Richd Phillips Esqr

From the Author

A PRACTICAL TREATISE
ON
WARMING BUILDINGS,
ETC. ETC.

A PRACTICAL TREATISE

ON

WARMING BUILDINGS

BY

HOT WATER;

ON

VENTILATION,

AND THE

VARIOUS METHODS OF DISTRIBUTING ARTIFICIAL HEAT,
AND THEIR EFFECTS ON ANIMAL AND VEGETABLE PHYSIOLOGY.

TO WHICH ARE ADDED,

AN INQUIRY INTO THE LAWS OF RADIANT AND CONDUCTED HEAT,

THE CHEMICAL CONSTITUTION OF COAL,

AND THE

COMBUSTION OF SMOKE.

BY CHARLES HOOD, F.R.S. F.R.A.S. ETC.

SECOND EDITION, GREATLY ENLARGED, AND
ILLUSTRATED BY NUMEROUS WOOD CUTS.

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PREFACE TO THE SECOND EDITION.

A new edition of the TREATISE ON WARMING AND VENTILATING BUILDINGS being called for, advantage has been taken of this circumstance to extend and improve the original work as much as possible.

Notwithstanding the numerous improvements which have been made in the hot-water apparatus, since the publication of the first edition of this work, there appears to be nothing either to reject or to alter in that edition, though there is much which can with advantage be added to it. The present edition contains more than twice as much matter as the original work; but all that was therein given is still retained in the present volume, the additions being not necessary for correction, but merely for further illustration.

The principal object of this work being strictly of a practical character, the most simple definitions which were possible have been adopted in explaining the various subjects brought under consideration.

But the deficiencies which the more scientific class of readers might thus discover, have, it is hoped, to some extent been remedied, by copious notes on many points of scientific interest, and still more extensive references to other authors, whose works treat upon any of the numerous subjects which are discussed in the following pages. By these means the work is rendered more useful to practical men, who require only simple facts, in the most concise form; while to the scientific inquirer sufficient information is afforded to enable him at once to refer to the best sources of information, in order to test the correctness of the reasoning on which the conclusions are founded.

Since the publication of the first edition of this work, ample opportunities have occurred for testing in every variety of form, the accuracy of the rules and calculations which were there given, for constructing and apportioning the hot-water apparatus to the varying circumstances under which it is applied. The most important of the calculations are those on the heated surface required to warm a given building, and the proper size of the boiler and the furnace. The data on which were founded the rules and tables for calculating these proportions were carefully compared, both experimentally and practically; and the extensive use which has been made of these rules with perfect success, leaves no doubt whatever as to their complete accuracy.

In the present work there have been incorporated several papers by the author on various correlative subjects, which have been read before the Institution of Civil Engineers; and also the author's articles on "Stoves" and "Ventilation," published in the ENCYCLOPÆDIA METROPOLITANA.

In treating on Ventilation, the causes of the important physiological effects which result from breathing impure air have been investigated at considerable length; and also the effects produced by various methods of heating buildings. It is not expected that the present attempt to elucidate this subject, will assist in any considerable degree, to correct the extraordinary neglect with which this important branch of practical science has always been treated. The complete correction of this evil will necessarily be extremely slow, and must follow the general diffusion of intelligence, and the extension of scientific knowledge. But, in however slight a degree the observations in the present work may tend to accomplish this object, and to draw attention to the facts connected with it, the attempt to illustrate the philosophical principles of this important branch of science will probably be regarded as not without its utility.

The chapter on the Chemical Constitution of Coal and the Combustion of Smoke will, it is hoped, give a correct view of the principles on which the combustion of smoke may be combined with far greater economy of fuel, than at present obtains by the usual most imperfect methods of burning bituminous coal. Several most important errors appear to be prevalent on this subject; and the inventors of some of the projects for consuming smoke, have contributed not a little to the spreading of popular errors, arising either from the want of a correct knowledge of the true chemical principles of combustion, or from a desire to exhibit more prominently the advantages of their own peculiar inventions. The true principles of combustion can be applied to furnaces in a variety of ways; and as it is probable that some legislative enactments will be made for the purpose of abating the nuisance of smoke, the remarks on this subject will shew that it is directly to the interest of the proprietors of furnaces to consume the smoke, and that no corresponding disadvantages will attend the operation.

