure. The same precautions must be taken in the construction of culverts as in the laying of pipes. They must have a good firm foundation and a good bond with the surrounding embankment. Imperviousness is secured by the use of a rich mortar and by plastering on the outside with Portland cement mortar neat or 1 to 1. Cut-off walls or projecting courses should be built around the outside at intervals as described for pipe outlets. At the connection with the gate house a cut-off wall is put in through which the pipes pass, and which must sustain the full head of water.

Figs. 16 and 17 show the two general methods of laying pipes through embankments.

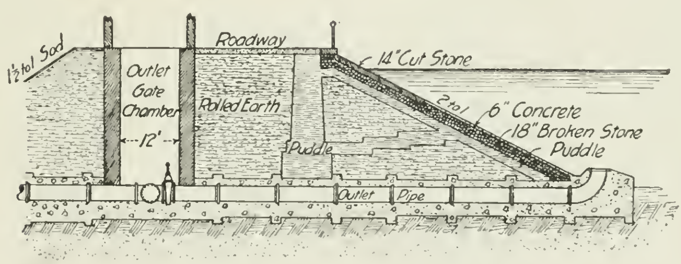


Fig. 16. Section Through Minneapolis Reservoir.

49. Gate Chambers. The gates or valves controlling the flow through the outlet pipes are placed in small masonry chambers, which, besides allowing of convenient operation of and access to the valves, also usually contain screening chambers and valve arrangements whereby water may be drawn from different levels. Gate chambers are preferably placed at or near the upper end of the outlet pipes in order that the pressure therein may be under control. They are, however, sometimes placed at the outer toe of the embankment, but this is undesirable, as it is impossible to shut off the water from the pipes in case of leakage except by the use of divers. Fig. 16 shows the gate chamber placed near the middle of the embankment, while Fig. 17 shows it placed at the upper end of the outlet pipe. One advantage of the latter arrangement is that water may be drawn from different levels so as always to get water of the best quality. Fig. 18 shows a gate chamber for a small works located as in Fig. 17.

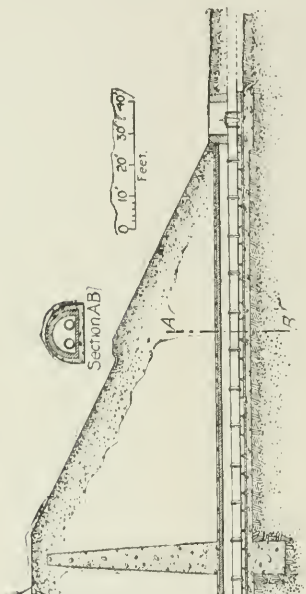


Fig. 17. Section Through Embankment and Gate Chamber.

The masonry of the chamber is usually of heavy rubble, faced with ashlar and lined with hard brick or cut stone. It should be laid in rich Portland-cement mortar to secure imperviousness. The walls will vary in thickness with their unsupported length, or the size of interior chamber, but the exterior walls are usually made 3 to 4 feet thick at the top, with an increase of about three-fourths inch to 1 inch in thickness per foot of depth, the batter being made on the outside for convenience and to furnish a better bond with the earthwork. Interior walls may be made of slightly less thickness. The foundation should be prepared with great care, as unequal settlement is liable to occur, causing cracks in the masonry of the culvert and displacing the outlet pipes.

Fish screens are usually copper-wire screens with $\frac{1}{8}$ to $\frac{1}{4}$-inch mesh, fastened to wooden or iron frames and arranged to slide in grooves in the masonry. They are arranged in pairs, and each screen is made up of several sections of a size convenient to handle.

The gate chamber is surmounted by a gate house in which is located the operating mechanism of valves and screens. As this building is frequently quite prominent, it is important that it be given an artistic treatment suited to the surroundings.

50. Waste Weirs. As already noted, one of the most fruitful causes of reservoir failures is insufficiency of waste weir capacity, resulting in the overflowing of the dam and its rapid destruction. Mention need only be made of the terrible Johnstown disaster in 1889, where, on account of insufficient wasteway, an earthen embankment was destroyed, resulting in the loss of over 2,000 lives and the destruction of property valued at 3 to 4 million dollars.

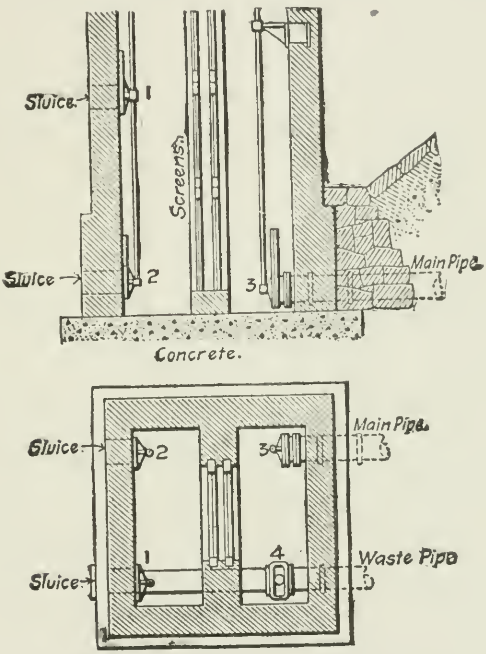


Fig. 18. Gate Chamber, Ipswich, Mass.

In section 14 the subject of maximum flood flows was fully discussed. The maximum flood having been estimated, it remains to provide some safe means whereby it may be passed to the valley below.

This is done in three different ways: (1) A wasteway may be excavated in the natural ground at one or both ends of the dam. Where the foundation is of rock this is a very safe and effective form of wasteway.

(2) The wasteway may sometimes be formed at some low point in the dividing ridge, and the water led to another valley.

(3) The third form of wasteway is provided by making a portion of the dam of masonry designed as a spillway, and placed at about the axis of the valley. The forms of such dams are discussed in detail in section 54. At the junction of the masonry and the earth portions, the lower slopes of the embankments must be retained by heavy wing walls built out from the masonry dam.

The requisite capacity being known, the length and depth of weir are to be determined. Either may be assumed and the other computed by means of the weir formulas as given in "Hydraulics." Weir heights will ordinarily range from 2 to 4 or 5 feet, with lengths of 50, 100, or even 500 feet, or more, depending on the required capacity. In any case the flood line determines the height of the main part of the dam, while the weir crest determines the storage capacity.

MASONRY DAMS.

51. General Conditions. Dams of masonry can safely be built only upon very firm foundations. Low dams of a height of 20 or 30 feet, and occasionally higher, have been founded on firm earth, but high masonry dams should be constructed on nothing less substantial than solid rock. In any case it is necessary to prevent practically all settlement, for with a material such as masonry any appreciable settlement is quite certain to cause cracks.

Masonry dams are designed in accordance with theoretical considerations so as to fulfill the following conditions: (1) The dam must not overturn or slide on its foundation, and (2) the pressures in the dam or foundation must be within safe limits.

The first consideration will govern the design of all dams up to a height of 100 feet or more and are therefore the only considerations which will be taken into account here.

Dams up to 30 or 40 feet in height are usually made trapezoidal in form, the saving obtained by making the faces curved or on broken lines not being enough to justify the extra trouble.

Let A B D C, Fig. 19, be a section of a trapezoidal dam. Let the dimensions be as represented in the figure. Further, let $w =$ weight of a unit volume of water, and $w' =$ weight of a unit volume of masonry. Let g = specific gravity of the masonry $= \frac{w'}{w}$.

The water pressure is represented by P and the weight of the dam by G, and it is assumed that the water level is at the top of the dam. We will consider a length of dam of one foot. The height is known and the top width a and front batter m are assumed. Usually the front face A C is made vertical, or at a slight batter of one inch to the foot or so. In the former case $m = 0$ and in the latter $m = \frac{1}{12} h$.

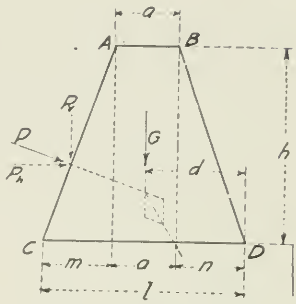


Fig. 19. Trapezoidal Dam.

From principles of mechanics we find the following value of the width of base l,

$$l = \sqrt{A + B^2} - B \qquad (3)$$

in which

$$A = a^2 + 2\,a\,m + \frac{h^2}{g} + \frac{m^2}{g}$$

and

$$B = \frac{m}{g} - \frac{m}{2} + \frac{a}{2}$$

In solving problems the numerical values of A and B should first be obtained and these values then substituted in the formula (3) for l.

If $m = 0$, as for a vertical face, then

$$l = \sqrt{\frac{5}{4}\,a^2 + \frac{h^2}{g}} - \frac{a}{2} \qquad (4)$$

Example. What width of base will be required if $h = 20$ ft., $a = 5$ ft.; and the weight of masonry be considered 2.3 times the weight of water, or $g = 2.3$. Let value of m be 2 feet, giving a batter of 1 in 10.

Getting first the values of A and B we have $A = 5 \times 5 + 2 \times 5 \times 2 + \frac{20 \times 20}{2.3} + \frac{2 \times 2}{2.3} = 221$. $B = \frac{2}{2.3} - \frac{2}{2} + \frac{5}{2} = 2.37$.

Then $l = \sqrt{221 + 2.37 \times 2.37} - 2.37 = 12.7$ ft. Ans.

For dams exceeding 30 or 40 feet in height, it is economy to build the lower face in the form of a curve or broken line. The simplest way of calculating the section of such a dam (up to a height of 100 feet at least) is to treat it at first as similar to the form previously considered, but with a vertical upper face and top width of 0. Then the formula for bottom width becomes

$$l = \frac{h}{\sqrt{g}} \qquad (5)$$

This gives the triangular section A B C in Fig. 20. This form can then be modified by adding a suitable width a at the top and joining the point F with the sloping face A C by a smooth curve F D.

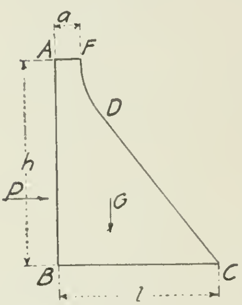


Fig. 20. Curved-Face Dam.

52. Top Width and Height Above Water Line. If the dam is to be used as a driveway, the top width will have to be at least 8 feet besides width of parapets. Otherwise the width and height above high-water line must be such as to secure stability against wave and ice action as just noted, and to prevent waves from washing over the top. In practice the width varies from a minimum of 4 to 5 feet for low dams to 15 or 20 feet for very high dams; and the height above high-water line from 2 or 3 feet to about 10 feet. In some cases much larger dimensions may be required for low dams than those given.

53. Construction. For large dams the foundation should be solid rock. In preparing the foundation surface all loose and partially decomposed material should be excavated until a firm base is reached. If the bottom is smooth it should be roughened by excavating shallow cavities in the rock. At points where crevices occur the excavation must be carried down to a solid bottom and all loose material must be removed. After an acceptable surface is reached it should be thoroughly washed or scrubbed with water in order that there may be a secure bond between the foundation and the masonry.

Uncoursed rubble or concrete is usually employed in dam construction. The object to be attained is to secure a homogeneous structure, free from all through joints or weak places of separation.

Concrete, well placed, is in this respect an ideal material. Rubble masonry, in which all joints are thoroughly filled with mortar, and larger spaces with concrete, has been used for most of the high dams.

In constructing the masonry the principal points to be emphasized are clean surfaces, irregular surfaces, joints absolutely filled with compact mortar, great care to give good bedding, and constant supervision. Mortar and cement should be thoroughly rammed into all spaces, using for this purpose suitable forms of rammers.

In the construction of dams of moderate height, earth backing is often carried up to the water level with a slope of 2 or 3 to 1, as in an earthen dam. If a dam is located on a porous or bad foundation or on one of earth, a good, compact backing will much reduce the percolation under the dam, and therefore the tendency of any upward pressure, and will add considerably to the safety of the structure. It is especially applicable to spillways in earthen embankments.

The arrangements for drawing water from the reservoir are similar in general to those described in the last chapter. The outlet pipes are built in the masonry at or near the lowest point of the dam, and terminate in a gate chamber constructed just above and in connection with the dam. The gate chamber has the same functions as explained in the case of earthen embankments. No danger is here to be apprehended from constructing the pipes in the body of the dam.

54. Masonry Waste Weirs. Masonry dams are not usually designed to allow water to pass over their entire length, but a certain portion only is made to act as a waste weir. The form of a masonry weir depends much upon local conditions, chief of which are height of dam, character of foundation, amount of ice and driftwood to be expected, and quantity of water to be provided for. A weir is essentially a dam with its top and lower face so constructed as to permit the water to pass over it without damage. Besides the design of the profile, the protection of the stream bed below the dam is a very important feature, as many dams have been undermined by failure at this point even where the bed has been solid rock.

Figs. 21, 22 and 23 show three forms of waste weirs. Fig. 21 permits the water to fall vertically and is suitable for small heights; Fig. 22 is preferable for larger quantities of water and greater heights; while Fig. 23 represents a form of construction suitable for the largest dams.

55. Timber Dams. Where a dam is constantly submerged, a timber structure is of a permanent nature, and will need repairs only on account of the wear of the apron. A timber dam may also be advisable in certain circumstances even when its life will be short, as, for example, where a temporary supply may be furnished pending the construction of more permanent works, or where the expense of permanent and costly structures is for the present prohibitory. Such dams are, however, used mostly for diversion purposes or for water power, and seldom for the storage of large volumes of water.

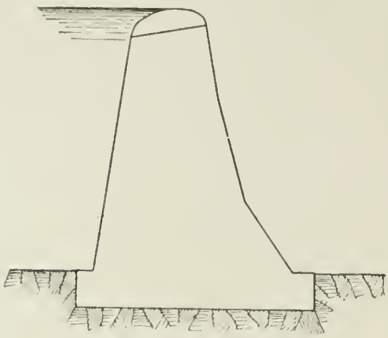


Fig. 21. Waste Weir.

Timber dams may be constructed on any kind of a foundation, but are usually built on rock or on a gravelly bed. They consist of cribs or frames built of logs or squared timber, filled with stone and clay, and planked over to render them water-tight. They may be built as separate cribs in sections, each section consisting of perhaps 3 to 4 cribs, or as one continuous framework. The former method is especially useful in dealing with large flows and irregular foundations, the stream being gradually closed as the sections are constructed. The cribs may also be filled and sunk separately so as to form piers on which a continuous structure may be built.

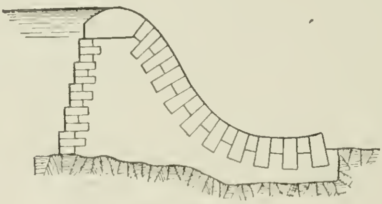


Fig. 22. Waste Weir.

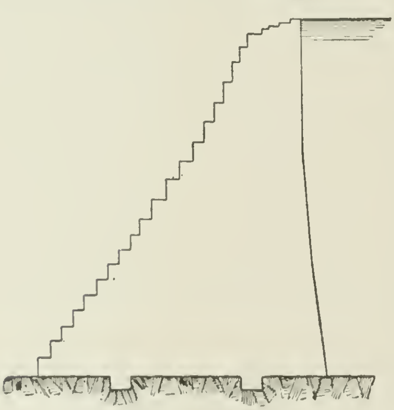


Fig. 23. Waste Weir.

The foundation of a crib dam, if soft, is prepared by dumping stone over the area to be built upon. In the framed dam the foundation must be more carefully prepared. Where it is soft the dam is supported on piling, and sheet-piling is used to prevent underflow. If the dam is built on a rock bottom, it must be bolted thereto. The framework is usually built with a sloping upper face and a series of

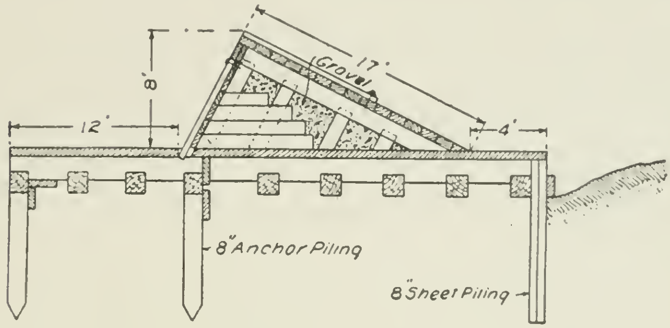


Fig. 24. Timber Weir.

stepped aprons below, or a single free wall to a water cushion. Rock and gravel, or puddle, is used for filling. Fig. 24 shows a form of dam on pile foundations and Fig. 25 a dam anchored to solid rock.

56. Loose Rock Dams. Dams composed largely of loose rock have been used to a considerable extent, and in some respects present

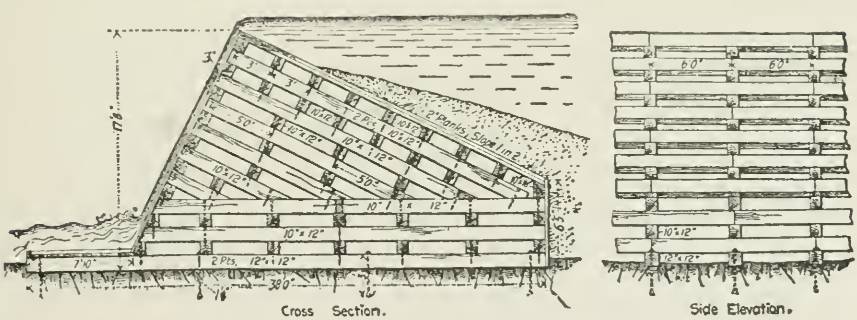
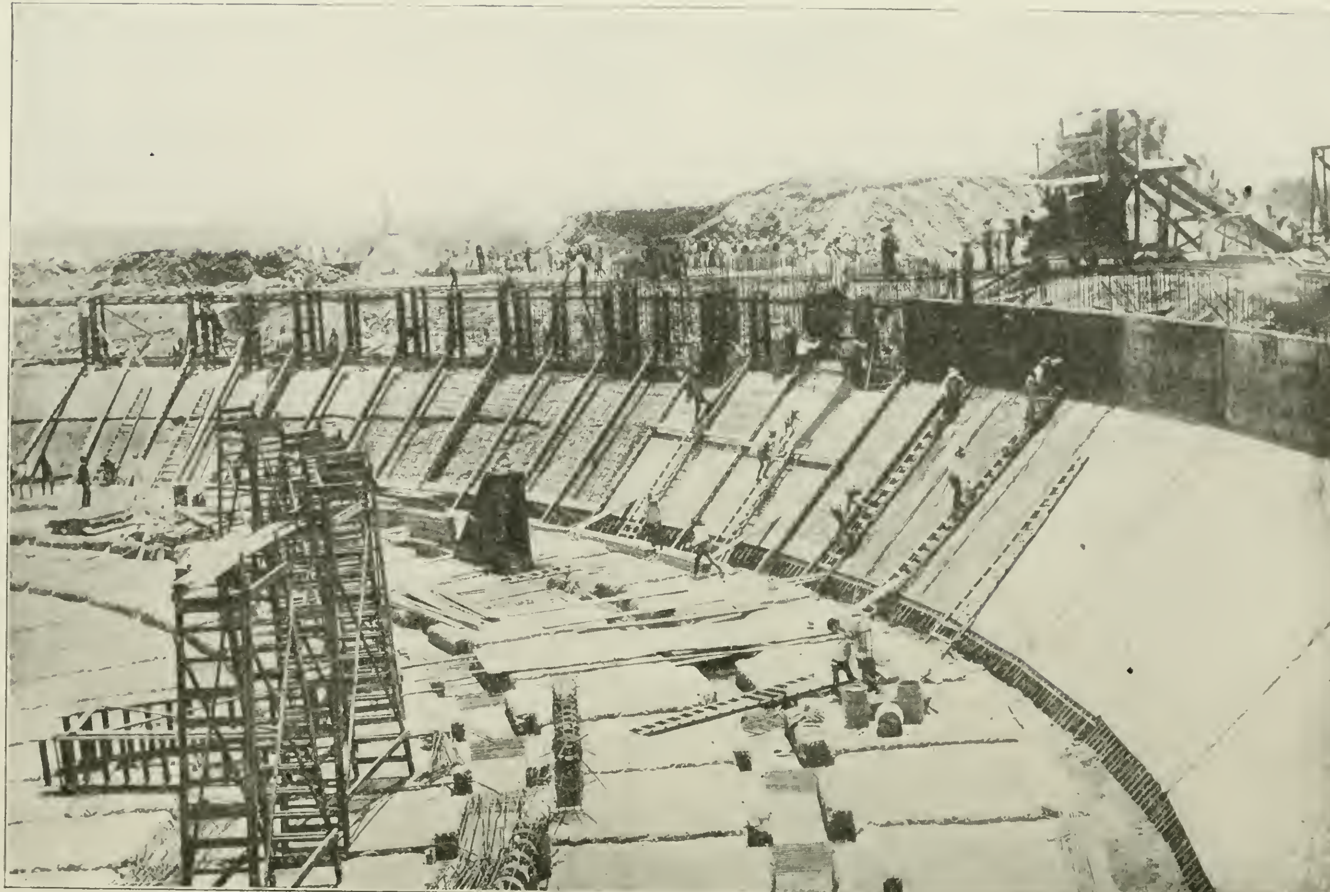


Fig. 25. Dam Anchored to Rock.

considereble advantages as to stability. Another advantage is that they can be constructed in running water, but the finished dam is not suited to act as a waste weir.

The body of the dam is made of loose rock placed with more or less care, and rendered comparatively impervious by a sheathing of plank, or by a facing of earth or fine material on the upper face, or, as in one case, by a core of steel. As regards stability the principle of construction is of the best. Since considerable percolation is likely to take place, such a dam cannot be founded on a material liable to scour; and if the dam is high, the foundation should be solid rock. The lower slope is usually 1 to 1, while the upper slope may be made $\frac{1}{3}$ or $\frac{1}{2}$ to 1; but to secure these steep slopes it is necessary to lay the stone for a considerable thickness as a dry wall. Above this wall the facing of timber or earth is placed. The former material is objectionable on account of its perishable nature.



CONSTRUCTION OF A REINFORCED-CONCRETE CIRCULAR RESERVOIR FOR THE CITY OF MEXICO

View showing excavations for column bases and floor-girders; also construction work on side walls.

Courtesy of Expanded Metal & Corrugated Bar Company, St. Louis, Mo.

WATER SUPPLY.

PART II.

CONDUITS AND PIPE LINES.

PIPES.

57. Materials and Stresses. Where the source of supply is at a considerable distance from the place of consumption the design and construction of the necessary works for conducting the water is a matter of great importance and demands special consideration. Usually a distant source is at a higher elevation than the city to be served, so that it will be possible to convey the water partly or wholly by gravity. In many cases, however, a part or the whole of the water will require pumping, so that the design will also involve a study of possible pumping arrangements. It will usually be necessary to consider several designs based upon different locations and often upon different types of conduits.

A variety of materials may be employed for the construction of water conduits. If the conduit is not under pressure, the form of construction used may be an open canal dug in the natural earth, or a masonry conduit in "cut and cover," or a tunnel. Where the water flows under pressure the first two types are not suitable and a pipe, or possibly a tunnel, must be employed.

The materials used for water pipes are cast iron, wrought iron, steel, wood, cement, vitrified clay, lead, and occasionally a few other materials. The important requirements for a water pipe are strength, durability, and low cost. The relative importance of these requirements will vary under different circumstances, and this will lead to the use of different materials in different cases.

The tensile stress in a water pipe under pressure is given by the formula in section 10, of Hydraulics,

$$S = \frac{pr}{t} \qquad (6)$$

where S = tensile stress per sq. inch
p = pressure in lb. per sq. in.
r = radius of the pipe in inches,
t = thickness of pipe in inches.

If f represents the safe tensile strength of a pipe material, then the required thickness to resist the pressure will be given by the formula

$$t = \frac{pr}{f} \qquad (7)$$

Example. What will be the required thickness of a steel pipe 3 ft. in diam. for a water pressure of 100 lb. per sq. in. assuming the safe stress = 10,000 lb. per sq. in.

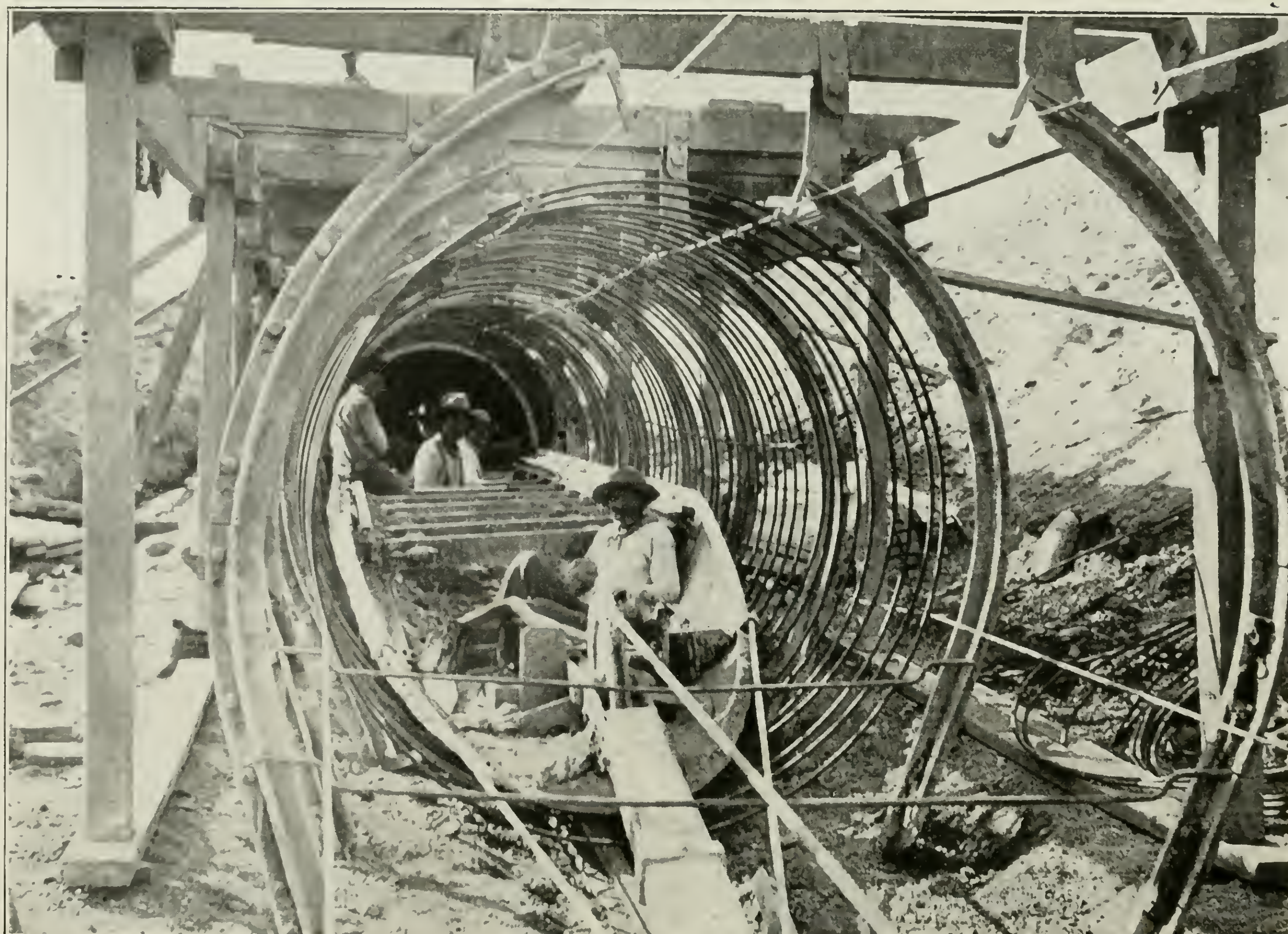
From formula 7, $t = \frac{100 \times 18}{10,000} = .18$ inch. Ans.

Besides the stress due to steady water pressure, the pipe must be strong enough to resist the shocks due to the sudden stoppage of flowing water, called *water hammer*, also the pressure of the surrounding earth and the action of other outside forces, changes of temperature, and blows and shocks received in transportation and construction. The stresses due to these additional forces cannot be accurately calculated; but they are allowed for in practice by various empirical rules.

58. Cast-Iron Pipe. Cast iron is the most widely used material for water pipe. By reason of its moderate cost, its durability, and the convenience with which it may be cast in any desired form it is almost universally employed for the pipes and various special forms of distributing systems. It is also frequently employed for large pipe lines, and is now easily obtained in any desired diameter up to 6 feet or more. Cast-iron pipes are made in lengths of about 12 feet, which are joined together usually by the bell-and-spigot joint run with lead. Branches and other irregular forms are used for connections. These are called special castings, or simply "specials."

A formula for the thickness of cast-iron pipe applicable to diameters up to 3 feet is as follows:

$$t = \frac{(p + 140 - 4r)}{3300} r + 0.25 \qquad (8)$$



BUILDING THE REINFORCING SKELETON OF A CONCRETE FLUME where t = thickness in inches;

p = static pressure in pounds per square inch;

r = radius of pipe in inches;

0.25 = allowance for eccentricity, deterioration, and safety in handling.

In Table No. 10 are given the thicknesses of pipe for various pressures, also the average weight per foot, and the total weight of 12-foot lengths, as employed by the Metropolitan Waterworks, of Boston.

TABLE 10.

Thickness and Weight of Water Pipe.

Diameter in Inches.	Class A. 115-foot Head.			Class B. 150-foot Head.			Class C. 200-ft. Head.			Class D. 250-ft. Head.			Class E. 300-ft. Head.		
	Thickness of Shell in Inches.	Average Weight per Foot.	Weight of 12-ft. Length.	Thickness of Shell in Inches.	Average Weight per Foot.	Weight of 12-ft. Length.	Thickness of Shell in Inches.	Average Weight per Foot.	Weight of 12-ft. Length.	Thickness of Shell in Inches.	Average Weight per Foot.	Weight of 12-ft. Length.	Thickness of Shell in Inches.	Average Weight per Foot.	Weight of 12 ft. Length.
4	....	......	......	....	......	....	....	....	....	0.40	19.2	230	0.45	21.2	255
6	....	......	......	....	......	....	....	....	....	0.46	31.7	380	0.50	34.6	415
8	....	......	......	....	......	....	....	....	....	0.52	47.1	565	0.55	50.0	600
10	....	......	......	....	......	....	....	....	....	0.60	66.7	800	0.63	70.0	840
12	....	......	......	0.57	75.8	910	0.61	80.8	970	0.65	85.8	1030	0.69	91.2	1095
14	....	......	......	0.61	94.2	1130	0.65	100.0	1200	0.70	107.5	1290	0.75	115.0	1380
16	....	......	......	0.65	115.0	1380	0.70	123.7	1485	0.75	132.5	1590	0.81	142.9	1715
20	....	......	......	0.73	160.8	1930	0.79	173.3	2080	0.85	186.2	2235	0.92	201.2	2415
24	....	......	......	0.80	210.4	2525	0.87	228.3	2740	0.95	248.7	2985	1.03	269.2	3230
30	....	......	......	0.92	302.1	3625	1.00	327.5	3930	1.10	361.2	4335	1.20	393.3	4270
36	0.93	366.7	4400	1.03	404.2	4850	1.13	441.7	5300	1.25	491.7	5900	1.36	533.3	6400
42	1.01	467.5	5610	1.14	524.2	6290	1.27	581.2	6975	1.40	645.8	7750	....	......	......
48	1.15	605.8	7270	1.25	655.8	7870	1.40	730.0	8760	1.55	818.3	9820	....	......	......
54	1.23	730.8	8770	1.35	797.5	9570	1.53	919.2	11030	....	......	......	....	......	......
60	1.35	885.8	10630	1.50	979.2	11750	1.70	1132.5	13590	....	......	......	....	......	......

59. Joints. The joint which is ordinarily employed in this country is the bell-and-spigot joint. The space between bell and spigot is filled with lead, which is calked solidly into place so as to be water-tight. Many forms of bell or socket have been devised, but practice has come to be quite uniform on this point.

In Table No. 11 are given various dimensions of standard bell and spigot of the Metropolitan Waterworks (Fig. 26), together with amounts of lead and packing required per joint.

The ordinary bell-and-spigot joint with lead packing will enable pipes to expand and contract under moderate changes of temperature such as occur with buried pipes.

Curves of large radius can be constructed with straight pipe by deflecting each length slightly. In this way it is possible, with a reasonable deflection, to lay 4 to 8-inch pipe to a curve of 150-foot

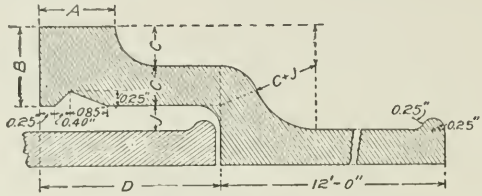


Fig. 26. Standard Bell and Spigot.

radius, a 16-inch pipe to a 250-foot radius, and a 36-inch pipe to a 500-foot radius.

TABLE 11.

Dimensions of Standard Bell and Spigot, Metropolitan Waterworks, Boston (Fig. 26).

Size of pipe.	Class.	Dimensions in inches.					Average wt. of lead per joint.		Weight of jute gasket per joint.
		A	B	C	D	J	With gasket.	Solid lead.	
4	All classes	1.50	1.30	0.65	3.00	0.40	7	9¼	.10
6	"	1.50	1.40	0.70	3.00	0.40	9¾	12¾	.15
8	"	1.50	1.50	0.75	3.50	0.40	12½	18¾	.25
10	"	1.50	1.50	0.75	3.50	0.40	15¼	23¼	.30
12	"	1.50	1.60	0.80	3.50	0.40	18	27	.35
14	"	1.50	1.70	0.85	3.50	0.40	20½	31	.40
16	"	1.75	1.80	0.90	4.00	0.50	31¼	50½	.65
20	"	1.75	2.00	1.00	4.00	0.50	38½	62	.80
24	"	2.00	2.10	1.05	4.00	0.50	45½	74	.95
30	B and C	2.00	2.30	1.15	4.50	0.50	56	100½	1.55
30	D and E	2.00	2.50	1.25	4.50	0.50	57	102	1.55
36	A, B, and C	2.00	2.50	1.25	4.50	0.50	67	120½	1.85
36	D and E	2.00	2.80	1.40	4.50	0.50	68½	122½	1.85
42	A, B, and C	2.00	2.80	1.40	5.00	0.50	77½	154	2.60
42	D	2.00	3.20	1.60	5.00	0.50	78½	156	2.60
48	A, B, and C	2.00	3.00	1.50	5.00	0.50	88½	176	3.00
48	D	2.25	3.50	1.75	5.00	0.50	89½	178	3.00
54	A and B	2.25	3.10	1.55	5.50	0.50	99½	215	3.95
54	C	2.25	3.90	1.95	5.50	0.50	100	215½	3.95
60	A and B	2.25	3.20	1.60	5.50	0.50	110½	239	4.40
60	C	2.25	4.20	2.10	5.50	0.50	111	241	4.40

60. Special Castings. The ordinary special castings required are the $\frac{1}{4}$, $\frac{1}{8}$, and $\frac{1}{16}$ bends or curves, T's and crosses, or three-way and four-way branches, Y branches, blow-off branches, offsets, sleeves, caps, and plugs. The various forms are illustrated in Fig. 27. Many of the larger cities have their own standard designs for specials as well as for straight pipe, which differ more or less from the manu-

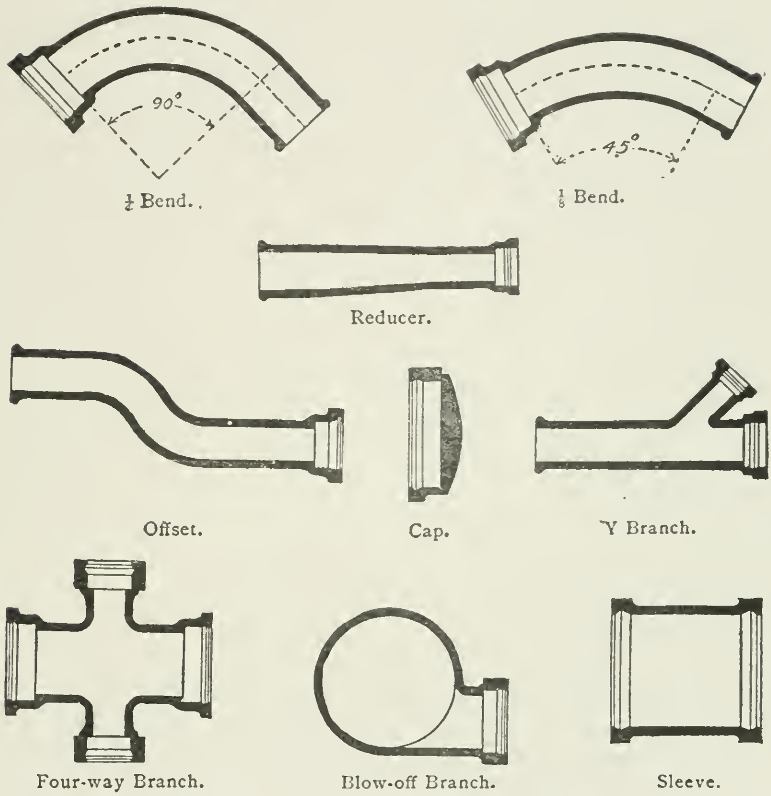


Fig. 27. Special Cast-iron Pipe Fittings.

facturers' standards. For the smaller cities it will be much the more economical to use either the manufacturers' standards or those of some neighboring large city.

The various branches are manufactured either with part bell and part spigot ends, or with all bell ends. The latter form is usually preferred for branches, as it enables connections to be readily made by means of pieces of pipe.

61. Wrought Iron and Steel Pipe. Wrought iron and steel have been used to a considerable extent for water pipes, and for large pipe lines these materials present considerable advantage over cast iron. Since steel is much stronger than cast iron, the use of it will give a much lighter pipe, an advantage as regards transportation, but a disadvantage as regards durability, especially for small sizes. Special forms are not so readily constructed of steel, so that for distributing mains cast iron is much preferable. Another disadvantage of steel pipe is that with the ordinary riveted joints a considerably larger pipe is required than if a smooth cast-iron pipe is used on account of the increased friction.

Small sizes of pipe may be made by means of the lap-welded joint, or the spirally-riveted joint, or the longitudinal lap-riveted joint. Such pipes are made in sections of 12 or 15 feet which are connected in the field in various ways, such as by a screw coupling, or by means of a cast-iron bell and a spigot consisting of a steel or wrought-iron band, or by riveting, or by merely driving the sections together. For large sizes riveted longitudinal and circular joints are usually employed. Single sheets are bent and riveted to form one section of pipe, which may be made either cylindrical in form, or made with a slight taper and the sections put together stove-pipe fashion. The design of the riveting is too large a subject to be taken up here.

Changes in direction are usually made by forming one or more joints at a small bevel. Two or three standard bevels of small angle may be adopted, and any desired curve made by the use of one or more of these bevels. Branches, etc., for the ordinary sizes of pipes, are usually made of cast iron and are riveted or bolted firmly to the steel pipe. Valves are joined to the pipe in a similar manner by means of cast-iron flanges.

62. Wooden Pipe. The manufacture of bored pipe for water mains has been somewhat revived in recent years, and a considerable amount of such pipe is now manufactured under the name of "improved Wyckoff pipe." The pipe is made from solid logs, but it depends for strength upon spiral bands of flat iron which are wound tightly about it from end to end. The exterior of the pipe is coated with pitch as a protection to the bands. The joints are made by means of wooden thimbles fitting tightly in mortises in the ends of the pipe, and, in laying, the sections are driven together by means of a wooden ram. The interior surface is smooth and continuous.

The pipe is made in sections 8 feet long, and in sizes from 2 to 17 inches in diameter. The bands are spaced according to the pressure. Branch connections are made by means of cast-iron specials which have long sockets into which the wooden pipe is driven. About 1,500 miles of this pipe is reported to be now in use. It is very durable and is said to cost somewhat less than cast iron where the transportation charges are not excessive. Wooden stave pipe is another form that has been extensively used in the West.

The durability of wooden pipe is chiefly a question of the life of the bands. Wood, itself, when kept saturated with water, has an almost indefinite life, old water mains in Philadelphia, New York, and Boston having been found perfectly sound after sixty or seventy years of use.

63. Vitrified Clay Pipe has been employed in a few places for conduits. It is cheap, indestructible, and when the joints are carefully made the leakage is very small. It is generally used under no pressure, but in one or two instances has been designed to carry considerable pressures.

64. Materials for Service Pipes. Service pipes, or pipes for conducting water to individual consumers, are made of a considerable variety of materials. Galvanized, tin-lined, lead-lined, and cement-lined iron pipe are widely used, but the most common is lead pipe. Lead pipe is practically indestructible, but rather expensive and heavy for high pressures. In some places it cannot be used with safety on account of the danger of lead poisoning. Certain waters only will attack lead to a sufficient extent to render its use dangerous, but, despite the study that has been put upon the subject, it is not yet fully known, without actual experiment, what effect various classes of waters will have.

Tin-lined pipe is now being used to a considerable extent. It is quite expensive, but the experience with it so far indicates that it may be very durable.

CONSTRUCTION OF CONDUITS.

65. Classes of Conduits. Conduits are divided into two general classes: (1) those in which the water surface is free and the conduit therefore not under pressure, and (2) those flowing under pressure. To the first class belong open canals, flumes, aqueducts, and usually tunnels, and to the latter belong pipe lines of iron, steel, wood, or other material capable of resisting hydraulic pressure, and sometimes tunnels. Conduits of the first class must obviously be constructed with a slope equal to that designed for the water surface, or equal to the hydraulic gradient. This will be a very light and uniform slope, and such conduits will therefore often require in their construction long detours to avoid hills and valleys, or resort must be had to high bridges, embankments, cuttings, or tunnels. Conduits of the second class may be constructed at any elevation below the hydraulic grade line.

Long conduits usually include both masonry aqueducts and pipe lines, each class being used where most suitable. The former is used as a rule where the ground lies near or above the hydraulic grade line, and the latter where it lies below for any considerable distance. High and long aqueduct bridges are no longer built, a pressure conduit being substituted, which may follow the ground profile closely.

66. Canals. The open canal is not often used for conveying water for city use, but for irrigation purposes it is the common form of conduit. For the former purpose it has several objections, such as loss of water by percolation and evaporation, exposure of water to pollution from surface drainage and otherwise, and exposure to summer heat, which not only warms the water but promotes vegetable growth. However, where a canal can be constructed with little cutting or embankment, and where the material is nearly impervious, it may be the best form of construction.

The allowable velocities for unprotected canals vary from about $1\frac{1}{2}$ to 2 feet average velocity for light sandy soils, $2\frac{1}{2}$ to 3 feet for ordinary firm soils, and 3 to 4 feet for hard clay and gravel. In rock or hardpan 5 to 6 feet may be allowed. A velocity of 2 to 3 feet per second is sufficient to prevent silt deposits and the growth of weeds.

The velocity and discharge for any given slope and cross-section is calculated from Kutter's formula as explained in Hydraulics. In using this formula the selection of a proper value of n is a matter of much uncertainty. For unlined channels it is usually taken at .020 to .025. If vegetation is allowed to accumulate in the canal, a large allowance must be made for increased resistance caused thereby. The cross-section of a canal is usually trapezoidal in form. Fig. 28

shows a section built principally by embankment. Clay puddle is placed in the center of each embankment.

Side slopes in ordinary soils will vary from 1 to 1 for hard clay and gravel, to 3 to 1 or 4 to 1 for fine sand. The tops of the bank should be from 1 to 2 feet above the water line. If the soil is very porous, a lining of concrete or puddle may be necessary.

At sharp bends, and wherever the velocity exceeds the safe velocity for the material, some form of revetment is necessary. This may be merely a layer of gravel, or a paving laid dry or in cement, or a layer of concrete, according to the velocity of the water.

Waste weirs and sluice gates should be provided at intervals along the canal to prevent flooding and to permit of rapid emptying, but the flow in the canal is regulated for the most part by sluice gates at the head of the canal. These and other forms of canal gates are supported either by masonry walls or by timber framework.

Canals are carried across valleys on trestles or bridges, or, in the case of short crossings, on embankments with a culvert or arched

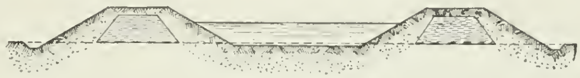


Fig. 28. Canal Section in Embankment.

bridge beneath. Under crossings are made by means of inverted siphons of pipe.

67. Masonry Conduits. For conveying relatively large quantities of water over territory where the conduit can readily follow the hydraulic grade line, the masonry conduit is a preferable form of construction. If properly constructed it is very durable, requires little attention, and if the topography is favorable it is much cheaper than large pipe conduits of iron or steel. Masonry is unsuited to withstand tensile stresses, hence it is not used to convey water under pressure. Masonry conduits should not often be employed for cross-sections less than 10 or 15 square feet, for, unless the location be very favorable, their cost for such small sizes is likely to be greater than that of steel or iron pipes. The velocity should preferably be such as to prevent deposit of sediment, which requires $2\frac{1}{2}$ to 3 feet per second average rate; and for brick or concrete masonry it should not exceed 6 or 7 feet per second. Higher velocities may be allowed if stone masonry of hard material is employed, or if a lining of iron or steel is used. If sufficient head is available, a smaller conduit will result if the velocity is made as large as the material will stand without danger of excessive wear.

Kutter's formula is usually employed in these calculations. (See Hydraulics.) The value of n to be used will vary with the character of the masonry about as given in Hydraulics.

Brick is the most suitable material for linings, and is commonly used also for the entire arch crown. For the side walls and foundation, rubble masonry or concrete is employed. For places of great wear paving brick in cement is a good substitute for granite. Concrete is better suited than either stone or brick for irregular forms and especially for light sections. For small aqueducts a rectangular form has often been used, as in Fig. 29, the cover being of stones, slabs, or arches. For large sizes the horseshoe shape is better adapted, as shown in Fig. 30, which represents the form adopted for a large conduit for Boston.

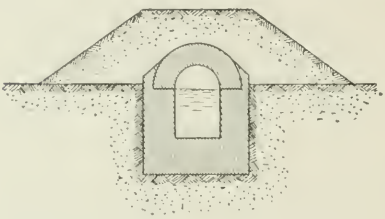


Fig. 29. Gallery, Vienna Waterworks.

The thickness of the arch is made about one-tenth to one-sixth the width of the opening, and of two, three, or four rings of brick, or a corresponding of concrete, depending on span and weight of covering. The arch is generally segmental in form. The invert, in compact ground, is made only thick enough to secure a firm and impervious bottom, two or three rings of brick, or a thin layer of concrete with brick lining, being usually employed. A timber foundation and sometimes piling may be required on soft soils. Settlement must be reduced to very low limits, or cracks and leakage will result. It is unnecessary to state that in work of this kind the masonry must be constructed with the most careful supervision. Concrete and stone masonry should be

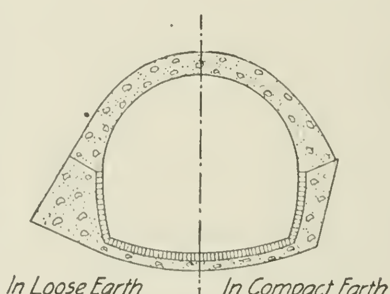


Fig. 30. Forms for Large Conduit.

given one or two finishing coats of thin neat cement to secure imperviousness, the last coat to be finished as smooth as practicable. If carefully done, and no settlement occurs, the leakage will be slight.

The aqueduct should be covered to a depth of 3 or 4 feet to prevent the formation of ice and to protect the masonry. Embankments should be given a slope of $1\frac{1}{2}$ to 2 horizontal to 1 vertical according to the nature of the material. They should be trimmed to a rounded outline and then sodded.

Culverts for crossing small streams, and bridges for larger ones, are a part of the design. Some of the most monumental works of history are the bridges which have been built for carrying aqueducts. Large aqueduct bridges are now seldom constructed, pipe lines being substituted, but bridges of moderate size will often be the more economical design.

68. Pipe Lines. As to location, a pipe line must follow in general the variations of the ground surface, and such a location should be selected as will enable it to do so and at the same time give low pressures.

Where the total available head is fixed, the size required for any given capacity is readily determined by the table of the flow of water in pipes in Hydraulics. In case the water contains suspended matter, it is desirable to maintain a self-cleansing velocity of 2 to $2\frac{1}{2}$ feet per second, otherwise the sediment must be blown out at frequent intervals. If the line is divided into sections by reservoirs or overflows, the size of each section is determined independently of the others.

If pumps are used to force the water through the pipe then the proper size depends on the relative cost of pipe, and of pumping against an increased head. A large pipe gives low friction head of the water and therefore saves in pumping expenses, but a large pipe is more expensive than a small one. In general it may be assumed that a proper size of pipe is one which calls for a velocity of flow of from $1\frac{1}{2}$ to $2\frac{1}{2}$ feet per second, the former value for pipes of 6 to 12 inches in diameter, and the latter for pipes of 3 or 4 feet in diameter.

69. Laying of Pipes. Trenches for water pipe are not usually deep enough to require much bracing or sheeting, the depth being ordinarily only sufficient to give the necessary covering. Deep trenches will, however, be required occasionally, as where the pipe line crosses a high ridge extending above the hydraulic gradient.

The laying of cast-iron pipe is usually begun at a valve or special. Small pipe up to 6 or 8 inches in diameter is easily handled without a derrick, the sections being lowered into the trench by two or three men. In laying, care should be taken to enter the pipe to its full depth and to see that there is sufficient joint space all around. If special strength is not required, this packing may nearly fill the space back of the enlargement or V-shaped space in the bell. The remaining space is filled with molten lead. In pouring the joint the lead is guided into the space by a jointer, commonly made of clay formed around a length of rope. This is placed about the pipe so as to press against the hub, except at the top, where an opening is made for pouring. Patent jointers are better for large pipe and difficult work. After pouring, the lead is loosened somewhat from the pipe by means of a chisel and set up by calking iron and hammer. To do good work there should be plenty of room around and under the pipe. In wet trenches and with small pipe, two or three sections may be joined before lowering. Riveted pipe should be connected up in as long sections as practicable before being transported to the trench, so that as much of the riveting may be done by power riveters as possible.

When placed in the trench the pipe should have an even bearing on firm soil or on blocking, and should be well supported while the joints are being riveted. The riveting is usually done by hand, but power riveters have been used in a few cases. After riveting, all field joints should be calked, and these and all other abraded places painted. Some re-calking may be needed after the pipe is tested.

In constructing the pipe system one of the most important points to settle is the depth at which the pipes should be laid. In warm climates a covering of 2 to 3 feet is sufficient. In cold climates the depth to be adopted is that which will be sufficient to prevent freezing. In a general way it may be stated that for a latitude of 40° the depth of cover should be 4 to 6 feet and for 45° should be 6 to 8 feet, the smaller depths being used east of the lakes and the greater depths for the country between the lakes and the Rocky Mountains. In sandy soil the depth should be greater than in clay.

70. Special Details. To enable a pipe line to be readily inspected and repaired, stop valves should be inserted at intervals of 1 or 2 miles, and especially at important depressions and summits.

Otherwise to empty and refill a long conduit would require several days. Valves of all kinds and designs are furnished by various special manufacturing concerns.

At every summit of a pipe line and at shut-off valves there should be placed an air valve to permit the escape of air on filling, the entrance of air on emptying, and frequently the escape of air which may gradually accumulate at summits. At all depressions, blow-off valves should be provided, the waste pipes from which should be led to a sewer, stream, or drainage channel. These valves need be only about one-third the size of the main pipe. Check valves should be introduced at points where a breakage would permit a large loss of water by backward flow, such as at the entrance to reservoirs, at the foot of long upward inclines, and in force mains just beyond the pumps. Safety valves, or pressure-relief valves, are occasionally used at the ends of long pipe lines or wherever water hammer is especially to be feared. They are simple disk valves opening outwards and held in place by springs which are adjusted to the water pressure.

The upper end of a gravity pipe line is usually enclosed in masonry and provided with a sluice gate or valve. At this point it is also desirable to have a weir or measuring sluice. The lower end of a pipe line usually terminates in a reservoir, where again valves are provided and where connections may also be made directly with the pipe system.

In crossing under other structures, such as railways, buildings, sewers, etc., special precautions should be taken to avoid all danger of future breakage.

Streams are crossed either on bridges, or by laying the pipe beneath the stream bed, or by the use of a subway.

In this country the common practice in crossing a stream is to lay a cast-iron or steel pipe below the stream bed, or else to employ a bridge crossing. Where no bridge already exists the former will ordinarily be the cheaper; and in many cases, as in navigable channels, a bridge could not be permitted. In other cases it may be cheaper to build a bridge especially for this purpose. At the angles at ends of bridge and submerged crossings special care is necessary to keep the pipe from separating at the joints. If the pipe line crosses an existing bridge, it will usually be convenient to support it beneath the flooring. Where a bridge is built for the purpose, no floor system is put in, but merely suitable straps or stirrups to support the pipe.