C. H.

EARL STREET, BLACKFRIARS,
July, 1844.

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A
PRACTICAL TREATISE,
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PART FIRST:

ON WARMING BUILDINGS BY HOT WATER, AND ON THE LAWS OF HEAT, ETC.

INTRODUCTION.

THE practice of employing hot water, circulating through iron pipes, for diffusing artificial heat, is an invention of acknowledged utility. The present extensive and extending use of this invention renders it extremely desirable that its principles should be clearly defined, and the rules for its practical application laid down with precision: for without this knowledge, its success will be uncertain and its application limited.

It can scarcely excite surprise, that prejudices should formerly have existed against this invention, while its merits and its principles were alike imperfectly known. Even at the present time they are but partially understood; and, therefore, to investigate these two subjects, is the proposed object of the present treatise, with the view of facilitating its application, and extending the sphere of its utility.

There is scarcely any branch of science, or of art, in which an acquaintance with the laws of Nature does not enable us to derive greater advantages in its application than we could otherwise possess. Although it is true that we are still ignorant of the more subtile agents which exist in the vast chain of causation, the laws which regulate the various phenomena of nature, are sufficiently known to afford the most beneficial assistance to every branch of the arts and sciences: and the most recondite of scientific discoveries, as well as the most valuable inventions and improvements in the arts, are not more demonstrative of the truth of this assertion, than those which are the most simple and inartificial.

For an illustration of the utility of this knowledge, we may refer to the law of gravity; not only because it is, of all natural phenomena, the most constant in its operation, and the most universal in extent, but because its influence is closely connected with the present subject of inquiry.

That all falling bodies gravitate with the same velocity, and, therefore, descend through a certain definite space in a given time, is, we know, an *effect* of which gravity is the *cause.* It is on the operation of this invariable law, that many of our most valuable inventions depend. Its influence is equally exerted on all objects; as well the most dissimilar, as the most alike; as well the most mighty, as the most minute. It is this which gives stability to the grandest works of nature, as well as to the most minute or artificial of our own works; it is from this cause that we obtain the unerring action of our pendulums and clocks; and it is by this also we obtain the circulation of hot water, with which we warm our dwellings. But by a knowledge of the *cause* of these effects, of the extent of its operation, and of the laws by which it acts, we can, by varying the circumstances of a gravitating body, alter also the velocity of its descent. We accomplish this by bringing other causes into operation, which modify the result, notwithstanding the immutability of the laws of gravity: and thus we can modify and subject to our will, one of the most constant and universal agents in Nature, by a knowledge of the physical laws.

The study of the laws which govern natural phenomena,—which in all cases are so simple, so beautiful, so perfect,—is, therefore, one of the most fruitful sources of inquiry which the mechanician can pursue. Without it all his plans will either be modified copies of existing inventions, or they will degenerate into wild speculations, unsupported on any reasonable foundation.

This is particularly observable in the case before us. The numerous failures which have occurred in the practical application of the invention of heating buildings by the circulation of hot water, are all distinctly referrible to the want of this kind of knowledge, and not to the object aimed at being itself unattainable. But whenever the physical laws are intended to be employed as the principal agents in producing any mechanical effect, it is an indispensable condition that simplicity of action be kept in view. While it may further be observed, that the endeavours to trace and elucidate the operating causes of the various phenomena, which occur in the course of practical experiments, are the surest means of facilitating original discoveries, as well as of promoting new adaptations of recognised principles.

The origin of the invention of employing hot water for diffusing artificial heat appears to be hid in considerable obscurity. It is not improbable that, like many other discoveries, it has been evolved at various periods from the Alembic of Time. It seems, however, to have been first used in France by M. Bonnemain, in the year 1777, and was employed by him during several years for hatching chickens by artificial heat. About the year 1817, the Marquis de Chabannes employed a similar apparatus for heating a conservatory in this country, and the following year he published a pamphlet describing the apparatus and its application to different purposes. About the year 1822, Mr. Bacon and Mr. Atkinson both experimented on an apparatus somewhat different from those already mentioned; but it was the latter, who, undoubtedly, first gave to the apparatus the arrangement under which it is now generally used in its most simple form.