The amount of protection required to prevent freezing on bridges, or at other exposed places, depends upon the size of pipe, the amount of circulation during periods of minimum flow, the temperature of the air and the water, and upon the length of the exposed portion.

Small lines, especially distributing mains, require protection. This is usually furnished by placing the pipe in a wooden box and filling around it with some non-conducting substance, such as sawdust, mineral wool, asbestos, hair felt, and the like. A mixture of plaster of Paris and sawdust has been used with good results. Any packing to be effective should be kept dry. The packing is often arranged to give one or more dead air spaces around the pipe to aid in preventing radiation.

Various methods are employed in laying pipes beneath watercourses. In the case of small streams the usual method is to employ a cofferdam and lay the pipe as on dry land. Where the water cannot readily be excluded in this way the pipe must either be put together before lowering in place or must be laid by divers. Submerged pipe should, as a rule, be laid in a trench and carefully covered to prevent injury by waves, drift ice, boats, etc.

Various special details are used in submerged-pipe laying, such as the various forms of flexible joints to enable the pipe to conform to the grade of the trench, and special joints for easy connection where divers are employed. Submerged pipe should be thoroughly tested either in sections before laying, or better, after the line is completed, in which case compressed air can be used for the purpose. Leakage of air will be indicated by the appearance of bubbles, and the imperfect joints can then be calked by divers. The various methods of laying submerged pipe will now be described together with some of the special details used in this work.

(1) Where the stream is shallow, a common method of laying is first to connect the entire pipe, or large sections of it, on platforms extending across the stream, and to lower the portion so connected by means of screws. Ordinary joints can usually be employed and the pipe put together to fit the profile of the trench. Pipes can very conveniently be laid in this way from the ice during winter.

Two cases of this method of laying will be briefly noted. At Cedar Rapids, Ia., 600 feet of 16-inch pipe was laid in this way in a depth of $2\frac{1}{2}$ feet of water. A trench 2 feet deep was first excavated, and framed trestle bents set up 12 feet apart. A barge was then run between the legs of the trestles, the pipe put together on the barge and then slung by straps fastened to $1\frac{1}{4}$-inch threaded rods suspended from the trestles. When the entire pipe line was connected, it was all lowered together, electric-bell signals being used to secure simultaneous action among the several men stationed at the screws. The cost of laying was $1.25 per foot.

(2) Instead of connecting the entire pipe line and lowering all together, it may be lowered in sections by the aid of flexible joints, each section consisting of several lengths of pipe connected in the usual manner. The pipe can thus be laid and lowered from a short piece of trestle or from a barge. This method is especially suitable for deep water where trestles cannot readily be used.

(3) Many lines of submerged pipe have been laid by joining several lengths on shore, towing them into position, sinking them and connecting them by divers. This method is especially applicable for large pipe lines. It has been used for large intakes at Syracuse and at Milwaukee; also at Galveston, Nashville, Boston, and many other places.

71. Cost of Pipe Lines. The cost of pipe lines will vary greatly according to the cost of the material used. This element can readily be ascertained at any time by reference to current price lists, and the item of transportation can also be quite readily determined. Cast-iron pipes laid under average conditions will cost approximately as follows, assuming the pipe itself to cost $1\frac{1}{2}$ cents per lb

Size of pipe.	Cost per foot.
4 inch	$.50
6 "	.70
8 "	1.00
10 "	1.30
12 "	1.70
16 "	2.50
20 "	3.50
24 "	4.50

THE DISTRIBUTING SYSTEM.

Distribution Reservoirs.

72. Use. The rate at which water is actually used is not at all uniform, as fully pointed out in section 6. It varies from day to day according to the season, from hour to hour according to the time of day, and at times of large fires the rate will be greatly increased. If all parts of a system were to be designed of a capacity equal to the greatest possible rate of demand the cost would frequently be prohibitive, and in most cases it would not be the most economical plan. It will usually be more economical to store up a quantity of water in a small reservoir or elevated tank which may be drawn upon when the demand is excessive and thus relieve to some extent a part of the system.

For example, where the water is brought from the source through a long conduit, a distributing or equalizing reservoir will enable the conduit to be operated at a comparatively uniform rate and hence to be made of minimum size. Likewise such a reservoir will make it possible to reduce the capacity of pumps, or filters, or other similar works, and to operate them more uniformly and economically; or in the case of small works to operate the pumps at full capacity for a portion of the day only. In the case of a ground-water supply, a small reservoir will greatly increase the capacity of the source by making the demand more uniform. Again, in a large distributing system, several reservoirs placed at different points will effect considerable economy in the size of the pipe system. As a measure of safety against the interruption of the supply from accidents to conduit or machinery, distributing reservoirs are of great value.

In discussing forms of construction, reservoirs may be classified, according to the material employed, into (1) earthen reservoirs, (2) masonry reservoirs, (3) iron or steel reservoirs, and (4) wooden reservoirs. The first two kinds can conveniently be considered together, as the two materials are very often combined in the same structure. The last two will also be treated under the general title of standpipes and tanks.

When the reservoir does not need to be elevated above the natural surface, the most economical form, and the usual one for large capacities, is the open reservoir with earthen embankments. Such reservoirs are usually built with masonry walls, and covers partly in excavation and partly above the surface. If a reservoir requires to be considerably elevated, a steel standpipe or a tank of wood or steel is usually employed.

73. Capacity. Where it is possible to construct an inexpensive open reservoir at a suitable elevation and in a good location, it should be given a capacity of several days' supply. In practice the capacity of such reservoirs varies from 2 or 3 days' supply up to 8 or 10 days, and occasionally more.

Where, owing to the character of the topography, it becomes necessary to artificially elevate a reservoir in the form of a standpipe or elevated tank, the expense of construction becomes so great that the economical capacity is usually less than that mentioned under (1). The best capacity in this case depends much upon the size of the city. For large cities it is hardly practicable to provide much storage by means of artificially elevated reservoirs, the small standpipes which are often used in such cases serving merely to equalize the action of the pumps.

In small cities (up to a population of 50,000 or more) it is desirable to provide a small storage even at considerable cost, as a measure of safety and economy. The fire rate is here the principal consideration, and the minimum capacity should be such as to provide water at the maximum fire rate for a sufficient length of time to enable the pumping station to respond with ease and certainty. This is ordinarily taken as about one hour. Beyond this it will usually be desirable to add to the capacity enough to equalize the ordinary flow over several hours of the day, or, in the case of small works, to enable the pumping to be done by operating a part to the day only.

In general the best size of elevated tank will range from about 75,000 gallons for very small works up to 200,000 or 300,000 gallons for towns of the size mentioned above.

74. Location and Arrangement. The location of an elevated reservoir is governed in the first place by the topography, and the choice of location is therefore often very limited. In general a distributing reservoir should be located as centrally as possible with respect to the district to be served, as this will insure the most uniform and the highest pressures and will give the smallest size of main and branches.

In a gravity system the conduit is terminated at a reservoir, and if this reservoir is centrally located a longer conduit will be required than if it be placed near one side of the system. A proper balance must be struck between the two extremes. In a pumping system the pumps are usually located near one side of the city, and the reservoir is placed either in the vicinity of the pumps or at a more remote point in the system. In the first case all the water is usually passed through the reservoir, and the action of the pumps is very steady and uniform. In the second case a main usually leads to the reservoir from some point of the distributing system. The pumps force water directly into the system, and the reservoir takes only the surplus at times of low consumption and distributes it at times of high consumption. Certain portions of the area are thus served direct, and others are served from the reservoir. With this arrangement a more uniform pressure will be maintained in the mains, but the operation of the pumps will not be as uniform.

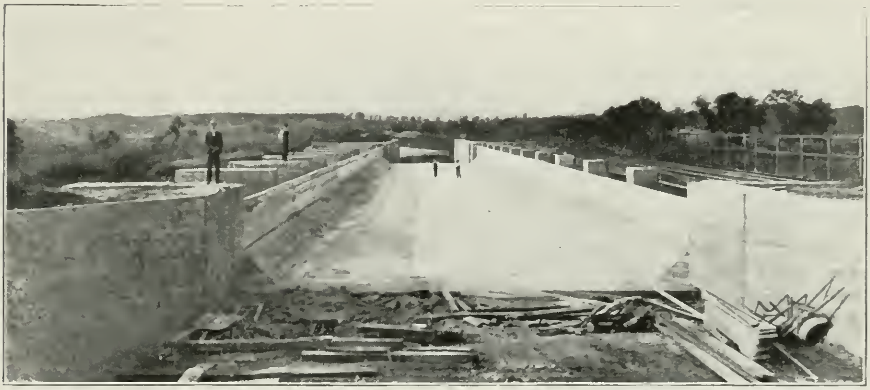
The proper elevation of a reservoir depends on the required pressure in the mains, a subject fully discussed in section 89.

EARTHEN AND MASONRY RESERVOIRS.

75. Form and Proportion. Earthen reservoirs are usually constructed partly by excavation and partly by the building up of embankments. If masonry walls are used in place of embankments, or as interior linings, the reservoir may be called a masonry reservoir. For single reservoirs the form most economical of material is the circular, but for large reservoirs the rectangular form is more convenient to construct and requires less land area. In practice the depths vary from 12 to 18 feet, for small covered reservoirs holding one million gallons or less, to 25, 30, or 35 feet, for open reservoirs holding 50 or 100 millions, depending upon local circumstances.

76. Construction. The construction of the embankment is based on the same principles as discussed in section 47, but the conditions are somewhat different from those obtaining with impounding reservoirs. In this case the foundation is frequently pervious and the embankment cannot be connected with an impervious stratum below. Under such conditions it is necessary to construct a water-tight lining over the entire area, and to carefully connect it with the water-tight portion of the embankment. Where a lining

Depositing Concrete for Lining of Aqueduct No. 7.



Lining of Aqueduct, Completed.

View of Completed Aqueduct.

CONSTRUCTION OF AN AQUEDUCT ON LINE OF ILLINOIS AND MISSISSIPPI CANAL

is not necessary to secure imperviousness, one is usually put in to facilitate the cleaning of the reservoir.

According to circumstances the entire embankment may be impervious, or imperviousness may be secured by a puddle or concrete core, or by a layer of puddle placed near the face. Fig. 31 shows a puddle being placed near the face and Fig. 32 shows a puddle core connected to the puddle lining of the bottom.

Imperviousness is usually secured in large masonry reservoirs by a layer of puddle placed back of the wall and thoroughly rammed, and the bottom lining is treated in a similar way. In small reservoirs more reliance is placed upon impervious masonry, made so by an asphalt coating, or, more commonly, by a coat of Portland-cement

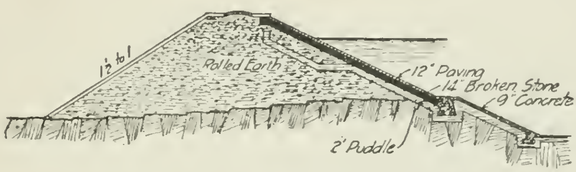


Fig. 31. Section of Reservoir Embankment, Pittsburg.

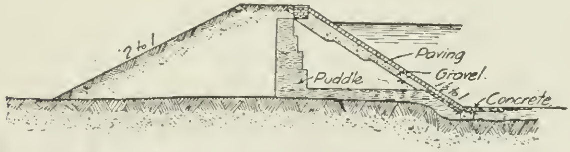


Fig. 32. Section of Reservoir Embankment, Brooklyn.

mortar, neat or 1 to 1, which it is well to finish by a brush coat of neat cement. The latter method is more likely to be satisfactory with covered reservoirs, where the temperature changes are small, than with open reservoirs.

While it is comparatively easy to secure imperviousness at the start by the use of cement, it is difficult to prevent the formation of slight cracks. These permit the water to find its way into the surrounding soil, and when the reservoir is quickly emptied this water exerts a back pressure on the walls and an upward pressure on the floor. The foundation for the walls should be broad enough to reduce settlement to very small limits, and as further precaution against cracks the floor lining should be constructed after the walls are complete, but should be thoroughly bonded thereto. Junctions between floors and walls are preferably made curved.

The most common form of lining consists of about $1\frac{1}{2}$ to 2 feet of puddle protected by a layer of concrete, brick, or stone paving, or sometimes only by gravel. On the slopes the concrete is usually covered with paving or replaced entirely by it, experience showing that unprotected concrete is apt to be injured by ice. A layer of paving brick laid in cement makes a good finish for a concrete lining which is to be frequently exposed. Concrete can be made impervious by plastering with cement mortar, neat or 1 to 1, but where it extends over large areas, cracks will form, due to temperature changes and to settlement of embankments. To minimize this difficulty, concrete may be laid in blocks, with asphalt joints between.

If ground water is met with, which is under considerable pressure, it will be necessary, in order to avoid rupture of the floor, to drain the soil beneath the lining. In some cases the ground water has been permitted to enter the reservoir, when its head exceeds that in the reservoir, through flap valves which will close when the difference of head is in the reverse direction. Drainage of the soil beneath the lining should be done with great caution, and especial care taken to surround all drains with gravel and sand so graded in fineness as to effectually prevent the washing out of any of the material. Seepage water is also sometimes taken care of by means of drains.

Asphalt has for some time been extensively used for reservoir linings on the Pacific coast, and recently its use has become quite general. Compared to concrete it has the advantages of elasticity and greater imperviousness, both of which are of great importance in this connection. Another advantage in many cases is its cheapness. Its chief disadvantage is the effect of the sun in rendering it more or less plastic and liable to creep if used on steep slopes. Its durability in water is also not fully determined. Great care and expert knowledge are required in determining the proper proportions of the various ingredients to give good results.

When the earth is firm and compact, asphalt linings can be placed directly upon it, and have frequently been so placed. Considerable settlement has in some cases taken place without cracking the lining, but this cannot, of course, be relied upon.

Reservoirs with masonry walls occupy less space than earthen reservoirs, but are more expensive to construct. They are, however, often the best form for small reservoirs where space is limited, and are a suitable form in case covers are required.

When the reservoir is excavated in firm earth or is backed by a well-compacted embankment, the earth serves to support the walls against water pressure. They must then be designed to sustain the earth pressure with reservoir empty. By adopting the circular form the masonry will resist largely by compression as a ring, and the dimensions can be considerably reduced below those required for a wall resisting by gravity alone. Several small circular reservoirs have been built of diameters of 50 to 75 feet, with walls from 16 to 22 inches in thickness.

The masonry may be of rubble, concrete, or brick, according to circumstances. If exposed, a lining of paving brick makes an excellent finish. It is needless to say that in all work of this character the greatest care should be taken to secure the best workmanship, particularly in the mixing and laying of concrete and the thorough filling of masonry joints with mortar, essentially as in dam construction.

77. Inlet Pipes and Valves. Distributing reservoirs are usually provided with separate inlet and outlet pipes, located preferably on different sides of the reservoir in order to promote circulation of the water. In earthen reservoirs these are constructed in the same manner as described in section 48. A by-pass should be provided to enable the reservoir to be cut out at any time. Where the reservoir serves merely as an equalizing reservoir, receiving only the surplus water from the distributing system, a single pipe will serve for both inlet and outlet.

In open masonry reservoirs gate chambers are conveniently built in connection with the reservoir wall. In covered reservoirs they are usually omitted, the valves being placed within the reservoir and operated from a suitable platform or from the oustide.

78. Covered Reservoirs. Ground waters should be stored in covered reservoirs, for the reason that such waters usually contain sufficient quantities of plant food to promote a luxuriant growth of vegetable organisms unless the light be excluded. Many cases have arisen of bad tastes and odors due to this cause which have been entirely removed by covering the reservoir. Filtered surface waters should also as a rule be stored in covered reservoirs, since by the process of filtration they are rendered somewhat similar in nature to ground waters. Where reservoirs are located in the densely populated portions of cities, covers are also advisable, in order to exclude soot and dust.

Covers are usually made of masonry, but wood has been used in a number of cases. It is much cheaper than masonry, but is much less durable and does not keep the water as cool in summer or wholly prevent freezing in winter.

A wooden cover for a large area may consist simply in a horizontal floor of boards, supported by a system of joists and girders resting on a series of wooden posts. For small areas the covers can readily be made sloping, and this is a preferable arrangement. Covers for small circular reservoirs and large wells are conveniently made conical, with the rafters resting against the wall or supported on light trusses.

Masonry covers consist usually of segmental or elliptical masonry arches supported by small brick piers; or, for very small reservoirs, a dome may be used. Above the arches, about 2 feet of earth is placed to prevent extreme variations of temperature and to protect the masonry, and embankments are constructed against the side walls to meet the covering above. The piers are spaced from 10 to 15 feet apart, and are made from 1 to 2 feet square in cross-section, depending upon the span and weight of filling.

Piers are usually made about 18 inches square of brick and spaced about 12 to 15 feet apart. Concrete is now generally used for the roof, being made in the form of groined arches of about 3 feet rise and 6 inches thick at the crown. Fig. 33 shows the interior of such a reservoir used as a filter.

79. Cost. The cost of reservoirs varies, of course, greatly according to local conditions, kind of reservoir and capacity. According to the capacity the cost per unit will be less the larger the reservoir. The actual cost of a large open reservoir varies from \$3 to \$5 per 1,000 gallons capacity. Covered masonry reservoirs will cost usually from \$10 to \$15 per 1,000 gallons capacity.

STANDPIPES AND ELEVATED TANKS.

80. Where a reservoir requires to be artificially elevated it is usually built as a standpipe—a tall slim tank resting on the ground—or as an elevated tank of steel or wood, supported by a tower of steel, wood, or masonry. Such an elevated reservoir may or may not be enclosed in a covering of masonry or wood, according to the necessities of the case and the notions of the designer.

Reservoirs of this type are relatively so expensive that a minimum amount of storage capacity is usually provided. As shown

Fig. 33. Covered Filter.

in section 72, they may be used in small towns to enable the pumps to be more economically operated; or in larger towns to provide for fire consumption for an hour or so. The capacities of standpipes and tanks range ordinarily from 50,000 gallons up to a maximum of about 1,500,000 gallons for small villages and cities up to 30,000 population or more. The useful capacity of a standpipe is only that part of the volume which is at a sufficient elevation to give the required pressure. All water below this level acts merely as a support for the portion above. There should therefore first be determined the lowest useful level of the water, and the pipe should then be made of the desired capacity above this plane.

81. Location. For storage purposes only, the location would be the same as that for any reservoir. To reduce the cost it is, however, desirable to place the tank on the highest ground available if it be within a reasonable distance. Too great distances will be undesirable on account of the cost of mains and the loss of head caused by a long line of pipe.

82. Design of the Standpipe. The chief elements in the design of a standpipe are the thickness of plates, the riveting, the foundation and anchorage and the pipe details. The forces to be considered in the design of a standpipe are the water pressure, the wind pressure, the weight of the pipe, and the action of ice. In what follows let h = distance in feet of any point of the pipe from the top, d = diameter of pipe in feet, r = radius in feet, and t = thickness of shell in inches at the given point.

From equations in Hydraulics we find that the water pressure causes a bursting stress per vertical lineal *inch* of pipe equal to

$$S = \frac{62.5hd}{2 \times 12} = 2.6hd \qquad (9)$$

The stress per square inch of metal is

$$s = \frac{2.6hd}{t} \qquad (10)$$

This is the only stress that need be considered in determining the plate thickness, as the effects of wind and weight are much smaller than this and cause a stress in a *vertical* direction.

The safe tensile stress on net section of metal, where but little ice is likely to form, may be taken at about 15,000 pounds per square inch. Where thick ice is to be expected the working stress should be reduced to 12,000 or even 10,000 pounds, to provide for the unknown ice stresses. The vertical joints will usually be so designed as to have an efficiency of 60 to 70 per cent. If a = safe stress on net section and e = efficiency, then by equation 10 the required thickness to resist the water pressure will be

$$t = \frac{2.6hd}{s} = \frac{2.6hd}{ae} \qquad (11)$$

or, if $a = 12{,}000$ and $e = \frac{2}{3}$, then, approximately,

$$t = \frac{2.6hd}{8{,}000} = .000325hd \qquad (12)$$

The thickness near the top should not be less than $\frac{1}{4}$ inch, or for very large pipes, $\frac{5}{16}$ inch. Plates thicker than 1 inch or $1\frac{1}{4}$ inches should be avoided.

The plates forming a standpipe are usually of such a width as to build 5 feet of pipe, and are from 8 to 10 feet long. Each course is preferably made cylindrical, and alternately an "inside" and an "outside" course.

The riveting of the vertical seams is the most important part of the construction, as this determines the strength and economy of the standpipe. Lap joints are most commonly used, but for thickness exceeding $\frac{1}{2}$ inch, double-butt strap joints are much preferable and are stronger.

Table No. 12 gives suitable proportions for riveted joints, to-

TABLE 12.

Proportions for Riveted Joints for Standpipes.

Kind of Joint on Vertical Seams.	Thickness of plate.	Diameter of rivet.	Pitch of rivets. Centre to centre.	Distance between Pitch-lines.	Distance of Pitch-line from edge of plate.	Efficiency, per cent.
	Inch.	Inches.	Inches.	Inches	Inches.	
Single-riveted lap	$\frac{1}{4}$	$\frac{5}{8}$	$1\frac{5}{8}$	.....	1	50
" " "	$\frac{5}{16}$	$\frac{5}{8}$	$1\frac{3}{4}$	.....	$1\frac{1}{8}$	
Double " "	$\frac{5}{16}$	$\frac{5}{8}$	$2\frac{5}{8}$	$2\frac{1}{8}$	$1\frac{1}{8}$	
" " "	$\frac{3}{8}$	$\frac{3}{4}$	$2\frac{5}{8}$	$2\frac{1}{8}$	$1\frac{1}{4}$	60
" " "	$\frac{7}{16}$	$\frac{3}{4}$	$2\frac{3}{4}$	$2\frac{1}{4}$	$1\frac{3}{8}$	
" " "	$\frac{1}{2}$	$\frac{7}{8}$	$2\frac{7}{8}$	$2\frac{3}{8}$	$1\frac{1}{2}$	
" " butt	$\frac{9}{16}$	$\frac{7}{8}$	$2\frac{7}{8}$	$2\frac{3}{8}$	$1\frac{5}{8}$	
" " "	$\frac{5}{8}$	$\frac{7}{8}$	$2\frac{7}{8}$	$2\frac{3}{8}$	$1\frac{5}{8}$	
" " "	$\frac{11}{16}$	1	$2\frac{7}{8}$	$2\frac{3}{8}$	$1\frac{3}{4}$	
" " "	$\frac{3}{4}$	1	3	$2\frac{1}{2}$	$1\frac{3}{4}$	
" " "	$\frac{13}{16}$	1	3	$2\frac{1}{2}$	$1\frac{7}{8}$	70
" " "	$\frac{7}{8}$	$1\frac{1}{8}$	3	$2\frac{1}{2}$	2	
" " "	$\frac{15}{16}$	$1\frac{1}{8}$	3	$2\frac{1}{2}$	2	
" " "	1	$1\frac{1}{4}$	$3\frac{1}{8}$	$2\frac{5}{8}$	$2\frac{1}{8}$	
Triple " "	1	$1\frac{1}{8}$	4	3	$2\frac{1}{8}$	75

gether with their approximate efficiencies or ratio of strength of joint to strength of plate.

Horizontal joints are made single-riveted lap joints, with rivet spacing of about three diameters. All seams should be thoroughly calked with a round-nosed calking tool, and any leaky seams which may exist when the pipe is filled should be recalked. The bottom is made of plates riveted up with circular and radial joints, the former being made lap joints and the latter butt joints. The thickness need be only enough to permit of good calking and to be durable,—about $\frac{1}{2}$ inch. This bottom plate is preferably connected to the side plates by means of a heavy angle on the outside, or one on both outside and inside the tank. The foundation should be made monolithic and sufficiently broad to give such low pressures on the soil that there will be practically no settlement. Failures have occurred due to poor work in this respect. Wind pressures should be carefully considered. Concrete is a very suitable material for foundation purposes.

Standpipes must be anchored to the foundation to prevent being overturned by the wind. The wind pressure is usually taken at 40 to 50 pounds per square foot on one-half the vertical projection of the tank. At the higher value the overturning moment in foot pounds at a distance h below the top is

$$M = 50 \times \frac{dh}{2} \times \frac{h}{2} = 12.5dh^2 \qquad (13)$$

This movement causes an uplift on the leeward side for each inch along the circumference of the pipe of

$$S^* = 1.33 \frac{h^2}{d} \text{ pounds.} \qquad (14)$$

Then if anchor bolts are placed p inches apart around the bottom of the tank the stress in each bolt will be

$$S \times p = 1.33 \frac{h^2}{d} \times p \qquad (15)$$

If numerous bolts are used, their size need not be great, and they may be put through the exterior bottom angle iron and the latter double-riveted to the pipe. If arranged in this way, they should be numerous enough so that the stress in one bolt is not greater than can

*The derivation of this equation comes from the formula $S = \frac{Mc}{I}$ of Mechanics in which I is the moment of inertia of the standpipe shell. The process of derivation cannot well be entered upon here.

be transmitted to the lower plates by four or five rivets, which will limit the size of bolts to about $1\frac{3}{4}$ times the diameter of the lower rivets. By spacing the bolts sufficiently close this arrangement may be followed in almost any case. If this method gives a large number of bolts, it will be simpler to use fewer and larger bolts, in which case they should be fastened to the standpipe by long vertical pieces of angles, and the bolts placed close to the pipe as shown in Fig. 34. The number of bolts should not be less than six in any case. Anchor bolts should extend well into the masonry and be fastened to anchor plates embedded therein.

Besides the overturning effect of the wind there is to be considered the collapsing effect on the empty pipe, especially near the top where the plates are thin. This cannot readily be computed, but must be provided for by an ample margin of strength at the top of the standpipe.

The effect of ice action is a very serious matter in unprotected standpipes, but is very difficult to calculate or provide for. The stresses caused by ice action can only be provided for by the use of a good quality of soft steel which will allow of deformation without injury, and by the use of a large factor of safety. It may well be questioned, in view of the uncertainties of the case, if all metal tanks built in cold climates should not be encased in masonry or wood. The importance of this matter is attested by the many accidents traceable to the action of ice.

The material used for standpipes should be soft, open-hearth steel, of a tensile strength of about 54,000 to 62,000 pounds per square inch. The best practice now calls for a grade corresponding to flange steel, with phosphorus limit of about .06 per cent, an elongation of 22 to 25 per cent, reduction of area of 50 per cent, and flat bending tests, both cold and after heating and quenching.

83. Pipes and Valves. Usually a single pipe serves both as inlet and outlet. This passes through an arched opening in the foundation, turns upwards and enters the standpipe at the bottom, and extends into it a foot or two. A lead joint is usually made in a bell casting riveted to the bottom of the pipe as shown in Fig. 34. A drain-pipe through which the tank may be drained or flushed should also be provided.

High-water electric alarms are advisable if the pipe be at some distance from the pumping station. The pressure indicated at the station is not a certain guide if branch mains are led off at intermediate points. For encased pipes or tanks a simple float, arranged to close an electric circuit, may be used. For exposed pipes, ice is likely to interfere, and in this case a pressure gauge placed in a vault and connected to the standpipe can be arranged to give an alarm at any desired pressure.

84. **Other Details**. The top should be stiffened against collapse by a heavy angle-iron, not less than 3 × 5 inches, and two such angles should be used for large pipes. The effect of the wind on an empty pipe is not only to cause a pressure on the outside, but to create a partial vacuum on the inside near the top. Several failures have occurred from lack of strength at this point.

It is not customary to roof standpipes, and for a tall slim pipe a roof would be of little use and no improvement to its appearance. With large, low pipes a conical roof of curved profile may well be adopted. It affords considerable protection and improves the appearance of the structure. It is usually made of sheet iron or copper, supported on light angle-iron ribs or a framework.

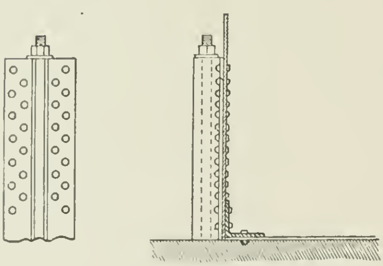


Fig. 34. Arrangement of Rivets.

A ladder should be built on the outside of the pipe, but none on the inside; and in general there should be no obstructions on the inside where ice is likely to form to any extent.

Standpipes should be well painted inside and out. For the interior, asphalt is probably the best material to use. After painting the interior, the pipe should be filled to detect leaks before the outside is coated.

A standpipe is often surrounded with a masonry shell in order to furnish protection from cold, or to improve the appearance of the structure. This shell may be of stone or brick, and is usually built enough larger than the pipe to permit of a stairway in the space between. The walls are usually made from $2\frac{1}{2}$ to 4 feet thick at the bottom and $1\frac{1}{2}$ to 2 feet at the top.

Encased pipes must be provided with overflows, which may be built either inside or outside the main pipe. For this type of structure, roofs are quite necessary, and should be carefully proportioned with respect to appearance. The masonry offers considerable opportunity for architectural treatment, and this feature should be referred to a competent architect.

85. Elevated Tanks. If the lower portion of the water in a standpipe is at too low an elevation for useful pressure, its only office is to furnish support to the useful part above. Where this useless zone is of any considerable depth the support can be more cheaply furnished by a steel trestle. Besides being cheaper, a tank is much less objectionable in appearance than a standpipe, and experience indicates that trouble from ice is less likely to occur. For roofed tanks a height equal to the diameter would not be far from the most economical proportions, but a height somewhat greater than this will usually look better.

The bottom of a tank supported on an iron trestle is usually made hemispherical, as this requires no support except at the outside edge where the legs of the tower are located. The thickness of side plates is the same as for standpipes, and the details are similar. If the bottom is hemispherical the stresses therein will be one-half those in the lowest side course of plates.

The tower consists of a steel trestle of four to eight legs. The material for this may be medium steel, and comparatively high working stresses may be used in its design, since the stresses are all dead- and wind-load stresses. Four legs are the smallest practicable number, but for tanks of large diameters the use of only four legs brings very heavy local stresses on the tank at the points of connection. Six or eight is a better number and presents a better appearance, but is more expensive. The stresses in the various parts of the tower and the design of the details belong to the domain of structural engineering and cannot be elaborated here. Suggestions for the upper column connections, the anchorage and the roof are given in Fig. 35.

Each column must be well anchored to the foundation, with a strength of anchorage equal to the maximum uplift due to wind acting on empty tank. The foundation should be rigid, and large and heavy enough to serve as anchorage and to give only safe pressures on the ground. There should be practically no settlement, as any unequal settlement will greatly change the stresses in the tower.

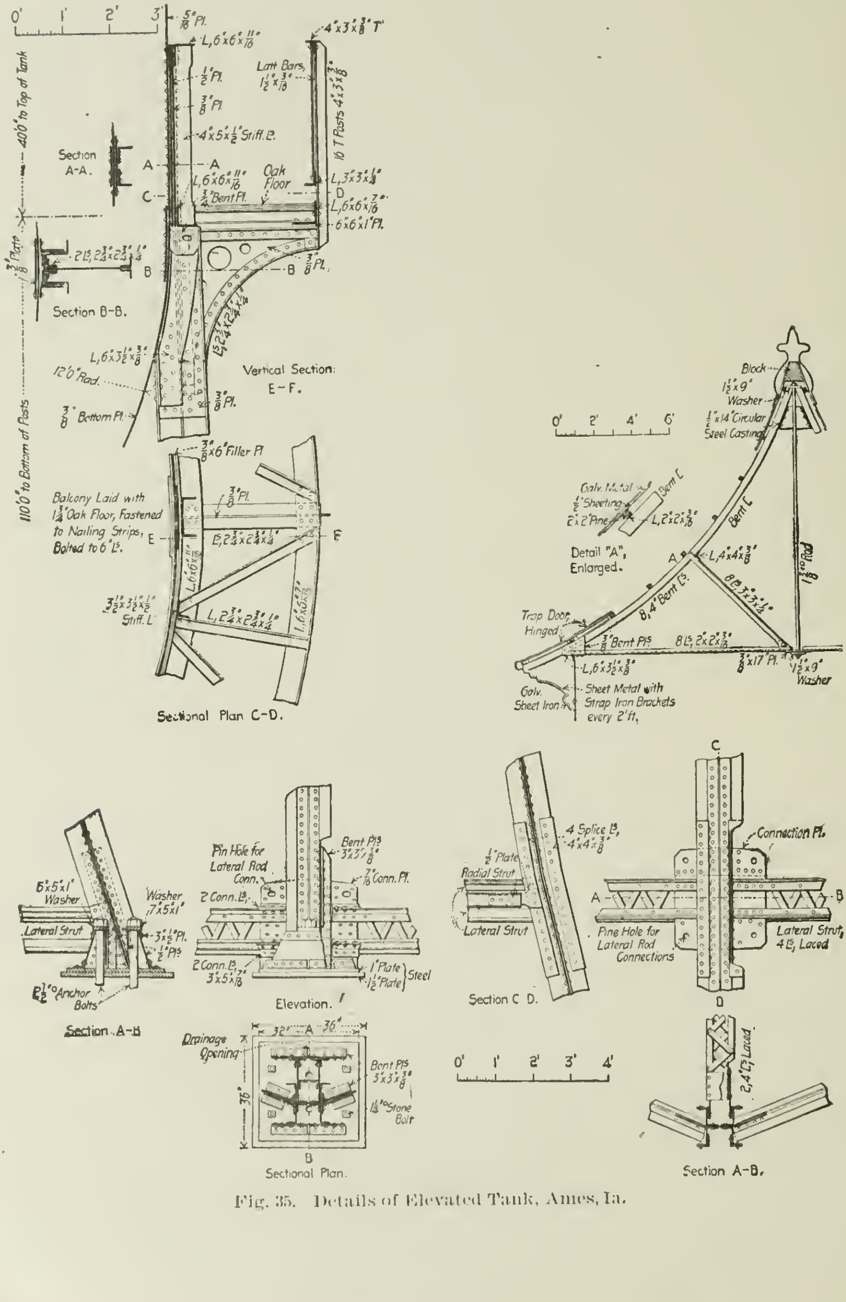


Fig. 35. Details of Elevated Tank, Ames, Ia.

The inlet pipe is usually made to enter the tank at the center of the bottom, and should be provided with an expansion joint. In cold climates the pipe must be protected by a frost casing, which is usually a simple wooden box with one or more air spaces and a packing of some non-conductive material. If the tank is encased, it will be necessary to provide an overflow pipe.

86. Wooden Tanks. Elevated tanks of wood are frequently used where low first cost is an essential element and the quantity to be stored does not exceed 50,000 to 75,000 gallons. Wooden tanks are cheap, and if well built will last fifteen or twenty years. The staves should be of good clear material and should be dressed to proper curvature on the outside. Hoops should be relatively thick to resist corrosion, and should be thoroughly coated with asphalt or other protective coating, before being put in place. Lugs and fastenings are a source of weakness. They should be carefully designed and of ample strength. The support of the floors must also be well looked after. The chief source of trouble with wooden tanks is in the weakening of the hoops by rusting from the inside.

Several failures of wooden tanks have occurred by the sudden bursting of the hoops, and it is questionable policy to construct such tanks where their failure is likely to endanger life, as it is quite certain that they will not be regularly inspected as they should be.

87. Storage Under Compressed Air. In small works, air chambers or their equivalent may be used to provide a considerable storage of water and thus avoid the use of standpipes or elevated tanks. In the design of such storage tanks the larger the proportion of air space the less will be the variation in water pressure as the tank is emptied. If V = volume of tank, and v = maximum volume of water stored, then $V - v$ = minimum volume of air. If the pressure, when containing the maximum volume of water, be P, then when the tank is just empty the pressure is $p = P\left(1 - \frac{v}{V}\right)$. Thus if $\frac{v}{V} = \frac{1}{3}$, then $p = \frac{2}{3}P$, and the variation in pressure is one-third the maximum. The less the desired variation in pressure the greater must be the tank capacity for a given water capacity. The air is maintained in the tank by occasionally admitting a little air into the pump.

A system of pressure storage having several advantages over that just described is the Acme Company's system, based on patents of Wm. E. Wortham and Oscar Darling. In this system the air is stored in a separate tank at a higher pressure than is ordinarily kept in the water tank. By reducing valves in the connecting pipes, the pressure on the water may be maintained constant, or may be increased in case of fire up to the pressure in the air tank. Air compressors must be used here to keep up the air supply. A number of plants of this kind have been installed. The use of a pressure storage system avoids all trouble from ice, and for very small quantities is cheaper than an elevated tank. A storage tank can also be located at the pumping station and the pressure easily controlled. For large quantities the system would be very expensive.

THE DISTRIBUTING PIPE SYSTEM.

88. **General Requirements.** A distributing system should be so designed that it will be able to supply adequate quantities of water to all consumers, and that this will be accomplished with economy and with reasonable security against interruption. With respect to the design of this part of a waterworks system, the uses of water naturally fall into two very distinct classes: (1) the ordinary, everyday use for domestic, commercial, and public purposes; and (2) the use for fire extinguishment. In the former case the consumption is relatively uniform over different portions of the city, and is also well distributed over many hours of the day; in the latter case the rate is likely to be extremely high for a very short period of time, but this excessive use of water will usually be confined to a comparatively small area. To supply water in the former case requires the wide distribution of moderate quantities, while in the latter case the problem is rather the concentration of large volumes within a narrow district, which district may be situated at any point in the system.

To supply water to all consumers requires that a pipe be laid in each street, except in those cases where the cross streets are not built upon. In the outlying districts, pipes are laid in those streets where the density of the population warrants it, according to the judgment of the management, but much difference in policy exists in respect to the matter of extensions. The distributing system includes, besides the pipes, the fire hydrants, service connections, valves, fountains, watering troughs, meters, and occasionally other details.

89. The Pressure Required. For ordinary service the pressure at any point should be sufficient to supply water at a reasonable rate in the upper stories of houses and factories, and in business blocks of ordinary height. This will require at the street level a pressure of from 20 to 30 pounds in residence districts, and usually from 30 to 35 pounds in business districts, according to the character of the buildings.

For fire purposes the pressure required in the mains depends upon whether it is intended that fire streams shall be furnished directly from the hydrants or whether steam fire engines are to be used. In small cities and towns it is of the greatest advantage to supply fire streams without the use of engines, and in most such places this method is adopted, fire engines being sometimes kept in reserve, for extraordinary conflagrations. In pumping systems the most common arrangement is to maintain only a moderate pressure for ordinary service, and at times of fires to shut off the reservoir or standpipe if there be one, and to furnish the necessary fire pressure direct from the pumps.

In large cities hydrant fire pressure is not so common, but if the supply is by gravity, and has plenty of head, a hydrant fire pressure can profitably be furnished, at least for all except the densest portion of the city or for very large fires. If hydrant fire pressure is to be supplied it should not be less than 60 pounds for residence districts and 70 pounds for business districts. Pressures 20 pounds higher than these are to be desired. If dependence is to be placed on fire engines, as is usual in large cities, the domestic pressure of 25 to 30 pounds is sufficient.

The pressures here considered are the hydrant pressures at times of maximum consumption, and refer to any point in the distributing system. If such pressures are maintained at the most remote points and at the higher elevations, the pressures on the lower ground and at points nearer the pumps or reservoir will of course be considerably higher. In the case of gravity supplies much higher pressures may be possible, but on account of the increased cost of plumbing and piping to withstand high pressures it will not be desirable often to exceed 130 to 140 pounds.

90. Number and Size of Fire Streams. The number of fire streams which should be simultaneously available in any given town will obviously vary greatly with the character of the buildings, width of streets, etc. For average conditions the number may be calculated from the formula

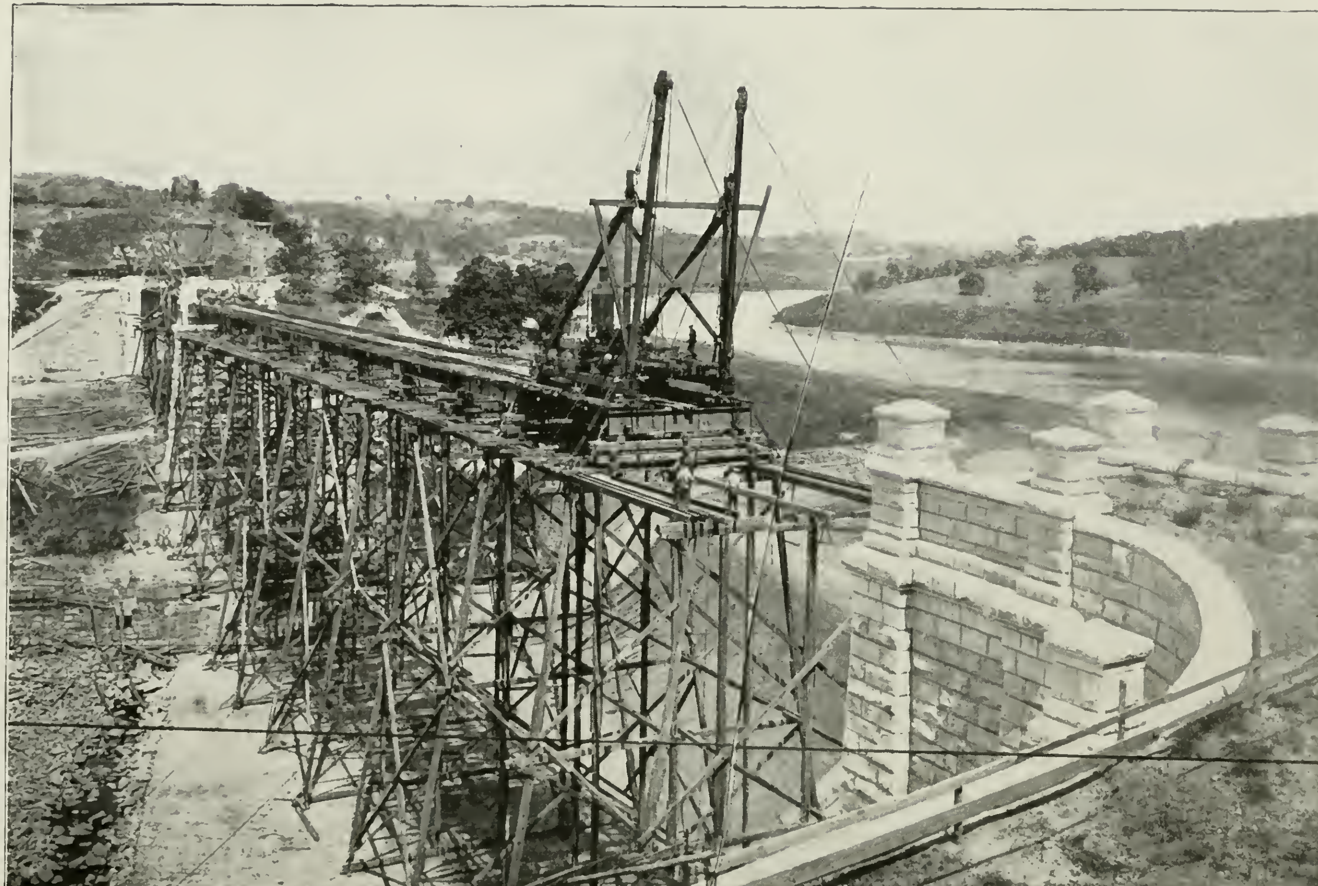
$$y = 2.8 \sqrt{x}, \qquad (16)$$

where $y =$ number of streams, and $x =$ population in thousands. About two-thirds of this number should be capable of being concentrated upon a single block or group of buildings.

In small cities and towns the requirements for fire protection may differ widely. For example, in a country town of 4,000 to 5,000 inhabitants, in which only a small mercantile business is carried on, the fire risk is not great, while in a town of the same size whose prosperity depends entirely upon two or three large factories, located, perhaps, in one large group of buildings, a fire would be a very serious matter. In the former case four or five fire streams would be sufficient, while in the latter case eight or ten should be supplied.

The number of fire streams is based upon a size of stream of about 250 gallons per minute, which is generally considered to be about right as an average value for good fire streams in business districts. For a residence district 175 to 200-gallon streams will usually meet the requirement. Fire hydrants must be sufficiently numerous and so located as to meet the requirements regarding number and size of fire streams set forth in the preceding paragraphs. Hydrants are one-way, two-way, three-way, etc., according to the number of hose connections provided. For most purposes the two-way hydrant is considered the most convenient, but in the dense portion of a large city, where many connections must be provided, three-way and four-way hydrants can be used to good advantage. Hydrants should, in any case, be numerous enough to enable the required number of streams to be furnished with a suitable nozzle pressure. At points where a large number of streams are required, fire cisterns are sometimes used instead of hydrants. These cisterns are fed by large pipes, and have an advantage over hydrants in that they allow several steamers to obtain their supply at one point.

For a 250-gallon stream the required nozzle pressure is 45 pounds and the loss of head per 100 feet of ordinary $2\frac{1}{2}$-inch hose is about 18 pounds (see Hydraulics), so that with a hydrant pressure of 100



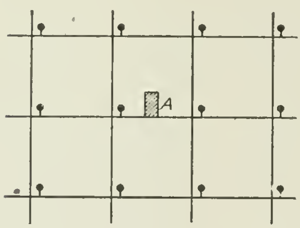
FALSEWORK FOR BRIDGE OVER OLD CROTON DAM AT CROTON LAKE
Waterworks system of New York City.

pounds the length of hose to supply a 250-gallon stream cannot exceed 300 feet. A 175-gallon stream, with a 1-inch nozzle, requires 35 pounds nozzle pressure, and causes a loss of head of 9 pounds per 100 feet of hose. With a hydrant pressure of 100 pounds the length of hose in this case might be 700 feet. With a hydrant pressure of 75 pounds, which is quite common, a 250-gallon stream could not be supplied through a length of hose greater than about 200 feet, and a 175-gallon stream through a length greater than about 450 feet. Hence the general rule that hydrants should be so spaced that no line of hose should exceed 500 to 600 feet, and for at least half of the streams required at any point the length of hose should not exceed 250 to 350 feet, according to the hydrant pressure. These lengths cannot be much increased even where fire-engines are used. In outlying districts two two-way hydrants should be available at any point, with a distance of not more than 500 to 600 feet to the more remote of the two.

The most convenient location for hydrants is at the street intersections, as they are then readily accessible from four directions. In cities of moderate size the required number of streams can readily be supplied by locating a hydrant at each street intersection, but in large cities intermediate hydrants are often necessary. Thus if the blocks in Fig. 36 are 300 feet long in each direction, and a two-way hydrant is placed at each corner, then a fire at A could be served from eight hydrants, with a maximum length of hose of about 450 feet, giving sixteen good fire streams; while a fire at a street corner could be served from thirteen hydrants, eight of which would, however, require hose lengths of 600 feet. With blocks 600 feet by 300 feet, as in Fig. 37, a two-way hydrant at each intersection would supply not less than eight streams at any point, without exceeding 600 feet of hose. If only four streams are required, then one-fourth of the hydrants might be omitted, or every other hydrant in alternate streets, as hydrants 1, 2, and 3.

91. General Arrangement of the Pipe System. From the data on page 9 it is evident that the fire demand will largely govern in the design of the pipe system. This is more and more true the smaller the town or district considered, and for single blocks the ordinary consumption can practically be neglected. To supply long, narrow districts, the general scheme would be to furnish the water mainly through a single large pipe of gradually decreasing size, with small parallel and branch mains supplying the side streets. For broad areas, such as comprise the larger portions of most cities, the general arrangement usually adopted is to provide large mains at intervals of $\frac{1}{4}$ to $\frac{1}{2}$ mile, and to fill in between these mains with smaller pipes, thus forming a gridiron system.

A general principle which should be kept in mind when laying out a system is to so arrange the large mains that the smaller cross mains may be fed from both ends, since a pipe so fed is equivalent to two pipes. It can furnish double the number of streams with the same loss of head, or the same number of streams with about one-fourth the loss of head, as when fed from one end only. This principle also makes it desirable to lay connecting pipes between separated districts,



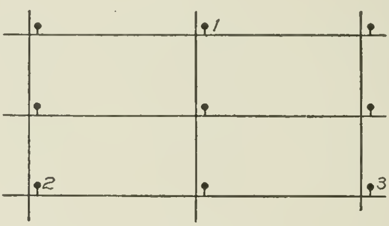


Fig. 36. Location of Hydrants. Fig. 37.

even when such pipes are not required for supplying local consumers. In the case of fire, each district may then be served from both ends. Dead ends are also objectionable on account of the stagnation which exists in the pipes and the deterioration of the water which is likely to ensue.

The size of mains and cross lines in the gridiron system will depend largely upon the number of fire-streams required at any point. In small cities, and outlying districts of large cities, 6-inch cross mains with 8, 10, or 12-inch pipes at intervals of four to six blocks is a common arrangement. Four-inch pipe should never be used to supply hydrants except where the pipe is comparatively short and is fed from larger pipes at each end.

92. Calculation of the Pipe System. For the purpose of calculating the distributing system it is necessary to know the maximum rate of consumption for the entire city, and for large and small sections of the same, with suitable consideration for future growth.

The rate for the entire city will enable the main supply conduit, or the principal force main, to be determined. For calculating the main distributing pipes the city should be divided into relatively large districts, corresponding to the most probable location of such main arteries; then for the smaller pipes the demand for still smaller sections must be considered, and so on.

The maximum rate of consumption for the entire city has already been discussed in section 6. From the data there given the ordinary maximum rate is seen to be from 200 to 250 per cent of the yearly average. If the yearly average be 100 gallons per capita daily, the maximum ordinary rate will then be about 250 gallons per capita per day, or 0.17 gallon per capita per minute. The maximum fire rate, assuming 250-gallon streams, is $250 \times 2.8\sqrt{x}, = 700\sqrt{x}$ gallons per minute, where x = population in thousands. Thus for a population of 1,000 the ordinary maximum rate may be about 170 gallons per minute, while the fire rate is likely to be 700 gallons, or four times as much.

After estimating the maximum rate of consumption for the city as a whole, the same should be done for the several districts, the probable future population, the maximum ordinary rate, and the maximum fire demand being estimated for each district independently. The data so collected will enable the main distributing pipes to be calculated. The size of the cross mains and smaller pipes will be determined almost entirely by the local requirement as to fire streams. For all practical purposes an arrangement of 6-inch pipe in one direction, and 4-inch pipe crossing these, is ample for cities up to about 10,000 inhabitants, and six-inch pipes in both directions will suffice for populations up to about 50,000. For villages up to 1,000 or 2,000 population and the residence districts of small cities all but the general supply main may be 4-inch provided there are no dead ends and that there is a cross line at least every other block.

The size of the main supply pipe and the main branches feeding isolated districts can be calculated by the aid of Table No. 12 of Hydraulics giving the friction loss in pipes, an estimate of the maximum rate of demand having been made. For most cases the desirable velocities in the main pipes will be from 3 to 6 feet per second for the maximum rate of flow. The lower velocity is that suitable for a plant where the available head is limited and not much friction loss can be permitted, as for example in a gravity system where the elevation of the source is barely sufficient to furnish the desired pressure. The higher velocity is suitable where a considerable loss of head may be allowed, as for example in a gravity system with a high source, or in a pumping system where the fire pressure is furnished by pumps and only during the fire.

The number of fire streams of 250 gallons per minute each which can be supplied reasonably through pipes of different size are given in Table No. 13, the smaller number corresponding approximately to the lower velocity mentioned above and the larger the higher velocity. Where a pipe is fed from both directions double the number of streams can be supplied.

TABLE 13.

Number of Fire Streams Obtainable From Pipes of Various Sizes.

Size of pipe.	No. of 250-gal. streams.
4	1
6	1– 2
8	2– 4
10	3– 6
12	4– 8
16	8–16
20	12–24
24	18–36

Example. A town of 3,000 inhabitants is to be supplied through a force main 4,000 feet long. Assuming the average daily consumption to be 75 gallons per capita and that the town is of average character as regards fire demands, what would be a suitable size of main?

Referring to section 6, we find that the maximum rate for ordinary use may be taken at 180 per cent of the average, which would be $1.80 \times 75 = 135$ gallons. The rate per minute will be $\frac{135 \times 3{,}000}{24 \times 60} = 280$ gallons. The number of fire streams required is by formula 16 equal to $2.8 + 3 = 4.8$ or, say, 5. Each being assumed as 250 gallons the total rate will equal $280 + 5 \times 250 = 1{,}530$ gallons per minute, or practically equal to 6 fire streams. From the table No. 13 we see that a 10-inch pipe may be used if a considerable loss of head is permissible or a 12-inch pipe if but little loss is desired. From Table 12 of Hydraulics the actual loss of head in the 10-inch pipe for a flow of 1,530 gallons per minute is 16 feet per 1000, or 64 feet for the entire length of main. For a 12-inch pipe the loss is only about 6.5 feet per 1,000, or 26 feet total. Where the available head is not more than 150 feet the former loss would be too great.

93. Separate Services for Different Elevations. Where the different parts of a town vary considerably in elevation, it is frequently advisable to divide the distributing system into two or more independent portions, each serving an area or zone situated between certain limiting elevations. It often happens that only a small portion of a city is at a high elevation, and by thus separating the systems of distribution a comparatively small amount of water will need to be raised to the maximum height, the greater portion being pumped against a much lower pressure. By this arrangement a large saving can be effected in the expense of pumping, and the use of excessive pressures in the lower districts will also be avoided.

Various arrangements may be made for supplying the different zones. Each zone may be practically an independent system, with its own pumping station and perhaps its own source of supply; or the pumps of a higher zone may be supplied by a reservoir located at a high point in the next lower zone; or the pumps of the different zones may all be located at the same station and obtain their supply from the same source. In the gravity system a division is often made so that the lowest zone is supplied by gravity, while the upper zones are supplied by pumps.

94. Location of Pipes and Valves. The distributing pipes should be so located with respect to street lines as to be readily found and to avoid other structures as far as practicable. The center of the street being usually reserved for the sewer, the water pipes are placed at some fixed distance, usually from 5 to 10 feet from the center. The side chosen should be the same throughout. The north side of east and west streets will be warmer than the south side.

Valves should be introduced in the system at frequent intervals so that comparatively small sections can be shut off for purposes of repairs, connections, etc. As a general rule, wherever a small pipe branches from a large one, the former should be provided with a valve. Thus with 10 or 12-inch pipes feeding 6-inch pipes, each of the latter should have a stop valve at each end. At intersections of large pipes a valve in each branch is usually desirable. In a network of small pipes of uniform size, a valve in each line at each intersection, or four in all, is rather more than necessary, but two at each intersection, or a valve in each line every two blocks, answers very well.

Valves, like pipe lines, should be located systematically. They are usually located in range either with the property line or the curb line, but sometimes are placed in the cross walks.

95. Hydrants. The general location of hydrants has already been considered in section 90. In fixing upon the exact location, and the side of the street on which each should be placed, a detailed examination should be made and the location determined with reference to important buildings, convenience of access in case of fires, etc. Generally the hydrant is placed on the same side of the street as the pipe, and is connected to the larger of two pipes where there is a choice.

Hydrants are of two general types—the post hydrant, in which the barrel of the hydrant extends 2 or 3 feet above the ground surface, and the flush hydrant, in which the barrel and nozzle are covered by a cast-iron box flush with the surface. The former is more commonly used, and as it is much more readily found and more conveniently operated, it is to be preferred, except perhaps in the congested districts of large cities, or on narrow streets where all obstructions should be avoided. Post hydrants are set just back of the curb line; flush hydrants, either in the sidewalk or in the street.

Many styles of hydrants are on the market, most of which will give reasonably good service if properly handled. Reliability of operation is the first essential, but next in importance is the requirement that the frictional loss in the hydrant shall be small. All waterways should be ample, and sharp angles and sudden changes in size should be avoided as much as possible. Considerable difference exists in different hydrants in this respect, with a corresponding difference in the amount of pressure lost. In Fig. 38 are shown two forms of hydrants which illustrate the two general types of valves used—the gate valve and the compression valve. In ordering hydrants care should be taken to have the nozzles of the same standard as those used in adjoining large cities, so that connections can readily be made to fire apparatus which may be borrowed in emergencies.

When a hydrant is closed after use, the water remaining in the barrel must be drained out through a drip, so arranged as to open when the main valve is closed. This is an important feature of the design, as a hydrant is likely to freeze if not thoroughly drained. The escaping water may be led away through a small drain pipe to a sewer, or a considerable body of broken stone and gravel may be filled around the base, into which the water may be allowed to drain.

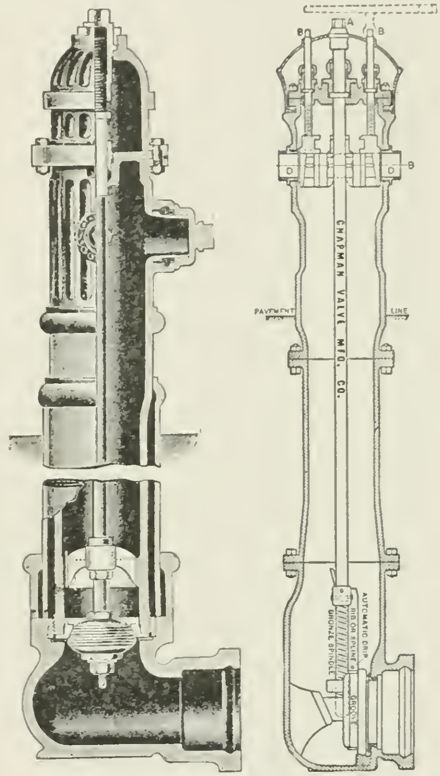


Fig. 38. Fire Hydrants.

In setting hydrants care should be taken to provide a firm base and to ram solidly back of the barrel. The hydrant branch should be covered at least as deep as the main, as this branch is essentially a dead end and is much more likely to freeze than the main itself.

96. Service Connections. Service pipes are usually from $\frac{3}{4}$ inch to 1 inch in diameter, and are made of lead, galvanized iron or tin-lined iron pipe. In making the connection between service pipe and main, the latter is tapped and a brass "corporation" cock screwed in. At the curb is usually placed another stop cock, with a suitable valve box, at which point the supply to the consumer is controlled.

Where pipes are laid in city streets, special care must be taken in backfilling and replacing the pavement. There is a wide difference of opinion as to the best method of backfilling, but probably the most certain way of getting the earth back without trouble from future settlement is by very thorough ramming of the material in a moist condition, but not wet. Such thorough ramming is difficult to secure, and it will usually be advisable to adopt the method of backfilling through a good depth of water. Hydrants are often deranged by being used for filling sprinkling carts. It is much preferable to provide water cranes for this purpose, numerous forms of which are on the market.

All constructive features pertaining to the distributing system should be carefully recorded on maps of adequate size and suitably indexed. The exact location of pipes, hydrants, and valves is of special importance. It will be convenient to have two sets of maps for this purpose—one on a small scale showing arrangement and size of piping and points of connection, and a set of large-scale maps, each one showing a comparatively small section of the system, on which the detailed information can be recorded.

OPERATION AND MAINTENANCE.

97. The maintenance of conduits and large pipe lines involves chiefly the work of cleaning and repairing. The various special structures should be frequently inspected to detect any sign of weakness, and in the case of large aqueducts the entire line should be regularly patrolled. If the water carries sediment and has a low velocity, the pipe line should be occasionally flushed by opening the blow-off valves.

Masonry conduits are likely to become coated with slime and organic growth, which will cause a large diminution of their carrying capacity, and if allowed to remain may affect the quality of the water. In such a case the aqueduct should be cleaned regularly once or twice a year, or at longer intervals, depending on the rapidity of the accumulations.

Large steel and cast-iron pipe lines will rarely need to be emptied for cleaning; but in some cases accumulations of organic growth have formed, which greatly obstructed the flow and which could not be removed by blowing off. In certain waters, particularly those relatively soft, the interior of cast-iron pipes corrode quite rapidly as explained elsewhere. This tuberculation, as it is called, often seriously reduces the carrying capacity of the pipe. The removal of such incrustation will restore a large part of the lost capacity, and may be a much more economical method of increasing the pressure in a system than by adding new pipes.

Large pipes can be cleaned by sending workmen through them, but ordinary pipes can only be cleaned by flushing or sending through them some form of mechanical scraper which nearly fills the pipe and which is propelled by the water pressure. Very badly corroded pipes have been successfully cleaned in this way.

To remove sediment from the pipe system use is made of blow-off valves or hydrants. Dead ends may need quite frequent flushing on account of odors and bad tastes developing in the stagnant water. Large leaks in mains will quickly make themselves known, especially if a recording pressure gauge is in use. Prompt action in shutting off the supply is often necessary to prevent heavy damage. Small leaks, if occurring in clay soil, will usually be indicated by the appearance of water at the surface, but in porous soils, and especially near sewers or drains, quite large leaks may go unnoticed for years.

A serious form of corrosion which has given trouble in many cities is the electrolysis which is caused by return currents from single-trolley electric railways. In this system the return current is supposed to pass through the rails, but as these are not insulated, a portion passes through the earth to neighboring pipes or other conductors leading in the right direction. This current then flows along the pipe with more or less resistance until it reaches a neighborhood where the rails or some other conductors are of lower potential than the pipe, this being usually in the vicinity of the power station. The current then leaves the pipe, and in so doing sets up corrosive electrolytic action.

Electrolytic corrosion is in some cases so rapid that pipes are practically eaten through in three to four years, and some of the worst cases have occurred where the pressure is but $1\frac{1}{2}$ volts. The remedies for electrolysis should apparently rest entirely with the railway companies. A very important aid in preventing electrolysis is the construction of a good return conductor by means of good rail bonding and the use of adequate return wires. Then in those districts where the pipes are of higher potential than the rails, if good, low resistance connections are made between rails and pipes, or from pipes to special return wires, the current will leave the pipes without passing into the ground and without causing trouble. Voltmeter tests between pipes and rails, at various points over the city, will determine the danger area.

Not infrequently considerable trouble arises from the freezing of service pipes which are not placed at a sufficient depth. Occasionally, also, small mains are frozen. Where the proper facilities exist the best way to thaw frozen pipes is by warming them with an electric current. For thawing service pipes a current of 200 to 300 amperes at a pressure of 50 volts is satisfactory, and will ordinarily thaw a pipe in from 20 to 30 minutes. The current can conveniently be taken from electric-light wires and reduced by a transformer.

Where the electrical method cannot be used steam may be employed, not only to warm the pipe, but to excavate through the frozen ground in a way similar to the operation of the water jet. The pipe may thus be reached at points 4 to 5 feet apart and gradually thawed out. Service pipes are often thawed by the use of a small steam pipe inserted in the service pipe through the house end, or from an opening at an excavation outside. Ground may be thawed by maintaining a fire on the surface for several hours, or more readily by the use of a gas flame projected against the soil.

Valves should be inspected occasionally to detect leakage and to ascertain if they are in working order and the boxes clean. Fire hydrants require very careful attention, especially in cold climates, as it is of the greatest importance that they be at all times available. The chief trouble with fire hydrants is from the freezing of the valves due to imperfect drainage, although a hydrant branch sometimes freezes up.

Hydrants should be carefully examined on the approach of cold weather and put in good condition. Valves should be tight and the hydrant thoroughly drained. If so located that the hydrant cannot be drained, it should be pumped out each time after being used. To ascertain if a hydrant is drained, a lead weight tied to a graduated cord can be let down through a nozzle. Hydrants should never be opened unnecessarily in cold weather, and never by others than those responsible for their condition. In very cold climates it is found desirable after using a hydrant to oil the packing and the nut at the top with kerosene in order to prevent sticking of the valve and nut.

To thaw frozen hydrants, a small portable steam boiler is commonly employed, which is provided with a length of hose for conducting steam to the bottom of the hydrant. Hot water may also be used, and for mild cases a little salt may be effective. After thawing, the water should always be pumped out.

In the management of the pumping station the best results can only be obtained by employing thoroughly competent men. The item most susceptible of variation is the cost of coal, and every effort should be made to reduce this to the lowest practicable limit. A daily record should be kept of the weight of coal and of ashes, so that the efficiency of the service can be known at all times. Reserve machinery should be operated frequently to make sure it is in good condition and can be started when called for. This is especially important where it is depended upon for fire pressure.

Records should, of course, be kept of the amount of water pumped per day, and the pressure maintained; also of the time during which special fire pressure is furnished, and the amount of water pumped at this pressure. Recording pressure gauges are of the greatest value in maintaining the efficiency of a plant.

The maintenance of earthen reservoirs calls for little more than has already been mentioned in section 76. The cleaning of such reservoirs may need to be done frequently. It is usually accomplished by flushing out the mud through the waste pipe by means of a hose, as in the cleaning of settling basins. Standpipes and tanks may require occasional flushing or blowing out, and will need to be repainted at intervals of a few years. They should also be inspected for signs of excessive corrosion or of electrolysis, and for any indication of weakness or wear at the base. Wooden tanks need rigid and frequent inspection to ascertain the condition of the wood and of the hoops. One or two of the latter will probably need to be occasionally removed to determine this point.

98. Detection and Prevention of Waste. From the data given in section 6 it was made evident that a very large percentage of the water supplied to American cities is wasted by the consumer and lost by leakage. In many cities the consumption of water is easily double the amount which can possibly be made use of, and in a very large proportion of them the wastage is fully one-third of the entire quantity supplied. This excessive use of water not only increases the cost of pumping unnecessarily, but adds to the expense in all parts of a waterworks system.

Unquestionably the easiest and most rational method of preventing the waste of water is by the use of meters, so that each consumer will pay for what he uses. It furnishes also the most equitable basis for charging up the cost of service, as by any other system the careful user is forced to pay for the water wasted by his careless neighbor. The use of meters is becoming much more general, and in most cities the larger consumers, at least, are now metered; but a very large part of the loss or waste is due to the small consumer, so that the full benefit of the system will not be felt until the use of meters becomes general. Usually much opposition is raised to the introduction of meters, but after they have been put into use the results are commonly such as to cause them to be greatly favored by the community. As a system of waste prevention it is always in service, and for that reason is far superior to any system of inspection. In nearly all cases the decrease in cost of supplying water after the adoption of meters much more than balances the cost of the meters.

If meters are not used, some method of inspection is highly desirable whereby the most serious cases of waste can be detected and the consumption kept within reasonable limits. The most common method is a house-to-house inspection, carried out one or more times per year for the purpose of examining the plumbing fixtures. Any leaky or imperfect fixture is ordered repaired, and the premises re-inspected shortly to make sure that the order has been complied with. Persistent refusal is followed by the shutting off of the supply.

One of the weak points of the meter system is that it fails to detect leaks in the mains or in the services beyond the meters. To localize a leak in a main, a waterphone may be used, which consists of a staff of wood or iron having at one end a diaphragm and ear piece similar to a telephone receiver. The staff is placed against the pavement over the pipe at various points, and the ear applied to the receiver, when any sound made by a leak is readily perceived.

Many different kinds of meters are on the market, most of which will give satisfactory service if properly treated, and many of them have been thoroughly tested by years of use. No new form of meter should be adopted without thorough and long continued tests, and in all cases it is well to specify the desired requirements of a meter, and to test all new meters, in order to insure uniformly good workmanship.

The general requirements of a meter are—a fair degree of accuracy, ability to register approximately quite small rates of flow, suitable capacity for a given loss of head, durability, and low cost. All of these requirements except that of durability can readily be determined by a brief test. Some notion of the durability can also be had by a careful inspection of the parts, and by running a meter at a rapid rate for a considerable period and again determining its accuracy and sensitiveness. Maintained accuracy, accessibility, and ease of repairs are the most important qualities of a meter.

Meters should be so designed that the various parts will be easily accessible and readily replaced, and the moving parts protected from serious injury by frost. The latter object is usually accomplished by frost bottoms of cast iron, or cast-iron cases, made so as to be more easily broken than other and more costly parts of the meter.

99. Water Rates. The several services performed by a waterworks are: (1) to furnish water for private use; (2) to furnish water for public use on the streets, and for sewers, fountains, public buildings, etc.; and (3) to furnish fire protection to property. In (1) and (2) the cost of service may be considered approximately proportional to the quantity of water supplied, but in (3) it is out of all proportion to the amount of water used, for while the cost of construction is greatly affected, the total amount of water consumed is slight. The extra cost involved in furnishing adequate fire protection is due to largely increased pumping capacity, increased size of mains, reservoirs, or standpipes, cost of hydrants, and increased cost of maintenance. Estimates of careful observers place the proportion of cost chargeable to fire protection at one-third or one-half the entire cost.

The sources of revenue are the water rates and the fund received by general taxation. The former are paid by those who use the water, and more or less in proportion to the amount used. The latter are paid by assessment on all taxable property. If the revenue be so raised that each interest served be charged according to the cost of the service, it would appear from the preceding section that the cost of furnishing water to private consumers should be paid by water rates; that the cost of supplying water for public purposes should be paid by taxation and according to the amount of water used; and that the cost of fire protection should also be met by taxation, since the individual is benefited by reason of the protection afforded to property.

The exact proportion of the revenue which should be derived from each source depends much upon local conditions, such as size of town, character of supply, etc. In many small towns the works are primarily installed for fire-protection purposes, in which case nearly all the expense should be met by taxation. It is also good policy to begin with fairly low water rates, so as to encourage the use of water, but to enable this to be done a large proportion of the expense will have to be met for a few years by taxation.

The proportion of the revenue to be derived from private consumers requires careful consideration in its adjustment. The most equitable method of apportioning the cost is by the meter system. In fixing rates under this system, allowance should be made for the fact that quite a large percentage of the water recorded at the pumping station cannot be accounted for, and rates per unit of volumes registered by the meters must be correspondingly raised.

Meter rates are usually graduated, that is, a less rate is charged for large quantities than for small ones. This is partly on the ground that the cost of meter maintenance, keeping of accounts, etc., is proportionally greater for small quantities, and partly by reason of the policy of encouraging the operation of factories which contribute largely to the general prosperity of the community, and which may require large amounts of water. In establishing a graduated schedule, it should be so made that the lower rate shall apply only to the additional water used beyond the limit of the next higher rate. A good example of such a schedule is as follows:

For the first	5,000	cu. ft.	per 6 months,		20	cts.	per	100	cu. ft.
" " next	15,000	"	"	"	10	"	"	100	"
" " "	10,000	"	"	"	5	"	"	100	"
" " "	30,000	"	"	"	3	"	"	100	"
" " "	30,000	"	"	"	2	"	"	100	"
" over	90,000	"	"	"	5	"	"	100	"

A minimum charge of $2.00 per 6 months is made.

An objection to the meter system which is often advanced is that it discourages the use of sufficient water for sanitary purposes, but this is entirely obviated by making a small minimum charge, such as given above, which will be enough to allow the use of an abundance of water for sanitary purposes, and at the same time will cover the expense of meter maintenance.

Most cities meter the larger consumers, but comparatively few have yet introduced the full meter system. In such cases private houses are charged mainly by the fixture. Usually a minimum family rate is charged for kitchen use, then an additional rate for each bath tub, water closet, wash bowl, stable hose, lawn hose, etc., with often other variations depending upon the number of rooms, number of occupants of the house, etc. Little data exists as to the actual amount of water used by different fixtures, and the rates are largely arbitrary.

PURIFICATION OF WATER.

100. Object and Methods. In the purification of public water supplies the primary object is usually to remove from the water any traces of pollution that may give rise to disease, or, in general, to remove any disease germs that may possibly infect the supply. It is often important also to remove the suspended matter where the water is turbid. Sometimes also the water contains so much dissolved mineral matter that it is desirable to remove a part of this to render the water more suitable for manufacturing as well as for domestic purposes. Thus, a very hard water is undesirable to use for boiler purposes as well as for culinary and laundry uses.

The various processes of purification may be divided into two general groups: (1) Those for the removal of suspended impurities, and (2) Those for the removal of dissolved impurities. Of the first class there are two general processes, sedimentation and filtration, both of which may be called natural processes. By sedimentation, water may be more or less freed of its suspended matters, including the bacteria, the efficiency of the treatment depending much upon the element of time. The process is carried out artificially in large storage reservoirs or in small special settling basins.

Filtration is accomplished in different ways. The most common is by means of the artificial sand filter bed, either as contained in masonry basins of large size, or confined in small tanks as in the so-called mechanical filters. The chief object is in all cases the removal of the suspended matters, and in most public supplies particular attention is paid to the removal of bacteria. The processes for the removal of dissolved impurities include the softening process, in which lime and magnesia are removed by chemical precipitation, and the process for the removal of iron in a similar manner. Such methods usually involve subsequent sedimentation or filtration for the removal of the precipitate.

SEDIMENTATION.

101. In streams such as would be considered suitable as sources of supply the sediment is principally of an inorganic nature, consisting of particles of sand and clay of various sizes. The amount and character of the sediment varies greatly from time to time; it depends largely upon the stage of water in the different tributaries, and upon the geological character of the various parts of the drainage area. In the Ohio River water at Louisville it varies from 1 to 5,000 parts per million, ranging ordinarily from 100 to 1,000; the bacteria varies from a few hundred per cubic centimeter to as high as 50,000. The size of the suspended particles also varies greatly. In some waters the finer particles of clay are less than 0.00001 inch in diameter, which is smaller even than bacteria. This great variation in amount and kind of sediment constitutes one of the most troublesome factors in connection with purification works for river supplies.

Where the body of quiescent water is sufficiently large, and the period of repose sufficiently long, this action of sedimentation becomes practically perfect, and a clear and greatly improved water is the result. Artificially, such high efficiency is often obtained where the water is collected in large impounding reservoirs holding several months' supply. Where, however, the supply is taken directly from a large sediment-bearing stream, very large reservoirs are usually impracticable on account of the great cost; and the period of time during which sedimentation can be operative must therefore be limited to a few days or even to a few hours. Such a limited amount of sedimentation is, however, of much value.

Where a water contains little that is objectionable besides the inorganic sediment, a degree of purification can often be obtained

FIGHTING A FIRE WITH NEW YORK CITY'S HIGH-PRESSURE WATER SUPPLY SYSTEM
Two Men and a Tripod are Required to Hold Each Nozzle.

by mere sedimentation which will render the water fairly acceptable. In many instances, however, a satisfactory water cannot be obtained without subsequent filtration; but in this case the process of sedimentation constitutes a very valuable and almost indispensable prerequisite to the final treatment. For a sewage-polluted water, sedimentation alone is an inadequate treatment, as the bacteria are not eliminated in sufficient numbers to insure safety.

Sedimentation may be employed as a preliminary treatment of a water that is to be filtered or it may be used as the final and only treatment. In the former case a fully clarified water is not essential, but in the latter case it is greatly to be desired, although not always possible.

There are two methods to be considered: (1) Plain sedimentation; (2) Sedimentation with the addition of a coagulant. For plain sedimentation a period of 24 hours' subsidence is about the minimum limit adopted, but this will seldom give a clear water. A considerably longer time is often necessary to give acceptable results. For some waters it requires weeks and even months to remove all the turbidity, while for others a settlement of a day or two accomplishes fairly good results. If the amount of suspended matter is measured by weight, a large proportion will settle in one or two days; but the reduction in turbidity is not correspondingly great, as it is the finer portions which exert the greatest influence upon the appearance of a water. In the case of the Mississippi at St. Louis, it is practically impossible to clarify the water in the spring by simple sedimentation, owing to the attenuated condition of the clay particles.

There is a marked degree of bacterial purification in sedimentation, yet it should be kept in mind that such a method is extremely hazardous, especially where the water supply is subject to any sewage pollution. Experience shows that sedimentation alone is insufficient to protect a city against a polluted water supply.

Various chemicals when added to water will combine with certain substances ordinarily present, forming precipitates which are more or less gelatinous in character. These act as coagulants to collect the finely divided suspended matter into relatively large masses which are much more readily removed by sedimentation or filtration. Color may also frequently be removed to a large extent by this treatment. If a water can be satisfactorily purified the greater part of the year by plain sedimentation, the use of a coagulant at other times as an aid in the process is well worth consideration.

Several substances can be used as coagulants. That most commonly employed is sulphate of alumina. When this substance is introduced into water containing carbonates and bicarbonates of lime and magnesia, it is decomposed, the sulphuric acid forming sulphates with the lime and magnesia, while the carbonic acid is set free, and the alumina unites with water to form a bulky gelatinous hydrate which constitutes the coagulating agent. If the water does not naturally contain a sufficient amount of alkalinity to decompose the necessary amount of coagulant, lime should be previously added to the water. The regulation of this matter must be put into the hands of an expert, as an excess of alum in the water is very undesirable if not actually dangerous.

The amount of chemical required depends upon the amount and character of the sediment, upon the degree of purification desired, and upon the time of settlement. It varies in practice from about $\frac{3}{4}$ grain to 3 or 4 grains per gallon. The proper amount can only be determined by experiment.

The rate of sedimentation depends greatly upon the amount of coagulant employed. It takes place much more quickly than where no coagulant is used, so that a large part of the action will occur in a few hours. With a fair amount of coagulant, the sediment remaining after 24 hours' subsidence will settle very slowly; and this period may be taken as about the maximum economical figure. Much less time than this can be used in many cases. Where the water contains large amounts of sediment, it will often be more economical to allow the coarser particles to settle before applying the coagulant. This will reduce the cost of chemicals and give a more satisfactory result.

Settling basins are constructed in accordance with the same general principles as other reservoirs; in fact, in many cases distributing reservoirs or storage reservoirs act also as settling basins Where, however, but a short time is allowed for settling, and reservoirs are intended for that special purpose, there are differences in detail which should be considered. Settling basins are usually supplied with water by means of low-service pumps, and from the basins the water flows into a clear-water reservoir, or to a pump well, or to filters, as the case may be.

102. Methods of Operation. There are two general methods of operating settling basins: (1) the constant-flow method, and (2) the intermittent or fill-and-draw method. In the former the water is allowed to flow at a very slow velocity through one or more reservoirs, during which time the settling takes place. In the latter the water is let into a basin and allowed to remain quiescent during the period of subsidence. It is then drawn off to as low a level as efficient clarification has taken place, and the basin refilled. It is probable that certain waters can be treated best by one system and others by the other system, but this is a matter which can only be determined by experiment. The method of fill-and-draw, used at St. Louis, is thought by the engineers in charge to be more suitable for conditions at that place.

In several plants using Missouri River water the constant-flow system is used. At Cincinnati, Ohio, the fill-and-draw method is used, but it is stated that this is on account of matters pertaining to the form of the basins which are purely local in character. In the fill-and-draw method no settlement of fine particles can commence until the operation of filling is completed, which condition materially reduces the time of subsidence. On the other hand, the water becomes more quiet than in the other process, and this operates to its advantage. If the basins are operated on the constant system, a single basin can be made to suffice—an arrangement quite suitable for a relatively clear water where sedimentation is a secondary matter, or merely a preparation for filtration. If there is much sediment, at least two basins are needed, in order that one may be cleaned without interrupting the supply. In case a coagulant is used after partial sedimentation, two basins would be necessary and three would be desirable. With the fill-and-draw method, the number becomes a question of economical construction and operation. This will usually be from 4 to 6.

For a single rectangular basin of given area the square is the most economical form. For a number of basins they should be made rectangular in shape with a width about three-fifths of the length and arranged side by side in one row.

In general, settling basins are built similar to ordinary reservoirs, partly in excavation and partly by embankment, so as to secure the greatest economy. Earthen slopes will usually be cheaper than masonry walls, but with the fill-and-draw method the former have the disadvantage of exposing the mud at each period of emptying. They are, however, more often used in spite of this. The depth of basins is made about such as to give the most economical construction, very shallow basins being avoided. The time of settlement is found not to be materially affected by depth.

Fig. 39 illustrates the arrangement of the large St. Louis basins. The basins are of 22,000,000 gallons drawing capacity each. They are built with masonry side and partition walls, and linings of concrete, on about 18 inches of puddle. Through the center runs a ditch having a slope of 1 per cent, and leading to a 24-inch drain pipe at the east end. The floor also slopes towards this ditch from both sides. The filling is done through a 60-inch pipe leading from a filling conduit of masonry. The drawing is done at the east end through two sluiceways, 4 by 5 feet in size, which take the water from about 5 feet above the bottom. The water passes thence through a 60-inch pipe into the main delivery conduit.

In the continuous flow system the object to be obtained is the distribution of the water on entering as evenly as may be across one side or one end of the basin so that it shall enter with as little disturbance as possible; then to draw it off in a similar manner from the opposite side, and from the stratum of clearest water. As far as possible all parts of the water should remain in the basin equal lengths of time, and all strong currents should be avoided. The ordinary inlet is usually a single large pipe laid through the embankment, or a single sluice gate in a gate chamber built in the walls. A better distribution of the water could be obtained by means of several inlets, or several branches from a single inlet pipe. The withdrawal of water in this system should take place from near the surface. Broad weirs formed in the wall, or made of iron troughs, are frequently used.

In the fill-and-draw system the inlet is arranged in the simplest way, as in an ordinary reservoir. The position of the outlet is of more importance. If but a single one is used, it will need to be at the lowest point of outflow, and so will not draw from the clearest stratum except near the end of the operation. The difference in clearness at different depths after 24 hours' subsidence or more is, however, not very great. To enable the sediment to be removed, the bottom of the basin should be made slightly sloping (1 to 2 per

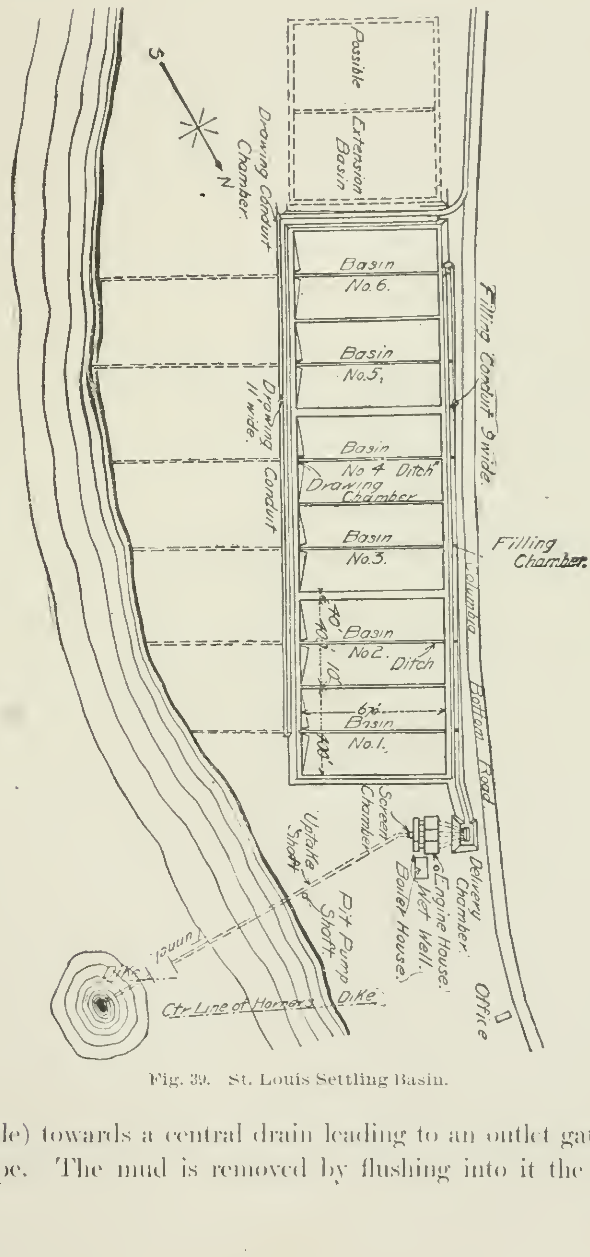


Fig. 39. St. Louis Settling Basin.

cent grade) towards a central drain leading to an outlet gate or to a drain pipe. The mud is removed by flushing into it the drain by means of a hose stream, supplied from a high-pressure main. The cleaning is done at intervals depending entirely upon the local conditions, and may be every month or so, or only at intervals of years. The longer the mud is allowed to remain the more compact it becomes and the more difficult to remove, but the change in compactness takes place quite slowly.

Where the basins are operated on the continuous-flow system and the water passes from them directly to the pumps, it is necessary to construct a small clear-water or pump well to avoid the necessity of too frequent adjustment of the rate of supply to the basins.

SLOW SAND FILTRATION.

103. The first filter of which we have any record was established in 1829 for the Chelsea Water Company, of London. The chief object of this filter was to remove turbidity, and in this it was a success. Its value in improving the water from a hygienic standpoint was also appreciated, although the principles underlying its action were not understood until some years later. As a consequence of the good results obtained from this filter, the filtration of all river-water supplies of London was made compulsory in 1855. Within the last fifteen or twenty years the use of sand filters has become almost universal abroad wherever surface waters are used. In Germany it is made compulsory. In the United States it is only very recently that this subject has received the attention that it merits, but within the last few years many small cities and several large ones have installed efficient filter plants.

In the slow sand filter the sand bed is constructed in large water-tight reservoirs, either open or covered, each having usually an area of from $\frac{1}{2}$ to $1\frac{1}{2}$ acres. On the bottom of the reservoir is first laid a system of drains, then above this are placed successive layers of broken stone and gravel of decreasing size, and finally a bed of from 2 to 5 feet of sand which forms the true filter. The water flows by gravity, or is pumped, upon the filter, passes through the under drains to a collecting well, and thence to the consumer. Water containing much sediment is usually first passed through settling basins, where a large part of the sediment is removed.

As the water filters through the sand, the friction causes some loss of head, which gradually increases as the filter becomes clogged with foreign matter. The rate of filtration is, however, maintained nearly uniform by suitable regulating devices which vary the head according to the resistance. When the working head has reached a certain fixed limit of a few feet, the water is shut off, the filter drained, and the surface cleaned by removing a thin layer of clogged sand. The operation is then resumed. Before the thickness of the sand layer becomes too greatly reduced, clean sand is added sufficient to restore the filter to its original depth.

Besides the method of construction, the chief characteristic of this system of filtration is the slow rate of operation, usually not exceeding 2 or 3 million gallons per acre per day.

The chief features to consider in this form of filter are the proper construction of sand bed and drains, the rate of filtration and its regulation, the loss of head, cleaning of beds, washing of sand, and the contr l of the operation by bacteriological tests.

104. Rate of Filtration. In the design of a filter plant the first question to be settled is the rate of filtration which shall be adopted. The higher the rate the less the area required and hence the less will be the first cost; but the cost of operation is not greatly affected by the rate. In general high rates of filtration will give less efficiency than low rates, but until the rate exceeds a certain amount the difference in efficiency is small.

Rates of filtration are in this country usually stated in terms of gallons per acre per day or per hour. The experience of European works has resulted in the adoption of a rate, for most places, of between 2 and 3 million gallons per acre per day, but in this country somewhat higher rates have been favored. Probably 3 or 4 million gallons is as high as it would in general be advisable to go in the design of a new plant. If subsequent operation shows that a higher rate can be adopted with efficiency and economy, the fact can be taken advantage of as the demand for water increases. It should not be overlooked that there may be cases, where, with a moderately polluted water, all the practical benefits of filtration can be secured at rates much higher than are usually employed. Each case demands independent consideration in order that the best and most economical solution may be arrived at. Sudden changes of rate are apt to produce disturbances in the filter and to give a reduced efficiency. In practice, absolute uniformity of operation is unnecessary, but sudden changes in rate should be avoided, and especially any large increase above the normal.

105. Capacity. The standard rate having been determined, the required net working capacity will be equal to the maximum rate of delivery divided by the assumed rate of filtration. To economize area and to avoid rapid changes in rate, a clear-water reservoir should be provided. The best size for this will depend on local conditions, but it will usually be desirable to have it of sufficient capacity to equalize the demand throughout the day. It will then be necessary to vary the rate of filtration only to accord with the daily variations in consumption. In section 6 it was shown that the maximum daily rate of consumption is likely to be about 150 per cent of the average, and with a clear-water reservoir of the capacity mentioned above, the filters must be designed to deliver at this maximum daily rate.

In addition to the area as above found, a reserve area for cleaning must be provided. For small works this will be one bed; for works containing several beds it will be necessary to allow one bed for each 5 to 10 beds, depending on the frequency of scraping and the time required for putting a filter into operation after cleaning. The proper size of beds is chiefly a question of economical construction. The larger the beds the less the cost per acre, but the greater will be the area out of service in the one or more reserve beds. Ordinarily the size for a considerable number of beds is from 1 to 1.5 acres for open beds, and from .4 to .8 acres for covered beds. For small total areas of .5 to 1 acre three beds would ordinarily be used, and for still smaller areas two beds. The economical number can in any case be determined by comparative estimates, but under ordinary conditions the number should be about as follows:

For a total area of 1 acre 3 to 4 beds.
" " " 3 " 5 " 6 "
" " " 6 " 7 " 10 "

Filter beds are usually made rectangular in form and arranged side by side in one or two rows according to the number. In general construction a filter basin is built in a way similar to small distributing reservoirs. (See section 76.) Earth embankments for the sides are cheaper than masonry walls, but require more ground. If the filters are covered, masonry walls are usually employed. Particular care must be taken to render the basin water-tight both on the bottom and at the sides. Cracks in division walls are likely to admit unfiltered water to the under drains and should be especially guarded against.

The depth of open filters is made only sufficient to contain the necessary depth of filtering materials and water, as explained subsequently, and still have a margin of 2 or 3 feet from the water surface to top of the embankment. This will give a total depth of 9 or 10 feet. In closed filters the distance from top of sand to cover must be sufficient to give head room for workmen when cleaning the filter, a distance of about 6 feet.

Covers for filters are constructed of the same general form and arrangement as described in section 78. Masonry or concrete vaulting is usually employed, although wood has been used; but the latter does not afford as good a protection from freezing or from summer heat. Admission for workmen is provided by a gangway leading from an opening at a point where the vaulting is raised. Walls and piers should be built with small offsets near the bottom in order to insure good filtration at that point. A covered filter is illustrated in Fig. 33.

The principal reason for covering filters is to avoid the difficulties connected with the operation of open filters in winter. To clean filters when covered with ice is a troublesome and expensive operation, requiring the removal of the ice or the use of special methods giving inferior results. If the filters are drained for cleaning, trouble also arises from the freezing of the sand. The cleaning of beds is thus not likely to be done as promptly as desirable, and the result of winter operation will be a decreased effective area and a lowered efficiency. Whether covers should be used depends upon the extent to which ice will form, the frequency of the occurrence of thaws which will enable a filter to be properly cleaned, and the length of time between cleanings as determined by the character of the water.

106. Filter Sand. Experiments show that very fine sand is considerably more efficient in removing bacteria than ordinary or coarse sand, but within the ordinary limits of size there is but little difference in efficiency. The finer sands, however, cause a steadier action and prevent disturbances due to scraping; they also cause a greater loss of head in the filter, and so make the action more uniform over the filter area. On the other hand, fine sand becomes clogged sooner than coarse and involves therefore more expense in cleaning.

It is desirable that a sand be fairly uniform in grain. If the particles vary greatly in size, it will be difficult to wash, and in fact will have much of the finer particles removed in the process, thus increasing the effective size. It is especially important that the sand should be of the same grade in all parts of the same filter in order that the frictional resistance, and therefore the rate of filtration, shall be uniform. In designing a filter it should be noted that the sand forms the filtering medium; the gravel serves simply to collect the filtered water with little resistance to flow. There is no object in having the main body of sand of different sizes.

The depth of sand must be sufficient to form an effective filter and, besides, to allow of several scrapings without renewing the sand. The effect of deep beds is similar to that of fine sand in steadying the action of a filter, and it has been clearly shown that the operation of beds 4 to 5 feet thick is not so much affected as that of beds 1 to 2 feet thick by such disturbances as variations in rate, scraping of beds, etc. A depth of 3 feet is about right, with one foot allowed for scraping.

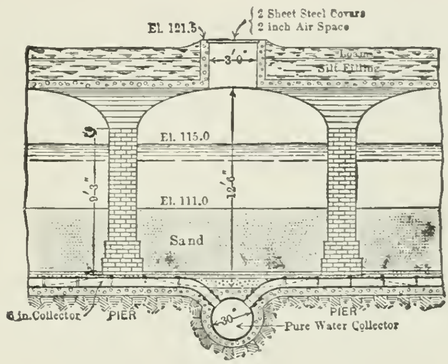
The depth of water on the filter should be sufficient to enable the desired maximum head to be used without reducing the pressure in the filter below atmospheric; and as the resistance is nearly all at the surface of the sand, the depth must be about equal to the maximum head to be used in forcing the water through the filter. The depth must also be greater than the thickest ice likely to form. Beyond these limiting depths any increase serves only to increase the expense of construction.

107. Drainage Systems. To collect the filtered water a system of under drains is necessary. The important points to be considered in its design are durability and freedom from derangement, and that the loss of head therein shall be small. The system of drains usually consists of a large central drain running the length of the filter, and branch drains at right angles thereto placed at regular intervals, usually of 8 to 12 feet. The central drain may be either of large vitrified pipe, as in Fig. 40, or of masonry. The branch drains are usually of 4 to 8-inch round or special tile, laid with open joints.

To conduct the water to the lateral drains, coarse gravel an inch or two in diameter is filled about the drains and spread in a layer of

6 inches or more in depth evenly over the floor of the filter, or, if the bottom of the filter is irregular, it may be arranged as shown in Fig. 40. Above this coarse gravel are then placed three or four layers of finer gravel, each successive layer being finer in size, but not so fine as to settle into the previously laid layer. The last layer is made fine enough to support the sand. The thickness of these layers need be only 2 or 3 inches if carefully laid, or just sufficient to insure that the next layer below is well covered.

The gravel used should be carefully screened and, if dirty, washed. It is readily sized by revolving or fixed screens, using for this purpose



Section through Main Drain.

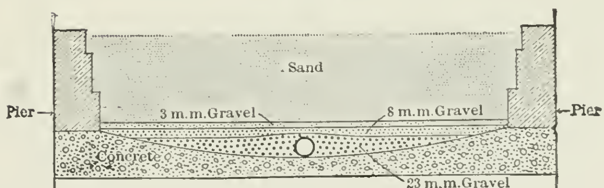


Fig. 40. Details of Drains, Albany Filter Beds.

three or four different sizes. The smallest should have about a $\frac{3}{16}$-inch mesh, and each larger size about double the size of mesh of the next preceding. As a filter becomes clogged the head necessary to cause filtration at the assumed rate increases. By allowing the head to increase to a high figure the filter can be operated longer without scraping and so a saving in operation effected. On the other hand, high losses of head require more pumping, a greater depth of filter, and have a detrimental effect in compacting the sand. A maximum loss of head of 4 or 5 feet may be taken as good practice.

108. Arrangement of Inlet and Outlet. Water is admitted to the filter through a single branch main at about the level of the surface of the sand. The flow is usually controlled by a valve operated by a float, so as to maintain the water in the filter at a constant level. A gate valve is provided in addition, to enable the water to be completely shut off at any time. If the water level on the filter is kept constant, the rate of filtration must be regulated, as the filter becomes clogged, by lowering the water level or reducing the pressure at the outlet. In the older filters no arrangement was provided for regulating each filter independently, but each was connected to the clear-water well by a short pipe fitted with an ordinary valve. The head on all filters was consequently always the same, except as it might be controlled by throttling at the valves. The effect of unequal heads on the rate of filtration, where some of the filters might be freshly cleaned and others badly clogged, can readily be imagined.

The regulation of head requires, first, some form of measuring device, such as a weir or orifice, by which the rate of filtration can be ascertained at any time by floats and indicators; and, second, the controlling of the head on this weir or orifice either by hand or automatically. Floats are also required to show the level on the filter and the head in the main drain, the difference of which is the working head on the filter. The apparatus for regulation is placed in one or more chambers with which the main drain of the filter connects.

Automatic regulators for delivering water at a constant rate are in use in a number of places. They usually consist of a weir in the form of a telescopic tube which is supported by means of a float in the chamber connecting with the under drain. By adjusting the float, the edge of the weir can be maintained at any desired distance below the water surface. Besides the inlet and outlet pipes, a drain pipe must be provided through which the water may be drawn off. This is usually connected with the chamber into which the main drain opens. An overflow pipe is also necessary to provide against any failure on the part of the inlet regulator. This connects with the drain pipe.

Arrangements should be made for wasting the filtered water in case it should be necessary, also for drawing off the water from above a filter down close to the sand layer in order to save time in emptying; and facilities should be provided for sampling water from various points in the system. By-passes should be provided to enable either settling basin or filters to be cut out if necessity arises. For furnishing water for sand-washing and various purposes, connection must be made with high-pressure mains.

109. Cleaning Filters. When a filter has become clogged and has reached its highest allowable loss of head, it is drained and then cleaned by removing by means of broad thin shovels a layer of clogged sand from ½ to 1 inch in thickness. The surface is then smoothed with a rake. The sand is removed from the filter by means of wheelbarrows or small cranes, and deposited at a convenient point where it is cleaned after a considerable quantity has accumulated—or is wasted in case it is cheaper to use new sand than to clean the old. After scraping, the filter is filled, preferably from below, with filtered water until covered 2 or 3 inches deep; then raw water is run on to the usual depth, and the filter again started into action. At intervals of a year or so, and before the layer of sand has been reduced below a desirable minimum thickness, the bed is restored to its original depth by the addition of clean sand. After cleaning and filling, the filter should be started slowly and gradually. The sand that has been removed is allowed to accumulate until it is desired to replace it in the bed. Before replacing it, however, it is washed to free it of the accumulated sediment. Various effective devices are employed for this washing operation.

110. Control of Filter Operations. The most accurate way in which to control the operation of filter plants is to subject the water to a bacterial examination. This should be made at frequent intervals so as to note any possible changes in quality. The experience with European filter systems has shown that an impairment in quality has not infrequently been detected in time to prevent outbreaks of disease. In the larger filter plants, a bacteriological laboratory should be installed, and daily tests of the effluent made. The filter beds should be arranged so that the effluent from each can be tested separately, and provision made so that the filtered water can be rejected from any one filter if not up to standard. The careful control of the operations is a matter of great importance. In testing filters as to their efficiency, samples should be collected at periods when the effluent is likely to be the least favorable, as during frost periods, heavy rains, and periods of greatest consumption.

111. Results of Filtration. The most apparent result of filtration is in the removal of all the suspended matter in the water; but more important than this, a sand filter will remove very nearly all the bacteria originally present in the water. This is specially exemplified in the reduction of the deathrate from typhoid fever following upon the installation of a filter plant. But to secure continually good results it is essential that such works as filter plants be under efficient control.

RAPID FILTERS.

112. The *Rapid*, or as it is often called, the *Mechanical Filter*, is a form of filter designed to accomplish results in the way of purification comparable with those obtained by the slow sand filter already discussed, but with a much smaller sand area. It is like the sand filter in that the filtering material consists of a bed of 2 to 4 feet of sand or crushed quartz, but in other respects the construction and operation are widely different. The chief points are the very rapid rate of filtration (100 to 125 million gallons per acre per day), the use of a coagulant to aid in filtration, and the manner of washing the sand bed. Methods of operation and mechanical details are, to a large extent, covered by patents, and the filters are manufactured and sold by various filter companies.

Briefly, the filter consists of a wooden, steel or concrete tank in which the filtering material is placed and supported on a system of screens of various designs. In some forms the tanks are open and operated by gravity, and in others are closed and operated by pressure from the pipe system. When the filters become clogged through the accumulation of sediment on the surface, they are washed by forcing water in a reverse direction through the sand. During this process, the sand is, in most cases, agitated by means of mechanical agitators reaching deeply into the sand layer or by means of compressed air.

Two well-known types of filters are illustrated in Figs. 41 and 42. In the first, the water enters the settling chamber at the bottom, passes up through the central tube to the top of the filter and thence downwards through the sand to the collecting pipes located between filter and settling tank. Where a coagulant is used it is introduced before admission to the filter bed. The figure shows the agitators which are operated when the filter is washed. When not in use they are raised out of the sand. The wash water passes off on all sides over the top of the inner tank. In the other type the settling tank is not connected with the filter. No agitators are used; but to loosen the sand air is passed through the bed from below. In both forms shown the filtration is by gravity. The Warren filter is another

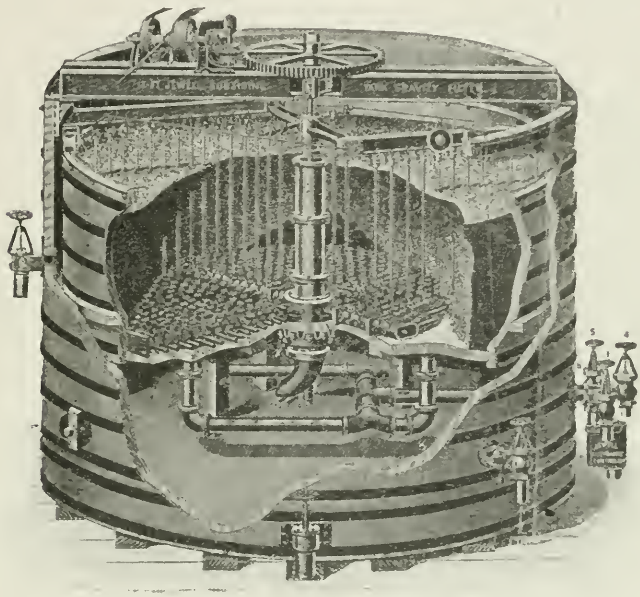


Fig. 41. Jewell Gravity Filter.

type commonly employed. It uses agitators like the Jewell, but the settling tank is disconnected from the filter.

113. Principles of Operation. The action of mechanical filters is somewhat unlike that of sand filters, although the results are not greatly different. The effect of a coagulant in gathering the sediment into relatively large masses has been explained in section 101. It aids filtration in this way and also forms a substitute for the organic coating on the sand grains and on the surface of the ordinary sand filter. It is the use of the coagulant which enables such high velocities to be employed. To avoid too frequent washing, it is common to employ heads as high as 10 to 12 feet, but with such high heads and velocities the sand becomes clogged to a considerable depth. The methods of washing, however, enable this sediment to be readily removed. The interval between washings, *i.e.*, the "run," is 24 hours or less, and the operation of washing requires about 15 to 20 minutes. The amount of wash water used is commonly from 2 to 5 per cent of the applied water, which fact must be considered in determining the gross capacity of the plant. Crushed quartz is often used for the filtering material, but ordinary sand would probably do as well if of very uniform grain so as not to be

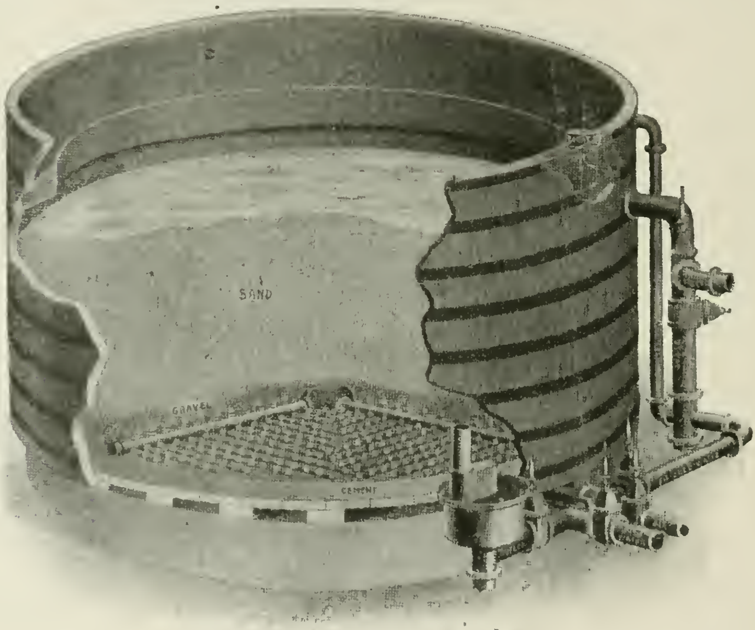


Fig. 42. Continental Gravity Filter.

carried away in the washing process. The coagulant employed is usually sulphate of alumina, but common alum is sometimes used. The relative merits of these and some other coagulants have been discussed in section 101. Ferrous sulphate is also employed as a coagulant with good results. Rapid filter plants were formerly installed by the companies who manufactured the mechanical devices, but some very complete plants have lately been designed and constructed under the supervision of consulting engineers. In this case some of the patented forms of strainers have been adopted and the other details been designed by the engineer in charge.

A SPLENDID EXAMPLE OF A SIDE-HILL FLUME

Total length of flume, 10 miles, diverting water of the Puyallup River, Washington, to supply the power plant of the Puget Sound Power Company at Electron.

In most of the early plants rapid filters have been adopted with particular reference to the removal of turbidity or color, but in some of the more recent plants the elimination of bacteria has been the chief object.

Extensive experiments with rapid filters indicate that when they are properly operated, turbidity can be practically all removed, a large percentage of color, and a considerable portion of dissolved organic matter. With the quantities of coagulant ordinarily used, they are probably slightly less efficient than sand filters in the removal of bacteria. In some places satisfactory clarification is obtained without a coagulant, but for good bacterial results a coagulant is necessary.

To obtain uniformly good results with economy requires very careful operation. The coagulant must be closely regulated to correspond with the quality of the water; in the case of waters low in alkalinity this is particularly necessary. The efficiency depends so entirely upon the control of these matters that the proper operation of a mechanical plant involves greater care on the part of the attendants than that of a sand filter. It is fully as important in this case also that the whole plant should be under the control of bacteriological tests, regularly and frequently made. Many points of operation, such as period between washings, wasting of water, thickness of sand layer, and best kind of sand, can be learned only after experience in the light of such analyses.

Considering the economic advantages of mechanical filters, it may be said that they are especially adapted to those cases where the cost of land is high, where the water is so turbid as to require large settling reservoirs with a sand filter plant, and in small plants where the unit for sand filters would be very small. They are also well adapted for the rapid removal of iron from ground waters or of the precipitate in softening plants. On the other hand, if the total annual expense of sand filters and mechanical filters is equal, the evidence points to the desirability of adopting sand filters, especially for sewage-laden waters, but the difference in efficiency is not great enough to warrant any considerable additional expense. With very turbid waters both systems are likely to prove unsatisfactory unless supplemented by adequate settling basins.