The honour of this invention has been claimed for Mr. Watt, prior to the time of M. Bonnemain using it in France; but there appear no grounds for supposing he ever employed it without the intervention of steam, as a distributor of heat by circulation, in the manner in which it is now used. The mere motion of hot water in pipes is an invention of far greater antiquity than the time either of Watt or Bonnemain. Seneca has accurately described the mode of heating the water in the Thermæ of Rome, of which Castell has given drawings;[1] and which shew that the method of heating baths by passing the water through the fire in a coil of pipes was known and practised previous to the Christian era: and except that the tubes were of brass, instead of iron, they were precisely similar, both in form and arrangement, to those used at the present day for the like purpose; the lapse of nineteen centuries having apparently added nothing to our knowledge on this subject.

Since the first introduction of the hot-water apparatus for warming buildings, the variations made in its more complicated arrangements appear to have been very gradually adopted. Each time that an apparatus has been erected, the experimentalist has deviated in some small degree from the model of that

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[1] Castell's Illustrations of the Villas of the Ancients, p. 10.

which preceded; apparently afraid of venturing on too great a variation, yet requiring, from contingent circumstances, some alteration of its form and application. This mode of proceeding, though natural while the principles were not thoroughly understood, has frequently led to both inconvenience and loss, in consequence of the numerous failures to which it has given rise, by unintentional deviations from the principles. In the present attempt to elucidate the subject, it will however be shewn that success needs not be uncertain, provided only that the laws of physics be justly applied and strictly adhered to.

Neither the capabilities of this method of warming, nor the various useful purposes to which it is applicable, are even yet fully appreciated. There are no buildings, however large, to which it cannot be advantageously adapted, nor any that present insurmountable difficulties in its practical application. And in many useful purposes connected with arts and manufactures, it can be most advantageously employed, though its application to these purposes has hitherto been greatly overlooked. Its merits, however, will best appear by the plainest statements of facts. We shall proceed, therefore, at once, to the main object which has been proposed—an investigation of the *principles* of this invention, as applied to the warming of buildings.

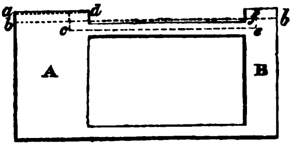
CHAPTER I.

Cause of Circulation of the Water—Inclination of the Pipes—Necessity for Air-vents—Open and Close Boilers—Pressure of Water—Effect produced on the Circulation by increased Height of the Pipe—Compression of Water—Branch Pipes—Variations in Level of Pipes.

(Art. 1.) In endeavouring to explain the principles of the various forms of apparatus in which hot water, circulating through iron pipes, is employed as a means for distributing artificial heat, the first object should be to point out, as clearly as possible, the power which produces the circulation of the water; for without a clear perception of this part of the subject, there will always be an uncertainty as to the results which will obtain, when any departure is made from the most simple form and arrangement of the different parts of the apparatus. It is this circulation which causes all the water in the apparatus to pass successively through the boiler, and then communicates the heat that is thus received from the fuel, to the various buildings or apartments which it is designed to warm. Without this circulation, those parts of the apparatus which are remote from the fire would not receive any heat; because water is so bad a conductor, that it is only when there exists perfect freedom of motion among its particles, that it acts at all as a conductor of heat, so far, at least, as regards any practical and useful effect. It is in a complete and perfect circulation, therefore, that the efficiency of a hot-water apparatus depends, and that the greatest amount of heat is obtained by it from a given quantity of fuel.

(2.) The only treatise hitherto published, in which any attempt has been made to explain the cause of the circulation of the water in this description of apparatus, is Mr. Tredgold's work on heating by steam; and the effect is there referred entirely to an erroneous cause. In the Appendix to that work, the cause of motion is thus explained. “ If the vessels A, B, and pipes, be filled with water, and heat be applied to the vessel A, the effect of heat will expand the water in the vessel A, and the surface will, in consequence, rise to a higher level *a d*, the former general level surface being *b b*. The density of the fluid in the vessel A will also decrease in consequence of its expansion; but as soon as the column *c d* (above the centre of the upper pipe) is of a greater weight than the column *f e*, motion will commence along the upper pipe from A to B, and the change this motion produces in the equilibrium of the fluid will cause a corresponding motion in the lower pipe from B to A.”