OTHER METHODS OF PURIFICATION.

114. Aeration. Aeration of a water, or the bringing of the water into close contact with the air, is useful in certain cases. It will have little or no effect upon organic matter present, but it does have a very important action in the case of waters coming from stagnant ponds and reservoirs in which putrefactive changes have taken place. Such waters will have offensive odors and tastes, due to the dissolved gases contained, and it is in the removal of these gases that the process of aeration can be successfully applied. It has been so used in a large number of cases.

Aeration may be accomplished by forcing air into the mains, or by passing the water over cascades or weirs, or by spraying it from a fountain into a reservoir as is done in many places, or by still other methods. The benefit of aeration explains why a well water raised by buckets is more commonly free from bad tastes and odors than where a pump is used, although such odors and tastes are not in themselves dangerous to the health.

115. Softening Water. Water is rendered hard by the presence of lime and magnesia, chiefly in the form of carbonates and sulphates, but occasionally as chlorids and nitrates. The carbonates cause so-called temporary hardness (removable by boiling), while the sulphates and other compounds cause permanent hardness. In using a hard water for washing purposes approximately 2 ounces of soap are neutralized or wasted for each 100 gallons of water for each grain per gallon of calcium carbonate or its equivalent. In boiler use the carbonates of lime and magnesia are precipitated, forming a deposit which can usually be removed by blowing out, unless accompanied by scale-forming substances. Sulphate of lime precipitates at high temperatures and forms a very hard, objectionable scale, particularly if the water contains other suspended matter. The softening of water is therefore of great economical importance.

The softening of water is accomplished by simple processes of chemical precipitation. To remove the carbonates, lime is used as the precipitant. The carbonates are held in solution chiefly by virtue of the carbonic acid dissolved in the water, and on adding lime the acid unites with it, forming carbonate of lime. In the case of hardness due to the carbonate of lime the reaction is

$$CaCO_3 + CO_2 + Ca(OH)_2 = 2CaCO_3 + H_2O.$$

The resulting carbonate is now but slightly soluble and so precipitates out.

The $CaCO_3$ (lime carbonate) and the CO_2 (carbonic acid) are present in the water; the $Ca(OH)_2$, ordinary lime, is the chemical added.

To remove the sulphate, sodium carbonate (Na_2CO_3) is used. The reaction is

$$CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4.$$

The carbonate of lime precipitates out as before while the sodium sulphate (Na_2SO_4) is not especially objectionable. Various methods of carrying out the details of the process, relating principally to the application of the chemical and the removal of the precipitate, have been devised. These are known under various names, but the general principle is the same in all. The lime is usually added in the form of lime water, a solution of slaked lime in water.

In general the water to be treated is run into large tanks, the chemical added and then the precipitate allowed to settle as far as practicable. The water is then drawn off and the remaining precipitate removed by rapid filtration. In purifying water for boiler use the precipitate can be removed to a sufficient extent by the use of settling tanks alone. The chemicals used are lime and usually soda ash, or crude sodium carbonate. The cost for such small plants is reported to be from 4 to 15 cents per 1,000 gallons.

Many scale preventives have been proposed for use in boilers, but probably the best in general use is sodium carbonate. This breaks up the sulphates as previously shown, and thus prevents the formation of a hard deposit; but the precipitation of the carbonates is increased by the process. The sodium sulphate remains in solution, but should not be allowed to concentrate too greatly or it will cause foaming.

116. Domestic Filters. Frequently it is advisable to purify water supplies for household use. For this purpose a large number of different filters have been devised, but many of these are so inefficient as to be worse than useless; for it not infrequently happens that the possession of a filter lulls the consumer into a state of false security. The best of these filters suitable for household use are those that are made of unglazed porcelain (Pasteur filter) or fine infusorial earth (Berkefeld filter). Both of these filters deliver a wholly germ-free filtrate when they are first put in service, but unless close attention is given them they sooner or later lose this property. Generally speaking, these filters should be cleaned and sterilized in boiling water or in steam under pressure once a week in order to kill out the germ life that has found lodgment in the pores. In this way not only is the sterility of the filtrate maintained, but the yield of filtered water is increased.

Filters of this class are not often used for municipal purification, but are admirably adapted for schools, garrisons, prisons, or hotels as well as for private use.

Other types of household filters, such as those constructed of porous stone, charcoal, or asbestos, have been on the market for many years. Judged from the popular standpoint of purity, which is generally the production of a clear water, many of the filters would be regarded as quite satisfactory, but as a means of removing germ life they possess for the most part but little merit.

Another method on which even greater reliance can be placed is the use of heat. There are no pathogenic bacteria that are liable to be distributed by the way of the water supply that are able to withstand the influence of boiling water for a period exceeding 10 to 15 minutes. Cholera and typhoid succumb in 5 minutes or less. In case of sudden outbreaks of disease or temporary disturbance of installed water supplies, this method can always be relied on with perfect safety. Boiling does not, however, render potable a water containing large amounts of organic matter, although it may destroy the disease germs that may be therein. By distillation a water can be obtained free from dissolved matter as well as bacteria. This process is extensively used on shipboard to obtain potable water from sea water, and in a few places on the seacoast for similar purposes.

PREPARING MICROSCOPIC SLIDES FROM BACTERIAL CULTURES

CHEMISTRY.

Chemistry is the science which treats of matter in its simplest forms, and the combinations of these forms which make up all material substances.

All animal and vegetable matter, and the solid rock and earthy substances which make up the earth's crust, undergo their changes according to chemical laws. The same is true of water and all other liquids, and of air and gases.

Thus we see that Chemistry relates to an enormous number of substances. The number of the various kinds of substances which exist on the earth is so great that they have never even been counted. Probably there are many substances in the common every-day things of life that have not yet been recognized by the most skilful chemists. However, many compounds have been described, and the chemical laws now known are of great value in finding out the composition of various substances.

The rudiments of Chemistry may be traced back to the ancient Egytians. The Arabs and Greeks sought to change metals into gold and searched for a liquid which would cure all ills and confer the blessing of perpetual life. These experimenters were called **Alchemists.**

During the second period in the history of Chemistry, chemical changes were said to be caused by a substance called **Phlogiston.** This substance was thought to be contained in all combustible matter, and the theory that fire showed the escape of phlogiston was upheld by the most learned chemists of the time.

The phlogiston theory was given up when Lavoisier, a French chemist, demonstrated his theories of combustion and chemical union. On account of his important experiments and discoveries, he is called the "father of Chemistry." Lavoisier proved that when combustible substances are burned, they combine with a gas called oxygen, forming new substances.

PHYSICAL AND CHEMICAL CHANGES.

The various substances with which we are familiar frequently undergo changes. It is important to know whether the change is physical or chemical. If the change is physical, the substance has the same essential properties as before the change. Chemical changes affect the nature of the substance and the new forms may have entirely different properties.

Sugar may be crushed into fine particles yet the small particles retain the sweet taste, white color and crystalline structure. This change is **physical** because the particles have been merely broken up and each fine particle retains the properties of a considerable quantity.

Suppose sugar is mixed with iron filings. The mixture is sweet and by means of a magnet the iron filings can be separated from the sugar and both substances be of the same state and condition as before. This change is physical but is usually called a mechanical mixture. If two or more substances are mixed together, and the resulting substance has the properties of the constituents, it is called a *mechanical mixture.*

Suppose we apply heat to the sugar, or pour sulphuric acid onto ordinary granulated sugar. The substances formed have different properties. Instead of white sugar, a black substance is formed which resembles charcoal. As the properties of this black substance are different from those of sugar, we say that the change is **chemical.**

MOLECULES AND ATOMS.

A small lump of sugar can be crushed or broken so as to form many smaller lumps, and these small lumps further divided into others still smaller. The lumps may be divided into such small particles that they cannot be seen, yet they possess the properties of sugar. Let us suppose this division is continued indefinitely. There will be a *smallest* particle of sugar. Or, there is a point where further sub-division by mechanical means is impossible. This smallest particle, called a molecule, can be subdivided only by chemical means, and the chemical agents cause new forms of matter. As the small particles, or molecule, cannot be divided by mechanical means, we say that a molecule is the smallest particle which exists alone and retains most of the properties of a considerable quantity of the substance. A **molecule** may be defined as being *the smallest quantity of matter that can exist by itself.*

The molecule can be divided by chemical means, but the particles thus formed, called atoms, cannot be further divided even chemically after a certain stage is reached. Thus, theoretically, pure sugar can be divided mechanically into molecules, and the molecules divided chemically into three forms of matter which cannot be further divided by any known means. These three substances are carbon (a solid at ordinary temperature), oxygen, (a gas at ordinary temperature), and hydrogen (a gas at ordinary temperature). Since these are the simplest forms and cannot be broken up, they are final divisions. Atoms generally do not exist separately or uncombined, the molecule being the smallest particle which exists alone. *An atom is the smallest particle of a substance that can exist, not alone, but combined with other atoms forming molecules.*

Briefly, we may say that an atom is very small and indivisible, either by physical or chemical means. It has a definite weight. All the atoms of an element are of the same weight. The atoms of a substance have an attraction for atoms of other substances.

A molecule is a group of atoms held together by the attractive force which they have for each other. The molecule can be divided by chemical agents into atoms. The molecules of a given substance always contain the same numbers and the same kinds of atoms.

ELEMENTS.

We know that sugar is broken up by sulphuric acid and the substances obtained have none of the characteristics of sugar. Two new substances were formed, carbon (or charcoal) and water. The water can be broken up into two gases, but the carbon cannot be divided so that new substances are formed. In other words, if carbon is divided or broken up, nothing but carbon is obtained.

The chemist can take carbon out of sugar, but he cannot take anything but carbon out of carbon. He can take oxygen out of sugar, but he cannot take anything but oxygen out of oxygen.

The science of Chemistry shows that all substances are made up of various combinations of simple forms of matter, which cannot, by any known means, be divided into other kinds of matter. Thus, sugar is a compound or combination of simple forms, and the simple forms carbon, oxygen, and hydrogen are called **elements.**

An element may be defined as being *a form of matter which chemists have not yet been able to break up into other forms of matter.*

The thousands of words in the English language are made up of combinations of letters of which there are less than thirty. The letters are the simple forms, or elements, and the words are the combinations, or substances. The millions of substances found on the earth are made up of various combinations of about seventy elements. The exact number of elements is not known, and new ones are being discovered from time to time.

The table on the opposite page gives a partial list of elements, their symbols or abbreviations, their atomic weights, their physical conditions at ordinary temperature and their specific gravities.

A large proportion of the elements are uncommon. Carbon, copper, gold, iron, lead, mercury, nickel, phosphorus, silver, suphur, tin, zinc, oxygen and nitrogen are almost the only ones that are familiar to most people.

Almost all of the elements exist in very small quantities. It has been estimated that an amount equal to ninety-nine one-hundredths of the solid, liquid and gaseous matter of the globe is made up of only thirteen elements, the remaining 60 (about) elements comprising only one one-hundredth.

SYMBOLS OF ELEMENTS.

Each element, or strictly speaking, each minute quantity of an element (called an atom) is designated by a letter, or a few letters, called its symbol. For most elements, the symbols are the initial letters of the names, thus for carbon, we write C, for

ELEMENTS.

Names.	Symbol.	Atomic Weight.	Physical condition at ordinary temperature.	Specific Gravity
Aluminum	$Al^{IV.}$	27.	Solid	2.60
Antimony	$Sb^{III, V.}$	120.	"	6.71
Argon	A	20 (?)	Gas	—
Arsenic	$As^{III, V.}$	75.	Solid	5.73
Barium	$Ba^{II.}$	137.	"	3.75
Bismuth	$Bi^{III, V.}$	208.	"	9.80
Boron	$B^{III.}$	11.	"	2.5 (?)
Bromine	$Br^{I, V.}$	80.	Liquid	3.187
Cadmium	$Cd^{II.}$	112.	Solid	8.60
Caesium	$Cs^{I.}$	133.	"	1.88
Calcium	$Ca^{II.}$	40.	"	1.57
Carbon	$C^{IV.}$	12.	"	3.5–.6
Cerium	$Ce^{III, IV.}$	141.	"	6.68
Chlorine	$Cl^{I, V.}$	35.5	Gas	2.450
Chromium	$Cr^{IV, VI.}$	52.	Solid	6.50
Cobalt	$Co^{II, IV.}$	59.	"	8.5–.7
Copper	$Cu^{II.}$	63.3	"	8.95
Fluorine	$F^{I.}$	19.	Gas	1.313
Gold	$Au^{I, III.}$	196.5	Solid	19.32
Hydrogen	$H^{I.}$	1.	Gas	0.069
Iodine	$I^{I, V.}$	127.	Solid	4.948
Iridium	$Ir^{II, IV, VI.}$	193.	Solid	22.42
Iron	$Fe^{II, IV, VI.}$	56.	"	7.86
Lead	$Pb^{II, IV.}$	207.	"	11.37
Magnesium	$Mg^{II, IV, VI.}$	24.	"	1.74
Manganese	$Mn^{II.}$	55.	"	8.03
Mercury	$Hg^{II.}$	200.	Liquid	13.55
Nickel	$Ni^{II, IV.}$	58.	Solid	8.90
Nitrogen	$N^{III, IV.}$	14.	Gas	0.971
Oxygen	$O^{II.}$	16.	"	1.105
Phosphorus	$P^{I, III, V.}$	31.	Solid	{Colorless 1.83, Red 2.20}
Platinum	$Pt^{II, IV.}$	195.	"	21.50
Potassium	$K^{I.}$	39.	"	0.87
Silicon	$Si^{I.V}$	28.	"	2.39
Silver	$Ag^{I.}$	108.	"	10.53
Sodium	$Na^{I.}$	23.	"	0.978
Strontium	$Sr^{II.}$	87.5	"	2.54
Sulphur	$S^{II, IV, VI.}$	32.	"	2.05
Tin	$Sn^{II, IV.}$	118.	"	7.29
Tungsten	$W^{IV, VI.}$	184.	"	19.12
Uranium	$U^{IV, VI.}$	239.8	"	18.70
Zinc	$Zn^{II,}$	65.	"	7.15

NOTE: The Roman numerals in the second column denote the valence of the element.

hydrogen H, for phosphorus P, etc. Some of the elements have symbols derived from their Latin or Greek names. Thus Au is the symbol for gold, because its Latin name is aurum; similarly Pb signifies lead, since its Latin name is plumbum. In the table, it will be noticed that there are nine elements whose names begin with the letter C. To avoid confusion, carbon has for its symbol, C, and the symbols of the other eight contain an additional distinguishing letter.

As we have said, the symbol stands for one atom. If more than one atom of an element is to be indicated, a subscript or sub-exponent is used. A coefficient is also frequently used to express a number of atoms of the same element. Thus 2Na or Na_2 means two atoms of sodium; and three atoms of iron may be indicated thus, Fe_3 or 3Fe.

Certain groups of atoms remain the same in a series of chemical compounds. To denote a number of these characteristic groups a parentheses and sub-exponent is used. The sub-exponent multiplies all the atoms inside of the parentheses; thus, $(OH)_4$ means four "hydrate" groups, or four atoms of oxygen and four of hydrogen, or O_4H_4.

We may have a molecule of a substance whose atoms are of different elements. Suppose we wish to indicate a molecule of a substance which is made up of one atom of sodium and one atom of chlorine. An atom of sodium is written Na and an atom of chlorine is written Cl. The molecule is indicated by writing the symbols close together as NaCl. A molecule composed of one atom of silver, one of nitrogen, and three of oxygen is written $AgNO_3$.

In case we desire to express 5 molecules of a compound, each molecule containing two atoms of hydrogen, one atom of sulphur and four atoms of oxygen, we write $5H_2SO_4$. This could be written $5\ (H_2SO_4)$. As in arithmetic or algebra, the coefficient 5 means that in the 5 molecules of H_2SO_4 there are $5 \times 2 = 10$ atoms of hydrogen, $5 \times 1 = 5$ atoms of sulphur, and $5 \times 4 = 20$ atoms of oxygen.

Thus it is seen that the sub-exponent applies only to the element which it follows, but a coefficient multiplies all the elements in the compound. In this way Chemistry resembles algebra. Again, let us examine the formula, $Cu(NO_3)_2$. The sub-exponent 2 applies to the parentheses and $Cu(NO_3)_2 = CuN_2O_6$; and $(NH_4)_2SO_4$ is the same as $N_2H_8SO_4$.

EXAMPLES FOR PRACTICE.

1. Give names for the following: Cu, Fe, S, Ni, O, Ag, Sn, Al and Zn.

2. Name these elements and state the indicated number of atoms of each; C_7, 3Ni, 4Pt, S_2, Sn_5, O_3 and 2H.

3. Write symbols for 4 atoms of phosphorus, 6 atoms of mercury, 3 atoms of iron and 5 atoms of carbon.

4. How many molecules in each of the following, and how many atoms of each element? 6HgO, $2CaCl_2$, $3Ca(PO_4)_2$, $2Fe_2(SO_4)_3$, $3Bi_2O_3$.

ATOMIC WEIGHT.

When we say that the specific gravity of lead is 11.37, we mean that lead is 11.37 times as heavy as water. In computing specific gravity we find the weight of a given volume of the substance, and the weight of an equal volume of water. By dividing the weight of the substance by the weight of an equal volume of water, we get the specific gravity. In other words, water is used as the standard or unit when finding specific gravity.

For gases, air is used instead of water. That is, if a gas has a specified gravity of 1.103, it is 1.103 times as heavy as an equal volume of air. In the table on page 7 the specific gravities of solid and liquid elements are referred to water as the standard, and the specific gravities of gaseous elements are referred to air as the unit.

Suppose we could compare an atom of oxygen with an atom of hydrogen; we would find that the atom of oxygen weighed 16 times as much as an atom of hydrogen. Also, if 1000 atoms of iron are compared with 1000 atoms of hydrogen, the iron will be found to be 56 times as heavy as the hydrogen. Since atoms are compared, this relation is called **atomic weight.**

Hydrogen is taken as the unit because its atom weighs less than an atom of any other substance.

The atomic weight of an element is the weight of its atom in terms of the weight of an atom of hydrogen, which is the standard or unit.

From the table we find that the atomic weight of carbon is 12, of nitrogen 14, and of lead 207.

It is impossible to see an atom, even with the most powerful optical instruments; therefore, it cannot be weighed. However, chemists have determined the atomic weights of the elements by comparing their compounds.

It is assumed that equal volumes of all gases have the same number of molecules if the temperature and pressure are alike. This assumption or law is the foundation of the chemical theory of to-day, and it is accepted by chemists generally.

If a gallon of nitrogen and a gallon of hydrogen are weighed (temperature and pressure constant), the ratio of the weight of the nitrogen to that of the hydrogen is the density of nitrogen. Since both are gases, it is called **vapor density.**

We may define vapor density as follows: *The vapor density of any gas is the weight of a given volume of it in terms of the weight of an equal volume of hydrogen at the same temperature and pressure.*

In making this computation, the gases must be of the same temperature because heat causes gases to expand, and the gas weighed at the higher temperature will contain fewer molecules.

The pressure also must be the same, for the greater the pressure, the greater the number of molecules in a given volume.

At a certain temperature and pressure, a gallon of hydrogen weighs .3264 grams and at the same temperature and pressure a gallon of oxygen weighs 5.2224 grams. The oxygen is consequently $\frac{5.2224}{.3264} = 16$ times heavier than the hydrogen. Then the vapor density of oxygen is 16.

The molecular weight of a gas is twice its vapor density. In other words, the vapor density is one-half the molecular weight. Then, as the vapor density of oxygen is 16, the molecular weight is $2 \times 16 = 32$. If there are two atoms in a molecule of oxygen, and the molecular weight is 32, the atomic weight is $\frac{32}{2} = 16$.

Thus for oxygen, the atomic weight and vapor density are the same, 16 ; but if there are three or four atoms in the molecule of an element, the atomic weight, being equal to the molecular weight divided by the number of atoms, will not equal the vapor density.

Let us consider the gas called carbon dioxide. We write the symbol CO_2 because it is made up of two parts oxygen and one part carbon. The atomic weight of carbon is, from the table, 12; the atomic weight of oxygen is 16, and as there are two atoms of oxygen and one of carbon in the molecule, the molecular weight is

$$12 + (2 \times 16) = 44.$$

The vapor density is one-half the molecular weight, or 22.

By finding the vapor density of gases, chemists have calculated the atomic and molecular weights. This method cannot however be used for some elements, as many substances have never been vaporized or cannot be vaporized under conditions which make weighing possible. For these elements the vapor densities, molecular and atomic weights are uncertain.

Another method is as follows: The atom is the smallest particle which can exist in composition or combination. Hence, the atomic weight is the *least combining weight.* By analyzing a great number of compounds, the smallest weight of an element is determined, and the other compounds contain a multiple of that weight. The least combining weight is the atomic weight.

The vapor density as found by one method and the atomic weight by another are generally the same, that is, if there are two atoms in the molecule. The vapor of mercury has a vapor density of $99\frac{1}{2}$, hence a molecular weight of 199. But the atomic weight is 199, hence there is one atom in a molecule.

MOLECULAR WEIGHT.

The weight of a molecule is found by adding together the weights of all the atoms in the molecule. Molecular weight, like atomic weight, is expressed in terms of the weight of the hydrogen atom.

We know that a molecule of common salt is composed of one atom of sodium, and one atom of chlorine. The sodium atom is 23 times as heavy as the hydrogen atom, or, its atomic weight is

23. The atomic weight of chlorine is 35.5. Therefore the molecular weight of a molecule of salt is $23 + 35.5 = 58.5$. In other words a molecule of salt NaCl is 58.5 times as heavy as an atom of hydrogen. Three molecules 3NaCl, weigh 175.5.

What is the molecular weight of copper nitrate, $Cu(NO_3)_2$? As we have seen, $Cu(NO_3)_2$ is the same as CuN_2O_6. This molecule is then made up of one atom of copper weighing 63.3, two atoms of nitrogen weighing $2 \times 14 = 28$, and six atoms of oxygen weighing $6 \times 16 = 96$. The molecular weight is $63.3 + 28 + 96 = 187.3$. Sometimes copper nitrate, in common with many other substances, has a crystalline form represented by $Cu(NO_3)_2 \cdot 3H_2O$. The $3H_2O$ is an essential part of the crystal, called "water crystallization" and must be added when finding the molecular weight. As $3H_2O = 3(2 + 16) = 54$, the molecular weight of crystallized copper nitrate $Cu(NO_3)_2 \cdot 3H_2O$ is $187.3 + 54 = 241.3$.

CHEMICAL AFFINITY.

In order that molecules may be formed from atoms, there must be some force to bind the atoms together. This force is called *chemical affinity* or *chemism*. This force corresponds to the physical force called cohesion.

A compound usually possesses properties which are entirely different from those of the elements of which it is composed. Water, for instance, is made up of two gases, hydrogen and oxygen. These two substances are gases, colorless and ordorless. When combined in the proper proportion, the compound is a liquid at ordinary temperatures.

Sugar ($C_{12}H_{22}O_{11}$), a white, sweet, crystalline substance, is formed by combining carbon, a black non crystalline substance, with oxygen and hydrogen, two colorless and odorless gases.

Of the constituent elements of cupric sulphate, $CuSO_4 \cdot 5H_2O$, copper is red, sulphur yellow, oxygen and hydrogen are colorless. Two are gases and two are solids. The cupric sulphate thus formed is a blue solid.

Chemical affinity takes away the properties of the elements and causes the compound to have new properties. Chemical affinity may act between atoms of the same kind, or atoms of different kinds. Also, it may be strong or weak, but it acts only at short distances.

TEST OF NEW YORK CITY'S HIGH-PRESSURE WATER SYSTEM

These Jets Surmount the Top of a Fifteen-Story Building

It is easy to separate the carbon from the other two elements in sugar, but it is more difficult to resolve water into its elements, hydrogen and oxygen. In other words, it is hard to break up the attraction that some elements have for others, but it can be done by heat, electricity and reagents. A **reagent** is a substance which produces chemical change such as an acid.

COMPOUNDS.

Chemical affinity binds atoms together to form molecules and compounds. Compounds are usually called by names taken from the elements of which they are composed, as hydrogen oxide, H_2O, (*water*), and carbon dioxide, CO_2.

Some compounds are composed of two elements as $NaCl$, chloride of sodium (*common salt*), and HCl, hydrogen chloride or *hydrochloric acid*. Other compounds contain three elements, as H_2SO_4 sulphate of hydrogen or *sulphuric acid*, and KOH, potassium hydrate.

UNION BY WEIGHT.

Before taking up the study of compounds and equations it will be necessary to understand the proportions in which elements combine. This study is based upon the two fundamental laws of chemistry which are as follows:

1. The law of Conservation of Matter.
2. The law of Definite Weight.

Law of Conservation of Matter. — *The sum of the weights of all the products in an experiment is exactly equal to the sum of the weights of all the factors.*

This law means that matter can neither be destroyed nor created. In other words, matter may be changed or transformed; it may be changed from solid to liquid or to invisible gas, or the volumes may be greatly increased, but the processes do not cause any loss or gain in weight.

Law of Definite Weight. — *Any chemical compound always contains the same elements in the same ratio by weight.*

Ferrous sulphide, FeS, always contains iron and sulphur, and always in the same proportion by weight. Thus, FeS is always made up of 56 parts of iron and 32 parts of sulphur. Potassium chlorate, $KClO_3$, always contains potassium, chlorine and oxygen. Also, in the compound, there are 39 parts (by weight) of potassium, K; 35 parts of chlorine, Cl; and $3 \times 16 = 48$ parts of oxygen, O.

Water is made from oxygen and hydrogen. Pure water always contains 8 parts oxygen (by weight) and 1 part hydrogen.

Suppose we wish to make oxygen from the compound, potassium chlorate, $KClO_3$. How much oxygen can we expect from 2 ounces?

First, we must know what proportion of the $KClO_3$ is oxygen. We know that there are 39 parts K, 35 parts Cl, and 48 parts O. Then of 122 parts, 48 are oxygen, and $\frac{48}{122} \times 2 = .787$ ounces (nearly).

VALENCE.

Atoms of the various elements differ in the number of atoms of other elements which they can hold in combination to form chemical compounds. Let us suppose that atoms have "hands" or "hooks" with which they can grasp other atoms. Some atoms have one hand, some two, some three, and so on. It is evident that an atom with two hands can hold two atoms having one hand, or it can hold one atom which has two hands, etc. Or we may consider that an atom has a certain number of "affinity points." The number of these affinity points determines the number of atoms which it can hold in chemical combination. This is what is known as the *valence* or quantivalence of an atom. Valence has no apparent relation to the strength of the affinity of atoms.

We must have a standard by which to measure valence. The combining power of hydrogen is a convenient measure of valence as its valence is always 1; in other words it seems to have but one "affinity point," or "hand." With elements which combine directly with hydrogen the valence is the number of hydrogen atoms which one atom will hold. Atoms which do not combine with H will usually replace H in its compounds and the number of atoms of H which such an atom will replace is its valence. Thus in NaCl the Na replaces one atom of H in HCl. Hence the valence of Na is 1. In H_2O one atom of O combines with two atoms of H, therefore the valence of O is 2. We may say that the hydrogen atom has one hook; two atoms must therefore have two hooks, and as oxygen is combined with two atoms of hydrogen, the oxygen element must have two hooks. Hence the valence is two. Fig. 1 shows some of the ways of representing the valences of elements.

Ammonia is a gas made up of three atoms of hydrogen and one atom of nitrogen; its symbol is then NH_3. What is the valence of N? The valence of hydrogen is one, and as one atom of nitrogen combines with three atoms of hydrogen, the valence of nitrogen must be three.

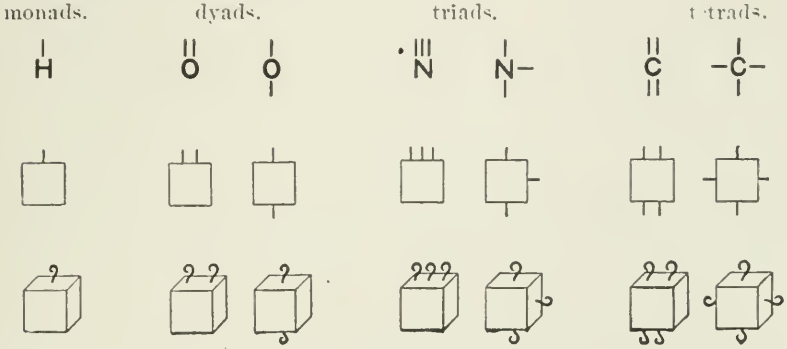


Fig. 1.

What is the valence of sodium, magnesium, bismuth and carbon from these symbols?

$$NaCl, MgCl_2, BiCl_3, CCl_4.$$

In NaCl, it is seen that one atom of sodium, Na, combines with one atom of Cl, hence its combining power is one. Again, we have the two compounds HCl and NaCl. From these symbols it is seen that one atom of Na replaces one atom of H, therefore the replacing value of Na is one.

In magnesium chloride, $MgCl_2$, one atom of magnesium combines with two atoms of chlorine. The valence of Mg is therefore two.

Chloride of bismuth, $BiCl_3$, is made up of one atom of bismuth and three atoms of chlorine. Then as one atom of Bi combines with three atoms of Cl the combining value of Bi is three.

Similarly four atoms of chlorine are necessary when combining with one atom of carbon, and the valence of C is four.

If these compounds were made by the action of HCl, the equations would be

$$Na + HCl = NaCl + H.$$
$$Mg + 2HCl = MgCl_2 + 2H.$$
$$Bi + 3HCl = BiCl_3 + 3H.$$
$$C + 4HCl = CCl_4 + 4H.$$

When an element combines with hydrogen, atom for atom, or replaces hydrogen, atom for atom, its valence is one and it is called *univalent.* The *bivalent* elements are those which require two atoms of hydrogen to replace one atom of the element, and the *trivalent* elements are those whose atoms select three atoms having a valence of one with which to unite. These elements are called monads, dyads and triads, etc.

Some elements have more than one valence. Phosphorus sometimes combines with three atoms of chlorine (PCl_3) and sometimes with five atoms (PCl_5). In the first case P is a triad, and in the second case a pentad.

The valence of an element is often indicated by marks at the right, as Na', Cu'', Bi''', C^{IV}.

EQUATIONS.

A chemical equation (sometimes called a reaction) is a short algebraic expression of a chemical change. If we heat together iron filings and sulphur, the result is iron sulphide, or we can say that

iron + sulphur = iron sulphide.

We know that a definite quantity of iron united with a definite quantity of sulphur, and the result was a definite quantity of iron sulphide. We may say that one atom of sulphur united with one atom of iron and formed a molecule of iron sulphide. Let us use the symbols of these elements and we can write,

$$Fe + S = FeS.$$

In fact, millions of atoms of iron united with an equal number of atoms of sulphur; but for simplicity and brevity, we write the equation for one atom of each.

The atomic weight of iron is 56, and that of sulphur is 32. Then 56 parts, by weight, of iron united with 32 parts by weight, of sulphur, to form 88 parts of iron sulphide.

Factors.		Product.
$Fe + S$	=	FeS
$56 + 32$	=	88

An equation represents the substances that are put together, and the substances obtained. Also, it shows the proportions of those used and of those obtained. Substances put together are called Factors, and those obtained Products. The factors are usually placed on the left-hand side of the equality sign, and the products on the right-hand side.

From the law of conservation of matter, we learned that matter cannot be created or destroyed. Therefore there must be as many atoms in the products as there were in the factors. Also there must be the same number of each kind of atoms on both sides of the equation.

Take the action of hydrochloric acid, HCl, on metallic zinc, Zn; the zinc disappears and bubbles of gas are given off.

$$Zn + HCl = ?$$

We know that hydrogen is given off. The valence of Zn is two, or, one atom of Zn will replace two atoms of H; but there is only one atom of H in one molecule of HCl; therefore we must have two molecules of HCl to give two atoms of H to be replaced. The equation (or reaction) then will be:

	Factors.		Product.
	$Zn + 2HCl$	=	$ZnCl_2 + 2H$
by atoms	$1 + [2 \times (1 + 1)]$	=	$(1 + 2) + 2$
or	$1 + 4$	=	$3 + 2$

The zinc replaces the hydrogen and combines with the chlorine, forming zinc chloride, $ZnCl_2$, and the hydrogen gas is set free. It is evident that there are five atoms on each side of the equation, also that on each side one of these is an atom of Zn, two are atoms of H and two are atoms of Cl.

Suppose sulphuric acid, H_2SO_4, is added to caustic soda, NaOH. Sulphate of soda, Na_2SO_4, and water, H_2O, will be formed.

$$NaOH + H_2SO_4 = Na_2SO_4 + H_2O — ?$$

We see that there are two atoms of Na in the products and only one in the factors, also three atoms of H on the left and only two on the right; therefore we must have two molecules of NaOH to furnish two atoms of Na, and the expression will then become

$$2NaOH + H_2SO_4 = Na_2SO_4 + 2H_2O$$

By atoms

$$2\times(1+1+1)+(2+1+4)=(2+1+4)+[2\times(2+1)]$$

or

$$6+7=7+6$$

The equation will now balance, for there are thirteen atoms on each side and also the same number of atoms of Na, O, H and S in the factors as in the products.

We may write many chemical equations which do not express chemical reactions. In order to write a true chemical reaction (equation) it must be known that a chemical action takes place and also what substances are formed.

Use of Chemical Equations. From the study of atomic and molecular weights we can find the weights of all factors used and all the products made in terms of the weight of an atom of hydrogen. Let us again consider the equation of the action of HCl on Zn.

$$Zn + 2HCl = ZnCl_2 + 2H$$

By weights this becomes $65 + 73 = 136 + 2$

For the atomic weight of Zn is 65, the molecular weight of $HCl = 1 + 35.5$, and of $2HCl = 2 \times 36.5 = 73$. The molecular weight of $ZnCl_2 = 65 + (2 \times 35.5) = 136$, and the weight of $2H = 2$.

Example.—How much hydrochloric acid will be required to dissolve 10 pounds of zinc? We see by the chemical equation that 65 parts by weight of zinc are dissolved in 73 parts by weight of HCl. The problem is then one of simple proportion.

Zn : 2HCl : : zinc : hydrochloric acid

65 : 73 : : 10 lbs. : x lbs.

$65x = 730$ $x = 11.23 +$ lbs. hydrochloric acid.

If more zinc is taken, the excess over 10 pounds will be left unacted upon, or if more than 11.23+ pounds of HCl is added to 10 pounds of zinc, the excess HCl will not be used up.

Another example: How much zinc chloride, $ZnCl_2$, will be produced from the 10 pounds of zinc?

$Zn : ZnCl_2 : :$ zinc : zinc chloride

$65 : 136 : : 10 : x$

$65x = 1360 \quad x = 21$ lbs. (nearly) of zinc chloride.

Thus we see that if we have the chemical equations and atomic weights we can calculate all the products and factors if we know the weight of one factor or product. This is very important in all chemical work.

EXAMPLES FOR PRACTICE.

(1) Complete the following:

(*a*) $S + ? = SO_2$ (*b*) $Fe + ?HCl = FeCl_2 + ?H$

(*c*) $CaCO_3$ (heated) $= CaO + ?$

(*d*) $Na_2CO_3 + ?HCl = ?NaCl + H_2O + CO_2$

(2) $C + 2O = CO_2$. How much CO_2 (carbon dioxide) will be made from 10 pounds of carbon? Ans. $36\frac{2}{3}$ pounds.

(3) $S + 2O = SO_2$. How much sulphur will be required to make 20 pounds of SO_2? Ans. 10 pounds.

(4) $Na_2CO_3 + H_2SO_4 = Na_2SO_4 + H_2O + CO_2$. How much sulphuric acid will be required to neutralize 12 pounds of sodium carbonate, Na_2CO_3? Ans. 11.1 pounds.

CHEMICAL ACTIONS.

Chemical action does not always take place when substances are mixed; but from countless experiments several general facts governing chemical action can be mentioned. Many of the elements are active chemically. Thus oxygen combines directly (forming oxides) with all elements except florine and argon; sulphur unites with many of the metals, forming sulphides; chlorine, bromine, and iodine form chlorides, bromides and iodides respectively. The oxygen in many compounds is easily separated, making them chemically active. They are called oxidizing agents, and as examples bichromate of potash, nitric acid, potassium chlorate and bleaching powder may be mentioned. Compounds called acids are very active chemically.

An Acid is a compound containing hydrogen which can be easily exchanged for a metal or other basic substance. Acids have a sour taste and cause effervescence when added to a carbonate, as, for instance, baking soda.

Basic Elements are the common metals and elements which act like them. Sodium, potassium and calcium are in reality metals and are much more "basic" than the familiar metals.

An Alkali is formed when a very basic element displaces one atom of hydrogen in H_2O forming a hydrate thus: $Na + H_2O = NaOH + H$. NaOH is called a sodium hydrate.

The hydrogen of an acid is easily exchanged for a metal when treated with an alkali. When the correct proportion of an acid is added to an alkali or other basic compound the characteristic properties of both the acid and base are lost. The acid and alkali are said to neutralize each other.

Salts. The substance formed by neutralizing an acid is called a salt. Water is also formed when a hydrate or an oxide is used to neutralize an acid.

(1) $HCl + KOH = KCl + H_2O$
(2) $2HNO_3 + Ca(OH)_2 = Ca(NO_3)_2 + 2H_2O$
(3) $H_2SO_4 + ZnO = ZnSO_4 + H_2O$.

When a metal is used, hydrogen is set free. Thus:

$$Fe + H_2SO_4 = FeSO_4 + H_2$$

The substances KCl, $Ca(NO_3)_2$, $ZnSO_4$ and $FeSO_4$ are salts, and are neutral substances with little chemical action.

When a volatile substance can be given off, chemical action will usually take place. Strong acids will displace weaker acids in salts; as, for example, $2HCl + FeS = FeCl_2 + H_2S$. Hydrogen sulphide, H_2S, is a gas and is expelled.

$$2HNO_3 + Na_2CO_3 = 2NaNO_3 + H_2O + CO_2.$$

Carbon dioxide, CO_2, is given off when a strong acid is added to a carbonate. Heating frequently assists the action. Nitric acid, HNO_3, is made by heating nitrate of soda with sulphuric acid; and hydrochloric acid, HCl, by heating common salt with sulphuric acid.

The reactions are:

(1) $H_2SO_4 + NaNO_3 = NaHSO_4 + HNO_3$
(2) $H_2SO_4 + 2NaCl = Na_2SO_4 + 2HCl$.

Solutions of all neutral salts can be mixed without apparent chemical action, unless an insoluble compound is formed. For example, a solution of common salt can be mixed with a solution of nitrate of soda without change. There are, however, many insoluble salts, of which lead sulphate is one. If a solution of lead nitrate be added to a solution of sodium sulphate, the mixture becomes white like milk, and after a short time a white powder, lead sulphate, $PbSO_4$, settles to the bottom. $Pb(NO_3)_2 + Na_2SO_4 = 2NaNO_3 + PbSO_4$. This is called a *precipitate*, because it is thrown down. The precipitate will continue to form until one or the other of the salts is exhausted.

Solubility. Many substances will dissolve in water, such as

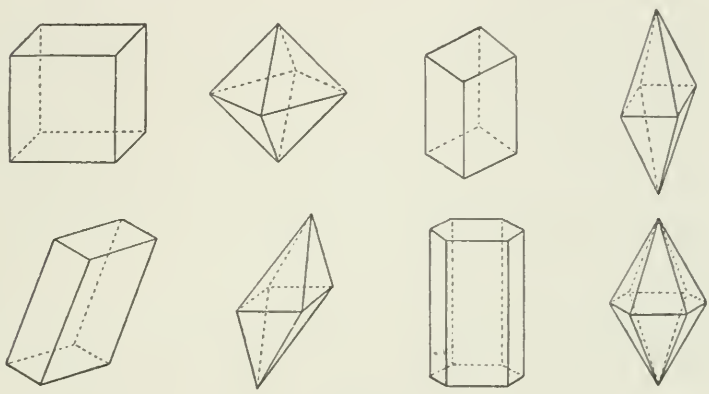


Fig. 2.

salts, acids, alkalis, sugar and gases. If a salt (or sugar) is placed in water, it disappears. If more and more salt is added, a point will at length be reached when no more salt will be dissolved. The solution is then said to be saturated. If, however, the saturated solution is heated, more salt (or sugar) can be dissolved. That is, in most cases heating water increases its capacity for retaining solids in solution. The reverse is true of gases, for more gas can be dissolved in cold water than in hot water.

If a hot saturated solution of a solid is cooled to ordinary temperature, some of the solid will be thrown out of the solution, or precipitated. The precipitate is often formed in very beautiful crystals, especially if the solution is cooled slowly. A few of the shapes are shown in Fig. 2.

OXYGEN.

Occurrence. — Oxygen is one of the most important elements. It is important because of its abundance, its activity, and the great number of compounds into which it enters. Oxygen makes up by weight fully one-half of the globe, including air, ocean and earth. The air is about one-fifth oxygen by weight; water is eight-ninths oxygen by weight, and the important minerals such as quartz, sand, &c., are about one-half oxygen.

The oxygen in water and in minerals is chemically combined, but when in air, it is simply mixed with the other gases.

Oxygen is essential to all animal matter. It sustains the vitality of man, of beasts and even of fish. Oxygen supports combustion, whether a single splinter is burning, or there is a great conflagration.

Discovery. — The first discovery of oxygen is generally attributed to Dr. Joseph Priestly, an English clergyman and scientist. Priestly performed his great experiment August 1, 1774, and this day has been called the birthday of modern chemistry.

So great was the interest in chemistry at this time, that two others discovered this important element at about the same time that Priestly did. These two were Scheele, an apothecary in Sweden, and Lavoisier, the French chemist. Scheele called it "fire air," but Lavoisier named it oxygen which means "acid former."

Lavoisier in giving the true explanation of combustion overthrew the Phlogiston theory and started modern chemistry.

Physical Properties. — Oxygen is a gas at ordinary temperatures and pressures. It is colorless, tasteless, odorless and a little heavier than air. It is soluble in water; it is to this property that fish owe their existence. About one volume of oxygen can be dissolved in 25 volumes of water.

Oxygen was, until recently, considered a permanent gas, that is, it could not be liquified. Experiments, conducted with apparatus capable of subjecting it to intense cold and great pressure, show that the gas can be liquified.

Chemical Properties. — The most striking of the chemical properties is the tendency to combine with other elementary substances. This is the reason for oxidation, rust and the decay of so many substances. Combustion is another example, but in this instance the oxygen does not unite except when the substances are heated. Thus, a building is surrounded and saturated, as it were, with oxygen, but it is harmless until heat produces combustion; then the oxygen combines with the other elements.

Oxygen is called a supporter of combustion. In fact, diamonds, iron and other substances, not ordinarily considered combustible, will burn brilliantly in pure oxygen gas.

At usual temperatures, oxygen combines slowly. If a piece of iron is made bright and then dipped in water, it becomes rusted in a few days; or if a piece of lead is filed until it is bright, it becomes covered with a dull colored coating of oxide of lead.

If air were undiluted oxygen, all animal life would be rapid. If a fire was started, it could be extinguished with difficulty.

Compounds. — As has been stated, oxygen combines with almost all of the elements. These compounds are called oxides.

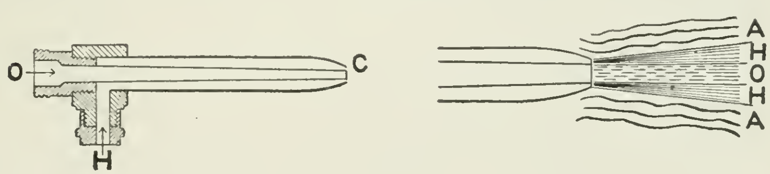


Fig. 3.

The most important of these is water. The compounds of oxygen which are the most important to the engineer, are water and the products of combustion. Oxygen is an important constituent of air, but air is a mixture and not a chemical compound. These substances, water, air and the products of combustion will be discussed later.

Uses. — The principal use of oxygen in nature is to sustain life. It also supports combustion. It is used in the oxy-hydrogen blow-pipe, and in the production of the calcium light.

The oxy-hydrogen blow-pipe consists of two concentric tubes, the inner one conveying oxygen and the outer hydrogen, as shown in Fig. 3. The gases come together at the end and are burned. The flame is almost colorless and has but little luminous power.

Its heat is, however, intense; the temperature being about 2000° F. This intense heat is made use of in melting and refining ores and alloys.

The calcium or lime light is made by directing the flame from the oxy-hydrogen blow-pipe upon a block or cylinder of lime. The intense heat produced by the burning of the gases, causes the lime to become white hot, and to give out a brilliant, dazzling light. Illuminating gas can be used in place of hydrogen. The calcium light is used for stereopticons, and for stage effects in theatres. It has been used in carrying on important engineering construction work during the night. At the present time, the electric light is taking the place of the lime light to a great extent.

Preparation. — Oxygen may be prepared in many ways. Priestly prepared it by heating red oxide of mercury. The process is represented by the equation,

$$2HgO = O_2 + 2Hg.$$
$$2\ (200 + 16) = 32 + (2 \times 200).$$
$$432 = 432.$$

The most usual method of preparing oxygen is by heating a substance called chlorate of potassium ($KClO_3$). The following formula explains the chemical change,

$$2\ KClO_3\ (\textit{heated}) = 2\ KCl + 3O_2$$

The heat sets free the oxygen and changes the chlorate of potassium to potassium chloride.

This substance, $KClO_3$, breaks up only at a comparatively high temperature and with explosive violence; but by mixing with it a little manganese dioxide (called black oxide of manganese) much less heat is required, and the oxygen evolves slowly and continuously. The manganese dioxide does not appear to take any chemical part in the process, but remains unchanged.

HYDROGEN.

Occurrence. — Hydrogen is rarely found on our globe uncombined or in a free condition. The reason for this is its great affinity for oxygen which is so abundant. In combination, hydrogen is very abundant and widely distributed. Hydrogen is in all water, wherever it may be. Besides water in the form of oceans, lakes, rivers, etc., it is one of the principal elements in animal and vegetable life. Hydrogen is a constituent of natural gas, meteorites, and most acids and bases.

Discovery. — Hydrogen was isolated in 1766 by an English chemist, Cavendish, who called the gas "inflammable air;" but Lavoisier named it *hydrogen* which means "*water former.*"

Cavendish was a very eccentric individual, having scientific pursuits the object of his life. His silent accurate work did much toward the progress of the science of Chemistry.

Physical Properties. Hydrogen is the lightest of gases, being only $\frac{1}{16}$ as heavy as oxygen. When pure it is colorless, odorless and tasteless. It is but slightly soluble in water. On account of its lightness it was formerly used for inflating balloons, but as hydrogen is expensive, illuminating gas is now used, although it is much heavier than hydrogen.

Hydrogen has been liquefied at—238° C and under a pressure of 300 pounds per sq. in. Also it has been solidified by Dewar.

Chemical Properties. — The most interesting and most striking property of hydrogen is its power to unite with oxygen. When oxygen and hydrogen unite, heat, light and flame appear, and a new chemical compound is produced. These are the phenomena of combustion.

Hydrogen will not unite with most metals. For a few elements, it has great attraction. Hydrogen combines with boiling sulphur, and has a strong affinity for chlorine, forming hydrochloric acid, HCl.

Under ordinary conditions, hydrogen will not combine with carbon, but there are hundreds of compounds of hydrogen and carbon, called hydrocarbons, CH_4, C_2H_6, etc.

Hydrogen burns in oxygen or in the air with a blue, almost colorless flame, of great heat. One pound of hydrogen will give out more heat in burning, than will a pound of any other substance.

As to its being a substitute for air, hydrogen in this respect differs radically from oxygen. Hydrogen will not support animal life, neither will it support combustion. An animal placed in a room filled with hydrogen expires almost immediately. If a candle, or a lighted match is placed in a jar of hydrogen, it goes out. The hydrogen seems to deprive the animal or the candle of their necessary oxygen.

Compounds. — Compounds containing hydrogen are exceedingly numerous; water, acids and hydrocarbons being among the most common.

Uses. — As an elementary gas, hydrogen has few uses. Its great lightness made it a desirable substance for balloons, and its great heating power made it invaluable for the oxy-hydrogen blow-pipe. However, on account of the high cost of hydrogen, illuminating gas is now used extensively in the above cases. It is, however, used by the chemist as the unit for density and atomic weight, and as the standard for valence. The great value of hydrogen is in its compounds rather than in an uncombined state.

Preparation. — The chemist can obtain hydrogen in many ways. As water is composed of oxygen and hydrogen, it is only necessary to decompose water into its constituent elements. This is done by means of an electric current.

The most common way to produce hydrogen is by the action of sulphuric acid on zinc. However, hydrochloric acid and other metals beside zinc can be used. The acid should be diluted somewhat, so that it will readily act on the zinc. The chemical change is represented by the following reaction:

$$Zn + H_2SO_4 = ZnSO_4 + H_2$$
$$65 + 98 = 161 + 2$$

In this experiment, zinc has changed places with the hydrogen and the hydrogen is left without anything with which to combine.

Hydrogen thus produced is seldom pure, as the various substances used are likely to contain substances which give some impurity to the gas thus formed.

WATER.

Now that we know something of the elements, oxygen and hydrogen, we can study the most important compound of these two elements.

The chemical history, properties and uses of water are both interesting and important, and if treated with any degree of thoroughness would furnish material for a volume.

Water is very abundant; it is necessary to both animal and plant life, and is extremely useful to man.

As to its abundance, one has but to look out upon the ocean from a high cliff to become convinced of the enormous quantity.

The oceans cover over three-fourths of the surface of the earth, and their depths may be measured in miles. Besides the ocean, there are numerous lakes, rivers, canals, &c.

Water is essential both to animals and plants. If water were banished from the earth, all animals would die almost instantly, and the vegetables would soon cease to grow. The blood which courses through our bodies is about seven-eighths water. The human body itself is more than half water. Vegetables, which form such a large part of the food of animals, are made up largely of water. Cucumbers contain about 97 per cent. water, and it is said that some forms of jelly-fish have been found to contain 99.9 per cent. of water.

Besides being necessary to the existence of man. water aids him in many ways. The oceans, rivers and lakes are the great highways upon which man carries on commerce. Many factories are run by water-power. But to the engineer, water, as water and steam, is of great importance. In most cases, it is the steam engine that furnishes power directly, or develops it to be transmitted by electricity or by compressed air.

Properties. — Water exists in three states, solid, liquid and gaseous. At ordinary temperature (60° F.) it is a liquid. As it is cooled it contracts slightly, until it reaches 39.2° F. expanding slightly thence to the freezing point 32° F. This property is of great value; when water freezes it expands, and as it then occupies a greater volume it becomes relatively lighter. On this account, ice rises to the surface of a lake and stays there forming a covering which prevents the water from becoming uninhabitable for fish. The same property prevents a lake from becoming a solid mass of ice which could not be melted by the summer sun. The expansion at the moment of solidification also causes the water in the crevices of rocks and in the soil to break up the rocks and prevent the surface of the soil from becoming hard.

Let us consider what effect water has on the climate. The heat of the sun in the tropics changes water into vapor; this vapor is carried by the winds to the colder portions of the earth where it is condensed and falls as rain or snow. In order to turn water into vapor, heat must be applied and stored up in the vapor.

When the vapor is condensed into water, heat is given out by the vapor. This process makes the tropics cooler, because heat is taken from the atmosphere and absorbed by the vapor, and makes the cold portions of the globe warmer because heat is evolved.