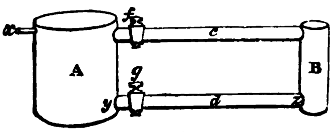
Fig. 1.



(3.) Now it is certain that this theory will not account for the circulation of the water, under all circumstances, and every variety of form, of the apparatus; and as the cause of motion must be the same in all cases, any explanation which will not apply universally must necessarily be erroneous. Were this the true cause of motion, there would be no difficulty in obtaining a circulation in all cases; for, according to this reasoning, whenever the level of the water is higher in the boiler than in the pipes —or even if an upright pipe were placed on the top of a close boiler, by which the pressure on the surface would be increased,—the water must, of necessity, circulate through the pipes: while, on the other hand, if this hypothesis were correct, the water in an apparatus, constructed as in the following figure, would not circulate at all.

(4.) Suppose the apparatus fig. 2, to be filled with cold water, and the two stop-cocks *f*, *g*, to be closed: on applying heat to the vessel A, the water it contains will expand in bulk, and a part of it will flow through the small waste pipe *x*, which is so placed as to prevent the water rising higher in the vessel A, than the top of the vessel B. The water which remains in the vessel A, after it has been heated, and a portion of it has passed through the waste pipe *x*, will evidently be lighter than it was before, while its height will remain unaltered. Suppose, now, the two cocks *f*, *g*, to be simultaneously opened; the hot water in the boiler A will immediately flow towards B through the upper pipe, and the cold water in B will flow into A through the lower pipe; although, by the above-mentioned hypothesis, unless the water in the vessel A, above the pipe *c*, were heavier, or rose to a higher level than the water in the vessel B, no circulation could take place. In this case, therefore, we must find another explanation of the cause of motion.

FIG. 2.



(5.) The power which produces circulation of the water will be found to arise from a different cause than that which is here stated; for we see that this reason is insufficient to account for the effect, even in one of the simplest forms of the apparatus.

(6.) In order to explain this, let us suppose heat to be applied to the boiler A, fig. 2. A dilatation of the volume of the water takes place, and it becomes lighter; the heated particles rising upwards through the colder ones, which latter sink to the bottom by their greater specific gravity, and they in their turn become heated and expanded like the others. This intestine motion continues until all the particles become equally heated, and have received as much heat as the fuel can impart to them. But as soon as the water in the boiler begins thus to acquire heat, and to become lighter than that which is in the opposite vessel B, the water in the lower horizontal pipe *d*, is pressed by a greater weight at *z* than at *y*, and it therefore moves towards A with a velocity and force equal to the difference in pressure at the two points *y* and *z*.[1] The water in the upper part of the vessel B would now assume a lower level, were it not that the pipe *c* furnishes a fresh supply of water from the boiler to replenish the deficiency. By means of this unequal pressure on the *lower* pipe, the water is forced to circulate through the apparatus, and it continues to do so as long as the water in B is colder, and therefore heavier, than that which is in the boiler; and as the water in the pipes is constantly parting with its heat, both by radiation and conduction, while that in the boiler is as continually receiving additional heat from the fire, an equality of temperature never can occur; if it did, the circulation would cease.

(7.) We see, then, that the cause of the circulation is the unequal pressure on the lower pipe of the apparatus; and that it is not the result of any alteration which takes place in the level of the water, as has been erroneously supposed. Indeed, the

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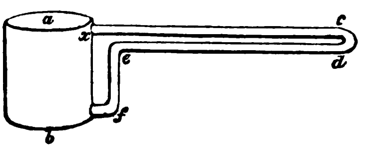
[1] To any person unacquainted with the science of Hydrostatics, this may probably appear erroneous; because the quantity of water contained in A is much greater than that in B. It is, however, one of the first laws of Hydrostatics, that the pressure of fluids depends for its amount on the height of the fluid only, and is wholly irrespective of the bulk, or actual quantity of fluid: therefore, a pipe which is not larger than a quill will transmit the same amount of pressure, as though it were a foot, or a yard, in diameter, provided the height be alike in both cases. (See Art. 16).

truth of this appears so plain, that it would scarcely require explanation at such a length, were it not that false opinions in this matter appear to have led to many errors in practice.

(8.) As the circulation is caused by the water in the descending pipe being colder, and therefore heavier than that which is in the boiler; it follows, as a necessary consequence, that the colder the water in the descending pipe shall be, relatively to that which is in the boiler, so much the more rapid will be its motion through the pipes. In such an arrangement of pipes as fig. 3, the water in the descending pipe *e f*, having to travel farther before it descends to the lower part of the boiler, than when the pipes are arranged as in fig. 2, it will of course be colder at the time of its descent, in the case, fig. 3, than in fig. 2, and therefore the circulation will be more rapid. The height of the descending pipe is supposed to be alike in both cases; because *c d* and *e f* are together equal to *a b*.

FIG. 3.

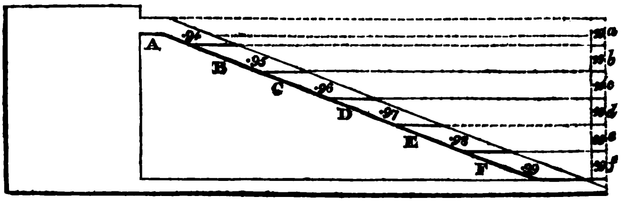


(9.) Some persons have imagined that if the pipes be inclined, so as to allow a gradual fall of the water in its return to the boiler, additional power will be gained; as, for instance, by inclining the lower pipe of fig. 3, so as to make the part *e* lower than *d*, and then reducing the vertical height of the return pipe *e f*. This, at first, appears very plausible, particularly with regard to some peculiar forms of the apparatus; but the principle is, in fact, entirely erroneous. The author of the Appendix to Tredgold's work, already quoted, in consequence of adopting the erroneous hypothesis, that the motion of the water commences in the upper pipe instead of the lower one, as already described, appears to recommend an inclination being given to the pipes in this manner; and he has described an apparatus that he erected, to which a fall of four feet was given to the water by this method.

This error appears to arise from treating the subject as a simple question of hydraulics, instead of a compound result of hydrodynamics. But in order to ascertain what is the effect of thus inclining the pipes, let us suppose an extreme case.

(10.) It is evident that the farther the water flows, the colder does it become. It must, therefore, be hotter at A (fig. 4) than it is at B, and hotter at B than C, and so on. Let us, now, suppose any arbitrary number to represent the specific gravity of the water at A; say, for instance, ·94. The water at B, in consequence of having flowed farther and therefore become colder and heavier, will be, we will suppose, of the specific gravity of ·95; at C, for the same reasons, it will be ·96, and so on to F, where, from having run the greatest distance from the boiler, it will be the heaviest of all;[1] and the sum of all these numbers represents the pressure at F. But had the pipe, instead of inclining gradually from the boiler, continued on a level to *a*, as represented by the dotted lines, the water would have been as cold, and therefore as heavy, at *a*, as, by the former arrangement, it is at F, and therefore its specific gravity

FIG. 4.



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[1] The real specific gravities could not conveniently be used in this illustration, as they would require several decimal places of figures. See Table IV. Appendix.

would be the same, namely, ·99. Now, as the pressure of water is at its vertical height, by dividing the vertical pipe, *a f*, in the same manner as we have done with the inclined pipe, we shall have *a*, *b*, *c*, *d*, *e*, *f*, each equal in altitude to the corresponding divisions of the inclined pipe; and as the specific gravity of each division is equal to ·99, the total number representing the sum of all these will shew the pressure at the point *f*. We shall hence find the pressure of the vertical pipe, compared with that of the inclined pipe, will be as 5·94 is to 5·79.[1]

(11.) It is evident from this, that there must be a considerable loss on the effective pressure, by making the pipe to incline below the horizontal level. Nor can this loss be compensated in any manner; for the total height being the same, whether the water descends through a vertical or through an inclined pipe, the force or pressure will only be equal to the specific gravity of the matter. And as there is actually more matter in a pipe filled with cold water than in a similar pipe filled with hot water, the gravitating force will be inversely proportional to the temperature; that is, it will be less in proportion as the temperature of the water is greater. There must, therefore, under all circumstances, be a positive loss of effect by inclining the pipe in the manner stated.[2]

(12.) In such a form of apparatus as fig. 3, there would be no circulation of the water, unless some

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[1] If the strict analogy were carried out, the difference ought to be greater than is here represented; because it is evident that instead of *a*, *b*, *c*, *d*, etc., being each of equal density, *b* will be heavier than *a*, and *c* heavier than *b*, and so on; but the illustration, as now given, will be sufficient to shew the principle.