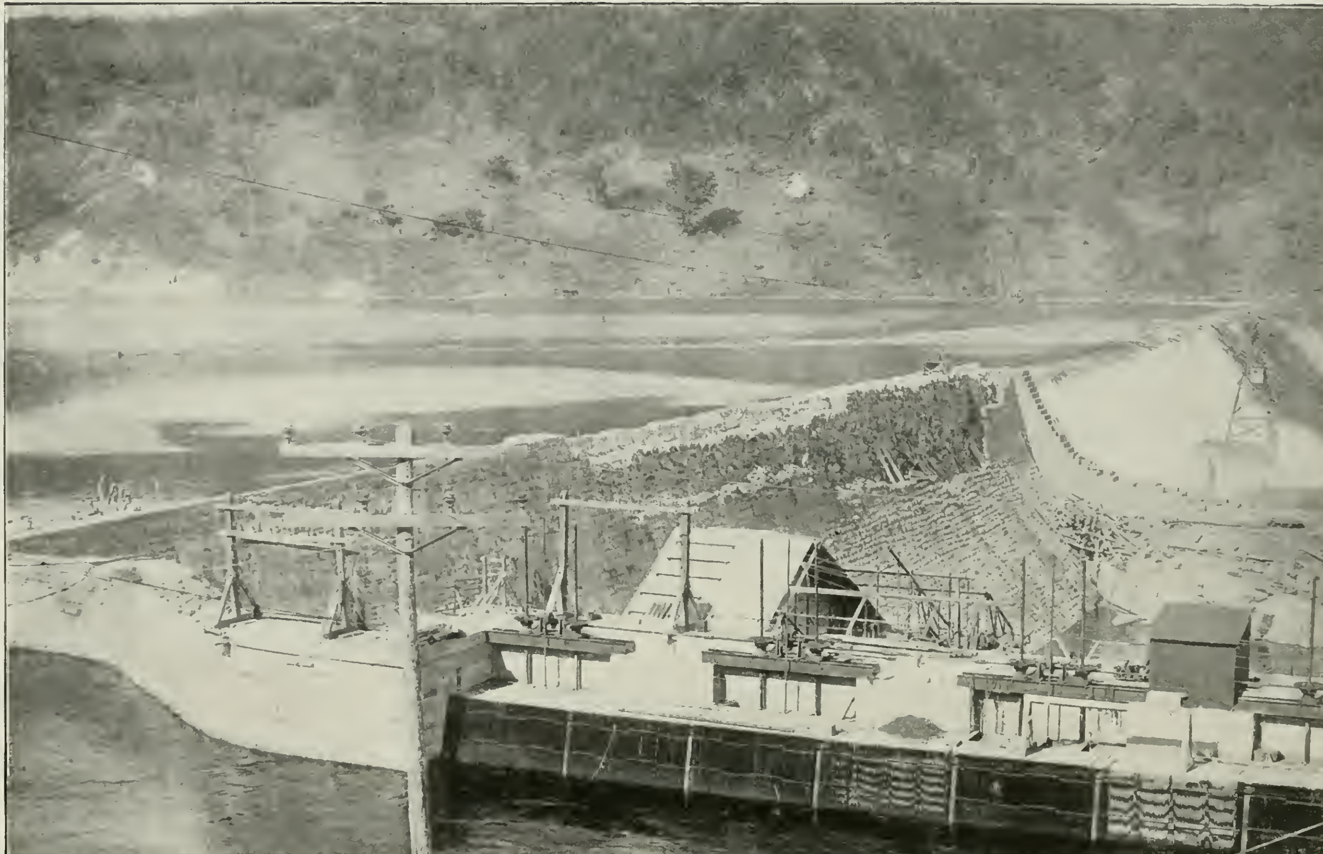
Thus the circulation of vapor is like a steam heating plant. The boilers are at the tropics, and the condensers, or radiators, are all over the globe. The sun's rays make the steam. This apparatus has the same principle as a boiler, but it works without tubes, shell or radiators.

There is another way that water tends to regulate the climate. In the hot days of summer, the water of a lake or the ocean becomes warmer. However, it takes more heat to raise the temperature of water one degree than it does to raise the land one degree. Thus, the water will absorb a large amount of heat without having its temperature raised to the extent that might be expected. In hot weather, heat is absorbed by the water, but its temperature is not very high, and as its temperature is low, it has a tendency to cool the surrounding land. Now in cold weather, the store of heat in the water is given out as the water cools. We may say that the ocean or a large lake, is a great reservoir, storing up the heat of summer, and giving it out in winter. This is the reason why the temperature near the ocean is not subject to as great variations as is that of the country far inland.

We know that water is formed of oxygen and hydrogen. This is true, but water as it is found on the earth is never absolutely pure. The fact that so many substances readily dissolve in water accounts for the numerous impurities. As rain falls from the clouds, it absorbs gases and solids. When it flows as a river, it dissolves small quantities of the substances with which it comes in contact.

There are two kinds of impurities, organic and inorganic. Organic matter usually tinges water yellow. Salts in spring waters are taken from the rocks and soil through which the water flowed.

Hard Water.— If water contains lime salts or magnesium salts in solution, it is called hard water. The reason why it is called hard is because of its action on soap. Soft water forms a lather and cleanses the skin, but hard water does not form a



CANAL AND DAM AT SPIER FALLS, NEW YORK

At this plant, which is controlled by the Hudson River Power Company, about 30,000 horse-power is developed, which, combined with the output from other water-power plants in the vicinity, is supplied to the shops of the General Electric Company at Schenectady, and also for light and power purposes to Albany, Troy, and other neighboring towns.

lather; the soap combines with the salts to form insoluble lime or magnesium compounds that appear as a scum on the surface. If water contains calcium bi-carbonate, $CaH_2(CO_3)_2$, the CO_2, may be expelled by boiling. The calcium carbonate, $CaCO_3$ is precipitated and appears as a crust or scale. If the water contains calcium sulphate, $CaSO_4$ it may be softened by means of sodium carbonate, Na_2CO_3.

Distillation. Water may be purified by distillation. This process consists in heating water to steam and then condensing the steam. Since most of the impurities are less volatile than water, the salts in the solution are left behind making the condensed steam, pure water. The apparatus used in distilling water is called a still and consists of a vessel for heating and vaporizing the water (called a retort) and a curved tube (called the coil or worm) for cooling the steam. The worm is surrounded by cold water. In Fig. 4 steam enters at A and when condensed flows out at B. The cooling water enters at C and flows out at D.

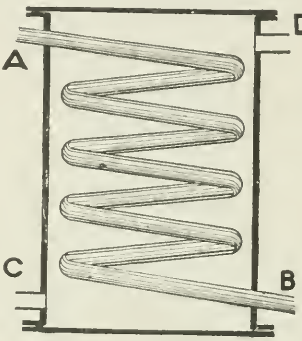


Fig. 4.

Distilled water has a flat taste because the carbon dioxide and air have been expelled.

NITROGEN.

Occurrence.—Nitrogen is a gas which is the chemical opposite of oxygen. Nitrogen exists in the air, and in a few compounds. It occurs free in the atmosphere, of which it is about 77 per cent. of the volume. The most common compounds containing nitrogen are the nitrates; potassium nitrate (KNO_3), and sodium nitrate ($NaNO_3$). Ammonium compounds, such as ammonium chloride (NH_4Cl), are also common.

Organic matter, both vegetable and animal, contains compounds of nitrogen.

Discovery.—Nitrogen was discovered or rather recognized as a constituent of air about the time when Cavendish, Priestly, Scheele, Lavoisier and other noted chemists were making such wonderful discoveries. At this time Rutherford showed that after animals have breathed in a certain volume of air, an inert gas is left behind.

Lavoisier named the gas azote, but Chaptal named it *nitrogen*, because of its existence in nitre, KNO_3.

Physical Properties.— Nitrogen, if pure, is a colorless, tasteless and odorless gas. It is a little lighter than air. By means of intense cold and great pressure, this gas, like others, has been liquified.

Chemical Properties.— The most striking property of nitrogen is extreme inactivity. It is very inert. It does not burn nor does it support combustion. It is not poisonous, but it gives no aid in supporting life. At high temperatures, nitrogen unites with some elements, but at ordinary temperatures it does not enter into chemical union with other substances.

Although inertness is the marked characteristic of nitrogen, yet this element is a constituent of many compounds which are active to a high degree. Among these are such explosives as gunpowder, nitro-glycerine and dynamite.

Compounds.— Many important compounds contain nitrogen. In nature, nitrogen is necessary to both animal and plant life. It is an important element of muscular fibre and of brain material. It is a constituent of ammonia gas, NH_3, and of a large number of compounds derived from it, which are so essential to plants.

Ammonia.— NH_3 is the principal compound of nitrogen and hydrogen. It is a colorless gas, having a very pungent odor and acrid taste. It is very soluble in water. Ammonia can be liquified and solidified by cold and pressure. Upon evaporating, ammonia absorbs heat, thus producing cold sufficient to freeze water. This property is made use of in refrigerating machines.

Ammonia and hydrochloric acid form ammonic chloride, NH_4Cl, a salt called sal ammoniac,

$$NH_3 + HCl = NH_4Cl.$$

With hydrogen and oxygen, nitrogen forms nitric acid, HNO_3, one of the three most important acids.

Uses.— The principal use of nitrogen is to dilute the active oxygen in the air and make the mixture suitable for breathing. Also on account of the dilution of the oxygen, the nitrogen prevents oxygen from having too rapid action in combustion. The uses of this gas in animal and plant life have been mentioned. Nitrogen unites with oxygen and forms several oxides, one of which, N_2O, is called laughing gas.

Preparation. —Nitrogen may be prepared from air by separating the other constituents from it. As oxygen is the other principal element, it may be burned out by means of phosphorus. As the air is confined in a jar, the burning phosphorus withdraws the oxygen leaving nitrogen. The union of oxygen and phosphorus may be expressed by the equation,

$$2P + 5O = P_2O_5.$$

The P_2O_5 is dissolved in water leaving nitrogen.

Nitrogen may also be separated from oxygen by passing dry air over red-hot copper confined in a tube.

$$Cu + O = CuO.$$

THE ATMOSPHERE.

The atmosphere, or air, which surrounds our globe is a vast ocean of gases. Human beings and other land animals dwell at the bottom of this ocean. The height to which the air extends is not known exactly. Formerly, it was supposed to extend about 50 miles from the surface of the earth; but at the present time some people think it extends to other planets.

Experiment shows that the density of air diminishes rapidly as one ascends. It has been calculated that at the height of about 40 miles the air is as rare as in the so-called vacuum of a good air pump. This calculation seems to show that if the atmosphere extends to the other planets, it must be exceedingly rare.

The ancients thought there were four elements, *earth*, *air*, *fire* and *water*. They called any gas air in the same way that any thin liquid was water. Until Priestly discovered oxygen, air was considered an element. Lavoisier was the first to make an analysis of the atmosphere.

Constituents. — There are five principal constituents of air. These are nitrogen, oxygen, argon, water (as a vapor) and carbon dioxide. Besides these, there are a great many other less important gases. Nitrogen, oxygen, and argon are called the permanent constituents, because their proportion is very nearly constant. The amount of water is very variable. Winds from deserts contain but little moisture; during the rainy season the atmosphere is almost constantly at the dew-point.

Suppose the air contains a certain amount of moisture. Now as the temperature of the air is lowered, a temperature will at length be reached at which the air will be just saturated with moisture. Further reduction of temperature will cause a part of this moisture to be precipitated. The temperature at which the air is just saturated is the dew point for the air under consideration. The dew point varies with the amount of moisture in the air.

Carbon dioxide, CO_2, forms 3 or 4 parts in 10,000 of the atmosphere. In the air above cities, in theatres, and in crowded rooms, the percentage is much larger. Although the percentage of CO_2 is small, yet the total quantity in the air is great.

Of the permanent constituents, nitrogen (the inert gas) forms about four-fifths of the whole; oxygen (the active element) forms about one-fifth, and argon nearly one per cent.

Argon is a comparatively new element, being discovered in 1894. It was found that when nitrogen was obtained from the atmosphere it was $\frac{1}{2}$ per cent. heavier than when made from chemical compounds. This fact lead to its discovery. Argon is of little importance. Its resemblance to nitrogen accounts for the late discovery. It is the most inert of all known substances, and combines chemically with no elements. It is more soluble in water than nitrogen, and has been liquified at —121° under a pressure of about 750 pounds per square inch. It freezes at —191°.

Besides the large number of gases found in the atmosphere, there are minute quantities of solid materials of many kinds. For instance, common salt is blown up into the atmosphere from the waves of the ocean and carried far inland.

The atmospheric ocean is like the liquid ocean in one respect. While rivers flow to the ocean, they carry along pulverized rock, vegetable matter, impure products from manufacturing establishments and washings from the soil. All these impurities find their way to the ocean. In the case of air, all living animals pour out with every breath from the lungs, waste materials from their bodies. Wherever fuel is burned or wherever a manufacturing plant allows the escape of gases or vapors or pulverized solids, these are mingled with the atmosphere. Thus the air is a great reservoir, in which are found almost all gaseous substances.

The various constituents of air exert various influences upon it. The oxygen is the active constituent ; it is the portion necessary to the existence of animals and combustion.

The chief duty of the nitrogen is to dilute the oxygen and weaken its excessive activities. Let us consider what would happen if the air were made up entirely of oxygen. It has already been said that iron and other metals burn in pure oxygen. Then if the air were pure oxygen, the heat in stoves would cause the iron to burn and the result would be that there would be no restraining the conflagation. The influence of argon is practically the same as that of nitrogen which it so strongly resembles.

The moisture in the air is of great value to animal and plant life. We know that water has a great capacity for retaining heat. When the sun's rays penetrate the atmosphere, some of the heat is absorbed by the earth and then imparted to the air above it. The moisture in the air hinders the escape of this heat. The heat thus imprisoned, as it were, greatly aids the growth of animals and plants. The earth imparts heat only to the layer of air immediately above it, as is shown by ascending a mountain ; the vegetation may be luxuriant at the base, but as the mountain is ascended, the richness of vegetation diminishes and a height is soon reached where perpetual cold and snow prevail ; no animals exist and only the lowest forms of vegetation can be found.

The glories of the sunrise and sunset are due to moisture in the air. The light shining through the drops of water that float about in the form of clouds, produces the beautiful effects.

Carbon dioxide, the fifth important constituent of air, is formed as has already been stated, when combustion takes place either in a fire or in animals. When an animal breathes, minute particles of animal tissue are burned, and one of the products of this combustion is carbon dioxide. For this reason, the animal body has been likened to a furnace.

On account of the large number of animals on the globe, and the immense quantity of coal that is burned, one might think that the carbon dioxide by continually increasing would soon form a large proportion of the atmosphere. Nature has wonderfully provided for this. The carbon dioxide, which is the waste matter of animals, is one of the foods for plants. Thus the trees of the forest are continually taking in the carbon dioxide and giving out pure oxygen, which is at the same time the refuse of plants, and the life giving oxygen which animals demand.

CHEMISTRY OF AIR.

On account of the abundance and importance of air, it has been studied with great care. It has been carefully analyzed. Experiment shows that air seems to be a chemical compound by reason of one fact — the two principal constituents, oxygen and nitrogen, have been found to exist in almost constant proportions. Every other consideration, however, seems to show that air is a mechanical mixture.

If air were a chemical compound, the proportions of the constituents would not vary, but the amount of oxygen is found to vary from 20.908 to 20.999 per cent.

Among other reasons for thinking air a mixture, is the following: Suppose air were composed of exactly 20 per cent. oxygen and 80 per cent. nitrogen, then the symbol would be N_4O. If four volumes of nitrogen are mixed with one volume of oxygen, the mixture behaves like atmospheric air. When the gases are brought together, no heat is either liberated or absorbed; also there is no condensation. These phenomena are observable in the case of chemical union. An investigation of the vapor density, also shows the air to be a mixture, and not a chemical compound.

CARBON.

Occurrence. — Carbon exists in nature in many forms. It is seldom found pure or uncombined, although many substances are made up largely of carbon. Carbon exists in three distinct forms; **amorphous carbon, graphite and diamond.** Amorphous means not crystalline. Graphite and diamond are the crystalline forms. Although these three forms bear no resemblance to one another, and their properties differ considerably, yet they are all varieties of the same element.

Discovery. — Carbon, as charcoal, was thought by the phlogistonists to be very pure phlogiston, because it burned leaving but little residue. Graphite was known to the alchemists; pencils were made of it in the sixteenth century. In 1772, Lavoisier burned a diamond, thus proving that it was not quartz. In 1796, equal weights of diamond, graphite and charcoal were burned, giving equal weights of carbon dioxide, CO_2. This proved that all these three substances were forms of carbon.

AMORPHOUS CARBON.

Amorphous carbon exists as charcoal, bone-coal, lamp-black, coke, gas carbon and mineral coal. Of these, mineral coal is found in the earth, the other forms being artificial products.

Charcoal is probably the most familiar form of carbon. Charcoal is not pure carbon, as it contains minerals and other impurities. It is made by heating wood without burning it, or only partially burning it. By heating wood for a time out of contact with air, the compounds which form the fiber are broken up and the gases driven off or burned. This process is called distillation, and as the compounds are destroyed, it is sometimes called destructive distillation.

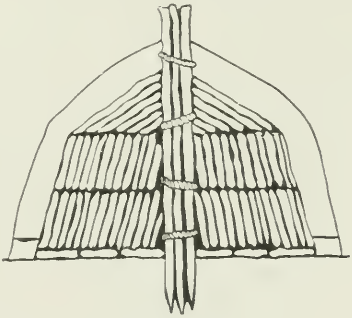


Fig. 5.

Charcoal is usually prepared by piling wood in a conical heap as shown in Fig. 5, covering it with sods and earth and letting it smoulder. Small openings are left for air. For this process a portion of the wood is burned and the rest only charred. The heat decomposes the wood, expelling the volatile gases. The product is a solid which consists mainly of charcoal.

Charcoal is a black, amorphous, porous substance, having neither taste nor odor. It is insoluble in any liquid, and cannot be melted or vaporized except in the electric furnace.

Animal charcoal is made by treating in a similar manner animal matter such as waste leather. When bones are burned, the volatile portions (water, ammonia etc.) are driven off, and the carbon is left deposited on calcium phosphate. This product is called **bone-black**, and is used in refining sugar.

Lamp-black is a nearly pure form of uncrystallized carbon. It is made by partially burning turpentine, oil, tar, resin etc., and collecting the unburned carbon or smoke.

The smoke flows into a chamber, as shown in Fig 6, where the sooty material collects on the walls and floor. It is scraped off and sold. Lamp-black is used in printers' ink, black paint, etc.

Coke is formed from soft coal. The coal is distilled upon the same principle as in wood. The process drives out the volatile gases, which are used for illuminating. Like charcoal it is very porous, but requires a high temperature to set it on fire. Coke is used for heating.

Gas Carbon is formed in the manufacture of coke and illuminating gas. It is very dense and hard.

Mineral Coal is a well-known compound of carbon. It is very abundant, being found in almost every country in the world. The United States has by far the largest amount.

Coal was once wood. It is the accumulated masses of the remains of a luxuriant vegetation of an early period of the history of our globe. Many centuries ago the earth contained vegetable life which was at least as rank as it is to-day. The earth's crust has been subject to upheaval and subsidence, which have caused the various layers to be contorted. Plant life was buried, and as time went on, it became covered with earthy matter, thus being subjected to pressure and also to a slow distillation by heat. This action of heat, pressure and percolating waters, changed the wood to coal.

Coal is found in two distinct varieties: Anthracite or hard coal, and Bituminous or soft coal.

Anthracite is rich in carbon, some varieties having about 90 per cent. It seems to have been formed from soft coal, under conditions of pressure and temperature which expelled the more volatile constituents. As anthracite coal has had most of its volatile gases expelled, it burns with little flame and will ignite only at a high temperature. It is used for heating houses, but it is more expensive than soft coal, and far less abundant.

Bituminous Coal has several sub-varieties, Cannel and Lignite. They are not as pure forms of carbon as bituminous coal. Peat is a low form of lignite or brown coal. Bituminous coal contains less carbon than hard coal, but is richer in hydrocarbons. It gives off considerable smoke and burns with much flame at a lower temperature than anthracite, On account of the volatile gases, it is much used for making illuminating gas and coke. Cannel coal is very rich in hydrocarbons, but is very expensive.

GRAPHITE.

Graphite, also called black-lead, plumbago, etc., is a compact and comparatively pure form of carbon. It is quite abundant and widely distributed. It is found in some places as a continuation of beds of anthracite coal which thus indicates its origin. Like coal, graphite seems to come from plant life.

Graphite is a soft, black crystalline mineral, insoluble in any substance at ordinary temperatures, and is almost infusible. Graphite is a good lubricant. It is practically infusible and unlike other forms of carbon can be burned only at the highest temperatures when it forms carbon dioxide, CO_2.

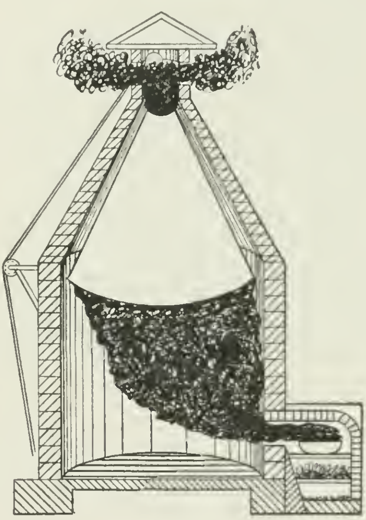


Fig. 6.

Carbon, as a graphite, is very useful. It is used as a lubricant, for facing molds for iron castings, for electrotype facings, lead pencils, stove polish and polish for gunpowder. On account of its infusibility and incombustibility, it is used for lining crucibles in which iron and steel are melted. Coal and graphite are of precisely the same chemical nature, yet while coal is burning in the fire, and thus furnishing intense heat for melting metals, the graphite, of which the crucible is made, resists heat and combustion and while allowing the metals to melt preserves them.

DIAMOND.

The diamond is nearly pure carbon crystallized. It is one of the most wonderful substances known. Diamonds are found in only a few places on the earth, and are not abundant. Since the time of the ancient Greeks and Romans, the diamond has been prized on account of its brilliancy, rareness, hardness and unchangeability. The largest diamond ever found weighed less than half a pound, and is valued at over half a million dollars. Diamonds are cut in exact geometrical shapes as shown in Fig. 7, by splitting off portions. They are then polished by rubbing them on a revolving plate upon which is a mixture of oil and diamond dust.

Diamond is the hardest substance known with the possible exception of the artificial product, boron. There have been many attempts to make diamonds by melting carbon and then letting it crystallize. By fusing carbon with iron, minute crystals have been produced.

The principal use of diamonds is as a precious stone. Because of its hardness, it is used for cutting glass, and poor varities are used in rock drills.

OTHER FORMS OF CARBON.

In addition to the three forms of carbon already briefly described, it exists in many compounds with other elements. It is found in the atmosphere in carbon dioxide gas. Also, it is one of the important constituents of petroleum. Marble and limestone contain enormous quantities of carbon. These minerals consist largely of calcic carbonate, $CaCO_3$. Almost all animal and vegetable matter contains carbon.

USES.

The uses of carbon in the form of charcoal, graphite and diamond have already been mentioned; but some of the more important uses are worthy of discussion. On account of the infusibility, carbon is used in the pencils of arc lights. It slowly burns away, but this is expected as the current flowing from one pencil to the other gives out intense heat as well as brilliant light.

Carbon, whether as wood, charcoal or bone-black, has a wonderful power of decolorizing liquids. When colored solutions are strained through a quantity of one of these forms of carbon, the carbon absorbs the coloring matter, and the liquid that has passed through is practically colorless. On account of this property, enormous quantities of bone-black are used for whitening syrups before they are crystallized to sugar.

A similar property to this, is the power that charcoal has of absorbing offensive gases. Hence, it is used as a disinfectant. If tainted meat is packed in freshly burned charcoal, it soon loses its odor.

COMPOUNDS.

There is a large number of compounds of carbon. The reason why the number is so great is that the valence of carbon is four. We saw that the valence of hydrogen is one, and that of oxygen is two, and that there are few compounds of these two elements. Now as carbon has four hooks with which to take hold of other substances, it naturally takes hold of a great many.

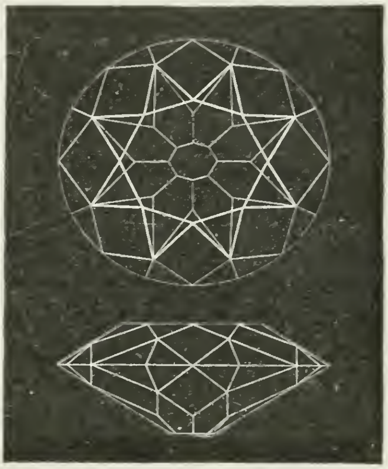


Fig. 7.

Although carbon is very inert at low temperatures, yet at high temperatures, carbon draws oxygen away from almost all known elements. It thus shows that its chemical force is superior to that possessed by any of them.

Carbon unites with oxygen forming carbon monoxide, CO, and carbon dioxide CO_2. These interesting and important compounds will be discussed with the subject Combustion, with which they are so intimately connected.

With other elements carbon forms many useful and important compounds. Many of these compounds belong to that branch of science called Organic Chemistry. Organic Chemistry was formerly considered as the chemistry of substances derived from existences that possess organs such as animals and plants. At present, however, it is considered to be the chemistry of carbon and its compounds.

This subject is of such an extent that it is impossible to discuss it here. The simple fact that organic compounds include vegetable juices, extracts, gums, resins, essences, acids, oils, alcohols, coloring matter and many others is an indication of the extent and importance of this branch.

Most of the substances thus named are compounds of hydrogen and carbon, or of carbon, hydrogen and oxygen.

ILLUMINATING GAS.

Illuminating gas is made by two methods. If made from carbon and water, it is called *water gas;* if made by the destructive distillation of bituminous coal, it is called *coal gas.*

Water Gas. — This gas is extensively used at the present time in large cities. The process of manufacture is briefly as follows: Superheated steam is passed through red hot anthracite coal, and the gases thus formed, collected. The chemical combination may be represented by this reaction,

$$H_2O + C = CO + 2H.$$

The coal, which is contained in large cylinders (Fig. 8), is set on fire, the combustion being accelerated by a strong air blast at A. While the coal is thus burning, CO and CO_2 are formed, and the CO_2 passes off through the hood H. When the coal is burning well, or is incandescent, the air blast A is closed, as is also the top of the cylinder at C. The valve E is now opened, and the superheated steam from the boiler enters the cylinder, passes up through the burning coal, and the products CO and H (see reaction) pass out the pipe D to a reservoir. When the steam has cooled the coal, the valve E is closed, and the coal again heated.

As both H and CO burn with a feeble flame, it is necessary to mix with these some substance which will make the gas give more light. The light-giving constituents are usually the hydrocarbons obtained by distilling naphtha or petroleum.

Coal Gas. — To make this gas, cylinders called retorts made of iron or fire clay are filled with soft coal and heated to over 1000° F. by a coal fire. The gases formed pass upward through the exit pipe to the hydraulic main, which is a large pipe through which water is kept flowing. The products of distillation which pass to the hydraulic main are liquid, semi-liquid and solid (hydrogen, carbon dioxide, sulphur, ammonium compounds, coal tar, &c); these are washed and some of them deposited in the main.

The insoluble gases pass to the condensers, which are a series of vertical pipes placed in the open air. As the gas is thus cooled, tarry liquids, which have been in the gas in the form of a vapor, are deposited.

Next the gas flows to the washers, or scrubbers, where it meets a falling spray of water which by absorbing ammonia (NH_3) and hydrogen sulphide H_2S washes the gas. It then goes to the purifiers, which are large iron boxes with a large number of shelves on which is dry quicklime, CaO, or hydrated ferric oxide. The quicklime absorbs H_2S and other acid gases. The gas is now pure enough for use, and passes into the large tanks called gas holders from which it goes to the consumers.

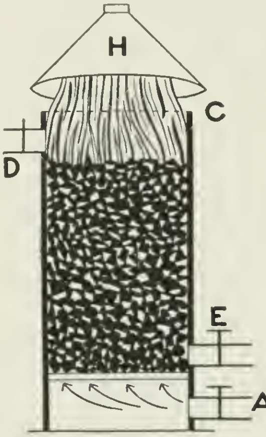


Fig. 8.

Composition. — When coal distilled gas is in its purest condition, it is a very complex substance and the proportions of the constituents vary somewhat. About 5 per cent. is made up of hydrocarbons, such as C_2H_2, C_6H_6, C_2H_4, &c. These hydrocarbons are the light-giving portions. Impurities, such as CO_2 and N make up about 5 per cent. more. The remaining 90 per cent. is made up of three gases which give but little light. These are H about 45 per cent., CH_4 about 40 per cent., and CO about 5 per cent.

Products. — There are three distinct classes of products of the distillation of coal; solids, liquids and gases. The solids are left in the retorts, the liquids are condensed in the coolers, and the gases are absorbed by quicklime and water, and pass to the gas-holder.

The **solids** are coke and gas carbon. Coke, the spongy substance left in the retort, is a form of carbon. It is used as a fuel. The **gas carbon** is a sort of scale, and is used for the carbons for electric lights.

The **liquids** consist of complicated mixtures of carbon compounds, but they are of great interest and importance. When coal gas was first made, these liquid products were thrown away, but little by little chemists began to recognize their value, and now they are very useful in the arts. From the filthy and offensive coal-tar, the most beautiful and brilliant dye-stuffs are made. These dyes are very permanent. One of the substances from coal-tar is benzole, a compound C_6H_6, from which the well-known aniline dyes are produced. The preparation of these dyes from the apparently worthless product, coal-tar, is a great achievement.

The gaseous products. — The gases generated in the process of coal-gas manufacture are numerous. Some are combustible, but have little illuminating power, such as hydrogen and carbon monoxide. Others, ethylene (C_2H_4), for instance, have high illuminating power. Nitrogen is always formed, but contributes nothing to the value of the gas. The sulphur compounds, H_2S, etc., burn, but form undesirable oxides of sulphur.

COMBUSTION.

Combustion is a rapid chemical combination of the substance that burns, and the substance that supports combustion. It is usually attended with light, and always with heat.

The two principal substances that burn are carbon and hydrogen, or their compounds; the supporter of combustion is oxygen. In addition to the two substances (the one that burns and the supporter), another condition is necessary — a temperature sufficiently high for the union of the substances.

If a stove is partly filled with wood or coal (both contain carbon and hydrogen), and the doors opened, the substances will not burn, although there is plenty of oxygen surrounding the lumps of coal, If, however, the temperature of the coal is raised sufficiently high, the wood or coal burns; or, chemical union takes place.

In order to have carbon, hydrogen or sulphur burn, they must be set on fire or kindled. In other words, the temperature of the substance must be raised to a certain degree before it will burn. This is called the kindling point, and the kindling point varies for different substances.

Flame indicates the combustion of a liquid or gas. Solids simply glow when burning, but do not give out flame.

Coal, the principal fuel used in engineering, is composed chiefly of carbon, the amount varying from about 50 per cent. to 85 per cent. In addition to carbon, coal contains compounds of hydrogen and carbon, called hydrocarbons. These are gases which burn with both light and heat. The third constituent of coal is called ash. It is an earthy substance which remains after the burning of the coal.

As already stated, combustion is a rapid chemical combination of oxygen with carbon and hydrocarbons. Oxygen and carbon have a very strong attraction for each other at high temperatures, and unite with great force, producing light and heat.

When coal is first thrown on the fire or placed on the dead plate, the heat from the fire drives off the hydrocarbons. These gases, being combustible, are burned above the fire or, as in the case of a marine boiler, in the combustion chamber. In order to have the hydrocarbons burn, enough oxygen must be admitted to unite with them, and the temperature must be sufficiently high. If these hydrocarbons do not burn, because of low temperature or of insufficient oxygen, they pass up the chimney and a large amount of available heat is lost.

After the hydrocarbons are driven off, the solid portion, coke, is left on the grate or dead plate. To burn the coke, air (containing oxygen) passes up between the grate bars and through the spaces between the pieces of coal.

In burning both hydrocarbons and carbon, or coke, certain new substances are formed, which are called products of combustion. These are gases, carbon dioxide, CO_2, carbon monoxide, CO and water, H_2O (as a vapor).

If there is plenty of oxygen present when hydrocarbons and carbon are burned, the products are CO_2 and H_2O. If there is insufficient oxygen, the products are CO and H_2O.

CARBON DIOXIDE.

This important and interesting gas is called carbon dioxide. carbonic acid, carbonic acid gas and carbonic anhydrid. Its importance and effect on animal and plant life have already been mentioned. The principal natural source in the atmosphere is the combustion of fuel. The gas is made up of carbon and oxygen, and as coal, wood, oil, illuminating gas, etc., are all carbonaceous substances this gas is formed whenever combustion takes place.

Carbon dioxide occurs combined in all carbonates; limestone, $CaCO_3$, being the most abundant.

To prepare carbon dioxide it is only necessary to cause some acid, as hydrochloric acid, to act on a carbonate, as calcium carbonate, $CaCO_3$. The gas thus liberated can be collected and used to ascertain its properties. The action of the acid on the carbonate may be expressed as follows:

$$CaCO_3 + 2\ HCl = CaCl_2 + H_2CO_3.$$

The H_2CO_3 (carbonic acid) is very unstable and breaks up almost as soon as formed into CO_2 and H_2O.

$$H_2CO_3 = H_2O + CO_2.$$

Carbon dioxide is formed whenever carbon burns with plenty of oxygen

$$C + 2O = CO_2.$$

Carbon dioxide is a heavy colorless gas with a pungent odor. On account of its weight, it does not mix readily with other gases or the air, but collects in the bottoms of wells and near the floors in rooms. CO_2 does not support combustion, nor is it a supporter of respiration.

Formerly it was thought that carbon dioxide was poisonous, but it is now thought that CO_2 causes death by excluding oxygen. The fact that carbon dioxide is beneficial to the system if taken into the stomach shows that it is not poisonous.

CO_2 is somewhat soluble in water, and when dissolved in water forms with it a weak, unstable acid, H_2CO_3.

The principal uses of carbon dioxide are as follows: It is used in making soda-water and artificial mineral water. Soda-water is simply water in which considerable CO_2 is dissolved; carbon dioxide being soluble in water. It is also used in chemical engines, because it does not support combustion. When H_2SO_4 unites with sodium carbonate Na_2CO_3, carbon dioxide is formed.

$$H_2SO_4 + Na_2CO_3 = H_2CO_3 + Na_2SO_4.$$

The carbonic acid, H_2CO_3, immediately breaks up into H_2O and CO_2.

The action of yeast in bread-raising is a kind of fermentation; the carbon dioxide and alcohol formed cause the dough to raise and make the bread porous.

CARBON MONOXIDE.

Carbon monoxide is not nearly as common as carbon dioxide. The reason is that the compound CO contains only one-half as much oxygen as does CO_2 and as it is only half saturated, it has a great affinity for oxygen. On account of the activity of CO, it readily combines with oxygen and other elements.

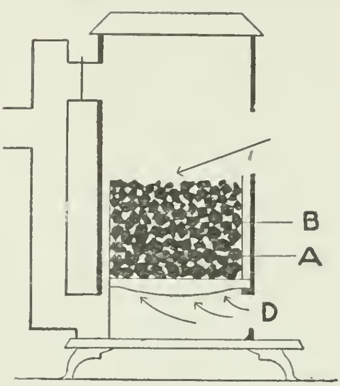


Fig. 9.

This gas, carbon monoxide, does not occur naturally anywhere, except in case of combustion in a limited amount of air. It forms one of the principal constituents of water gas.

Carbonic oxide is a colorless gas without taste and with but little odor. Its chief property is its poisonous nature. It is the deadly constituent of water gas.

As has already been stated, carbon dioxide is formed when combustion is carried on with an abundance of oxygen, and carbon monoxide when the supply of oxygen is limited. In this connection let us consider the ordinary coal stove, (Fig. 9). Air, containing oxygen, enters through the lower door D, and since there is plenty of oxygen, CO_2 is formed in the zone represented at A.

$$C + 2O = CO_2$$

As this carbon dioxide rises through the hot coal, where there is but little oxygen, it gives up one-half of its oxygen to the carbon of the coal, and carbon monoxide is formed in zone B.

$$CO_2 + C = 2CO.$$

When the gas, CO, reaches the surface of the coal, where it meets the oxygen which has entered the draft plate or grid in the upper door, it is changed to CO_2.

$$CO + O = CO_2$$

There is one great difference between carbon dioxide and carbon monoxide that is of importance to the engineer. CO_2 is not combustible while CO can be burned. Let us see how this fact affects the economy of a boiler.

If the air supply is not sufficient to form carbon dioxide, carbon monoxide, CO, is the product. This gas is combustible, and as it will give up considerable heat, if burned, it is undesirable to have it pass unburned up the chimney. This loss is prevented by burning the coal with more oxygen.

We thus see the necessity of admitting sufficient air to the coal, if we wish to run our boiler economically. However, we cannot open the doors and let in an unlimited supply of air, because too much air is a source of loss, as we shall see later. How then are we to know how much air to admit? While the fireman is shovelling coal and regulating the dampers, he cannot stop to figure out the amount of air he should use or is using, but he judges the right amount from the appearance of his fire, and the smoke that issues from the chimney.

By knowing a few principles of chemistry, and the chemical composition of the coal, we can calculate the amount of air theoretically necessary to burn the coal economically.

AMOUNT OF AIR NECESSARY TO BURN FUEL.

Air is composed of about 77 per cent. of nitrogen and argon, and 23 per cent. of oxygen. The oxygen is the only element that aids combustion; therefore, if one pound of air is admitted to the ashpit, only about one-fourth of a pound of oxygen aids combustion; the three-fourths of a pound of nitrogen is inert. The nitrogen is of no aid, but is a source of loss because it must be heated to the same temperature as that of the oxygen. For every pound of air admitted in excess of the amount necessary, three-fourths of a pound of nitrogen takes heat from the coal. Thus we see that the regulation of the air supply is exceedingly important.

If the proper amount of air is admitted, the hydrocarbons and carbon are burned, forming water (in the form of steam) and carbon dioxide. These gases, the products of combustion, together with heated nitrogen and smoke, pass up the chimney.

Carbon Dioxide.

We have already learned that the product obtained by burning carbon in oxygen is carbon dioxide gas, CO_2. This gas is composed of 12 parts carbon and 32 parts oxygen.

$$C = 12, O_2 = 2 \times 16 = 32.$$

Now, since 32 parts are oxygen and 12 parts are carbon, $\frac{32}{12}$ pounds of oxygen are necessary in burning one pound of carbon. In other words, for every pound of carbon that is burned in the furnace, $\frac{32}{12} = 2\frac{2}{3} = 2.67$ pounds of oxygen must be supplied to obtain the product CO_2. Air contains but 23 per cent. of oxygen; then to obtain 2.67 pounds of oxygen from the air, $2.67 \div .23 = 11.6$ pounds must be used.

We have said that 11.6 pounds of air furnishes 2.67 pounds of oxygen. It is evident that the remainder is nitrogen; or $11.6 - 2.67 = 8.93$ pounds of nitrogen are also obtained. Thus if one pound of carbon is burned in 11.6 pounds of air, the products are one pound of carbon, 2.67 pounds of oxygen (making 3.67 pounds of CO_2) and 8.93 pounds of nitrogen.

$$1 \text{ lb. C} + 2.67 \text{ lbs. O} + 8.93 \text{ lbs. N} = 12.6 \text{ lbs.}$$

This is the manner in which the 11.6 pounds of air and 1 pound of carbon unite.

We may say in brief that *to completely burn one pound of carbon we must use 11.6 pounds of air. From this 2.67 pounds of oxygen are used in combustion and 8.93 pounds of nitrogen pass up the chimney without aiding combustion.*

Water.

The product obtained by burning carbon is carbon dioxide; if hydrogen is burned, the product is water, H_2O. We know that water is 2 parts hydrogen and 16 parts oxygen.

$$H = 1, H_2 = 2, O = 16.$$

Then one pound of hydrogen requires $\frac{16}{2} = 8$ pounds of oxygen. To obtain 8 pounds of oxygen, 34.8 pounds of air are necessary, because air contains 23 per cent. oxygen and $8 \div .23 = 34.8$.

If one pound of hydrogen is burned in air, 34.8 pounds of air will be required, and we will get as products 8 pounds of oxygen and 1 pound of hydrogen (making 9 pounds of water) and $34.8 - 8 = 26.8$ pounds of nitrogen.

$$1 \text{ lb. H} + 8 \text{ lbs. O} + 26.8 \text{ lbs. N} = 35.8 \text{ lbs.}$$

To completely burn one pound of hydrogen, we must use 34.8 pounds of air. Of this 8 pounds of oxygen are used in combustion, and 26.8 pounds of nitrogen pass up the chimney without aiding combustion.

Carbon Monoxide.

If the combustion is not complete, the product is CO instead of CO_2. We see that this is so because in equal amounts of CO and CO_2, there is but one-half as much oxygen in the former as in the latter. As there is only one-half as much oxygen in CO as in CO_2, it takes only one-half as much oxygen to burn carbon to CO as it does to CO_2. We know that 11.6 pounds of air are necessary to burn carbon to CO_2; therefore to burn it to CO only $\frac{11.6}{2} = 5.8$ pounds of air are necessary.

If one pound of carbon is burned to CO, 5.8 pounds of air are necessary. Of this 5.8 pounds of air, 1.33 pounds of oxygen are used in combustion, and 4.47 pounds of nitrogen pass up the chimney.

The quantities of air required for combustion are as follows:

To burn one pound of

Carbon to CO_2 requires 11.6 pounds of air.

Carbon to CO requires 5.8 pounds of air.

Hydrogen to H_2O requires 34.8 pounds of air.

Coal is composed of hydrogen, carbon and a small amount of incombustible matter.

From the above we can calculate how much air is theoretically necessary to burn a pound of coal, if we know the amount of carbon and hydrogen in the coal.

Suppose we have a coal composed of the following;

Carbon,	85 per cent.
Hydrogen,	10 per cent.
Ash,	5 per cent.

Since it takes 11.6 pounds of air to burn 1 pound of carbon to CO_2, it would take $11.6 \times .85 = 9.86$ pounds of air to burn the carbon in 1 pound of coal.

To burn the hydrogen, 3.48 pounds of air are necessary because 34.8 pounds are necessary to burn 1 pound and $34.8 \times .10 = 3.48$.

Hence, it takes $9.86 + 3.48 = 13.34$ pounds of air to burn one pound of coal of the above composition.

To find the amount of air theoretically necessary to burn one pound of any fuel, we find the amount required to burn the carbon by multiplying the percentage of carbon by 11.6, and the amount required to burn the hydrogen by multiplying the percentage of hydrogen by 34.8. The sum of these two results is the desired quantity.

EXAMPLE FOR PRACTICE.

A certain kind of coal contains 87 per cent of carbon, 8 per cent of hydrogen, and 5 per cent ash. How many pounds of air will be required to burn one ton (2000 pounds)?

Ans. 25,752 pounds.

METALS.

Such elements as carbon, nitrogen and sulphur when combined with oxygen and hydrogen form acids: carbonic acid H_2CO_3, nitric acid HNO_3, sulphuric acid H_2SO_4. In addition to elements of this class—which we call *non-metals*,—there is a very large and important class of elements called *metals*, with which hydrogen and oxygen form *basic* substances. These basic compounds, such as sodium hydroxide NaOH, calcium hydroxide $Ca(OH)_2$ and ferric hydroxide $Fe(OH)_3$, combine readily with acids and destroy the peculiar properties of the acids, at the same time losing their own peculiarities. The new substance thus formed is a *salt;* water is always set free, as shown by the equation:

$$Ca(OH)_2 + H_2SO_4 = CaSO_4 + 2H_2O,$$

in which calcium hydroxide, or slacked lime, is represented as combining with sulphuric acid to form calcium sulphate, which when crystalized with water is called gypsum. This formation of hydroxides, which neutralize acids and thus form salts, is the characteristic chemical property of *metals*.

SODIUM.

This is the most common and important of a group of soft, silvery-white metals, which may be readily cut with a knife, and which rapidly tarnish in air. The other members of the group are lithium, potassium, rubidium and caesium. Of these, potassium alone is sufficiently abundant to be technically important at present.

Occurrence.—Sodium occurs abundantly in nature in the compounds sodium chloride or common salt, and sodium nitrate or Chili saltpetre. Many other compounds of it are found in smaller quantities. Common salt forms immense beds in many parts of the world, and at various depths from the surface of the earth. It constitutes the chief saline matter in sea water, and in the water of such bodies as the Great Salt Lake and the Dead Sea.

Discovery and Preparation.—Sodium was first isolated by Sir Humphry Davy in 1807, by the electrolysis of molten sodium hydroxide, and after a century of experimenting we have returned to this as the best method for its production, due to the reduction in the cost of electric power. In the Castner electrolytic process the sodium hydroxide—or *caustic soda* as it is called—is melted in an iron vessel through the bottom of which passes a negative electrode of graphite. To prevent the oxygen of the air from reaching the sodium, an iron cylinder closed at the upper end is placed over the cathode so that its mouth dips into the liquid electrolyte. The sodium and hydrogen set free at the cathode rise together to the surface. The gas escapes by bubbling out beneath the edge of the cylinder while the metal remains floating upon the fused caustic soda. The outer iron vessel serves as an anode.

Alkalies.—The term alkali, which is applied to the metals of this group, and sometimes also to their hydroxides and carbonates, was originally used to denote the salt obtained by treating the ashes of plants with water. From the ashes of land plants we obtain chiefly carbonate of potassium, which in the crude state is called *potash* from the method of its preparation. The ashes of seaweeds yield chiefly carbonate of sodium.

Properties.—As above stated sodium is a soft white metal, readily moulded by the fingers at ordinary temperatures. It is not affected by perfectly dry air or oxygen. It floats on water, decomposing the water touching it, setting free the hydrogen (which may be ignited), and forming sodium hydroxide which dissolves in the water.

$$2Na + 2H_2O = 2NaOH + H_2$$

The moisture of the atmosphere produces a film of sodium hydroxide which rapidly follows the knife when the bright metallic surface is exposed. By a further step the carbon dioxide in the air changes the surface to sodium carbonate.

Important Compounds.—*With Oxygen:* The only important oxide of sodium is the peroxide Na_2O_2 which is formed by heating sodium to 300°C (572° F.) in dry pure air, or by burning sodium in oxygen. It is a yellowish-white solid which decomposes in contact with water with considerable rise of temperature, and the formation of sodium hydroxide and oxygen.

$$Na_2O_2 + H_2O = 2NaOH + O$$

When slowly added to water or to dilute acids, hydrogen peroxide is formed.

$$Na_2O_2 + 2H_2O = 2NaOH + H_2O_2$$
$$Na_2O_2 + 2HCl = 2NaCl + H_2O_2$$

It is thus a powerful oxidizing agent in either acid or basic solutions, and is used for bleaching.

With Oxygen and Hydrogen.—Sodium hydroxide (Caustic Soda—NaOH). As already stated, this compound is formed when sodium or sodium peroxide comes in contact with water. It is manufactured in large quantities by the action of slaked lime on a boiling solution of sodium carbonate.

$$Na_2CO_3 + Ca(OH)_2 = CaCO_3 + 2NaOH$$

The calcicum carbonate is almost insoluble, while the sodium hydroxide solution is drawn off and evaporated for the market. It is now made quite largely by the electrolysis of brine, the chlorine being collected for the manufacture of bleaching powder, and the sodium acting on the water to form the hydroxide.

$$2NaCl = Na_2 + Cl_2$$
$$Na_2 + 2H_2O = 2NaOH + H_2$$

Sodium hydrate is a white, deliquescent (water absorbing) solid, strongly alkaline and caustic. It is largely used in the manufactures, especially in soap making. The salts of sodium are of great commercial importance, many of them being made in enormous quantities. The starting point for their manufacture is common salt.

Sodium Chloride, or common salt, is dug as rock salt from the great natural beds in Austria, Germany, Spain, Louisiana, New York, and elsewhere. It is also obtained by the evaporation of the water of the ocean or of salt springs and wells, by the heat of the sun or by artificial heat.

Sodium Carbonate, (soda, washing soda, sal-soda) is next to the chloride the most important salt. It occurs in nature in the alkaline beds and waters of Egypt, America, and elsewhere. The ash of sea weeds was the former source of it; now it is manufactured in great quantities by either the Le Blanc process, or the Solvay process, or the electrolytic process. The first was discovered by Le Blanc in France in 1794, and consists of three parts. In the first place common salt is warmed with strong sulphuric acid in a shallow iron pan in a *salt cake* furnace, forming acid sodium sulphate and hydrogen chloride gas.

$$2NaCl + H_2SO_4 = NaHSO_4 + NaCl + HCl$$

The hydrogen chloride passes off and is absorbed by water, forming the hydrochloric acid of commerce. The mixture of sodium hydrogen sulphate and sodium chloride is then raked into another part of the furnace and heated until the remaining hydrogen of the sulphate has been replaced by sodium, forming the *salt cake*.

$$NaHSO_4 + NaCl = Na_2SO_4 + HCl$$

The hydrogen chloride is absorbed as before. Purified salt cake when crystallized is known as Glauber's Salt. The second step is to mix the salt cake with crushed coal and with calcium carbonate in the form of pure lime stone or chalk, and heat the mass in a *black ash* furnace. Here the carbon of the coal reduces the sodium sulphate to sulphide, which is acted on by the calcium carbonate forming calcium sulphide and sodium carbonate.

$$Na_2SO_4 + 2C = Na_2S + 2CO_2$$
$$Na_2S + CaCO_3 = Na_2CO_3 + CaS$$

The product is called Black Ash. This is next leached or lixiviated in tanks with water, the arrangement being such that the nearly saturated water acts on fresh black ash, while the fresh water extracts the last of the sodium carbonate from the nearly exhausted ash. Carbon dioxide is now blown through the liquid to change to the carbonate any sodium hydroxide that may be present. Then in shallow tanks the solution is evaporated to dryness by waste heat from the furnaces, and the crystals calcined and purified. This yields the *calcined purified soda* or soda ash of commerce. If this is dissolved in warm water, the impurities allowed to settle, and the clear solution drawn off and crystallized at the temperature of the atmosphere, we obtain *soda crystals* or *sal-soda* of the formula $Na_2CO_3 \cdot 10\ H_2O$, containing about 60 per cent of water. From this Baking Soda or *sodium bicarbonate*—$NaHCO_3$—can be made by exposing the crystals on a grating to the action of carbon dioxide.

$$CO_2 + Na_2CO_3 \cdot 10\ H_2O = 2NaHCO_3 + 9H_2O$$

The excess of water runs away through the grating. The Ammonia-Soda process or Solvay process was invented by Dyar & Hemming in England in 1838, but did not become a commercial success until after 1863, when the Belgian chemist Solvay constructed an apparatus which, with later improvements, promised to manufacture the greater part of the world's supply of soda. The condition which makes the process possible is that sodium bicarbonate is but slightly soluble in a cold, concentrated solution of ammonium chloride. When therefore carbon dioxide is pumped into the base of a tower, nearly filled with a cold concentrated solution of common salt saturated with ammonia, we have sodium bicarbonate formed as small crystals which gradually sink to the bottom of the tower. It is removed and freed from liquid by centrifugal machines or filter pumps.

$$NaCl + NH_3 + CO_2 + H_2O = NaHCO_3 + NH_4Cl$$

The temperature is kept at 35° C. (95° F.) by the circulation of cold water in pipes. Part of the carbon dioxide is prepared by heating limestone in special limekilns, and the lime thus produced is used for setting free the ammonia from the ammonium chloride, so that it may be used again.

$$CaCO_3 = CaO + CO_2$$

$$2NH_4Cl + CaO = CaCl_2 + H_2O + 2NH_3$$

A large portion of the sodium bicarbonate is calcined to form normal sodium carbonate, and from this action carbon dioxide is also obtained for use in the carbonating tower.

$$2NaHCO_3 \text{ heated} = Na_2CO_3 + H_2O + CO_2$$

The only waste produced is calcium chloride.

Where electricity can be obtained cheaply, the production of sodium hydroxide, as mentioned above, by electrolysis of a solution of common salt, and from it sodium carbonate, promises to become a possible rival to the older methods.

Two classes of apparatus are used. In one the sodium, as set free at the cathode, is absorbed by a liquid metal, mercury or molten lead, and this alloy is presently decomposed by water or steam, yielding sodium hydroxide and hydrogen. In the other form, the chlorine is set free by an anode at the upper surface of the brine and prevented from combining with the caustic soda around the cathode at the bottom by a porous diaphragm of asbestos or similar material. The chlorine is used for making bleaching liquids or powder.

Sodium Nitrate, ($NaNO_3$)—or Chili saltpetre—is found in immense quantities in Chili, mixed with other salts, in the caliche beds. It is purified by solution and crystallization, and exported for the manufacture of nitric acid, potassium nitrate, and fertilizers.

Sodium Phosphate, ($Na_2HPO_4 \cdot 12\ H_2O$) is made by adding sodium carbonate to a solution of calcium phosphate and evaporating. It is a crystalline salt containing over 60 per cent of water.

Sodium Thiosulphate, ($Na_2S_2O_3 \cdot 5\ H_2O$) commonly called sodium "hyposulphite," or "hypo," is largely used in photography as a *fixing* agent, to dissolve away the excess of silver salt on a developing plate. It does this by forming a double thiosulphate of silver and sodium, which is soluble in water, and therefore removed by the washing. It is also used to remove excess of bleaching powder from materials bleached with chlorine. In its manufacture caustic soda or sodium sulphite solution is treated with sulphur.

$$Na_2SO_3 + S = Na_2S_2O_3$$

$$6NaOH + 4S = Na_2S_2O_3 + 2Na_2S + 3H_2O$$

CALCIUM.

As sodium may be taken as the type of a group of metals comprising also lithium, potassium, caesium and ribidium, so calcium, in its properties and compounds, is the familiar representative of a group, of which the other members are strontium and barium. Beryllium and magnesium are very closely related to this group, and many of the statements regarding the compounds of calcium are true of magnesium as well.