[2] It must not be supposed that this reasoning at all applies to any case of pure hydraulics. If the question were only as regards a fluid of uniform temperature, then the greatest effect would be obtained by using an inclined pipe; but the fluid, which we are now regarding, is one of a varying density and temperature, which materially alters the conditional results.

plan were adopted by which the air would be dislodged from the pipes, and a ready escape provided for it. Nothing is more necessary to be attended to than this; for, in the more complicated forms of the apparatus, the want of an efficient means of discharging the air has been the cause of innumerable failures. Suppose we require the apparatus fig. 3 to be filled with water; by pouring it in at the boiler, the pipe *e f* will of course be filled simultaneously with it, and then the lower pipe *d;* and the water will then gradually rise higher in the boiler until it partially fills the upper pipe. At last the orifice of the pipe *x* will become full, and the air which is in the pipe *c x*, being thus prevented from escaping, will be forced towards *c* by the weight of water behind it; and if the quantity of air be sufficiently large, it will entirely prevent the junction of the water at *c*, and cut off the communication between the two pipes at *c d*. If an opening be now made in the pipe at *c*, the air will immediately escape, being forced out by the greater density of the water; and, therefore, either a valve or a cock must be placed there, to allow of its discharge, for otherwise no circulation of the water can ensue. As water, while boiling, always evolves air, it is not sufficient merely to discharge the air from the pipes on first filling them with water, because it is continually accumulating:[1] and in many instances, particularly with a close-topped boiler, it is desirable to have the air-vent self-acting; either by using a valve, or a small open pipe: in others, a cock will often be found most convenient.

(13.) The size of the vent is not material, as a very small opening will be sufficient to allow the

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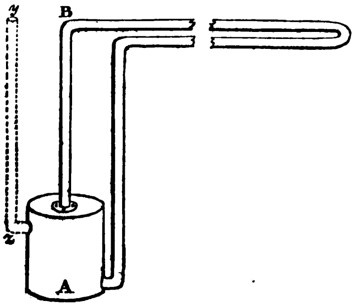
[1] If the water were always kept boiling, the air, after being once expelled, would not again accumulate. But when the water cools it again imbibes air; and thus a continual discharge of air occurs in a hot-water apparatus.

air to escape. For the rapidity of motion in fluids, when pressed by equal weights, being inversely proportional to their specific gravities, as water is 827 times more dense than air, an aperture which is sufficiently large to empty a pipe in fourteen minutes if it contained water, would, if it contained air, empty it in about one second.[1] Air being so very much lighter than water, it is of course necessary that the vents provided for its escape be placed in the highest part of the apparatus, for it is there it will always lodge; and sometimes it will be found necessary to have several vents in different parts of the apparatus.

Though it is perfectly easy, as far as the mere mechanical operation is concerned, to provide for the discharge of the air from the pipes, it requires much consideration and careful study to direct the application of those mechanical means to the exact spot where they will be useful. The subject will, therefore, be again adverted to in a subsequent chapter, when we have investigated the principles of the apparatus in some of its more complex forms of arrangement.

(14.) The plan of the boiler and pipes which has been given in the preceding figures, is applicable to comparatively but few purposes: for, in consequence of the boiler being open at the top, the pipes must be laid level with it, otherwise the water would overflow. When the pipes are required to rise higher than the boiler, the latter must be closed at the top, and the pipes can then be carried upwards to any required height. This arrange-

Fig. 5.



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[1] Manchester Memoirs, vol. v. p. 398; and Nicholson's Journal, vol. ii. p. 269.

ment possesses considerable advantages; for the higher we make the ascending and descending pipes, the more rapid is the circulation of the water.[1] This consequence necessarily results from the principles already explained; because, as motion is obtained in consequence of the difference in weight of the ascending and descending columns of water, the greater the height of these columns, the greater must be the difference in their weight, and therefore the greater must be the force and velocity of motion.