Occurrence.—Calcium is one of the ten principal constituents of the earth's crust. Carbonate of calcium—$CaCO_3$—is found in particularly large quantities in nature as limestone, marble, chalk, and calcite. Marl, which is used in making Portland Cement, is largely calcium carbonate. Mountain limestone or dolomite, consists of a double carbonate of calcium and magnesium—$CaCO_3 \cdot MgCO_3$. Many of the crystalline minerals, as feldspar and mica, contain calcium silicate. The sulphate occurs in great deposits, as gypsum and alabaster. Calcium phosphate is an important constituent of artificial fertilizers, and occurs as the minerals apatite and phosphorite.

Preparation.—No important use has yet been found for the metal calcium, so that its preparation is of chemical interest only. Its use in place of aluminium is proposed, in steel making, to take out impurities and assist in the production of sound ingots. It can be made by decomposing dry fused calcium iodide with red-hot sodium, and also by electrolyzing the iodide or chloride in a manner similar to that in which sodium is obtained from sodium hydroxide.

Properties.—Calcium is a silvery-white metal, quite soft and malleable, but less so than sodium and potassium. It burns brilliantly when heated in the air, combining with both the oxygen and nitrogen. It decomposes water readily, forming the hydroxide.

Compounds.—Calcium Oxide (CaO) is the common substance quick-lime or unslaked lime. It is made in large quantities by heating calcium carbonate—limestone, marble, oyster shells, etc.—in furnaces called limekilns.

$$CaCO_3 = CaO + CO_2$$

Quicklime melts only at a very high temperature, and when strongly heated glows very brilliantly,—the lime-light. It absorbs moisture and carbon dioxide from the air, and so goes back into calcium carbonate.

$$CaO + H_2O = Ca(OH)_2 \text{ slaked lime.}$$
$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$$

This action is made of great service in construction work. Water is added to quicklime, which combines vigorously with it, forming slaked lime, and setting free considerable heat. This slaked lime is mixed with sand into a paste called *mortar*, which gradually absorbs carbon dioxide, and hardens into a mixture of limestone and sand, binding together bricks or stones into solid walls. The sand prevents the mortar from being squeezed out from between the stones or bricks, and also prevents its shrinking when drying. When heated with clay, quicklime combines with the alumina and silica, and the resulting compounds, when finely pulverized, are the *Portland Cement* of commerce. This material differs from the mortar described above, in that it will *set* or harden under water.

Calcium Hydroxide.—When quicklime comes in contact with water it combines readily with it, at the same time expanding greatly and crumbling to a powder. The heat accompanying this slaking is so great as to occasionally ignite cars or other wooden receptacles containing the lime. Calcium hydroxide is somewhat soluble in water, and the clear solution is the well-known basic liquid—*lime-water.* When exposed to carbon dioxide a film of calcium carbonate is formed on the surface of lime-water, and if the gas be blown through the water, a milky fluid results, due to the particles of calcium carbonate formed. This may be observed by blowing with a small tube through a clear solution of lime-water. The CO_2 of of the breath forms calcium carbonate, $CaCO_3$ which appears as a white cloud. On continued blowing this cloud will begin to disappear, showing that the calcium carbonate at first precipitated is beginning to be dissolved by the CO_2 gas.

Calcium Carbonate.—As noted above this compound forms a considerable portion of the earth's crust, under the names limestone, marble, and chalk. While practically insoluble in pure water, it is dissolved by water containing carbon dioxide. Rain water which absorbs carbon dioxide from the air, therefore dissolves calcium carbonate quite appreciably, one result being the formation of caves of greater or less extent in limestone countries. The waters of springs, wells, rivers and lakes, for the same reason, contain dissolved in them, usually several grains of limestone per gallon. When such water is heated the carbon dioxide dissolved in it is expelled, and the limestone being no longer soluble is precipitated, resulting in the formation of the *scale* found in tea-kettles and boilers. To steam users this is a serious evil, as a lining of one-fourth of an inch of scale in a boiler, necessitates the use of about 30 per cent more fuel, to obtain similar quantities of steam.

When soap is added to water in which salts of the heavy metals—calcium, iron, zinc, magnesium, etc.—are dissolved, the soap will form little if any lather at first, but instead forms an insoluble, curdy material, which is really a soap containing the calcium, or other metal. Such water is known as *hard* water, in contrast with rain or other waters which at once form lather with soap. As salts of calcium, especially the carbonate and sulphate, are by far the most common in natural water, the attempts to soften water are usually aimed at these substances. We have seen that the solubility of calcium carbonate depends on the presence of carbon dioxide, and that the expulsion of this gas by heat results in the precipitation of the carbonate. One efficient way of preventing the formation of scale in a limestone country, is therefore the use of feed-water heaters. Lime water in proper quantity added to boiler-feed water in tanks, will combine with the carbon dioxide in the water, and so cause the precipitation of the carbonate.

$$CaCO_3 \cdot CO_2 + Ca(OH)_2 = CaCO_3 + CaCO_3 + H_2O$$

Waters containing calcium carbonate or magnesium carbonate in solution are known as *temporarily hard* waters, because they can be softened by boiling as above indicated. Other salts, which cannot be so readily removed, make water *permanently hard.*

Calcium chloride.—($CaCl_2$.) This salt is formed when calcium oxide or hydroxide or carbonate is dissolved in hydrochloric acid.

$$CaO + 2HCl = CaCl_2 + H_2O$$
$$CaCO_3 + 2HCl = CaCl_2 + H_2O + CO_2$$

Calcium chloride will form crystals containing water, for example, $CaCl_2 \cdot 6H_2O$, and when the water is removed by strong heat, the anhydrous salt will readily absorb water again. On account of being thus hygroscopic, calcium chloride is frequently used for drying gases or liquids.

Chloride of Lime.—This is the name often given to a substance formed by saturating slaked lime with chlorine. Its composition is probably represented by the formula $CaOCl_2$. It is a white powder which readily sets free chlorine, when treated with an acid.

$$CaOCl_2 + 2HCl = CaCl_2 + H_2O + Cl_2$$
$$CaOCl_2 + H_2SO_4 = CaSO_4 + H_2O + Cl_2$$

The chlorine thus obtained is largely used for bleaching cotton and linen, and the chloride of lime is therefore called *Bleaching Powder.*

Calcium Sulphate occurs in nature as gypsum ($CaSO_4 \cdot 2\,H_2O$). It is slightly soluble in water, but enough of it is found in many waters used for steam making to form an extremely hard scale in the boilers. Its complete removal before the water enters the boiler, is an important and unsettled problem, but the addition of a proper amount of sodium carbonate is of considerable help.

When carefully heated to 230° F., gypsum loses about three-fourths of its water of crystallization. The resulting powder, when stirred with water into a paste, *sets* firmly, or becomes a hard mass, and under the name of *Plaster of Paris* is largely used for making casts.

Calcium Phosphate ($Ca_3(PO_4)_2$) occurs in nature as the mineral phosphorite, and also in the bones of vertebrate animals. When treated with sulphuric acid in proper proportions, this insoluble normal phosphate is changed to the soluble *primary* phosphate, which is then used as an artificial fertilizer, under the name of *superphosphate of lime.*

$$Ca_3\,(PO_4)_2 + 2H_2SO_4 = 2CaSO_4 + CaH_4\,(PO_4)_2$$

Calcium Silicate ($CaSiO_3$) is important because it is a constituent of almost all sorts of glass. Alone, it is very hard to fuse, and tends to become crystalline, but when mixed with potassium silicate, K_2SiO_3, or sodium silicate, Na_2SiO_3, the mass becomes fusible at moderate temperature, transparent, amorphous, and practically insoluble in all ordinary liquids. This is the common window glass and bottle glass of commerce. It is made by fusing together clean sand, lime, and soda. By using lead oxide instead of lime, we obtain a glass that is softer and more fusible, but is highly refractive, and takes a beautiful lustre when polished. It is used for *cut glass* ware.

ACIDS.

The three acids most common and important commercially are sulphuric acid; H_2SO_4; hydrochloric acid, HCl; and nitric acid, HNO_3.

Sulphuric Acid is the most important chemical in the arts because it is the basis of many chemical industries, and its low cost gives it preference over other acids. It is made from sulphur or the sulphur in iron pyrites, FeS_2. The sulphur is burned to sulphur dioxide, SO_2; oxygen in the presence of water is added producing sulphuric acid. The reactions are:

$$(1)\quad S + O_2 = SO_2$$

$$(2)\quad SO_2 + O + H_2O = H_2SO_4$$

The action of the oxygen of the air on SO_2 is very slow and the aid of the oxides of nitrogen is necessary to make the process a success.

Nitrogen peroxide NO_2 parts with one atom of oxygen easily in the presence of SO_2 and moisture, forming sulphuric acid and NO gas.

$$SO_2 + NO_2 + H_2O = H_2SO_4 + NO$$

When the NO gas thus formed comes in contact with atmospheric oxygen the NO readily takes on an atom of oxygen and is restored to NO_2. Thus the NO_2 acts as a "carrier of oxygen." By a suitable arrangement of absorbing towers these oxides of nitrogen are used over and over again.

The manufacture of sulphuric acid takes place in a series of immense sheet-lead chambers, which may be over one hundred feet long. The FeS_2 or sulphur is burned in kilns, and the SO_2 gas passes through a tower where it takes up NO gas and moisture. It then passes into the first chamber where more water is introduced in the form of steam. The sulphuric acid forms at once as a white mist which gradually settles to the bottom of the chamber. The process continues in the following chambers and the NO_2 gas is absorbed in a tower at the end of the series to be used over again. The process is continuous. The weak "chamber acid" formed is evaporated in lead pans and finally in platinum to form the thick, heavy, oily liquid commonly called "oil of vitriol." This contains about 95 per cent of real sulphuric acid, H_2SO_4.

Sulphuric acid of high strength is now being made by the contact or "calalitic" process. In this process a mixture of sulphur dioxide, SO_2 and air is passed through a heated tube containing spongy platinum. In some unknown way, the heated platinum brings the SO_2 and the oxygen of the air together forming SO_3 which combines with water making H_2SO_4. This new process bids fair to replace the "lead chamber" process.

The sulphates of lead, barium and strontium are insoluble, and that of calcium only slightly so; other sulphates are soluble.

Hydrochloric acid is made, as is described in the manufacture of soda ash by the LeBlanc process, by heating common salt with sulphuric acid. In this country where the LeBlanc process is not used, the hydrochloric acid is the principal product and the sulphate of soda also obtained is the bi-product. The hydrochloric acid gas, HCl, given off is absorbed by water in earthenware receivers and towers until the solution is of a certain strength, when it is drawn off into glass carboys for sale, making the "muriatic acid" of commerce. It varies in strength from 36 per cent to 29 per cent real HCl gas. When chemically pure it is colorless, but the usual commercial acid is colored yellow from a small amount of iron. All the salts of this acid are very soluble with the exception of the chloride of silver, one of the chlorides of mercury and the chloride of lead; this last is soluble in hot water. Hydrochloric acid is a better solvent than sulphuric acid for some substances.

Nitric acid is produced by heating nitrate of soda with sulphuric acid and condensing the nitric acid driven off in glass or earthen receivers. The pure acid is colorless, but the commercial acid is frequently colored yellow or red by the oxides of nitrogen. It is sold in glass bottles or carboys in strength from 67 per cent to 53 per cent real HNO_3. This acid is the best solvent for most metals because it combines an oxidizing action with its dissolving properties. It is frequently used in connection with the other acids for this reason. A mixture of three parts hydrochloric acid and one part nitric acid forms *aqua regia*, which will dissolve the noble metals, gold and platinum.

PASTEUR IN HIS LABORATORY

Pasteur was the First to Develop the Study of Bacteria—the Active Agents in the Spread of Contagious Diseases and in the Contamination of Water Supplies, and the Useful Agents in Sewage Disposal.

BACTERIOLOGY AND SANITATION

INTRODUCTION

Ours is an age when the people, even of the poorly educated classes, accept without skepticism or surprise the news of a great scientific discovery, yet it is barely seventy years ago that the world received with almost incredulous astonishment the announcement that "Beer yeast consists of small spherules which have the property of multiplying and are, therefore, a living and not a dead chemical substance; that they further *appear* to belong to the vegetable kingdom and to be in some manner intimately connected with the process of fermentation."

When Latour communicated the above observation on yeast to the Paris Academy of Science, June 12, 1837, the whole scientific world was taken by storm, so great was the novelty, boldness, and originality of the conception that these insignificant particles, heretofore reckoned as of little or no account, should be endowed with functions of such responsibility and importance.

At the time when Latour was sowing the first seeds of this great gospel of fermentation, started curiously enough and almost simultaneously across the Rhine, by Schwaan and Kutzing, its greatest subsequent apostle and champion, Louis Pasteur, was only a lad of fifteen, buried in a little town in the provinces of France. Yet some thirty odd years later there was not a country in the whole world where Pasteur's name was not known and associated with these classical investigations in fermentation, in the pursuit of which he spent so many years of his life, and which have proved of such incalculable benefit to the world of commerce as well as science. He cleared away the débris of misconception which had so long concealed from view the vital character of the changes associated with these processes and started the bacterial ball—if it may so be called—rolling with a will,

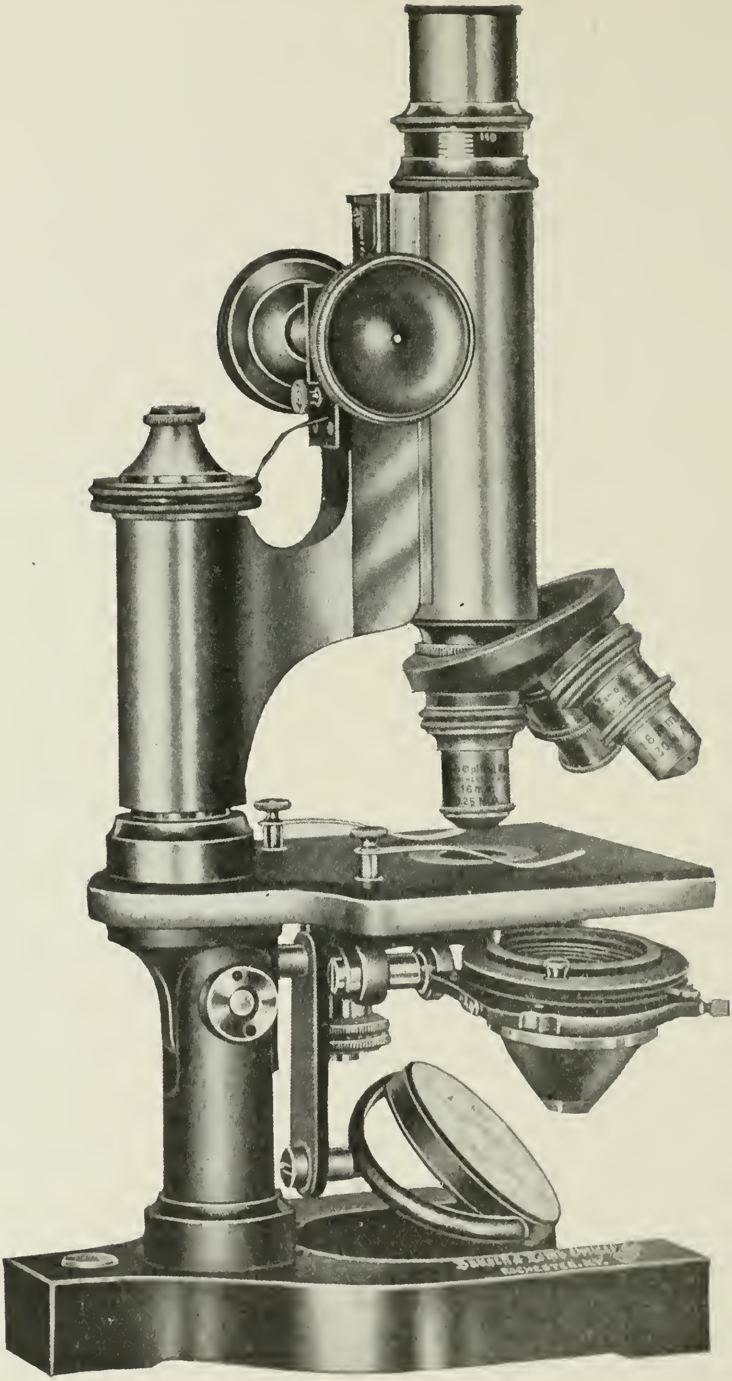


Fig. 1. A Modern Compound Microscope.

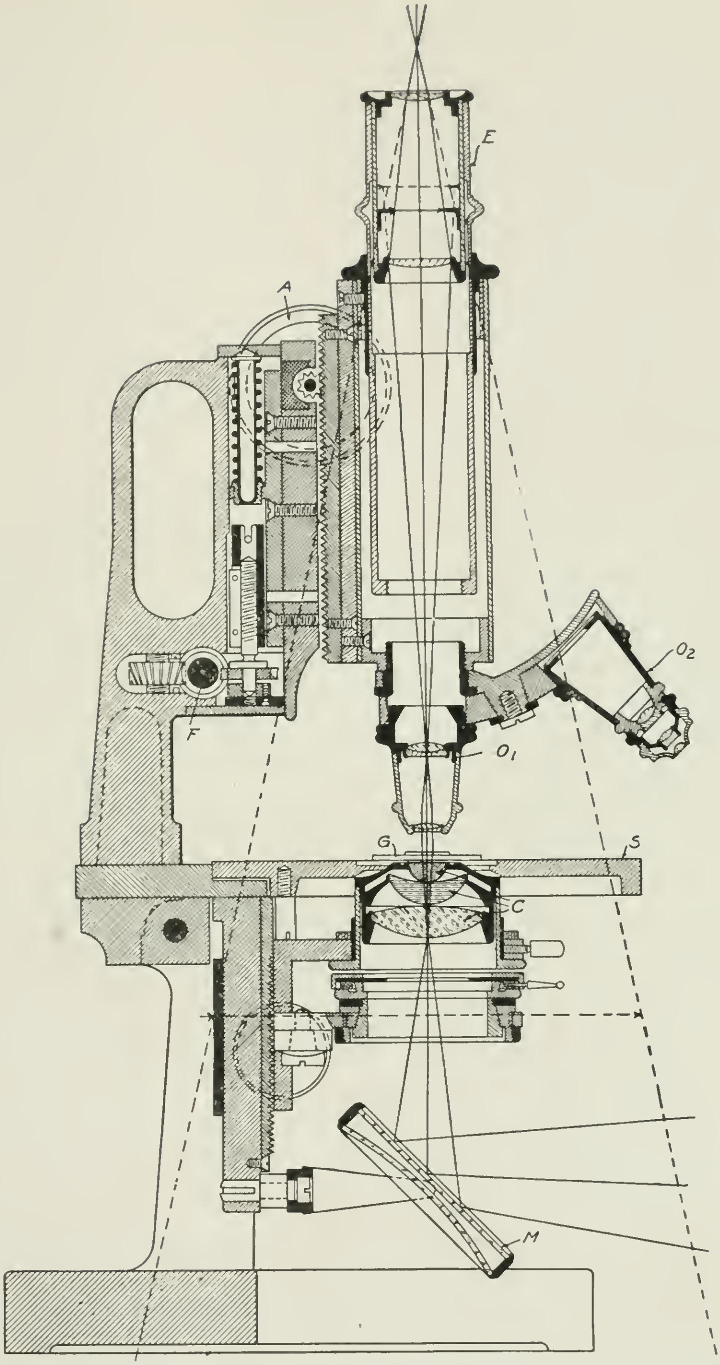


Fig. 2. Section of Compound Microscope, Showing Path of the Light Rays.
E, eye piece; O_1 and O_2, achromatic objectives; C, Abbé condenser for concentrating the light; M, mirror; S, stage on which specimens are placed; G, specimen on cover glass for examination; A, coarse adjustment screw for focusing; F, fine adjustment screw.

and information concerning these minute particles of living matter was readily gathered up from all directions.

The recognition so long refused to bacteria was now ungrudgingly given them and it was realized at last that, in the words of M. Duclaux, "Whenever and wherever there is decomposition of organic matter, whether it be the case of a weed or an oak, of a worm or a whale, the work is exclusively performed by infinitely small organisms. They are the important and almost the only agent of universal hygiene; they clear away more quickly than the dogs of Constantinople or the wild beasts of the desert what remains of all that has had life; they protect the living against the dead. In fact, they do more — for if there are still living beings, if, since the hundreds of centuries the world has been inhabited, life continues, it is to them we owe it."

To-day the science of bacteriology has revolutionized our ideas of disease, has robbed it of its horror, and has taught us the laws of right living, obedience to which will effectually prevent the spreading, at least, if not the recurrence, of epidemics of such well-known maladies as cholera, plague, typhoid fever, and smallpox.

HISTORY OF BACTERIOLOGY

The honor of being the first to see bacteria and identify roughly their form undoubtedly belongs to a Dutch lens-maker named Van Leeuwenhoek, who, in the latter part of the seventeenth century, saw through his microscope "Tiny animals which moved about in the most amusing fashion." After nearly a century, the Danish zoölogist, Müller, discovered many structural details, of which his predecessors had been ignorant, and succeeded in describing so faithfully several kinds of bacteria that they can be identified to-day. However, progress was exceedingly slow and, although Ehrenberg (1795-1876) did much important work in classifying and naming some of the principal forms, no great increase in the knowledge of these invisible organisms was recorded.

The Compound Microscope. The reason for the lack of development noted above, which, in the light of subsequent discoveries is perfectly clear to us, was the imperfection of the tools with which these men had to work. Bacteriology, being the study of living things much too small for the naked eye to see, was dependent in its own development upon the improvement of the compound microscope, an instrument which had been invented as early as 1650 but, owing to its imperfect construction, was incapable of furnishing the higher magnifying powers which were necessary to make visible the structure of these minute organisms. Between the period 1815 to 1830, however, the long looked for improvement came and what is known as the *achromatic objective* was invented. This attachment to the microscope, together with improvements in quality and workmanship of the lenses, not only cleared the microscopic field of disturbing colors due to the dispersion of light, thereby making extremely high magnifications possible, but also immensely increased what in lens parlance is known as *definition*, or *detail*. Figs. 1 and 2

Fig. 3. Favus Culture (man). (From *Kolle & Wassermann.*)

Fig. 4. Yeast Ferment. (From *Kolle & Wassermann.*)

show the modern microscope with which magnifications of 3,000 or more diameters are perfectly possible; Leeuwenhoek probably could not have obtained over 100. Almost immediately this device bore fruit in its application to bacteriology. In 1837, an Italian inventor, Bassi, announced that *muscardine*, a contagious disease of silkworms previously not understood, was really due to a parasite. Two years later a still more startling discovery was made by Schoenlein that *favus*, a rather rare disease of the human scalp, was also due to a parasitic fungus growing at the roots of the hair, Fig. 3.

Fermentation a Disease. Reference has already been made to a contribution from the botanists to the effect that the whole process of fermentation was one of growth of microscopic fungi, Figs. 4 and 5. This latter theory of Latour was not accepted without a struggle and the powerful opposition of Liebig retarded its acceptance for some time; but it was finally made clear by the work of Pasteur, between 1857 and 1863 that live *yeast* is the real *ferment* of the alcoholic fermentation. It could hardly fail to occur to any thoughtful person possessed of sufficient knowledge of the facts, that if this theory were true for certain diseases of *wine* and *beer* it might well be true for certain diseases of *animals* because of the great similarity in the steps by which the diseases progress in their respective surroundings. As an illustration it might be well to take the fermentation of apple

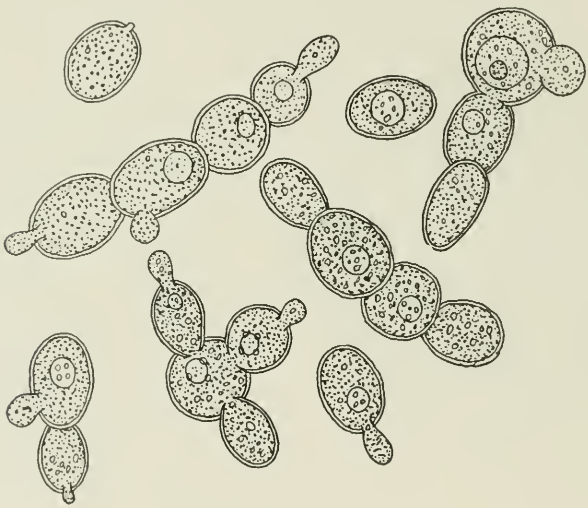


Fig. 5. A Yeast Garden.

juice, or cider, and smallpox. To begin with the apple, its skin protects the flesh of the apple from contamination by the air. On this being removed, however, and the juice pressed out, it is at once exposed to air, to dust, to the press and the sides of the vessel which contains it. At first the juice is sweet and unfermented but after a time the well-known change takes place during which the cider becomes, as is said, *hard*. This process is called *working* or the active fermentation of the cider, and is accompanied by a slight rise in temperature. It is also well known that gas is given off by the cider and the sugar is replaced by alcohol; for this reason the whole process is called *alcoholic fermentation*. This fermentation is not indefinitely prolonged but after a certain time all action ceases and the liquid assumes a permanent state. Since the work of Louis Pasteur, it is known that what really happened during this process was first, the seeding of the apple juice by wild yeast; second, the slow growth during a period of quiet; third, its active growth and working during the time of greatest fermentation; and fourth, the gradual disappearance of all activity.

To turn to the case of smallpox the process is as follows: A patient who is peculiarly susceptible must be exposed to the disease either by contact with a person already infected, or by clothing, letters, or food which have been handled by such a person. After such an exposure there is a period during which no change takes place, but soon the disease begins to show itself by the appearance of certain symptoms which have become well known to physicians. A little later headache and other troubles appear and the patient becomes seriously ill. A rise of temperature, or fever, is discovered, and eruption and other marks of smallpox appear. This process continues until the crisis is reached, when if death does not supervene, recovery slowly ensues, the patient gradually becoming free from the disease. The patient who recovers is now *immune* from further recurrence of this malady. In other words, just as the cider is susceptible only once to alcoholic fermentation so the smallpox patient is incapable of a second attack of the disease. A study of the progress in these two illustrations will show the striking similarity.

Pasteur and the Silkworm Disease. Pasteur who had so largely contributed to the understanding of this microscopic development in the case of yeasts, was destined to show the accuracy of the parallel between fermentation and disease, which has just been given, in a very startling way. As has been said, his investigations were up to 1863 confined to the study of beer and wine fermentation. In 1865 he responded to an urgent call from the French government to study the famous *silkworm disease*. Inasmuch as the successful solution of this disease was a great factor in establishing bacteriology as a true science, the admirable report of Pasteur's son-in-law, M. V. Radot*, is given in brief, as follows:

"The life of the population of certain departments in the South of France hangs on the existence of silkworms. Fig. 6. In each

*Reprint from "Louis Pasteur: His Life and Labors." by permission of D Appleton and Company.

house there is nothing to be seen but hurdles, over which the worms crawl. They are placed even in the kitchens, and often in well-to-do families they occupy the best rooms. In the largest cultivations, regular stages of these hurdles are raised one above the other, in immense sheds, under roofs of disjointed tiles, where thousands and thousands of silkworms crawl upon the litters, which they have the instinct never to leave. Great or small, the silkworm-rearing establishments exist everywhere. When people accost each other, instead of saying, 'How are you?' they say 'How are the silkworms?' In the night they get up to feed them or to keep up around them a suitable temperature. And then what anxiety is felt at the least change of weather! Will not the mulberry leaves be wet? Will the worms digest well? Digestion is a matter of great importance to the health of the worms, which do nothing all their lives but eat! Their appetites become especially insatiable during the last days of rearing. All the world is then astir, day and night. Sacks of leaves are incessantly brought in and spread out on the litters. Fig. 7. Sometimes the noise of the worms munching these leaves resembles that of rain falling upon thick bushes. With what impatience is the moment waited for when the worms arrive at the last moulting! Their bodies swollen with silk, they mount upon the brambles prepared for them, where

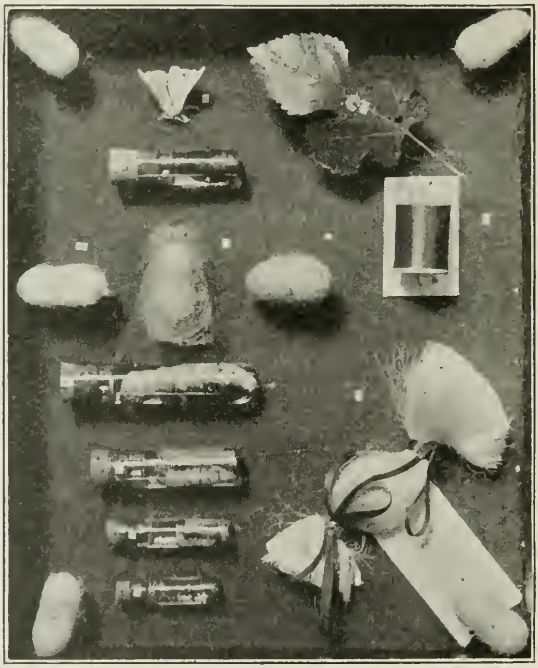


Fig. 6. The Silkworm in Various Stages of Development, its Cocoons and the Finished Silk.

they shut themselves up in their golden prisons and become chrysalides. Fig. 8. What days of rejoicing are those in which the cocoons are gathered; when, to use the words of Olivier de Serres, the silk harvest is garnered in! . . .

"In the epidemic which ravaged the silkworm nurseries in 1849, the symptoms were numerous and changeable. Sometimes the disease exhibited itself immediately. Many of the eggs were sterile, or the worms died during the first days of their existence. Often the hatching was excellent, and the worms arrived at the first moulting, but that moulting was a failure. A great number of the worms

Fig. 7. Mulberry Trees and the Leaf Pickers.

taking little nourishment at each repast, remained smaller than the others, having a rather shining appearance and a blackish tint. Instead of all the worms going through the phases of this first moulting together, as is usually the case in a batch of silkworms, they began to present a marked inequality, which displayed itself more and more at each successive moulting. Instead of the worms swarming on the tables, as if their number was uniformly augmenting, empty spaces were everywhere seen; every morning corpses were collected on the litters.

"Sometimes the disease manifested itself under still more painful circumstances. The batch would progress favorably to the third, and even to the fourth moulting, the uniform size and the health of the worms leaving nothing to be desired; but after the fourth moulting, the alarm of the husbandman began. The worms did not turn

Fig. 8. Silkworms Feeding upon the Leaves of the Mulberry Tree, Their Favorite Food.

white, they retained a rusty tint, their appetite diminished, they even turned away from the leaves which were offered to them. Spots appeared on their bodies, black bruises irregularly scattered over the head, the rings, the false feet, and the spur. Here and there dead worms were to be seen. On lifting the litter, numbers of corpses would be found. Every batch attacked was a lost batch. In 1850 and 1851 there were renewed failures. Some cultivators attributed these accidents to bad eggs, and got their supplies from abroad.

"At first everything went as well as could be wished. The year 1853, in which many of these eggs were reared in France, was one of the most productive of this century. As many as twenty-six millions of kilogrammes (about 28,500 tons) of cocoons were collected, which produced a revenue of 130,000,000 francs. But the year following, when the eggs produced by the moths of these fine crops of foreign origin were tried, a singular degeneracy was immediately recognized. The eggs were of no more value than the French eggs. It was, in fact, a struggle with an epidemic. How was it to be arrested? Would it be always necessary to have recourse to foreign seed? And what if the epidemic spread into Italy, Spain, and the other silk-cultivating countries?

"The thing dreaded came to pass. The plague spread; Spain and Italy were smitten. It became necessary to seek for eggs in the Islands of the Archipelago, in Greece, or in Turkey. These eggs, at first very good, became infected in their turn in their native country; the epidemic had spread even to that distance. The eggs were then procured from Syria and the provinces of the Caucasus. The plague followed the trade in the eggs. In 1864, all the cultivations, from whatever corner of Europe they came, were either diseased or suspected of being so. In the extreme East, Japan alone still remained healthy.

"Agricultural societies, governments, all the world, were preoccupied with this scourge and its invading march. It was said to be some malady like cholera which attacked the silkworms. Hundreds of pamphlets were published each year. The most foolish remedies were proposed, as quite infallible—from flowers of sulphur, cinders, and soot spread over the worms, or over the leaves of the mulberry, to gaseous fumigations of chlorine, of tar, and of sulphurous acid. Wine, rum, absinthe, were prescribed for the worms, and after the absinthe it was advised to try creosote and nitrate of silver. In 1863 the Minister of Agriculture signed an agreement with an Italian who had offered for purchase a process destined to combat the disease of the silkworms, by which he, the Minister, engaged himself, in case the efficacy of the remedy was established, to pay 500,000 francs as an indemnity to the Italian silk cultivator. Experiments were instituted in twelve departments, but without any favorable result. In 1865, the weight of the cocoons had fallen to four million kilogrammes. This entailed a loss of 100,000,000 francs.

"The Senate was assailed by a despairing petition signed by thirty-six hundred mayors, municipal councillors, and capitalists of the silk-cultivating departments. The great scientific authority of M. Dumas, his knowledge of silk husbandry, his sympathy for one of the departments most severely smitten, the Gard, his own native place, all contributed to cause him to be nominated *Reporter of the Commission.* While drawing up his report, the idea occurred to him of trying to persuade Pasteur to undertake researches as to the best means of combating the epidemic.

"Pasteur at first declined this offer. It was at the moment when the results of his investigations on organized ferments opened to him a wide career; it was at the time when, as an application of his latest studies, he had just recognized the true theory of the manufacture of vinegar, and had discovered the cause of the diseases of wines; it was, in short, at the moment when, after having thrown light upon the question of spontaneous generation, the infinitely little appeared infinitely great. He saw living ferments present everywhere, whether as agents of decomposition employed to render back to the atmosphere all that had lived, or as direct authors of contagious diseases. And now it was proposed to him to quit this path, where his footing was sure, which offered him an unlimited horizon in all directions, to enter on an unknown road, perhaps without an outlet. Might he not expose himself to the loss of months, perhaps of years, in barren efforts?

"M. Dumas insisted. 'I attach,' said he to his old pupil, now become his colleague and his friend, 'an extreme value to your fixing your attention upon the question which interests my poor country. Its misery is beyond anything that you can imagine.'

" 'But consider,' said Pasteur, 'that I have never handled a silkworm.'

" 'So much the better,' replied M. Dumas. 'If you know nothing about the subject, you will have no other ideas than those which come to you from your own observations.'

"Pasteur allowed himself to be persuaded . . . and on June 6, 1865, started for Alais. The emotion he felt on the actual spot where the plague raged in all its force, in the presence of a problem requiring solution, caused him at once to forget the sacrifices he had made in quitting his laboratory at the École Normale. He determined not to return to Paris until he had exhausted all the subjects requiring study, and had triumphed over the plague.

"One of the most recent and the most comprehensive memoirs upon the terrible epidemic had been presented to the Academy of Sciences by M. de Quatrefages. One paragraph of this paper had forcibly struck Pasteur. M. de Quatrefages related that some Italian naturalists . . . had discovered in the worms and moths of the silkworm minute corpuscles visible only with the microscope. . . . This instrument had already rendered such services to Pasteur in his delicate experiments on ferments that he was fascinated by the thought of resuming it again as an instrument of research. . . .

"In a few hours after his arrival he had already proved the presence of corpuscles in certain worms, and was able to show them to the President and several members of the Agricultural Committee, who had never seen them. . . .

"It was necessary to know if there existed the relation of cause and effect between the corpuscles and the disease. This was the great point to be elucidated. . . .

"One of the first cares of Pasteur was to settle the question as to the contagion of the disease. Many hypotheses had been formed regarding this contagion, but few experiments had been made, and none of them were decisive. Opinions, also, were very much divided. . .

"But whatever the divergences of opinion might be, every one, at all events, believed in the existence of a poisonous medium rendered epidemic by some occult influence. Pasteur soon succeeded, by accurate experiments, in proving absolutely that the evil was contagious. . . . All the disasters that were known to have happened in the silkworm nurseries, their extent, and their varied forms were faithfully reproduced. Pasteur created at will any required manifestation of the disease. . . .

"For five years Pasteur returned annually for some months to Alais. The little house nestling among the trees, called *Pont-Guisket*, became at the time his habitation and his silkworm nursery. . . .

"All of the obscurity which enveloped the origin of the diseases of silkworms had now been dispelled. Pasteur had arrived at such accurate knowledge both of the causes of the evil and their different manifestations that he was able to produce at will either of the two important characteristic diseases. He could so regulate the intensity of the disease as to cause it to appear on a given day, almost at a given hour . . . to triumph over the disease called *pébrine* which was so threatening, Pasteur devised a series of observations as simple as they were ingenious . . . this process of securing sound eggs is now universally adopted. . . .

Fig. 9. Examining a Drop of Liquid to Preve the Presence of Disease Germs.

"But if Pasteur brought back wealth to ruined countries, if he had returned to Paris happy in the victory he had earned, he had also undergone such fatigues and had so overdrawn himself in the use of the microscope while absorbed in his daily and varied experiments, that in October,. 1868, he was struck with paralysis of one side. Seeing, as he thought, death approaching, he dictated to his wife a last note on the studies which he had so much at heart. This note was communicated to the Academy of Science eight days after this terrible trial.

"A soul like his possessing so great a mastery over the body ended by triumphing over the affliction. Paralyzed on the left side, Pasteur never recovered the use of his limbs, and to this day (1884), sixteen years after the attack, he limps like a wounded man."

TENTH STREET, COLON, BEFORE CLEANING AND PAVING
Compare with View of the Same Street after Paving on Page 299

Antiseptic Surgery. When the news of Pasteur's discovery reached London, Lord Lister, already an eminent surgeon of Edinburgh, became convinced that the many diseases of wounds which so often result seriously to the patient, were infections and if so must be preventable by proper precautions. Accordingly, he set to work to develop methods along the lines suggested by these discoveries, and by the use of antiseptic dressings, sprays, and sterilized instruments, he was enabled to bring about such a change in surgical methods that these precautions have become the standard methods in surgery since that time. Operations formerly dreaded are now done with perfect assurance and constant success. Operating rooms and hospitals are built with the one idea of exclusion or control of the micro-organisms which are the principal enemies of the patient and the surgeon.

Liquid Cultures. The great value of Pasteur's work, aside from the immediate theoretical results which he obtained, lay in his establishment of the method of growing the bacteria which he was studying and his emphasis of the importance of having these cultures pure. He was, it is true, compelled to use what is known as *liquid* cultivation, that is, the use of a liquid food such as beef broth, on which the bacteria could feed and multiply. Nevertheless, by a long process, he was able to obtain cultures which were fairly pure. Pasteur, therefore, has earned the right to be called the *founder* of bacteriology. It remained, however, for Robert Koch to establish bacteriology as a science; and it is to this noted scientist that the tremendous development in bacteriology during the last twenty-five years is due.

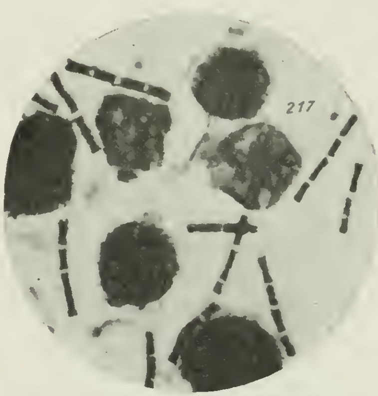
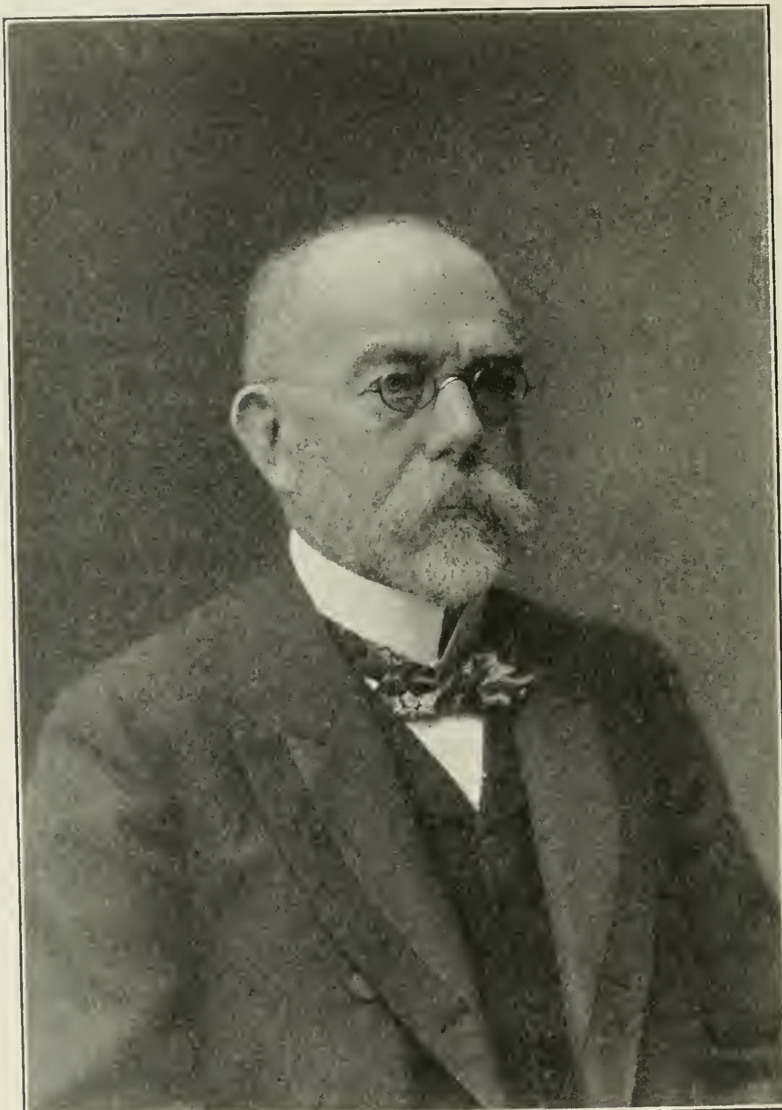


Fig. 10. Anthrax Bacilli in Spleen. (From *Kolle & Wassermann.*)

Koch's first contribution was the positive proof that the disease of cattle and sheep and horses, called *anthrax*, was bacterial in its nature, and also that the bacteria are the *cause* and not the *consequence* of the disease itself, a point which up to this time had been very much in doubt. On



Robert Koch, Who Made Bacteriology a Science.

examining the bodies of cattle dead of anthrax, Koch found, by microscopic examination, Fig. 9, small rods or sticks, Fig. 10, in the blood and other organs. He transferred a small amount of blood or other tissue, charged with these mysterious rods, to a comparatively large portion of the liquid which constitutes the aqueous humor of the ox's eye. This latter was to be the medium upon which the bacteria were to grow. After a few days or even hours the rods had multiplied enormously, while the tissue which was carried over with them was not increased in the least. By successive transfers of this infected portion of the medium to other

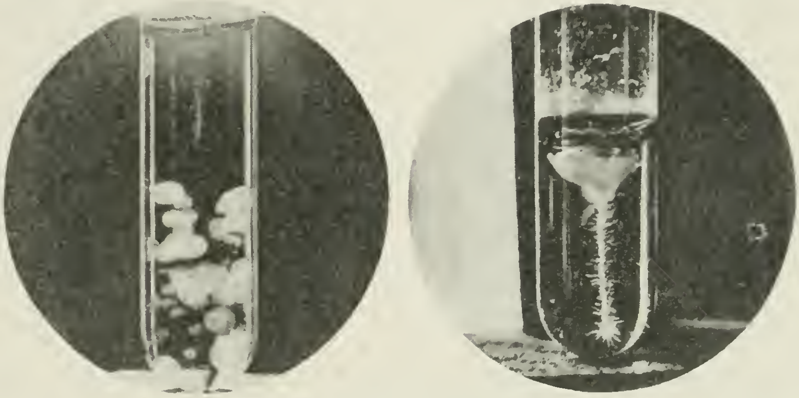


Fig. 11. Typical Solid Cultures.
(From *Gunther*.)

portions of uninfected liquid, Koch was at last able to obtain what would be called a *pure* culture, in which none but living organisms remain and, in fact, in which probably none of the parent organisms existed. Koch reasoned that, if these bacilli were the active agents in the production of the disease of anthrax, and could be placed in the system of a perfectly healthy animal, they would induce an attack of the disease in this new subject. He, therefore, proceeded to inoculate healthy animals with his pure cultures with the result that they promptly manifested symptoms of the disease and died.

Robert Koch and Solid Cultures. This result gave to the study of bacteriology a tremendous stimulus and from 1875, the date of Koch's discovery, until 1881, the progress was brilliant if slow. At the latter date Koch made another discovery which hastened further development most wonderfully. The difficulty with the liquid cultures, aside from the skill necessary to obtain by repeated transfer of the infected material a comparatively pure culture, has been that the bacteria as they developed could move from one part of the liquid to another and gather in groups or colonies. As a consequence, if different varieties of bacteria were present, their colonies would soon

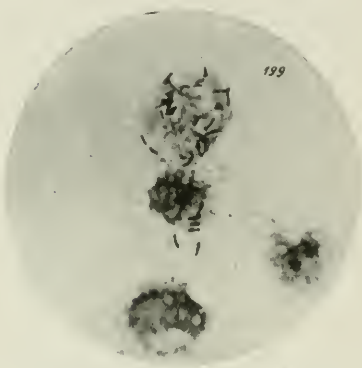


Fig. 12. Human Tuberculosis Bacilli (from lung).
(From *Kolle & Wassermann.*)

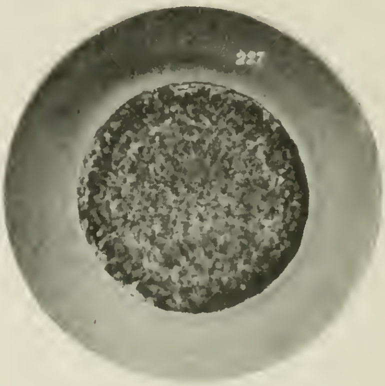


Fig. 13. Asiatic Cholera Colony.
(From *Kolle & Wassermann.*)

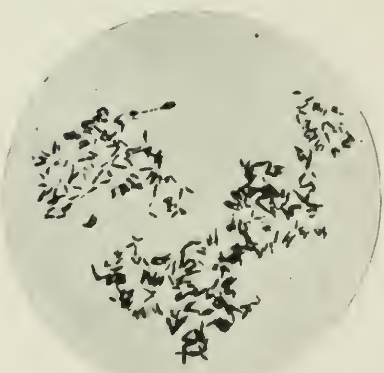


Fig. 14. Diphtheria Bacilli.
(From *Gunther.*)

Fig. 15. Typhoid Bacillus (with flagella).
(From *Kolle & Wassermann.*)

become mixed and any particular variety could not be separated. In 1881, Koch hit upon a plan of using *solid* cultures, Fig. 11. By thickening the beef broth or other liquid medium while hot with gelatine or agar, the medium on cooling became a soft moist jelly capable of being melted with a gentle heat and solidifying at room temperature. It will be apparent on a moment's thought that this method would simplify the growing of proper cultures immensely, as the medium would become solid before the bacteria had started their active growth. Each organism would then be surrounded by its own food, which was at the same time its house, in which it could multiply, but without being able to scatter its progeny to other parts of the medium. After a certain period of growth these colonies would be visible to the naked eye in a tube containing such a culture and at any time a portion of the medium could be removed and the bacteria studied under the microscope. From the date of this discovery bacteriology as a science developed by leaps and bounds. One year after his method of *solid* cultures was devised, Koch announced the discovery of the micro-organism of tuberculosis, Fig. 12. In the following year he added to the list the bacillus of Asiatic cholera, a colony of which is shown in Fig. 13 (see also Fig. 36), and the following two years witnessed the discovery of a number of important bacteria including the diphtheria bacillus by Klebs, Fig. 14; the tetanus or lock-jaw organism by Nicolaier; and a more definite knowledge through Gaffky of the bacillus of typhoid fever, Fig. 15, which had been discovered in 1880, by Eberth under the old method of liquid cultures.

To-day, scattered throughout the civilized world, are bacteriological laboratories, filled with the necessary apparatus and manned by a corps of skilled research men and technical assistants who are searching for further knowledge in regard to the already known organisms and the discovery of the few which still resist their painstaking search. Every up-to-date medical man knows his bacteriology and can by its help detect each of the well-known diseases which used to be such a menace to humn life, can watch its progress by means of these analyses, and in a great number of cases bring about a cure. Surgeons and hospital experts have developed antiseptic surgery to such a degree that infections from operations have been reduced to cases of only the grossest carelessness. Every civilized nation is making large appropriations for work along bacteriological and sanitary lines, the benefits from which have shown themselves, for example, in the lack of the diseases characteristic of military camps and battlefields during times of war. The Japanese operations during the recent war with Russia, and the tremendous improvements in sanitary conditions in Havana and Panama, all contribute their testimony to the efficacy of the methods evolved through the aid of this wonderful science.

CLASSIFICATION OF BACTERIAL FORMS

It would be neither possible nor desirable in this short sketch to give any details regarding the structure or mode of development of bacterial forms. The number and variety are so great that their classification resembles in its complexity that of our visible forms in the vegetable kingdom and would lead into discussions not pertinent to the subject of sanitation. However, it is perhaps desirable to gain a general view of the characteristics which are made use of by the bacteriologist in keeping track of his very large and constantly increasing family. When classed according to form, they drop with greater or less facility into three groups known as the *rod* form or *bacillus*, the *ball* form or *coccus*, and the *spiral* form or *spirillum*, as illustrated by Figs. 16, 17, and 18. This

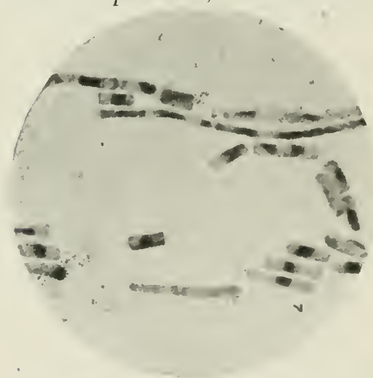


Fig. 16. Rod Form (Bacillus). (From *Kolle & Wassermann.*)

Fig. 17. Ball Form (Coccus). (From *Kolle & Wassermann.*)

classification was much used in the early development of the science as evidenced by the names given to the various forms such as, *bacillus typhosus* and *streptococcus*. Of course, it must not be imagined that a bacteriologist of to-day would make use of this classification alone in identifying any particular bacteria for which he was searching. Many delicate tests are in his possession which include acid reactions, the effect of the bacteria upon different stains and upon different animals, the presence of motor apparatus (flagella), Fig. 15, and a multitude of other tests, the knowledge of which belongs to the technic of bacteriology.

A classification which is an important one in many ways, is based upon the ability of the bacteria to sustain life with or without oxygen, namely, *aerobic* and *anaerobic*. This classification becomes rather important, in understanding for example, the bacterial action in the intermittent filter, which will be discussed later. The reason for this lies in the fact that, whereas some of the destructive work in sewage is performed by the anaërobic variety, a very important part is performed by the class of bacteria which need air in order to perform their functions, therefore, necessitating an *intermittent* flow of sewage.

Fig. 18. Spiral Form (Spirillum). (From *Kolle & Wassermann.*)

Still another classification of bacteria which will be appreciated by the layman, divides our numerous micro-organisms into *harmless* and *harmful* bacteria—a classification, however, which is not always definite because of the fact that a bacterium often gives markedly different reactions in different animals. For example, the bacillus of typhoid fever, when swallowed by man, will nearly always produce serious and fatal illness, but when fed to cattle will produce no effect. Fortunately for man the number in the first class very much exceeds that in the second; and there is a further comforting thought that notwithstanding the few black sheep in the flock, the great majority are working for our good, in fact, are the principal factors in making this world a habitable one.

Useful Bacteria. Notwithstanding the fact that the ultimate purpose of this paper is to give a general knowledge of the forms which are dangerous to man, and which must be guarded against by proper sanitary methods, a few words in passing regarding *useful* bacteria will not be amiss.

To quote from Elliott's *Household Bacteriology*: "As soon as an organism begins to live it begins to die; that is, certain cells or parts of cells die and are cast off from the rest, in order that the whole body may not be injured. Animals and plants die and become dangerous to animal life, especially to man; in fact, the wastes of life, even of his own, are man's greatest menace. Here comes to his aid these microscopic scavengers, the bacteria. Through their agency all dead animal and vegetable matter is changed into the chemical compounds or elements of which it was originally constructed and which are themselves either harmless or helpful to the life of the world."

Fig. 19. Roots of Sweet Pea Showing Nodules.

A tree falls in the woods, an animal dies in the jungle; immediately come millions of bacteria from the soil and the air and so modify the dead tissue that it becomes harmless and its useful ingredients are returned to earth.

Nitrifying Bacteria. Again, all animal life is dependent directly or indirectly upon the vegetable kingdom for food, while plants use as their foods, gases, water, and the various salts which are held in solution by the moisture in the earth. One of the most important elements necessary for plant life is *nitrogen,* a substance which the plant is unable to extract directly from the air but must obtain through the soil. This results in the soil becoming impoverished by this continuous demand for nitrogen, until the use of fertilizers is necessary to bring the supply back to normal. It had long been noticed, however, that the soil when allowed to *rest* for a period would of itself, apparently, increase its nitrogen supply. This action is now known to be due entirely to the soil bacteria which have, by their ceaseless action upon the nitrogen of the air, drawn a part of this inexhaustible supply into the ground in such a form that it can be made use of by the plants. This fact has resulted, in recent years, in the practice of inoculating an exhausted soil with artificially grown bacteria, a method, however, which has had only indifferent success, owing, no doubt, to a failure to understand all the conditions of the problem.

Another fact, long known in agricultural circles, but until recently not understood, has been explained by means of these *nitrifying* bacteria, viz, the fertilizing effect of peas, beans, clover, etc., Figs. 19 and 20. These belong to a class of crops which does not impoverish the soil but rather increases its richness in nitrogen. It has been found

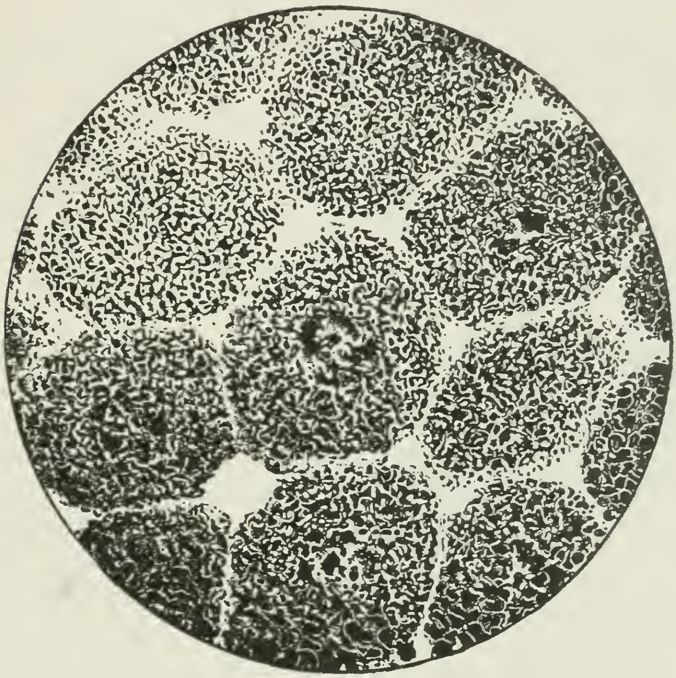


Fig. 20. Cells of Clover Tubercule, Showing Bacilli Highly Magnified.

by experiment that these plants have attached to their roots, nodules or lumps, containing large colonies of these useful bacteria which are storing up nitrogen from the air. The plant, by a process not understood, is able to draw upon these stores to build up its own tissues and so when this *green manure* is plowed under the soil the nitrates which it contains increase the fertility of the earth.

Other Useful Forms. There are many other forms of useful bacteria and only a few can even be mentioned in passing. The tanning of hides involves the treatment of the leather in several fermentation baths, in all of which bacteria are the active agents of fermentation. There are also certain bacterial forms which are active in the formation of indigo, in the ratting of flax, in tobacco curing, butter and cheese making, etc.

"It is seen, therefore, that just as among the hundreds of beautiful flowers in the woods and fields there is the *poison dogwood*; or among the luscious mushrooms there is one deadly variety; or in the large city among the useful law-abiding citizens, there is an occasional thief or murderer; so among the millions of helpful bacteria there are a few which will act harmfully upon the bodies of man and animals." It is undoubtedly true that the study of the helpful forms has done as much to broaden man's understanding and widen the field of his industrial pursuits as the knowledge of the virulent forms has been of service in enabling him to control their operations and prevent great loss of life.

PREVENTION OR CONTROL OF BACTERIA IN THE HUMAN BODY

Toxins. All that has so far been said in regard to bacteria and their action in diseases does not give any idea of the form which this harmful action may take. There are at least three ways in which their influence may be felt; first, by the obstruction produced in the system by the presence of the organisms themselves; second, by the robbery of food which should otherwise have gone to the body itself; and third, by the formation of substances harmful to the body and, therefore, classed as essentially poisonous. For some time the first two of these possibilities only were considered, but soon after, by the active work of Koch and others, the effects of the bacteria in the systems of such susceptible animals as the guinea pig and rabbit, Fig. 21, were carefully studied and the fact was made clear that the third method of influence was the essential one in the operation and growth of disease. It is now universally recognized that the principal method by which the bacteria produce their harmful effects is in the generation of poisonous products called *toxins*, resulting from the operation of living ferments within or upon the organism. In the process of fermentation of apple juice the toxin is alcohol, while in the development of the various contagious diseases, each microbe produces its own toxic substance which must be understood and treated accord-

Fig. 21. Inoculating Guinea Pigs with Germs to Recover Them in the Blood.

ing to its characteristics. In other words, as yeast produces alcohol, so the diphtheria bacillus produces diphtheriatoxin, the typhoid fever bacillus, typhotoxin, and so on.

Vital Resistance and Susceptibility. If the presence of these deadly bacteria in a human organ, for example, is granted, then their activity in new surroundings depends upon whether the soil is to their liking and whether only feeble efforts are put forth to combat them. Nature has provided the body of the average man with a *vital resistance* to disease, that is, a power to withstand the ordinary attacks of these invading hosts. When the resistance is particularly low the body is called *susceptible.* It thus comes to pass that in any contagious disease the energy and virulence of the attacking agents are pitted against the resistance of the patient and a struggle ensues for the mastery. The active control of the sanitary situation, therefore, involves on the one hand, such control of the environment of these active agents of disease that their attacks may be weakened; and on the other hand, such improvement in the general health of the community that the body resistance may be sufficient to withstand attack. The general public is very apt to consider only the violent epidemics which are due to some violation of sanitary laws, and the methods necessary to arrest the progress of the disease, disregarding entirely the slow but ultimately beneficial effects of fresh air, cleanliness, and the many other sanitary precautions which bring about a more healthful condition and a higher body resistance. And yet, when it is remembered that the great epidemics come seldom, affect a small number only, and pass quickly, while filth and bad air act unfavorably on a much larger number and are always present, keeping the people constantly weakened and open to the attack of disease, the latter problem would seem to be at least equally important. It is certainly true that the improvement in general public health renders the occurrence of epidemics less frequent and widespread; hence the chief work of sanitation is in the careful supervision of man's surroundings and the improvement in the habits of those who otherwise would be oblivious to their personal responsibility in the life of the community.

Immunity. When the vital resistance, through either a perfect constitution or exceptional surroundings, becomes abnormally high so that all forms of disease can be thrown off without harmful effect, the organism is said to be *immune.* This subject of *immunity* is one of great importance but is by no means understood. It is, nevertheless, well known that, in addition to a comparative immunity against infectious diseases which is found in all robust and healthy persons, an astonishing immunity is developed in a body in which a contagious disease has done its work. In the first case several natural agencies might contribute to the routing of the microbes, among which might be mentioned the skin as a mechanical defense, and the gastric and other juices of the body as among the physiological defenses. Of the latter class, might also be mentioned the white blood corpuscles or *phagocytes,* which, according to Metchinkoff, besides acting as degesting cells and as scavengers, are also the chief defenders of the body against the bacteria which have invaded the system. "As soon as the infective agents have penetrated into the body, a whole army of white blood corpuscles proceed toward the menaced spot, Fig. 22, there to enter into a struggle with the micro-organisms."

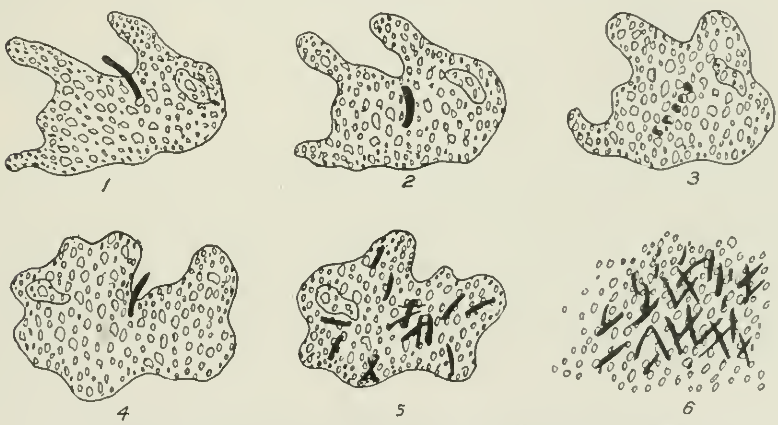


Fig. 22. A Pictorial Combat between Phagocytes and Bacteria.
1, 2, 3, show entry and repulse of the bacterium. 3, 4, 5, represent a triumph for the bacteria.

This natural immunity, or more properly, resistance, is not as perfect as that which is given to the body through the mysterious influence of disease itself. However, bacteriologists, by following the lead which this phenomenon has given them, have discovered methods by which an *artificial immunity* may be developed.

Artificial Immunity. The first systematic step toward this artificial immunity from disease was taken in the case of smallpox. The work took the form of the inoculation of some *matter*, obtained from eruptions on the body of a smallpox patient, under the skin of a healthy person who chose to suffer a mild form of the disease when well, rather than undergo it in more virulent form and possibly succumb when the body resistance was low. This method had come to Constantinople from the far East, possibly originating with the Chinese, and was first introduced into England in 1717, through the agency of Lady Montagu, the wife of the British Ambassador. Through her correspondence with influential persons in England the method was adopted there, and later in America. To us of this day it is hard to conceive of the terrible ravages of this disease even as late as the middle of the eighteenth century. A writer, Dr. Brooke, in 1766, made the statement that "In the ordinary course and duration of human life *scarce one in a thousand* escapes the smallpox." It would be easy to multiply authoritative statements of the prevalence of the disease, and yet by this simple process of inoculation, and later by the equally efficient but less violent method of vaccination, the disease has become rare in about the same proportion as it was frequent in the days before these preventive methods were inaugurated.

Vaccination. The method of vaccination to prevent smallpox was discovered by Dr. Jenner in 1796. Of course, he knew nothing at that time in regard to the bacterial nature of the disease, and if he could listen to-day to our up-to-date talk about bacteria, microbes, toxins, and antitoxins, he would not understand a word of it; but, nevertheless, he blazed the trail which led, through artificial immunity, to the salvation of man from one of the most dreaded scourges to which he was subject. It was known in Jenner's time that persons who milked cows having sores on their udders due to an infection called *cowpox,* often showed symptoms of the same disease through the appearance of sores upon their hands. These soon healed after a slight illness, and it was later noticed that such persons were nearly, if not wholly, immune to the disease of smallpox. Dr. Jenner studied this carefully and reached the conclusion that if a person were inoculated with a small portion of the material taken from a cow infected with cowpox, this would produce an effect similar to that obtained through the process which had already been practiced, of inoculation with matter from a human smallpox patient. After many experiments, his conclusions were completely verified, and now large and carefully

Fig. 23. Injection of the Diphtheria Culture into the Horse.

Fig. 24. Drawing the Blood from an Immune Horse in Order to Obtain the Antitoxic Serum.

managed establishments are devoted to the preparation of *virus*, as it is called, which can be used in vaccination. By the latter process the susceptibility is reduced to a minimum, but the protection wears off as time passes and re-vaccination is necessary. The present agitation in many localities in regard to anti-vaccination shows how little the general public knows of this disease and the terrible dread which it caused before the preventive methods were discovered. It is curious to see to what extent persons who, of their own free will, or on the advice of their physicians, cheerfully and even eagerly swallow medicines of unknown, possibly deadly, character, will refuse to obey their medical advisors when they recommend vaccination. It is quite true that some of the agitation against vaccination has been caused by impure virus and careless methods of administering it; but even under these conditions, the gain is so tremendous that their criticisms seem idle and irrelvant.

Fig. 25. Sterilized Bottles Full of Blood. The dark portion shows where the red blood corpuscles have settled out, leaving the plasma at the top, from which the serum is obtained.

Antitoxins. Another method of producing artificial immunity was discovered, in 1892, by Behring and Kitasato in their work on diphtheria. It was discovered by them that the serum—the liquid portion of blood after the coagulum has been removed—from an animal which had been made immune to the poison of diphtheria was able, even in a test tube, to neutralize or impair the virulence of this same poison or toxin; and further, that the serum from an animal which was not immune was not able to do this. Clearly then, substances exist in the serum from an immune animal which were not there before the animal was made immune and our present theory of immunity rests upon this fact. The process of making a body immune according to the serum theory may be described according to Dr. William Sedgewick as follows:

TENTH STREET, COLON, AFTER CLEANING AND PAVING
Note the Improvement in Sanitary Condition over the View Shown on Page 282

"The microbe, or its toxin, irritates the cells of its host. These produce defensive secretions or antitoxins which tend to neutralize the poison or to diminish the activity of the bacillus, or both. If victory is assumed for the cells the condition of temporary immunity or convalescence is found. Victory for the microbe means continued

Fig. 26. Autopsy on Guinea Pig, to Discover Effect of Diphtheria Germs and Recovery Due to Antitoxin.

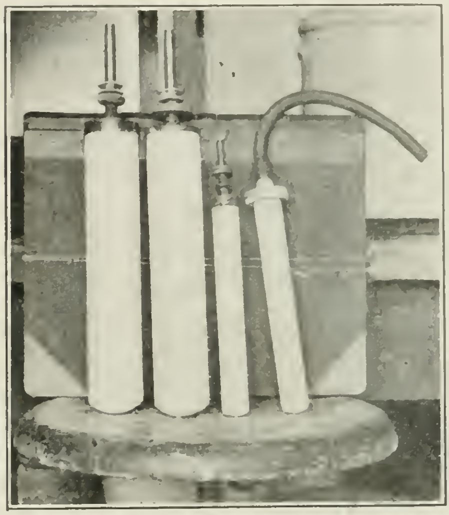


Fig. 27. Filters Used for Filtering the Plasma.

disease or death, as shown in Fig. 22. If it may be assumed that the cells of the body continue to secrete more or less of this preventive substance or that they remain for a long time peculiarly sensitive to even minute doses of the toxin in question, the persistence of more or less immunity can be understood." It is quite possible that the white blood corpuscles are the active agents in producing this defensive secretion.

Fig. 28. Pneumonia Streptococcus Culture One Day Old. (From *Kolle & Wassermann.*)

The methods for the production of the antitoxin serum for diphtheria have been carefully developed. First a pure culture of the diphtheria bacillus is obtained and a small portion of the infected fluid is injected under the skin of a horse, Fig. 23. The animal contracts the disease in a mild form and soon recovers. These injections are continued at intervals until the horse no longer shows any effects. The animal is now immune and when blood is drawn from it, Fig. 24, and properly treated to allow the red corpuscles to settle out, Fig. 25, the serum from this blood is found to contain the required antitoxin. The effect of this is usually studied by the inoculation of the guinea pig with diphtheria germs, and a further inoculation of the preventing serum. An autopsy, as shown in Fig. 26, reveals the action of the toxins and antitoxins. This serum is carefully filtered through porus cups, as shown in Fig. 27, and then injected into patients actually ill with diphtheria as a reinforcing medicine, or into persons *exposed* to the disease. This method has brought about a reduction of over one-half of the deaths from this disease.

Fig. 29. Tetanus (lock jaw) Bacterial Culture Three Days Old. (From *Kolle & Wassermann.*)

Fig. 30. Streptococci Found in Pus. (From *Kolle & Wassermann.*)

As soon as this antitoxin was discovered for diphtheria, all eager experimenters turned their attention to other diseases with the idea that similar sera could be discovered for pneumonia, Fig. 28, tuberculosis, plague, typhoid fever, cholera, and blood-poisoning. At the present date, however, few of these infectious bacteria have been brought into captivity. Antitoxic sera for tetanus (lock-jaw), caused by the bacillus shown in Fig. 29, and some forms of blood-poisoning, Fig. 30, have been tried with fair success, but for the most part, efforts have failed. With the knowledge already obtained from bacteriological study, however, sanitary methods have been developed which effectually control typhoid and cholera epidemics, while the *fresh air treatment* and the use of Koch's *tuberculin* in various forms are improving the hold of physicians upon the ravages of tuberculosis.

The facts given in the foregoing summary represent naturally an extremely brief presentation of the essential points in the development of the study of bacteriology but they will suffice to emphasize and make clear the reasons for the preventive methods of sanitation of the present day. It is enough for us to know that *none of the infectious diseases are now believed to rise spontaneously but only more or less directly from previous cases of the same disease.* It is believed that in every instance there must be an actual invasion of, or at least contact with, a susceptible patient by the micro-organism of the disease in question. Once inside or upon the patient the organisms may grow and multiply, producing at the same time their own peculiar poisons precisely as yeast—in wine, beer, or other fruit juices—produces alcohol as one outcome of its peculiar vital activity. The effects produced in the person are believed to be due to the specific poisons of which he may die, or from which he may recover and thereby become immune.

THE PROBLEMS OF SANITATION

*"Twenty-five years ago Mr. Frederic Harrison, writing of the nineteenth century, gave us this picture of London, the largest city of the modern world, and, indeed, of all time.

> To bury Middlesex and Surrey under miles of flimsy houses; to crowd into them millions and millions of over-worked, under-fed, half-taught, and often squalid men and women; to turn the silver Thames into the biggest sewer recorded in history; to leave us all to drink the sewerage water, to breath the carbonized air, to be closed up in a labyrinth of dull, sooty, unwholesome streets; to leave hundreds and thousands confined there, with gin, and bad air,

*Part of a lecture delivered before the Harvey Society, New York, Oct. 26, 1907, by Professor E. O. Jordan, University of Chicago. (Published by the *American Medical Association.*)

and hard work, and low wages, breeding contagious diseases, and sinking into despair of soul and feebler conditions of body; and then to sing pæans and shout, because the ground shakes and the air is shrill with the roar of infinite engines and machines, because the blank streets are lit up with garish gas lamps, and more garish electric lamps, and the postoffice carries billions of letters, and the railways every day carry 100,000 persons in and out of the huge factory we call the greatest metropolis of the civilized world—this is surely not the last word in civilization.

"We need not pause now to inquire whether this characterization of the London of the nineteenth century was correct, or, admitting that it was, whether it is now true of London or any other city; whether the human race at the beginning of the twentieth century is still dazzled and bewildered by its sudden material acquisitions; whether we are even now rushing violently down a steep place into the sea; I would simply ask you to remark the largest part that faults and defects of sanitation play in Mr. Harrison's eloquent indictment. Some of the hardest things said about the nineteenth century by its critics refer to the neglect of public hygiene. Again and again the luxury of a few and the comfort of more are contrasted with the unhygienic conditions under which many others are forced to live and work. Unhygienic conditions in themselves are nothing new. In medieval London, and indeed throughout Europe, the dwelling places and mode of living of the majority of the citizens were far more unwholesome, far more conducive to the spread of infectious disease than in the London of 1882 or 1907. Mr. Harrison himself in another connection thus pictures the life of the Middle Ages:

The old Greek and Roman religion of external cleanliness was turned into a sin. The outward and visible sign of sanctity now was to be unclean. No one was clean, but the devout Christian was unutterably foul. The tone of the Middle Ages in the matter of dirt was a form of mental disease. Cooped up in castles and walled cities, with narrow courts and sunless alleys, they would pass day and night in the same clothes, within the same airless, gloomy, windowless, and pestiferous chambers; they would go to bed without night-clothes and sleep under unclean sheepskins and frieze rugs; they would wear the same leather, fur, and woolen garments for a life time, and even for successive generations; they ate their meals without forks, and covered up the orts with rushes; they flung their refuse out of the windows into the street or piled it up in the backyard; the streets were narrow, unpaved, crooked lanes, through which, under the very palace turrets, men and beasts tramped knee-deep in noisome mire. This was at intervals varied with fetid rivulets and open cesspools; every church was crammed with rotting corpses and surrounded with graveyards, sodden with cadaveric liquids, and strewn with disinterred bones. Round these charnel houses and pestiferous churches were piled old, decaying, wooden houses, their sole air being these deadly exhalations, and their sole water supply being these polluted streams or wells dug in this reeking soil. Even in the palaces and castles of the rich the same bestial habits prevailed. Prisoners rotted in noisome dungeons under the banqueting hall; corpses were buried under the floor of the private chapel; scores of soldiers and attendants slept in gangs for months together in the same hall or guardroom, where they ate and drank, played and fought.

"At all events the city slum is not a modern institution. The main difference between the medieval and the modern attitude towards unhygienic conditions lies in our having now become awake to the sources of disease and death and to the knowledge that much disease is preventable. The public conscience to-day winces and rebels at the sight of evils once regarded with indifference or helplessness. So long as mankind supposed that, in the language of Cruden's *Concordance*, "disease and death are the consequences and effects of sin," so long did a bewildered resignation accompany the mysterious visitations of Providence. For many this was radically and permanently changed when the germ theory gave to the human race for the first time in its history a rational theory of disease susceptible of experimental verification. When that fact was established that much disease could be prevented, an enduring foundation was laid for works of sanitation.

"The campaign against disease can be carried on in various ways. Individual cases of disease can be nursed with all the care that experience has shown to conduct to recovery, suitable drugs may be administered, surgical interference resorted to, individual peculiarities studied and taken advantage of; in fact, all the resources of modern medicine can be focused on the state of disturbance or abnormality in the individual patient. Such treatment has saved in the past, and will save in the future, many lives dear to friends and family and of incalculable value to country and race.

"As a mass-method of attacking disease, however, it is distinctly palliative and not remedial. There is no man in his right mind who would not rather avoid disease altogether than be healed of a malady even by the most skillful physician. For many and evident reasons prevention must in the long run take precedence over cure.

"Preventive measures fall conveniently into two classes—those dealing with the physical well-being and resistance of the individual, such as diet, muscular exercise, sleep, fatigue, the use of stimulants and narcotics, and the general efficiency of the bodily functions; and secondly, those having special reference to environmental conditions or affecting many persons or communities. The methods that the individual may adopt to ward off disease and enhance resistance lie within the scope of personal hygiene; those that involve larger or smaller groups of individuals, constitute the province of public hygiene or sanitation.

The Rôle of Personal Hygiene. "The methods for the furtherance of personal hygiene must be largely educative in character, and it must be recognized that the progress possible in this direction is distinctly limited by inherited constitutional factors. The prevention of disease and premature death is in many cases impossible even if the strictest and most efficacious regimen be maintained and if the hostile action of outside agencies be successfully avoided. In other words, some organisms carry within themselves the seeds of decay which germinate early and come to fruition in spite of all individual endeavors. A congenitally feeble or defective mechanism may be strengthened, but cannot be remade. In most instances, however, measures of personal hygiene avail powerfully in promoting normal life and happiness and in some degree in preventing premature death. I need only mention the high resistance to many infectious diseases possessed by the well-nourished, properly exercised, undrugged individual. Improvement in personal hygiene must depend to a great extent on education, must necessarily be slow, and its success in preventing disease be conditioned in large part by the inherited constitution.

Public Hygiene. "Any distinction between personal hygiene and public hygiene cannot in the nature of things be an absolute one. The stream cannot rise higher than its source, the welfare of the group is determined by that of the individuals composing it. More and more, too, the concerns of personal hygiene are tending to become problems of public hygiene. Bodily cleanliness is essentially a personal matter; it would be an absurdity in the present state of public opinion to legislate for compulsory bathing, and yet the establishment of free public baths is everywhere recognized as an important measure of public sanitation. The same thing applies to exercise and the establishment of municipal playgrounds and gymnasia. The principle is perfectly sound. Primarily the function of public hygiene is both to avert from the community as a whole the consequences of misdoing, neglect or ignorance on the part of any one, or any number, of its members, and to provide for groups of individuals, conditions as favorable for health and happiness as the most intelligent and far-seeing could demand for themselves. Such conditions may not always be those that the least intelligent or most greedy members of the community desire, but from the point of view of public hygiene they are none the less inevitable.

"Up to the present, measures of sanitation have affected chiefly the infectious diseases. This is shown, for example, by the list of the ten leading causes of death in Massachusetts in 1856 and in 1904, Table 1.

TABLE I

The Ten Leading Reported Causes of Death in Massachusetts in Order of Frequency

1856	1904
Consumption	Heart Disease
*Scarlet Fever	Consumption
Brain Disease	Pneumonia
Old Age	Diseases of Brain and Cord
Pneumonia	Diseases of Kidneys
*Typhoid Fever	Cancer
*Dysentery	Cholera Infantum
Heart Disease	Accidents
Cholera Infantum	Bronchitis
Diphtheria and Croup	Diarrhea and Cholera Morbus

"It is here seen that the diseases that have been displaced are largely the infectious diseases. It is not possible in all cases to determine the factors that have been operative in the decline, and in some cases causes beyond our control have perhaps been at work, but undoubtedly measures of quarantine, isolation, school hygiene, and other protective devices adopted by the community have played a part in the shrinking of once prevalent infections. In some instances the effect of methods of sanitation is not to be mistaken. One of the most remarkable, as indeed one of the best understood

*In 1904 typhoid fever had dropped to thirteenth, dysentery to seventeenth, and scarlet fever to twenty-first place.

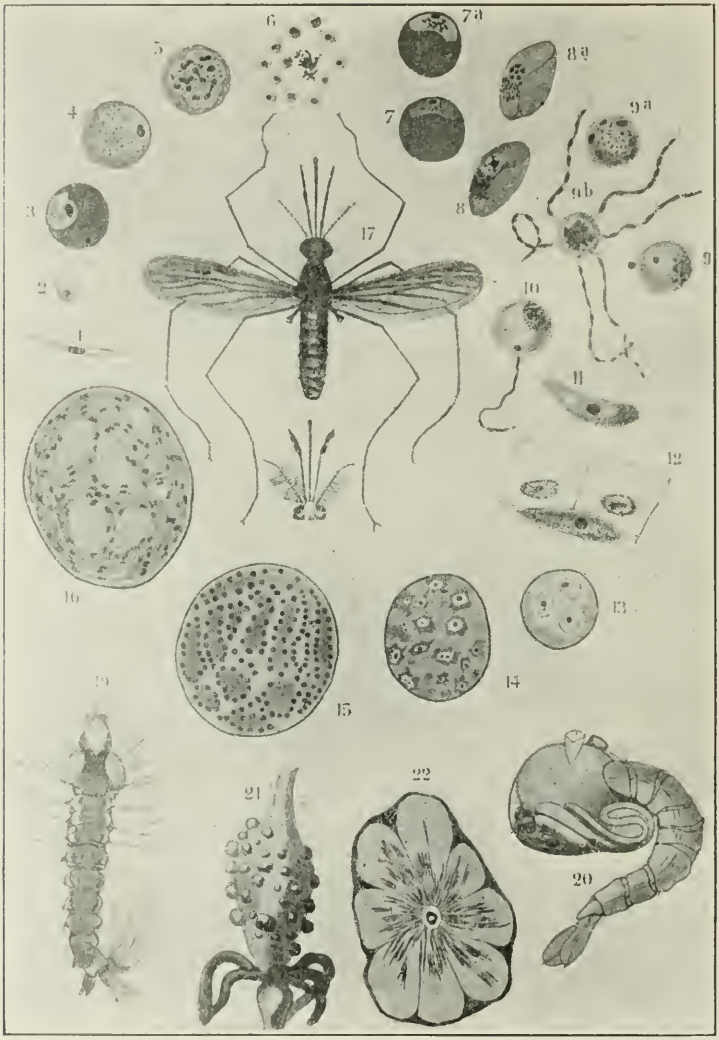


Fig. 31. (After Leuchart-Chun's Wall-Digram.)

ANOPHELES AND THE MALARIA GERM

1, 2. The malaria germ, *Plasmodium*, introduced by a mosquito bite into human blood. 3-5. After penetrating a red-blood cell; its growth at the expense of the latter. 6. Its vegetative multiplication. 7, 8. Crescentic forms (for further development the germs must at this point be transferred from the man to the mosquito). 9. Female germ-cell; 9a, 9b, Male germ-cell. 10. Conjugation of 9 with one of the vibratile arms of 9b. 11. Malaria germ resulting from such conjugation in stomach of mosquito. 12-16. Multiplication (encystment and sporulation) of the malaria germ in the body of the mosquito, with production of many forms like 1 (cycle completed). 17. Female malarial mosquito, *Anopheles claviger;* head of male below. 19, 20. Mosquito larva and pupa. 21. Stomach of mosquito, showing tumors produced by 16. 22. Cross-section salivary gland of mosquito, showing malarial microbes which have wandered into it—from the tumors in 21—and now ready to be transferred with saliva into persons bitten.

examples of the efficacy of sanitary features, is afforded in the influence of improved public water supply on typhoid fever. . . .

"It is surely no small matter that we have come to the point where considerable groups of influential men and women are willing to undertake the task of making plain to the general public the momentous character of these questions. A concerted and persistent campaign of education backed by scientific investigation is likely to have greater weight in moulding public opinion than the isolated appeals of reformers and philanthropists, however timely

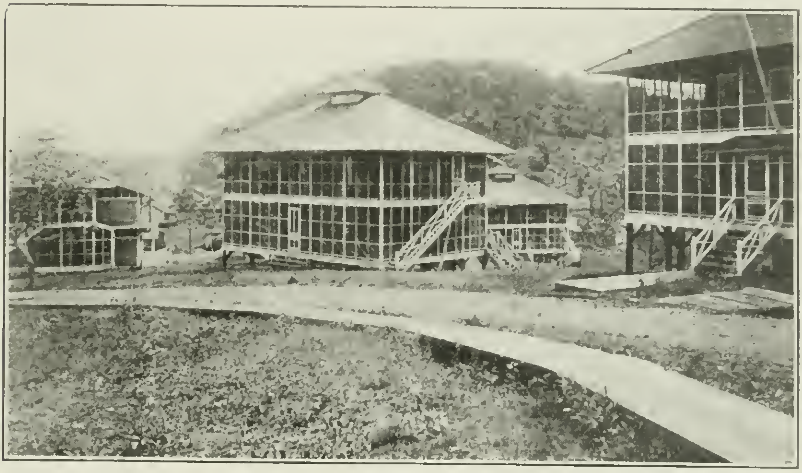


Fig. 32. Houses in the Canal Zone (Panama) Showing Wire Screening Serves to Protect the Inmates from the Mosquito.

and well directed. The great measure of success already achieved by the crusade against tuberculosis at least serves to encourage this belief.

"It is evident, I think, that with the increasing complexity of the social structure, the field of public hygiene will continue for some time to broaden. Many matters affecting the physical well-being of society which are now overlooked, ignored, or regarded as a necessary part of keeping the pace, will come to be seen in their true light."

INFECTION AND CONTAGION

Mediums. As has been already stated, nature has provided a normally high resistance through the mediums of the skin as an external defense against bacteria, and agencies like the gastric juices

Fig. 33. View of Bottle Alley, Colon, September, 1906. These standing pools are the breeding places for the malaria infected mosquito.

Fig. 31. View of Bottle Alley, Colon, June, 1907, Showing Proper Paving and Drainage Methods in the Canal Zone.

and the white blood corpuscles as their enemies within the human system. Infection occurs, under ordinary circumstances, only when these safeguards are broken down in various ways.

The Skin. An apple is provided with its skin and if this is not punctured in any way the apple grows uninterruptedly and develops into the healthy ripened fruit; but if, by a fall or the peck of a bird, this armor is pierced, immediately the organisms in the air enter through this breach, attack the fleshy part of the apple, and begin the work of destruction. It is the same way with the body; a cut may be a very simple matter if caused by an uninfected knife, for example, but if the wound is left open to infection from dust and things which are unclean, or if the instrument which produced the cut happens to be unclean itself and leaves the unhealthy organisms in the wound as it passes through, the effect is the same. The infection soon shows itself in inflammation which may spread locally, fester, and cause great discomfiture if not actual danger when not attended to. If the germs are of an unusually virulent type they may pass into the blood, and if the resistance of the patient is low, may produce extremely rapid changes in the body condition, causing high fever, blood-poison, and possibly death.

Another method of infection through the skin, which has only recently received the attention it deserved, is that of the possibility of infection through the bites of the mosquito and infection by contact with bacteria carried by flies. The former pest has been definitely proved to be responsible for the spread of the characteristic tropical diseases of malaria and yellow fever. In the case of malaria, the fact that the spread of the disease occurred usually near swampy ground, and that the disease was prevalent in country districts rather than in cities, and further that its breaking out was a consequence of extensive soil excavation, all of these idiosyncrasies of malaria fever can now be explained through the creation or maintenance of breeding grounds of the mosquito. Of course, it must not be supposed that the mosquito itself is infected except as it has become so through sucking the blood of a person already subject to an attack of malaria. The contagion, therefore, is due to the fact that the mosquito, so inoculated, passes on the disease germ by biting a person not so afflicted, Fig. 31. It is clear then, that when the available supply of malaria parasites is cut off the bite of the mosquito can no longer convey infection. The plan therefore which has been followed is in brief, first, to carefully screen all dwelling houses, especially those containing malaria patients, Fig 32, and to kill the malaria bacilli already in the patients by the use of quinine; then by draining off all pools of standing water and properly screening all water reservoirs, rain barrels, and such other feeding grounds, to prevent in a great measure the propogation of mosquitoes in inhabited districts. These methods have been used very successfully in Havana and other cities of Cuba, as well as in Panama, as shown by the improvement of an alley in Colon brought about by the American sanitary engineering corps, Figs. 33 and 34, who have transformed these places from regions where malaria was rampant and the mosquito was a pest from which infection could hardly be avoided, into healthy communities where people can sleep peacefully without any preventive methods against the mosquito. The conclusive evidence obtained by the American Military officers, at great personal risk and with admirable courage—that the yellow fever is transmissible in the same way—has enabled the sanitary expert to practically stamp out this disease, or at least to control it by rigorous quarantine regulations, within certain limited districts. By such methods both of these dread diseases which interfered to such a terrible extent with the active work of the French government on the Panama canal, have been put under almost absolute control, enabling the American government to carry on its work in peace and without any great loss of life.

The Alimentary Canal. The more usual avenues of infection, however, are through actual contact with disease germs which are present in the air or on the clothing of persons who are already diseased. These bacteria find their way through the mouth into the alimentary canal where they are ready to begin their operations if the resistance is not too great. Nature has provided in the digestive track various conditions which are unfavorable to the ordinary bacteria; for example, the acid conditions of the gastric juices is fatal to nearly all of the bacteria present in uncooked food and to very many disease germs. The gastric juice is, however, not often sufficient to cope with these organisms and the alimentary canal may be considered in general a rather favorable breeding ground for the bacteria. Many of these germs are carried on through the digestive system and thrown off without harm to the host. If absorbed by the blood, the white blood corpuscles or *phagocytes*, Fig. 22, will attempt to devour them, and if their power is sufficient will accomplish their destruction.

Diphtheria germs, for instance, work by finding lodgment upon the tissues of the throat, grow and multiply upon the normal secretions and food materials there present, and in the course of their development produce the poisonous substance already mentioned as the toxin of diphtheria. This first paralyzes or otherwise interferes with the healthy action of the linings of the throat, whereupon, these cells failing to do their duty, an abnormal secretion of lymph produces the well-known *white patches* so common in diphtheritic throats. At the same time the poison is being absorbed into the general circulation, causing the general symptoms characteristic of the disease. The curves in Fig. 35 show how quickly the throats of the school children respond to contagion from the diphtheria germs thrown off from the bodies of those already infected, when they are kept closely confined in ill-ventilated school rooms.

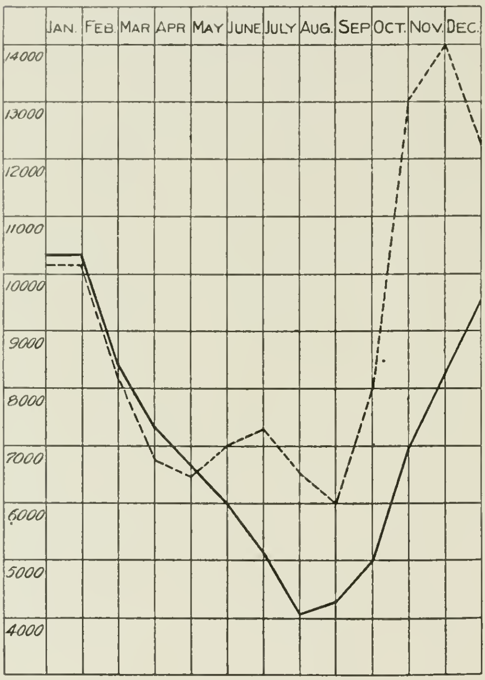


Fig. 35. Diphtheria Chart.
Broken line, school children 5 to 14 years. Solid line, children from birth to 5 years of age.

In Asiatic cholera the infection takes the form of an invasion and an extensive fermentation of the contents of the alimentary canal with tremendous multiplication of the mirco-organisms concerned. At the same time the characteristic poison of cholera is supposedly liberated and absorbed through the walls of the canal, giving rise to the characteristic symptoms such as vomiting, fever, sweating, and delirium.

Sources. If a search is made for the source of these germs which have reached the body from the infected knife or blade splinter, or from the air we breathe, the statement that all the disease germs are spread from cases of the disease itself will seemingly force the responsibility for the creation of these dangerous organisms upon man and other animals. It was formerly supposed that the soil and various other unhealthy materials were extremely fertile sources of infectious diseases; in other words, that the germs not only existed but thrived and multiplied in the earth. It was thought, for example, and is still held by some, that the typhoid fever micro-organism passes a portion of its life in the soil, especially in filthy soil. There is no question, however, that to-day the prevailing opinion is that these germs require body contact in order to develop to any great degree. The recent discovery of the rôle played by the mosquito in the conveyance of malaria and yellow fever merely shows that diseases long associated with swamps and stagnant pools have had their sources only in the animal bodies which inhabited such places. If, therefore, it be true that man and other animals are the principal *original sources* of infection, it thus follows as a matter of course that their excreta are its principal original vehicles, Fig. 36. These would include not only discharges from the digestive tract but the nose, lungs, pores of the skin, etc.; involving, in fact, all avenues by which material can be thrown off from the body. It is interesting to note that the expired air from the lungs formerly so much dreaded by those who watched at the bed-side, appears, according to the careful investigations, to be the least dangerous of all excreta, being practically germ free.

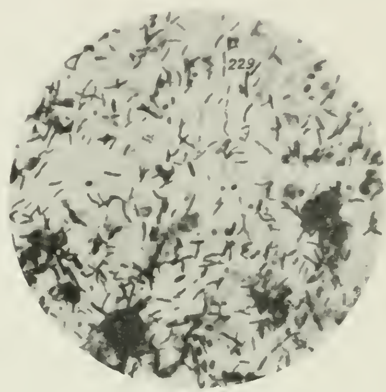


Fig. 36. From Excreta of Cholera Patient on the 23rd Day of Sickness. (From *Kolle & Wassermann.*)

The *secondary vehicles of infectious diseases* which sanitation must combat are the soil, air, water and animals. From the skin the surrounding air may first become infected and then move on laden with disease. Likewise the sputum from the mouth or the discharge from the bowels may be slowly mingled with a stream so that the seemingly pure water way contain unseen and unsuspected germs of deadly disease. Or again, the earth impregnated with human excreta may be dried, pulverized, and as dust blown hither and yon by the wind, infect the human throat, and become the means of inflicting diseases such as diphtheria and tuberculosis.

Fig. 37. A Dust Garden. *a*, mould; *b*, bacteria.

THE CARRIERS OF DISEASE

The Soil. As has already been said, the idea that the soil offers a fertile breeding ground for noxious bacteria has been practically abandoned. That it is inhabited, however, by millions of useful living organisms which carry on important organic transformations is freely admitted, and it would not be surprising if among the many, a few of the disease-producing variety, like the microbe which causes tetanus, would be found to grow in some soils. Nevertheless, it may be considered that the body of the earth is quite free from dangerous bacteria except where it forms the medium through which the infected excreta of man and animals can unite with the ground waters and thus infect the streams and rivers. The surface layers of the soil are not so free from contaminations and, becoming pulverized, rise in clouds of dust to infect the air, irritate the nasal and bronchial passages, and perhaps cause serious afflictions. The presence of the infecting bacteria are easily seen by making a culture as shown in Fig. 37, the spots marked *a* being mould cultures, and those marked *b* are due to dangerous bacteria.

The Atmosphere. *"Few people realize that, with the advent of autumn, the great majority of the swarms of bacteria which have been circulating in the air during the hot summer months take their leave of us and disappear.

"Practically, however, we are all conscious of this fact, for we know what greater difficulties attend the keeping of food sweet and wholesome in the summer than are met with in the winter. . . . Bacterial operations are, however, distinctly favored by the accident of temperature, the warmth of the summer encouraging their vitality and multiplication. We know that as regards mere numbers the bacteria in air may vary from 0 to millions in a couple of gallons, these extremes being dependent upon the surrounding conditions or relative purity of the atmosphere.

"Out at sea, beyond the reach of land breezes, it is no uncommon thing to find none whatever; on mountains and even hills of humble elevation, the lack of bacteria is very marked if there are no abnormal or untoward circumstances contributing to their distribution. In illustration of this, the recent investigations of the air on the summit of Mont Blanc by M. Jean Binot are of especial interest, inasmuch as the altitude at which they were carried out is the highest at which the search after bacteria has so far been pursued. . . . As was to be anticipated, frequently no bacteria at all were found, and it was only when such comparatively large volumes of air as one thousand litres (about 200 gallons) were explored, that microbes in numbers varying from four to eleven were discovered. The air of the country is far freer from microbial life than that of cities; whilst open spaces, such as those afforded by the public parks, are paradises of purity compared with the streets with their attendant bacterial slums.

"That it is no exaggeration to describe streets from the bacterial

*From Frankland's *Bacteria in Daily Life.*

point of view as *slums,* is to be gathered from the fact that much less than a thimbleful of that dust which is associated with the blustering days of March and the scorching pavements of summer, may contain from nine hundred to one hundred and sixty millions of bacteria.

"There can be no doubt, therefore, that dust forms a very important distributing agent for micro-organisms; dust particles, aided by the wind, being to bacteria what the modern motor-car, with its benzine or electric current, is to the ambitious itinerant of the present day. Attached to dust, bacteria get transmitted with the greatest facility from place to place, and hence the significance of their presence in dust. . . . Bacteria, however, survive this desiccation process much better when they are herded together in large numbers than when they have to face such untoward conditions as isolated individuals. This has been well illustrated in the case of diphtheria bacilli, and the difference in their powers of endurance under these respective conditions is very striking. Thus when a few only were exposed to a very dry atmosphere on silken threads, they disappeared after eight days; but when somewhat larger numbers were taken they contrived to exist for eighteen days; whilst when great multitudes of them were herded together, even one hundred and forty days' starvation in these desert like surroundings could not entirely stamp out their vitality.

"This dangerous property possessed by the germs of diphtheria should, if possible, increase the vigilance with which the outbreaks of this disease are watched and dealt with. Abel cites an instance in which a wooden toy in the sick-room of a child suffering from diphtheria was found six months later to have virulent diphtheria bacilli upon it.

"That the bacillus of consumption should have been very frequently found in dust by different investigators is hardly surprising when it is realized that the sputum of consumptive persons may contain the tubercle germ in large numbers, and that only desultory efforts have been made to suppress that highly objectionable and most reprehensible practice of indiscriminate expectoration. Considering that the certified deaths from tuberculosis in 1901, in England and Wales alone, reached the enormous total of 42,408,* and bearing in mind the hardy character of the bacillus tuberculosis when present

*The number in the United States during 1900 was [illegible],000. (Jordan) in sputum, it having been found alive in the latter even when kept in a dry condition after ten months, it is not too much to demand that vigorous measures should be taken by the legislature to cope with what is now regarded as one of the most fruitful means of spreading consumption . . . .

"Some years ago Messrs. Carnelley, Haldane, and Anderson carried out an elaborate series of investigations on the air of dwelling houses in some of the poorest parts of Dundee. The samples were taken during the night, between 12:30 a. m. and 4:30 a. m., and in their report the authors state that the one-roomed tenements were mostly those of the very poor; 'sometimes as many as six or even eight persons occupied the one bed,' whilst in other cases there was no bed at all. As regards the number of bacteria present in the air in these one-roomed houses, an average of several examinations amounted to sixty per quart; in two-roomed houses it was reduced to forty-six, and in houses of four rooms and upwards only nine micro-organisms in the same volume of air were discovered.

"On comparing the mortality statistics with the composition of the air of dwelling houses of different dimensions, the authors arrive at the following conclusions: 'That, as we pass from four-roomed to three-, two-, and one-roomed houses, not only does the air become more and more impure, as indicated by the increase in the carbonic acid and organic matter, and more especially of the micro-organisms, but there is a corresponding and similar increase in the death-rate, together with a marked lowering of the mean age at death.'

"Mention may also here be made of the investigations made by these gentlemen on the air of *board* schools, which showed that in those buildings where mechanical ventilation was used the carbonic acid gas was three-fifths, the organic matter one-seventh, and the micro-organisms less than one-ninth of what was found in schools ventilated by the ordinary methods. In commenting upon this series of investigations, the authors write: 'When we come to consider that the children who attend the average school for six hours a day are during that time subjected to an atmosphere containing on an average nearly nineteen volumes of carbonic acid per 10,000, and a very large proportion of organic matter, and no less than 155 micro-organisms at least per quart, we need not be surprised at the unhealthy appearance of very many of the children. It must also be borne in mind that many of them are exposed for nine hours more to an atmosphere which is about five times as impure as that of an ordinary bedroom in a middle-class house. They are thus breathing, for at least fifteen hours out of the twenty-four, a highly impure atmosphere. The effects of this are often intensified, as is well known, by insufficient food and clothing, both of which must render them less capable of resisting the impure air. The fact that these schools become, after a time, habitually infected by bacteria renders it probable that they also become "permanent foci of infection for various diseases and particularly, perhaps, for tubercular disease in its various forms." ' "

Illustrations could be multiplied without number to show the harmful effects of impure and insufficient air as found among the dwellings of the poor; and the many efforts of municipalities and private philanthropic individuals to improve these conditions, testify to the active state of the public conscience, and to an appreciation of the value of sanitary methods in bringing about a better condition of the public health.

Filth and Filth Diseases. A rather important change of ideas due to modern bacteriology is the present view of filth and filth diseases. In the earlier days before the bacteria and their ways were understood there were many *filth diseases* which were so named because of the idea that filth was not only the vehicle but the actual breeder of the infectious disease. This was applied, for example, to typhoid fever, a view which has since been entirely abandoned. The modern theories of filth and its dangers are very different from these. It is first and always a convenient vehicle of disease but, in modern sanitation at any rate, it is seldom more than this unless it serves to produce a depressing effect, thereby lowering the body resistance. In other words, filth is looked upon as dangerous by the sanitarian of to-day chiefly because it may hold in its composition the germs of disease in more or less virulent form but not because it may be a *breeding place*. Therefore, there are no *filth diseases* as such, and sanitary boards have no design, in the care of the dirt of the streets or the disposal of putrifying garbage and refuse, other than the removal, by cremation, by dumping in the sea, or plowing under the soil, of some of the *carriers* of diseases and the reduction thereby, of the chances of contamination of its public supplies of water, milk, etc,

Personal Cleanliness. A love of cleanliness is perhaps not inborn but is the result of civilization, of education, of a development of a bodily righteousness which shows itself in an abhorence of dirt either on one's person or his surroundings. In this day of understanding there is an added incentive in the fact that to be clean is, at least in a measure, to be free from infectious diseases, and this, coupled with an intelligent care of one's surroundings, of the supply of food, of milk, and of water, brings about the best possible condition of public health. The use of cooking methods, *i. e.*, high temperatures in the preparation of our foods, has been one of the most valuable aids in the destruction of our invisible enemies, aside from its value in making eating worth living for. Again, some of the channels through which personal uncleanliness or the more virulent personal infections have been wont to act, have received especial attention during the past few years. The public drinking cups, communion cups, roller towels, barbers' shaving mugs and razors, and the many other articles which, if used in common, tend to bring about the transfer of the disease germs from one body to another, have been, where possible, abolished and a sufficiently widespread knowledge of and sentiment against such things have been instilled into the public mind to bring about the proper sanitary regulation. Public drinking fountains of an approved type are being installed everywhere, while the old *town pump* is rapidly becoming classed as an *undesirable citizen.*

Sewage a Carrier of Disease. The disposal of the waste products of life by means of a well-ordered sewerage system has become well-nigh universal and, as sewage is at all times more or less highly infected with disease germs, its final disposition becomes an important factor to the sanitary expert. The old adage—"Eternal vigilance is the price of peace"—applies not only to war against municipalities and powers but to the bacterial campaigns as well. As Dr. Sedgewick puts it "the chain of public health is no stronger than its weakest link, and therefore, no matter how clean and wholesome all other conditions may be, if there is one point at which the germs of infectious disease may find admission into the body, danger may be imminent."

Disposal by Running Streams. Up to within a few years ago there was a well-defined theory that "running water purifies itself."

This fact was used to justify the practice by many towns and cities which were located on the banks of rivers and lakes, of drawing their water supply from above the town and emptying the sewage below, without a thought as to possible conditions which would result in a contamination of the water supply by the sewage of the town above or the influence of the town's own sewage upon the water supply of the people below them. There were, therefore, a number of cases of dangerous polution of river waters, which resulted in epidemics of greater or less severity. The theory itself is based upon the obvious fact that although a very large amount of sewage might be suddenly poured into the stream at a given point, it is only necessary to follow the stream for a comparatively short distance to find the results of such pollution, if not entirely wanting, reduced to a small amount. Naturally only one conclusion could be drawn, viz, that the water had purified itself. A point which was not taken fully into account in the early history of this method—the amount of purification due to dilution—has been more carefully worked out, with the result that extreme care is now exercised in furnishing a proper proportion of water for a given amount of sewage and in the use, where necessary, of filters either for the sewage or for the water supply. Several other elements, as for example, swiftness of the current, nature of the sub-soil, and time element have been taken into consideration with the result that the method of sewage disposal by flowing streams when accompanied by the proper amount of regulations has been found a very useful, inexpensive, and not at all dangerous practice.

The use of lakes as sewage depositories has also been made with considerable success and unless the volume of sewage proved too great, as in the case of Chicago, the practice of drawing the water supply from this same lake at a properly distant point, has not been found dangerous. In all of these cases the factors, in addition to that of dilution, which contribute to the extermination of the bacteria, are the coolness of the water, which produces either death or inaction; scarcity of food due to the excessive dilution; and the slow settling to the bottom of the sediment, in which the bacteria are growing.

Intermittent Filtration. In a previous discussion of the various types of useful bacteria, the fact was mentioned that there were in the earth many forms of microbes of the *nitrifying variety*, whose office it was to transform organic material into inorganic substances which the plants could use as food. These useful micro-organisms can account for the disappearance of the fertilizer which the farmer spreads so generously over his fields and plows into the soil each year, and the products of its decomposition are the things which make the difference between fertile and barren soil. If, then, the sewage is allowed to flow out upon an area, there to soak into the earth and give to these bacteria the opportunity of transforming the dangerous material into harmless and, in fact, needful nitrates, this constitutes a very useful and exceedingly effective method of sewage disposal. It is one of the most primitive methods and has been used to very good advantage by cities as large as Berlin.

The early exponents of this method considered that the purification was due in a large measure to an oxidation through exposure to the air, and it was with this idea of the process that the Rivers Pollution Commission of Great Britain, appointed in 1868, carried on many valuable experiments, resulting in the adoption of the method in England and Germany. However, no further data of particular importance were obtained until some most interesting experiments were taken up along modern bacteriological lines by the state of Massachusetts. In 1886, a commission was appointed to go into the subject with great thoroughness and establish an experimental station, which, by the way, was probably the first one of its kind. These experiments were extremely exhaustive in character and covered the range of purification of sewage upon land by intermittent filtration, and by electrical and chemical separation. The method of intermittent filters is one of the most useful and will be the only one discussed.