(15). The advantages which may be derived from an increased height in the ascending pipe, cannot however be applied in an unlimited manner; because it might lead to inconvenience, and even be attended with some degree of danger to the apparatus, if the increased height were not regulated by certain rules, and these, when ascertained, applied with judgment.

(16.) The pressure produced by water is calculated by its columnar height, reckoned from the bottom of the vessel in which it is contained. Whether the vessel be open at the top and very deep, or closed at the top and very shallow, but with a pipe attached to the top, like the boiler and pipe A B, fig. 5, the pressure will be exactly alike in either case, if the deep open boiler be equal in height to that of the shallow boiler and upright pipe conjointly; notwithstanding the quantity of water may be 10 times, or 100 times, larger in the one case than the other. Neither is the pressure increased, however large may be the diameter of the pipe which is used; nor is it lessened if the pipe be inserted at the side of the boiler, as in the dotted lines *y z*, fig. 5, instead of being placed on the top.

(17.) As the pressure of water on each square inch

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[1] In this and the preceding figures, the pipes are drawn so as to shew the flow and return pipes lying one above the other. A moment's consideration will satisfy any one that the effect will be the same, if they were placed side by side on the same level; and frequently this arrangement is far more convenient.

of surface increases at the rate of about half-a-pound,[1] for every foot of perpendicular height, if the height from the bottom of the boiler to the top of the pipe be six feet, the pressure on the bottom will be three pounds on every square inch of surface; but if the boiler be two feet high, the pressure on the top—which will be a pressure upwards—will be only two pounds on every square inch of surface, because it will only have four perpendicular feet of water above it. If the height of the pipe be increased to 28 feet, and the depth of the boiler be two feet, as before, making 30 feet together, the pressure will be 15 lbs. on each square inch of the bottom, 14 lbs. on each square inch of the top, and an average pressure of 14½ lbs. on each square inch of the sides of the boiler. Suppose now, a boiler to be three feet long, two feet wide, and two feet deep, with a pipe 28 feet high from the top of the boiler; when the apparatus is filled with water there will be a pressure on the boiler of 66,816 lbs., or very nearly 30 tons.[2]

(18.) When a great pressure is used in a hot-water apparatus, in the manner here described, it is necessary that the materials of the boiler should be stronger than they otherwise need be; and more care is also required in making the joints very sound, for

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[1] The exact weight of a perpendicular foot of water, with a base in one square inch, is 3030·24 *grains*, at the temperature of 60°; which is therefore only ·4328 of a pound avoirdupois. A column of water 30 feet high only gives a pressure of 12·68 lbs. instead of 15 lbs. as usually reckoned; and therefore the real height of a column of water, which will give a pressure equal to one atmosphere, must be 34½ feet.

[2] This enormous pressure on vessels which contain water does not occur in the case of pipes merely used for *the conveyance* of water; for in this case, when the water runs out of the lower end of a long vertical pipe as fast as it runs in at the top, although it be always kept perfectly full, still there may probably be no pressure whatever on any part of the pipe, however great its length may be.—*Robison's Mechanical Philosophy*, vol. ii, p. 580, et seq.

attaching the pipes to the boiler, so as to prevent any leakage. But when these mechanical difficulties are overcome, the amount of danger arising from a great pressure of water must not be over-rated, for it might otherwise deter some persons from adopting this form of the apparatus, notwithstanding its numerous advantages.

(19.) The great danger that arises from the bursting of a steam apparatus, is in consequence of the elastic force of steam, which, at very high temperatures, is immense. But water possesses very little elasticity compared with steam, its expansive force being almost inappreciable under ordinary circumstances. At the pressure of 15lbs. per square inch, the water in the boiler last described, which holds about 75 gallons, would be compressed rather less than *one cubic inch*, or about $\frac{1}{35}$ part of a pint.[1] The expansive force of the water in this apparatus, therefore, even supposing it were to burst, would be perfectly harmless; for it could only expand as much as it had been compressed; namely, *one cubic inch.* The effect on a boiler, by the pressure of the water, will be precisely similar to a weight pressing upon it, equal to the estimated pressure of the water; which is quite different from the sudden and violent force produced by the expansive power of steam. As an apparatus of this kind could never be forced asunder, as in the explosion of a steam boiler, the only result, under the worst circumstances that could occur, would be a leakage of the water, in consequence of the cracking of some part of the boiler.