This method had been used with considerable success in England and Germany, but the knowledge available was very limited, and there was no assurance that conditions of climate, soils; sewage, etc., would not make impossible the adoption of the same methods in Massachusetts. Accordingly, a series of careful experiments were begun to test the purifying capacity of various soils common in Massachusetts. For this purpose a number of large wooden tubs of sixteen feet in diameter were used which were carefully filled with different materials ranging from muck and garden loam on the one hand, to different grades of sand on the other, the latter ranging from fine sand even to large pebbles. The soil or sand to be tested was in each case supported by a layer of stone and gravel and drained underneath through a pipe which emptied into a large measuring basin. The sewage to be experimented upon was drawn from one of the main sewers of the city of Lawrence, and was the ordinary domestic city sewage free from manufacturing wastes. The result was astonishing to say the least. Many people who witnessed the experiments felt certain that the filters would become clogged and foul. They did not know that Berlin disposes of all its sewage upon land. They forgot that the farmer lays on yearly a layer of filth and plows it into the ground. As soon as a few days had passed and the filters had become thoroughly established, the filtrate showed a decided improvement and soon was bright and clear. Analyses showed that the output was *purified sewage*, comparatively free from odor, and with only a few scattered bacteria. The surprising part of the whole matter was that the filters showed no signs of clogging and no disagreeable odors developed. It was a strange fact that the fine loam which many supposed would be the most efficient in producing purification, was really the least effective, the texture being too fine to allow sewage to percolate freely. On the other hand, the sands all worked to good advantage, the fine grains working best; but strange to say the only office of the grains of sand or the pebbles was that of providing the little pits on their surface as places in which the *bacteria* could lodge and thereby detain and work over the organic matters in the sewage. In other words, the little channels through which the sewage passed became populated with swarms of bacteria which were able to modify the material held in solution so that it passed out of the filter in harmless forms, that is, the action of the intermittent filter was almost entirely chemical and bacterial. It is clear, therefore, that this process is not *filtration* in the strict sense of the word but merely a method of splitting up the sewage by means of the millions of canals between the sand grains so that the bacteria, which lodge along the walls of these canals, can effectually dispose of the harmful products. In this process both the aërobic and anaërobic varieties of bacteria are active, a fact which was brought out by the necessity of the flow of sewage being *intermittent* in order to obtain the best results; a continuous flow prevented the aërobic bacteria from obtaining the air necessary for their active existence.

The results of these experiments were quickly applied in Massachusetts and elsewhere. All that needed to be determined was whether the soil of that particular section was of a quality to produce the proper purification, after which the method of land-disposal of sewage could be installed with perfect confidence. As to where the numerous living bacteria always present in crude sewage have disappeared, it might be said that some are mechanically detained in the upper layers of the earth, others perish from lack of food either near the surface or probably in the lower layers of the filter, while those that pass through the filter undoubtedly are so weakened by the lack of food in the filtered sewage that they soon die. At any rate, it has been found in most cases that the water after passing through well-built intermittent filters is sufficiently pure to be drunk with impunity. There are many other methods which have been advocated and brought into more or less general use, but the scope of this article will allow only the mention of such devices as irrigation and sewage farming, chemical precipitation, electrolytic action, and the fermentation or septic process. Each may have a particular value under certain local conditions, none ever becoming universal, but all contributing to the destruction of dangerous material and the improvement of sanitary conditions in general. For further information concerning sewage disposal and purification, the student is referred to pages 134 to 149 in Marston's *Sewers and Drains*.

Water an Active Agent in the Spread of Disease. *"It may be safely assumed that there are few natural waters on the surface of the earth that do not receive a perceptible amount of the sewage, drainage, or waste resulting from human activity and habitation. Now the experience of the human race has shown that many of these natural bodies of water are used as a source of water supply by considerable populations without any strikingly noticeable injurious effects. If all the dangerous elements, or, to put it more specifically, all the pathogenic (disease causing) bacteria, entering bodies of water remained there in their original numbers without change, it needs little imagination to picture the difficulty there would be in obtaining a supply of even moderately wholesome drinking water. We know that this is not the case, and it is apparent that in nature some sort of change occurs which results in the destruction or dis-

*From *Natural Purification of Streams*, by Professor E. O. Jordan, University of Chicago.

appearance of the offensive and disease-producing elements that are introduced from time to time into most bodies of water.

"It has been wittily said that what is wanted in a drinking water is innocence rather than repentance, but it must be remembered also that very few large communities are in a position to obtain a virginally pure supply. In practically every civilized country the rivers, large and small, receive the sewage or drainage of a more or less extensive population; and the same is true of the large ponds and

Fig. 38. Water Supply System in a Large Cuban Town.

lakes. It has been estimated by Hazen that the water supplied to approximately 52 per cent. of the urban population—in cities of over 25,000—of the United States is unsatisfactory. The large and increasing consumption of water by the inhabitants of modern cities and towns renders the obtaining of a sufficient quantity of uncontaminated water always difficult and in most cases impossible. For the majority of public water supplies, recourse is had to sources known to be more or less polluted at some stage in their history. The reckless practice of some cities in using such water without artificial purification shows that a considerable degree of natural purification must occur, otherwise the consequences of the neglect of elementary precautions would be far more disastrous than they are." For example, the water system for a large town in Cuba, Fig. 38, would hardly be considered ideal from a sanitary standpoint. Yet even with these primitive methods, cases of infections are no doubt comparatively rare.

Cholera. The most common of the dangerous infections to which are attributable the pollution of the water supply are cholera and typhoid fever, and a study of the occurrence and behavior of these maladies should be of great interest to the sanitarian. Both attack the digestive tract, Fig. 39, but the former is much more rapid in its development and more deadly in its effects. It has been the cause of many serious epidemics of which the one in London, in 1854, and the one in Hamburg, in 1892, will be taken as typical. The epidemic of 1854 occurred in St. James' Parish, a district inhabited by about 36,000 persons, and the deaths from cholera amounted, for a period of seventeen weeks, to 700, or about 220 per 10,000. During this same epidemic a neighboring parish had only nine deaths in 10,000. The origin of the infection was for some time in doubt but finally, by the very careful and skillful deductions of Dr John Snow and others, the finger of suspicion pointed to a public drinking pump in Broad street, Fig. 40. The handle of the pump was at once removed, and a subsequent investigation of the surroundings, made by Mr. York, showed a startling source of contamination. Of course, at that time, bacteriology was in its infancy, and the cholera bacillus had not been identified; consequently, the information regarding the occurrence of cases within the district, the deaths among those who used the Broad street pump, the influence of this same well upon cases in other districts, the exemption of certain factories which had their own

Fig. 39. Typhoid Bacillus Colony. (From *Kolle & Wassermann.*)

Fig. 40. Asiatic Cholera and the Broad Street Pump, London, 1854.
Large dots show location of pumps; small dots, location of fatal cholera cases; broken line, boundary of equal distances between Broad street pump and other pumps. (From *original map* by Dr. John Snow.)

drinking water supply, all of this material had to be collected with painstaking care. If the authorities had known what we know now, an analysis of the water would have shown at once its infected condition. As it was, the investigation of the surrounding soil showed that a defective drain, foul with the excreta from the inmates of a near-by house, one of which had an attack of cholera, had caused the contamination.

The cholera epidemic at Hamburg, occurring as it did in 1892, after the methods of bacterial detection had been fairly well developed, proved a most instructive though costly lesson in sanitation, and its occurrence brought to the notice of the scientific men the danger of accepting the theory of purification of streams, without due regard to conditions. To quote again from Frankland's *Bacteria in Daily Life*—"In the year 1885, Dr. Koch's new bacteriological water tests had been introduced in the examination of the London water supply and yet their acceptance at that early date had not been sufficiently general to make their influence felt in many cities on the Continent. The general public was waiting for a startling demonstration which came to hand in this cholera epidemic in Hamburg and Altona. These two cities were both dependent upon the river Elbe for their water supply but, whereas in the case of Hamburg the intake was situated above the city, the supply for Altona was abstracted below Hamburg, after it had received the sewage of a population of nearly 800,000 persons. The Hamburg water was, therefore, to start with, relatively pure when compared with that destined for the use of Altona, but let us see what was the fate of these cities as regards cholera. Situated side by side, in fact with nothing in their surroundings or the nature of their development to especially distinguish them, in the one, cholera swept away thousands, while in the other, the scourge was scarcely felt. In Hamburg the deaths amounted to 1,250 per 100,000, while in Altona, to but 221. So clearly defined moreover, was the path pursued by the cholera that the street marking the division between the two cities showed numerous cases of cholera on the Hamburg side and none on that of Altona."

In seeking an explanation of this anomalous situation it must be remembered that the Hamburg water to start with was supposedly in a comparatively pure condition, and had been delivered in Hamburg just as it was drawn from the river; whereas the Altona water, though much more foul when taken from the river, had been carefully filtered through sand before delivery. Evidently the waters of the Elbe had become infected by cholera germs above Hamburg, probably from a case on ship-board, and as no provisions for removing the germs were made, they were able to enter the bodies of the inhabitants and accomplish their deadly work. Altona's experience gave abundant testimony to the efficacy of the sand filters, as these were able to kill the large proportion of cholera germs which reached the water supply through the infected sewage of Hamburg.

It is a curious fact, however, that after the ravages of the cholera had almost died out in Hamburg, suddenly an unexpected epidemic occurred in Altona, which, after a searching inquiry by Dr. Koch, was traced to the fact that during the winter one of the sand filters had become frozen, and this rendered it incapable of retaining the bacteria which passed through it. As the water supplied to the system came from all the filters, only one of which was defective, the bacteria were so diluted that this epidemic did not prove very severe. It is needless to add that, with this severe experience as a lesson, the city of Hamburg and, in fact, many other cities of the Continent, were not slow in introducing filters in connection with their water systems.

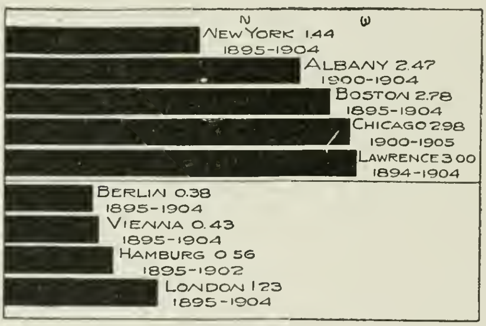


Fig. 41. Typhoid death rates in American and European cities, Albany, Lawrence, and Hamburg, after installation of filters; Chicago, after opening of the sanitary drainage canal. The remarkable case of the City of Washington, D. C., is purposely left out. There the installation of a modern sand filtration plant (November, 1905), was followed in the next year (1906) by a higher typhoid death rate (4.93) than had been recorded for either of the three preceding years (1903, 4.50; 1904, 4.38; 1905, 4.39). (From Jordan's *Problems of Sanitation.*)

Typhoid Fever. Notwithstanding the swift ravages of cholera, its deadly attacks are comparatively infrequent, and, in addition to this, our bacteriological friends have been able to bring the disease under nearly perfect control. Not so, however, with typhoid fever, which is much more prevalent and is moreover, difficult to regulate owing to the slow development of the bacillus. This micro-organism does not make its presence known for about two weeks after infection has occurred, and consequently if this infection has come through the water supply, all signs of the bacteria have disappeared from the water in that length of time. Yet, in spite of these uncertainties, the evidence has long pointed to the drinking water as being the chief agent of infection in typhoid, and, therefore, the efforts of the sanitarian have been to improve the condition of public water supplies either by changing the sources or by the establishment of filters. The improvements in Europe have been of a more substantial character than those in the United States as evidenced by statistics shown in Fig. 41, these differences being largely accounted for by the fact that the greater density of population in the old country necessitates more care and inspection of the water and milk supplies.

To show the apparent round-about methods of the infections, the case of Plymouth, Pa., in 1885 is cited, the facts coming indirectly from Dr. S. H. Taylor's report contained in the *First Annual Report of the Pennsylvania State Board of Health*, 1886. Plymouth, at this time, was a town of 8,000 inhabitants and had an apparently excellent but limited supply of water from a mountain stream. On this stream, the Plymouth Water Company had from time to time established reservoirs to conserve the supply until, at the time of the epidemic, it had a series of four such receptacles with a total capacity of ten million gallons. The situation from the standpoint of the sanitary expert was further complicated by the fact that the month previous to the outbreak, pumpings from the Susquehanna river were used to help out the reservoir supply which had been found inadequate. In April, the typhoid storm broke and as a result, out of 8,000 inhabitants 1,104 were taken ill with typhoid fever and 114 died. The investigations of this fearful outbreak proved, after careful search and painstaking labor, that the company's reservoirs had been at fault and that the whole supply had been contaminated through carelessness in handling a virulent case of typhoid which had occurred in a house situated on the bank of the mountain stream, just below the highest reservoir.

A man in this house had a long illness of typhoid lasting from January 2nd until April, and during the whole time, the night nurse had made a practice of throwing out the excreta on the snow and frozen ground near the bank of the stream. The spring rains of March had undoubtedly washed this into the stream, thereby infecting the third reservoir. On the evening of March 26th, the superintendent of the water company visited the reservoirs and found practically no water in the first and second but a good deal in the third, due to the fact that the pipe leading from No. 3 to No 2 had been frozen up. The superintendent promptly had this thawed out, which allowed the infected water in the third reservoir to enter into the water system and produce the epidemic. Dr. Taylor in his conclusions, says:

"It is safe to say that this was one of the most remarkable epidemics in the history of typhoid fever, and it teaches us some important lessons, at fearful cost. One is, that in any case of typhoid fever, no matter how mild, nor how far removed from the haunts of men,

TABLE II

Deaths per 100,000 Inhabitants

	From Apr., 1888, to Mar., 1889	From Apr., 1889, to Mar., 1890	From Apr., 1890, to Mar., 1891	From Apr., 1891, to Mar., 1892	From Apr. 1892, to Mar., 1893	Average Apr., 1888, to Mar., 1893
Concord, N. H.	70.5	29.5	53.0	29.4	11.8	38.8
Manchester, N. H. .	29.9	41.8	43.6	11.15	20.7	29.5
Nashua, N. H..	68.9	42.5	5.3	89.8	31.8	47 7
Lowell, Mass.	86.3	83.9	195.4	81.7	85.6	106.6I
Lawrence, Mass. . . .	125.2	118.1	187.0	91.6	114.1	127.2
Haverhill, Mass	22.8	30.3	33.9	30.2	64.0	46.3
Newburyport, Mass.	14.4	28.8	57.6	28.8	50.4	36.0

the greatest possible care should be exercised in thoroughly disinfecting the poisonous stools. The origin of all this sorrow and desolation occurred miles away, on the mountain side, far removed from the populous town, and in a solitary house situated upon the bank of a swift-running stream. The attending physician did not know that this stream supplied the reservoirs with drinking water. Here, if any place, it might seem excusable to take less than ordinary precautions; but the sequal shows that in every case the most rigid attention to detail in destroying these poisonous germs should be enjoined upon nurses and others in charge of typhoid fever patients, while the history of this epidemic will but add another to the list of such histories which should serve to impress medical men, at least, with the great necessity for perfect cleanliness—a lesson which mankind at large is slow to learn."

Dr. Sedgewick, during the progress of his monumental work as biologist to the State Board of Health of Massachusetts, investigated an epidemic of typhoid fever in the towns of Lowell and Lawrence, which are both situated on the Merrimac river and obtain their water from it in the raw condition. Several other towns of New Hampshire and Massachusetts situated on this same river were like Lowell and Lawrence as to climate and pursuits, but, unlike them, obtained their water supply from pure mountain streams and the typhoid fever mortality was correspondingly low as shown in Table II.*

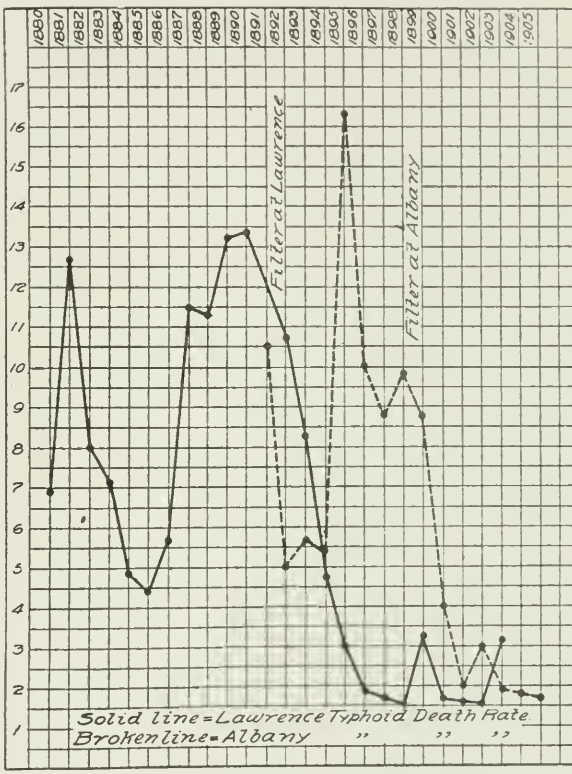


Fig. 42. Curves Showing the effect of the Introduction of Filters on the Typhoid Death Rate in Lawrence and Albany.

During the year of the epidemic, 1890-91, as will be noticed by consulting the table, the typhoid cases in Lowell and Lawrence jumped to nearly double the normal, which was in itself high enough. About 1,500 cases were identified in these two cities during the period of greatest infection and as Lawrence was only nine miles below Lowell, it was evident that in this case the theory of *purification of streams* had broken down. It was very clear that a change of method was imperative and the city of Lowell obtained a ground water supply while the city

*From Sedgewick's *Principles of Sanitation and the Public Health.*

of Lawrence installed filters. The result of this change in Lowell, was the reduction of the deaths in 100,000 population from 97 to 21, and in Lawrence, from 121 to 26, Fig. 42. Similarly the installation of approved filters in Zurich reduced the death rate from 76 to 10; in Hamburg, from 47 to 7; in Albany, from 104 to 38. Vienna, by abandoning the Danube as a water source, lowered its typhoid fever death rate from over 100 to about 6; and Chicago, by the use of the 4-mile intake in Lake Michigan, diminished her rate from 115 to 35. Some of these facts are shown graphically in Fig. 43, taken from Fuertes' *Water and Public Health.*

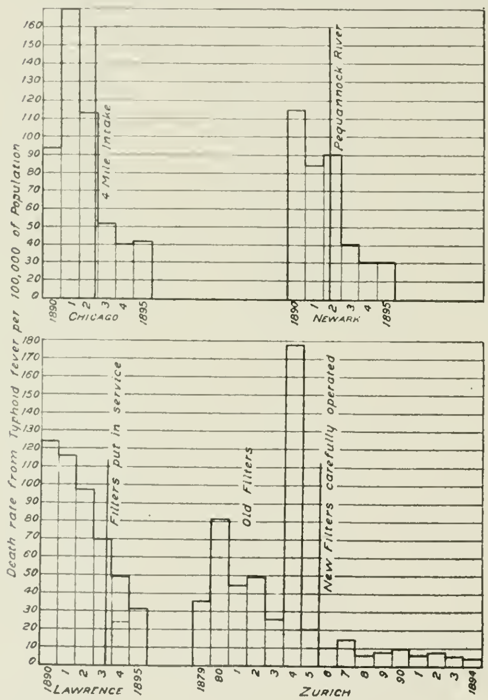


Fig. 43. Graphical Illustration of the Coincidence of the Drop in Typhoid Death Rate with Improvement of Water Supply.

A recent and very instructive example in support of the theory of *purification of streams* is given by the use of the Chicago drainage canal as the carrier of the sewage of Chicago into the Illinois river. Following the more recent opinions regarding the fallacy of this principle, an injunction was gotten out by the State of Missouri against the State of Illinois and the Sanitary District of Chicago, to restrain them from emptying the Chicago sewage from the drainage canal into the Illinois river and thence into the Mississippi, a method which, according to the claims of the plaintiff, prejudiced the St. Louis water supply, which was obtained from the Mississippi. The testimony in this case was most voluminous and expert opinions from the acknowledged authorities of the country were heard during the session. It would be impossible to even review the mass of data which was collected, but some of the most salient facts are taken from Professor Jordan's monograph on *Natural Purification of Streams.*

"Stripped of all technicalities, the question at issue in the suit on the Chicago drainage canal really is, how far can typhoid bacilli travel in the water of a particular flowing stream and arrive in such a condition as, in the legal phrase, 'to constitute a menace and a danger' to the inhabitants of a distant city or state. It is obvious that the problem is not one of space so much as of time; that it is not so much the distance over which a bacillus has to pass as it is

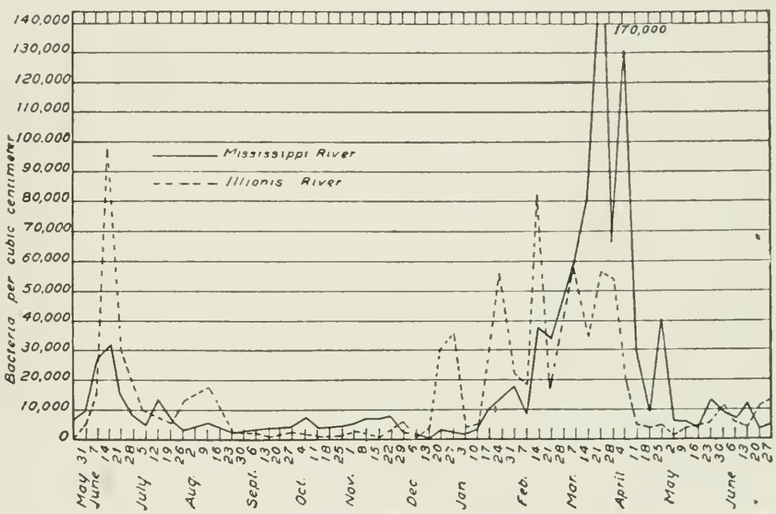


Fig. 44. Curve Showing Bacterial Content in Mississippi and Illinois Rivers for One Year. (From Government Report on River Pollution.)

the time consumed in traversing the stretch of river between the two points. The problem at bottom is essentially that of the longevity of the typhoid bacillus in a given water, whether of a river or a lake. As is well known, the conditions affecting this longevity are many and varied, and the experimental evidence shows that the length of life of this micro-organism is greater in some waters than in others and is influenced by a variety of concomitant conditions. Practically, then, *every inquiry into the alleged self-purification of streams must partake of the nature of an independent and separate investigation,* and must, for the present, be carried on without too much reference to the results obtained under other conditions. It has rarely been found possible to experiment directly with the typhoid bacillus under conditions identical with those obtained in a given river. It is therefore necessary to rely provisionally upon data of an indirect and inferential character, and it is these latter only that are ordinarily considered in a study of any particular case. The indirect evidence is of several kinds and of different degrees of value."

Many cases are on record of the coincidence of water pollution at a certain point with the appearance of typhoid fever at various other points along a water course—with the allowance of a proper

TABLE III

Desplaines and Illinois Rivers, Chicago to Grafton

Stations Collecting	Distance from Bridgeport in Miles	No. of Colonies per c.c.	No. of Determinations
Bridgeport	0	1,245,000	19
Lockport	29	650,000	30
Joliet	33	486,000	28
Morris	57	439,000	26
Ottawa	81	27,400	26
LaSalle	95	16,300	31
Henry	123	11,200	29
Averyville	159	3,660	30
Wesley City	165	758,000	22
Pekin	175	492,600	29
Havana	199	16,800	26
Beardstown	231	14,000	26
Kampsville	288	4,800	19
Grafton	318	10,200	28

time interval—such as the one already mentioned of the Merrimac river; but, Professor Jordan continues, "No such relation could be traced between the prevalence of typhoid fever in Chicago and St. Louis. If such a connection obtained it would be supposed that the curves of the disease would be much alike and that the St. Louis curve would be slightly retarded in time. As a matter of fact a comparison made by the writer of the published deaths from typhoid fever in these two cities by months and by years showed no relation whatever as evidenced by the curves, Fig. 44. Sometimes the Chicago minimum and maximum rates precede those for St. Louis by a period of from two to eleven months; sometimes they follow the latter, and sometimes they coincide with them. A similar outcome attended the attempt to connect high water or low water stages in the Illinois river with typhoid fever in St. Louis.

"The analytical data may next be considered. It is my opinion that the ordinary chemical sanitary water analysis, at its best of doubtful value, is not well adapted for throwing much light upon the problem of the self-purification of streams. The chlorine determination can have practically no significance, and even the determination of the nitrogen compounds is of little real importance. It cannot be said that the process of decomposition and the processes that lead to

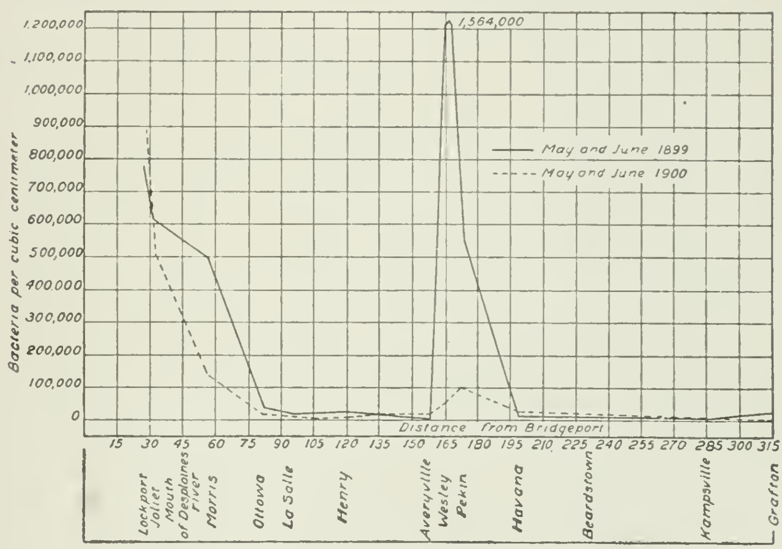


Fig. 45. Bacterial Content of Illinois River from Bridgeport to Grafton.

the destruction of dangerous bacteria run a strictly parallel course either in septic tanks or in polluted rivers.

"It is also true that the mere number of bacteria in a water is no absolute criterion of the purity of the water. At the same time it must be admitted that the fate of typhoid bacilli introduced into a river is probably more closely correlated with that of other sewage bacteria than with oxidation changes in chemical constituents. The diminution in the numbers of bacteria in the Desplaines and Illinois rivers from Chicago to *Grafton is shown in Table III and graphically in Fig. 45.

*Grafton is situated at the junction of the Illinois and Mississippi rivers.

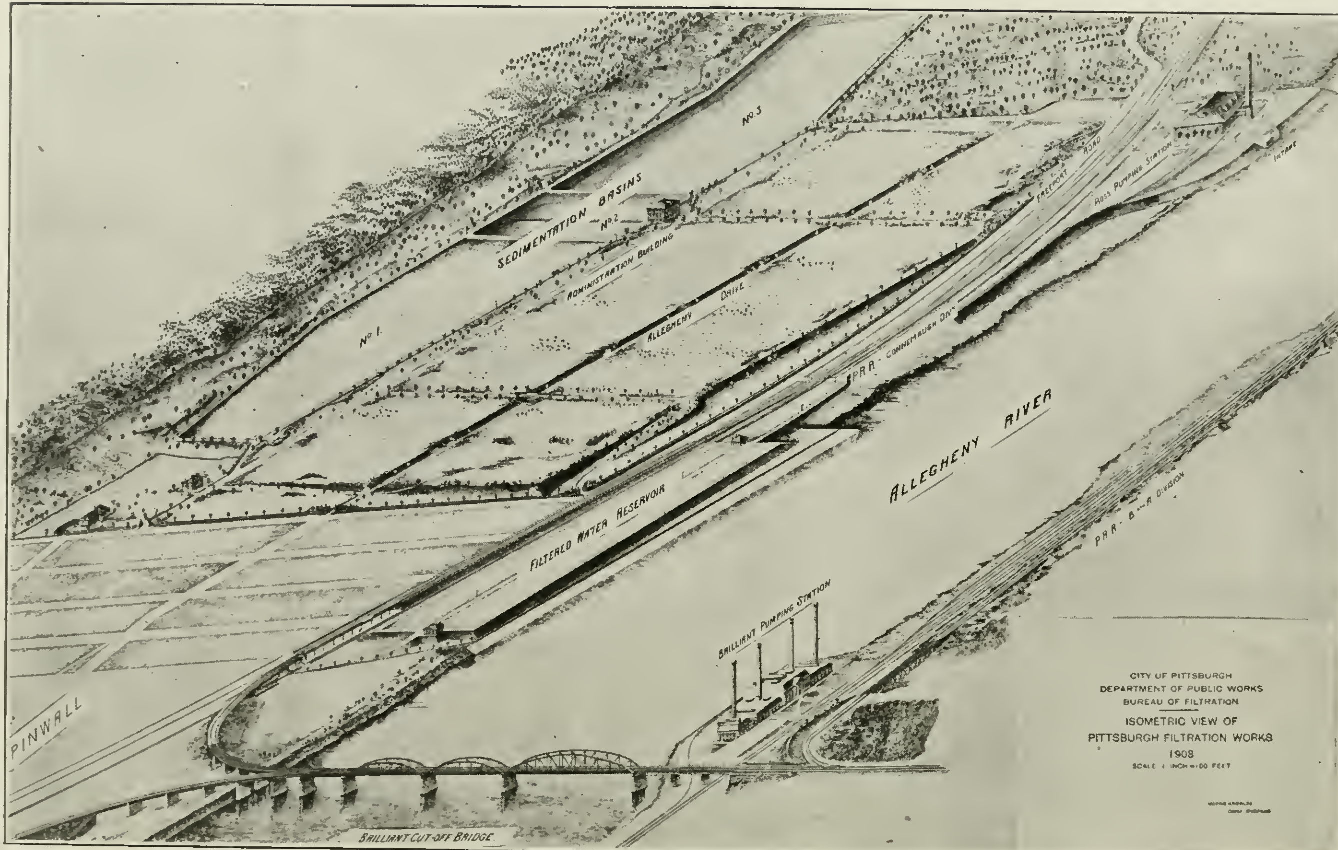


Fig. 46. Filtration Works of the City of Pittsburg.

"There is no reason to suppose that the typhoid bacillus is any more resistant than the average sewage bacteria, and the enormous reduction in the numbers of the latter shown in the table would seem to indicate a similarly high and speedy mortality among typhoid bacilli introduced into a flowing stream.

"Considered as a general proposition, the self-purification of streams has received more attention than its practical importance would appear to warrant. Under actual conditions implicit reliance on

Fig. 47. Birds-eye View of Sedimentation Basin under Construction, Showing Ross Pumping Station in the Distance.

the natural purification of a river water is usually misplaced. A stream may conceivably rid itself of infection, if such infection be introduced at only one point, but may, nevertheless, be so exposed to contamination at other points along its course as to be totally unfit as a source of public water supply. Efficient control over the water sheds of such streams as the Mississippi, Illinois, and Missouri is obviously quite impracticable. It is only under such very unusual conditions as exist along the lower Mississippi that a river has a chance to work out its own salvation. If continuous contamination be withheld for a certain number of miles, or rather days, then *self-*

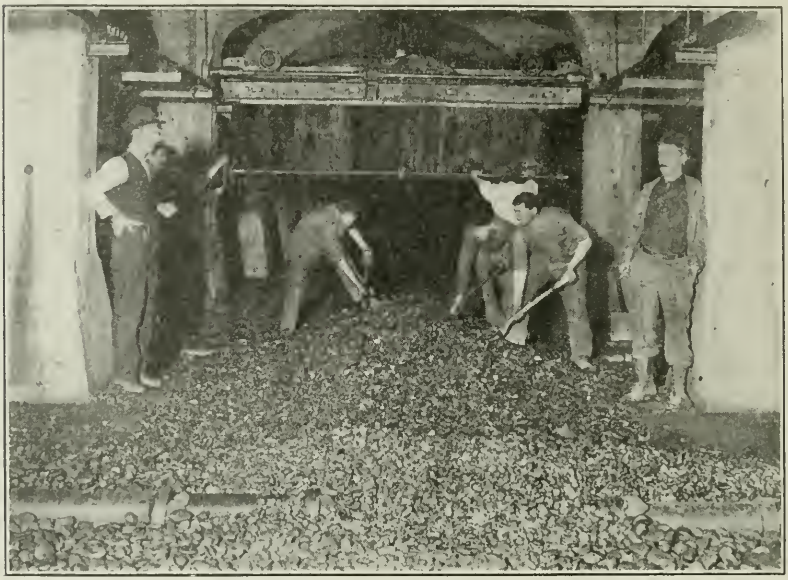


Fig. 48. Introduction of Graded Gravel in Filter Beds.

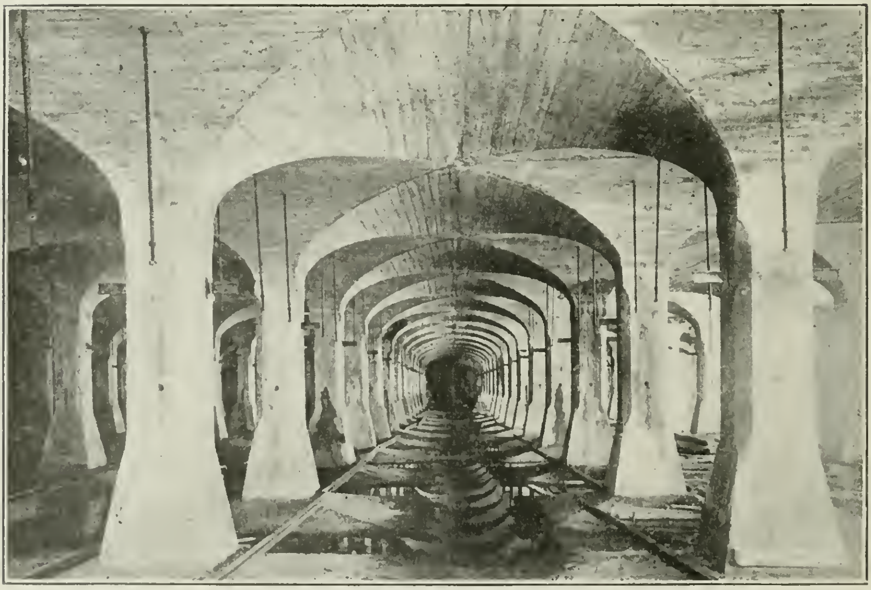


Fig. 49. Interior of Filter Bed before the Admission of Sand and Gravel.

purification may become a factor worthy of consideration. Such a condition is evidently rare.

"The other extreme of opinion is equally untenable. Such an assertion as the following has been made, that 'water once polluted is unsafe for domestic use unless artificially purified.' No such sweeping statement can be justified unless based on a belief in the immortality of disease germs. All that we know about the bacteria of water-born diseases goes to prove that they never multiply in water even when this is highly polluted, that they die out rather rapidly, and that even the few more resistant individuals lose their virulence and do not long retain their power of producing infection."

The foregoing facts on the purification of water supply serve to show to what extent the typhoid death-rate can be controlled by proper sanitary precautions. In spite of these remarkable facts, there has been a noticeable slowness on the part of many communities in profiting by the lessons which they teach. Many towns and cities, especially in the United States, have remained unobservant and negligent as if they were waiting for some local demonstration which would cost many lives to prove to them that such precautionary measures are necessary. A method that has not only reduced the deaths from typhoid fever by about 75 per cent., but also has reduced the number of cases proportionally, is worthy of universal adoption. It is an admitted fact that if a new antitoxin were discovered which would reduce the fatality of typhoid fever from 12 per 100 cases to 3, the world would sound the praises of its discoverer; nevertheless, the fact that the introduction of a pure water supply has brought about quite as large a reduction in the death rate, and has conferred the added benefit of preventing the occurrence of a smaller proportion of cases, not only causes comparatively little interest but actual indifference on the part of the general public. On the other hand, a number of American municipalties have installed expensive filtration plants in an effort to obtain a pure water supply. The city of Pittsburg has installed such a system, some of the details of which are shown in Figs. 46, 47, 48, and 49.

Danger of Infection from Milk Supply. Of the many other vehicles of infectious disease there remains only one which seems to come within the scope of this article. It might be considered that *ice* should be treated as a more or less dangerous carrier of micro-organisms, but it has been rather well proven that the scientific theory that *water purifies itself on freezing* still holds. Many analyses of natural ice have been made and the only condition which brings about any large degree of contamination is the case where the ice forms in such shallow water that it is impossible for the bacteria already present in the water to avoid being imprisoned in the ice.

When we come to the subject of *milk*, however, this important human food is found to be one of the most dangerous carriers of disease that we have. For a long time milk was looked upon with perfect security as being one of the natural foods which need give man no cause for worry; but in late years, while maintaining its reputation, even under the scrutiny of the chemist, as regards its food value, and its comparative cheapness, it has sadly lost caste with bacteriologists, and sufficient agitation has been developed to bring about tremendous changes in the care which this product receives in its passage from the cow to the human stomach. The main changes in the handling process have been in the care exercised in milking the cows, the requisite cleanliness to be observed, the bottling of the product soon after it is taken from the cow—or if some of the modern sterilizing processes are used, putting the milk in germ-free receptacles immediately after sterilization—and finally, the keeping of the milk at a comparative low temperature during the entire period.

The milk is usually tested to find the number of bacteria per cubic centimeter as follows: One c.c. of the milk is taken and diluted with about 100 c.c. of pure water; then 1 c.c. of this diluted liquid is mixed with sterilized gelatine and poured into a flat glass dish and covered, to await the growth of the culture. Each bacterium feeds upon the gelatine and forms its own colony, as shown by the round dots in Figs. 50 and 51. By counting these dots and multiplying by the dilution factor, the number of bacteria present in the milk is obtained. Evidently the sample shown in Fig. 50 is much more free from the germs than that of Fig. 51.

Professor H. L Russell, of the Wisconsin Experimental Station, cites in his little volume on *Dairy and Bacteriology*, an instructive experiment — as reported by Frankland in *Bacteria in Daily Life*—which shows the possibility of preventing the milk from becoming infected by its surroundings when taken from the cow.

"A cow pastured in a meadow was selected for the experiment, and the milking was done out of doors, so as to eliminate as far as possible any intrusion of disturbing foreign factors into the experiment, such as the access of microbes from the air in the milking-shed. The cow was first partially milked without any precautions whatever being taken, and during the process a small glass dish containing a layer of sterile nutrient gelatine was exposed for one minute beneath the animal's body, in close proximity to the milk-pail. The milking was then interrupted, and before being resumed the udder and

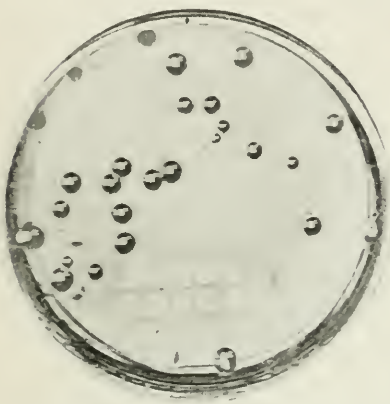


Fig. 50. Culture from Sample of Pure Milk (Heinemann).

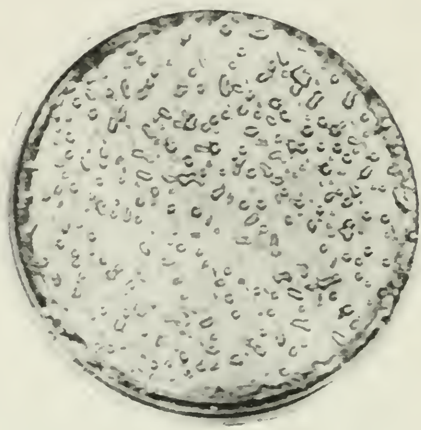


Fig. 51. Culture from Sample of Ordinary Milk (Heinemann).

legs of the animal were thoroughly cleansed with water; a second gelatine surface was then exposed in the same place and for the same length of time. The results of these two experiments are very instructive. When the cow was milked without any special precaution being taken, 3,250 bacteria were deposited per minute on an area equal to the surface of a ten-inch milk-pail; after, however, the animal had been cleansed, only 115 bacteria were deposited per minute on the same area.

"Thus a large number of organisms can, by very simple precautions and very little extra trouble, be effectually prevented from obtaining access to milk. Even in the event of the milk being subsequently *pasteurized*, clean milking is of very great importance; but still more imperative is it when it is destined for consumption in its raw, uncooked condition. If we consider how cows become covered with dirt and slime, that obstinately adhere to them when they wade through stagnant ponds and mud, and realize the chance thus afforded for malevolent microbes to exchange their unsavory surroundings for so satisfactory and nourishing a material as milk, then indeed precautions of cleanliness, however troublesome, will not appear superfluous.

"That a very real relationship does exist between the bacterial and dirt contents of milk has been clearly shown by actual investigation. A German scientist has made a special study of the subject, and has determined in a large number of milk samples the amount of foreign impurities present per litre, and the accompanying bacterial population per cubic centimeter.

"The following results may be taken as typical of those obtained: In milk containing 36.8 milligrammes of dirt per quart as many as 12,897,600 bacteria were present per cubic centimeter; in cleaner samples, with 20.7 milligrammes of dirt per quart, the number of bacteria fell to 7,079,820; whilst in a still more satisfactory sample, containing 5.2 milligrammes of dirt per quart, there were 3,338,775 bacteria per cubic centimeter.

"Such results indicate how important a factor is scrupulous cleanliness in milking operations in determining the initial purity of milk, for there is no doubt that bacterial impurities in milk are in the first instance, to a very great extent, controlled by the solid impurities present. . . . It follows as a natural sequence that all the cans and vessels used for dairy purposes should be absolutely beyond suspicion of contamination. Professor Russell has shown by actual experiment that, even where the vessels are in good condition and fairly well cleaned, the milk has a very different bacterial population when collected in them and in vessels *sterilized by steam*.

"Two covered cans were taken, one of which had been cleaned in the ordinary way, and the other sterilized by steam for half an hour. Previous to milking, the animal was carefully cleaned, and special precautions were taken to avoid raising dust, whilst the first milk, always rife with bacteria, was rejected. Directly after milking, bacterial gelatine-plates were respectively prepared from the milk in these two pails, with the following results: In one cubic centimeter of milk taken from the sterilized pail there were 165 bacteria; in that taken from the ordinary pail as many as 4,265 were found.

"Another experiment illustrates perhaps even more strikingly the effect of cleanly operations in milking upon the initial bacterial content of milk. The preliminary precautionary measures were carried out by an ordinary workman, and are in no sense so refined as to be beyond the reach of ordinary daily practice. 'The milk was received in steamed pails, the udder of the animal, before milking, was thoroughly carded, and then moistened with water, so as to prevent dislodgment of dirt. Care was taken that the barn air was free from dust, and in milking, the first few streams of milk were rejected. The milk from a cow treated in this way contained 330

Fig. 52. A Cuban Milkman.

bacteria per cubic centimeter, while that of the mixed herd, taken under the usual conditions, contained 15,500 in the same volume. The experiment was repeated under winter conditions, at which time the mixed milk showed 7,600 bacteria per cubic centimeter, while the carefully secured milk only had 210 in the same volume. In each of these instances the milk secured with greater care remained sweet over twenty-four hours longer than the ordinary milk.' "

To illustrate the effect of temperature upon the ability of the bacteria already present in the milk to breed successfully, Table IV, taken from Jordan's *General Bacteriology*, is here presented.

When it is remembered that the minimum number of bacteria which is considered safe by the Board of Health is 500,000 in each cubic centimeter, and further that a temperature as low as 4 to 6°C.—equivalent to 38 to 42°F.—produces a great amount of sluggishness in the bacteria, it will be realized to what an enormous extent these active little organisms must multiply at a temperature considerably higher than these. The temperature of the milk in the goat-skin bags which the Cuban milkman has upon his horse, Fig. 52, must be highly conducive to bacterial breeding, to say nothing of the many other hygienic defficiencies shown in his outfit, and yet this picture represents a condition which can be seen to-day in almost any locality in Cuba. The figures given in Table IV are based upon the number of bacteria found in each cubic centimeter of milk.

TABLE IV

Showing Effect of Age and Temperature upon Bacteria Content per c.c. of Milk

Carefully Selected		
Age	4°C. (38°F)	6°C. (43°F)
24 hrs.	2,500	3,100
48 "	3,600	12,000
96 "	218,000	1,500,000
108 "	4,209,000	80 millions
Ordinary		
Age	4°C.	6°C.
24 hrs.	38,000	42,000
48 "	56,000	360,000
96 "	4.3 millions	12 millions
108 "	38 millions	300 millions

Several processes of treating milk to reduce the number of bacteria before it is supplied to the consumer have been devised. They can be only briefly mentioned here. The oldest and most natural one is that of *sterilization* by boiling. There is no question as to the efficacy of this process so far as the destruction of germ life goes but it has several important disadvantages in the fact of the change in flavor due to the boiling, and in the alteration of the milk so as to make it less digestible, especially for infants. This disadvantage has led to a process known as *pasteurization*, so called in honor of Pasteur. This process consists in heating the milk to about 160 °F., which temperature is maintained for from 20 to 30 minutes, a sufficient time in which to kill all disease germs and most of the harmless germs which produce fermentation of the milk and yet produce only a slight alteration in the taste. The processes of producing condensed milk and cream and modified milk are hardly along the line of general milk supply and need not be discussed. Enough has been said, however, to show that attention must be directed with extreme care to the supplies of milk which are introduced in our homes and that this useful product is on a par with our water supply as a fertile source of disease.

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*The Author wishes to acknowledge having gathered his material largely from the following sources: Sedgewick's *Principles of Sanitary Science and Public Health* (Appleton); Frankland's *Bacteria in Daily Life* (Longmans, Green & Co.); Eliott's *Household Bacteriology* (American School of Home Economics); and Jordan's *General Bacteriology*—to which the student who designs to pursue further reading is referred. The bibliography of the subject of sanitation is particularly complete in Dr. Sedgewick's work. The Author also wishes to express his appreciation of the friendly assistance and advice of Professor Jordan and Dr. Heinemann of the University of Chicago.

REVIEW QUESTIONS.

PRACTICAL TEST QUESTIONS.

In the foregoing sections of this Cyclopedia numerous illustrative examples are worked out in detail in order to show the application of the various methods and principles. Accompanying these are examples for practice which will aid the reader in fixing the principles in mind.

In the following pages are given a large number of test questions and problems which afford a valuable means of testing the reader's knowledge of the subjects treated. They will be found excellent practice for those preparing for Civil Service Examinations. In some cases numerical answers are given as a further aid in this work.

REVIEW QUESTIONS

ON THE SUBJECT OF

HYDRAULICS

---

1. What will be the exact weight of 1 U. S. gallon of distilled water at a temperature of 160° F.?

2. How much higher will a water barometer stand at a place 500 feet above sea level than it will when 4,000 feet above sea level?

3. Assuming that it is practicable to lift water by suction a distance equal to three-fourths the theoretical height as shown by the water barometer, how high is a suction lift practicable at a place located 6,000 feet above sea level?

4. What will be the pressure per sq. inch on the bottom or side of a vessel containing water, at a point 20 feet below the water surface?

5. In Fig. 2, how heavy a weight W will be supported by a weight P equal to 100 pounds, the area of W being 20 sq. in. and that of P. being 2 sq. in.?

6. What is the total pressure on the side of a vessel 10 in. wide and filled with water to a depth of 8 inches?

7. What is the pressure on the face of a plate 10×10-in. in area, inclined at an angle of 10° from the vertical, and submerged so that the center of the plate is 30 in. below the surface?

8. What are the horizontal and vertical components of the pressure in question 7?

9. What is the stress per sq. in. in a pipe 10 in. internal diameter and $\frac{1}{2}$ in. thick, under a pressure head of water of 100 lb. per sq. inch?

10. If the safe stress on cast iron is 5,000 lb. per sq. in., what is the necessary thickness of a cast iron pipe 12 in. in diam-

eter to resist a bursting pressure due to a head of water of 150 feet?

11. What is the total pressure on the vertical face of a dam one foot long and having a depth of water in front of it of 25 feet?

12. At what depth is the center of pressure in question 11?

13. What will be the buoyant effect exerted upon a submerged body having a volume of 2,000 cu. in.?

14. Is the buoyant effect upon a body different when the body is placed at different depths in the water, being wholly submerged in all cases?

15. A body of a specific gravity of 1.5 is submerged. What will be its weight in air per cubic foot of volume? What will be its weight in water?

16. How should orifices be made to be reliable for measuring water?

17. What is meant by the "coefficient of contraction"? The "coefficient of discharge?"

18. If the coefficient of discharge is .6 what will be the discharge through an orifice 2 in. in diameter, under a head of 2 feet?

19. If the coefficient of contraction is .65 in question 18, what is the actual area of the jet at its reduced section?

20. Using Tables 3 and 4 what is the discharge from a round and a square orifice under a head of 10 feet, the orifices being respectively 6 in. in diameter and 6 in. × 6 in. square?

21. What is the discharge of a square orifice of the same actual *area* as the round orifice of question 20, and under the same head?

22. Using a coefficient of discharge of .60 what is the necessary diameter of a round orifice to discharge 2 cu. ft. per second under a head of 20 ft.?

23. How should a weir be arranged to give reliable results in the measurement of water?

24. What is meant by the "velocity of approach"?

25. Using Table No. 7, what is the discharge of a weir 5 ft. long under a head of 12 inches?

26. Using formula 25, what will be the answer to question 25? What is the difference between the two methods in per cent?

REVIEW QUESTIONS

ON THE SUBJECT OF

WATER SUPPLY

PART I

---

1. How does the use of water vary month by month and day by day?

2. How do surface and ground waters compare generally as to quality?

3. What is a fair amount of water consumption per capita for various purposes?

4. If rain is falling at the rate of 4 inches per hour and the run off is one-half as fast, what will be the flow in cubic feet per second from a drainage area of 10 square miles?

5. If the least annual run-off of a drainage area of 10 square miles be equal to 8 inches in depth, how many people will this provide for if the consumption averages 100 gallons per head per day, assuming there is storage capacity sufficient to utilize all the run-off for the year?

6. What storage capacity will be required in the above case if all the 8 inches runs into the reservoir in 5 months, leaving 7 months' demand to be met from the reservoir?

7. What conditions make it possible to secure artesian wells?

8. In what sort of material are we likely to find the most ground water available?

9. About what rate of consumption for fire purposes would be expected in a city of 25,000 inhabitants?

10. What causes the occurrence of springs?

11. What causes water to flow through the ground?

12. What are the most important uses of a public water supply?

13. What are the advantages and disadvantages of timber dams?

REVIEW QUESTIONS

ON THE SUBJECT OF

WATER SUPPLY

PART II

---

1. Calculate the necessary thickness of a cast-iron pipe 12 in. in diameter, to carry a water pressure of 175 lb. per sq. in.

2. If cast-iron pipe costs $30.00 per ton, what will be the cost of one mile of 8-in. pipe designed for a 250 ft. head?

3. Under what conditions are masonry conduits the most suitable forms of conduit for carrying water?

4. Compare the masonry conduit with iron pipe in regard to cost, durability, and the conditions under which they are the best form of construction.

5. When may conduits of vitrified clay pipe be used to advantage?

6. What is the function of a distributing reservoir?

7. Under what conditions is it desirable to employ reservoirs of earth; of masonry; of steel in the form of tanks or towers?

8. What capacity must a tank have to store water sufficient for one hour's fire use at a reasonable maximum rate in a town of 8,000 inhabitants?

9. What is the use of puddle in reservoir walls?

10. What precautions are to be observed in the construction of reservoir embankments?

11. What are the advantages of covered reservoirs?

12. Determine the thickness of a standpipe at points 10 feet apart from the top downward whose dimensions are: height 120 ft.; diameter 18 ft.

REVIEW QUESTIONS

ON THE SUBJECT OF

CHEMISTRY.

---

1. What do you understand by an atom? A molecule?

2. What is the standard of molecular weight?

3. Name all the elements you have ever seen.

4. Without looking at the table on page 7, write the symbols of iron, calcium, sodium, lead, carbon, sulphur, aluminum, silver, oxygen, chlorine, hydrogen, potassium, nitrogen, zinc and magnesium.

5. What is the law of conservation of matter?

6. Write the formula for water, common salt, sulphuric acid, sodium carbonate, carbon dioxide, lime, ammonium hydrate, hydrochloric acid, nitric acid, and sulphur.

7. Write the equation of sulphuric acid on lime (calcium oxide).

8. What is the atomic weight of oxygen, carbon, nitrogen, iron, calcium?

9. Why is distilled water pure?

10. What is "hard" water? What is the cause of temporary hardness? What is the cause of permanent hardness?

11. Give the molecular weight of common salt, $NaCl$; of sodium carbonate, Na_2CO_3; of sulphuric acid, H_2SO_4; of ammonium sulphate, $(NH_4)_2SO_4$.

12. Name the two principal processes for making sodium carbonate.

13. What are the products of combustion when coal is burned in plenty of air?

14. What happens in a chemical change?

REVIEW QUESTIONS

ON THE SUBJECT OF

BACTERIOLOGY AND SANITATION

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1. Give briefly the process of fermentation of any fruit juice. What is the result of the fermentation?

2. Why will grape juice, when heated and placed immediately in clean, air-tight bottles, remain sweet almost indefinitely?

3. Give briefly the work done by Louis Pasteur in developing bacteriology.

4. In what particulars are *solid* cultures an improvement over *liquid* cultures?

5. Show how Koch proved that the bacteria were the *cause* and not the *result* of the disease.

6. Name the three classes of bacteria according to form. Can you put any of the well-known bacteria in the class in which they belong?

7. Are bacteria all harmful? If not, name some useful types and show how they help.

8. In what ways are the noxious bacteria harmful to man?

9. What do you understand by *vital resistance?*

10. Can you give the reason for a person, who has been working hard for some time, taking cold and contracting pneumonia, say, whereas under ordinary circumstances the attack would probably have been confined to a *bad cold?*

11. How many things can you name which will bring about an *immunity* from disease in a person?

12. What are the *phagocytes,* and what is one of their important functions?

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