(20.) Neither the principle, nor the practical

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[1] According to the experiments of Professor Oerstead, the compression of water is ·0000461 by a pressure of 15lbs. per square inch; and he has found that it proceeds *pari passu*, as far as 65 atmospheres, which was the limit to which his experiments extended. This compression is about equal to reducing a given bulk of water $\frac{1}{16}$ of its volume by a pressure of 20,000lbs. per square inch.—*Report Brit. Scientific Association*, vol. ii. p. 353.

working of the apparatus, is in the least affected by having any additional number of pipes leading out of or into the boiler. The effect is the same whether there are more flow pipes than return pipes, or conversely, more return pipes than flow pipes. If there be two or more flow pipes, whether they lead from the boiler separately, or branch from one main pipe, or whether they lead from opposite sides of the boiler, or all from one side, each range of pipes will act separately and have a velocity of circulation peculiar to itself: and one range of pipes may act efficiently, while another, though attached to the same boiler, may have no circulation whatever through it; and this effect will not be altered, whether the pipes return into the boiler separately, or all unite into one main pipe. The pressure, supposing the pipes to rise vertically from the boiler, will likewise be precisely the same, however numerous the pipes may be. This circumstance is one of the peculiarities which distinguish fluids from solids. For if the fluid in any close vessel be pressed by the fluid contained in an upright pipe, so as to produce a pressure of 10lbs. on the square inch; if a second pipe, capable of exerting a similar pressure with the first, be placed upon the same vessel, the united pressure will still be only 10lbs. per square inch; and it would be no more, though ever so large a number of pipes were added, provided the vertical height were not increased.

(21.) One advantage may be attained by causing the water to rise from the boiler by an ascending pipe, as in fig. 5, which cannot be accomplished by any other means; and it is of considerable importance to ascertain its true effect, as it has produced consequences which are not generally attributed to the right cause.

The force and velocity of motion of the water, being proportional to the vertical height of the ascending and descending pipes; by increasing this height, a facility is afforded for taking the pipes below the horizontal level, as, for instance, when it is required to pass them under a doorway, or other similar obstruction, before they finally descend to the bottom of the boiler. Innumerable failures have occurred in attempting to make the water descend and again to ascend in this manner, the success of the experiment depending entirely upon the vertical height of the ascending pipe above the boiler. These alterations of the horizontal level, which are frequently very desirable, have, of course, their limits, beyond which they cannot be carried; and it is from not having ascertained what are these limits, and what the cause of the limitation, that such uncertainty has hitherto prevailed with regard to this experiment; for it frequently succeeds, but more frequently fails, in practice. It will be most convenient, however, to consider this object after we have ascertained what is the amount of the *motive power* of the water in this kind of apparatus.

CHAPTER II.

On the Motive Power of the Water—On increasing the Motive Power—Velocity of Circulation—Circulation of Water below the Boiler — Air Vents — Supply Cisterns — Expansion of Pipes, etc.

(22.) It has already been mentioned, that the power which produces circulation of the water, is the unequal pressure on the return pipe, in consequence of the greater specific gravity of the water in the descending pipe, above that which is in the boiler. Whether this force acts on a long length of return pipe, as y z, fig. 2, or only on a very short length, as f, fig. 3, the result will be precisely similar.

(23.) Now, it is evident that, if this unequal pressure is the *vis viva*, or motive power, which sets in motion the whole quantity of water in the apparatus, it is only necessary, in order to ascertain the exact amount of this force, that we know the specific gravities of the two columns of water; and the difference will, of course, be the effective pressure, or motive power. This can be accurately determined when the respective temperatures of the water in the boiler and in the descending pipe are known.[1]

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[1] A thermometer suitable for this purpose was long since proposed by M. Fourier, and called by him the thermometer of contact. It consists of a very small iron cup, just large enough to hold the bulb of the thermometer, but without a bottom to it. Over the bottom, a piece of goldbeater's skin is to be tied, and the cup is then to have a little mercury put in it, into which the bulb of the thermometer is to dip. The cup, when placed on any hot surface, will accurately shew the temperature, the contact between the skin and the surface being extremely perfect.

(24.) As this difference of temperature rarely exceeds a very few degrees in ordinary cases, the difference in the weight of the two columns must necessarily be very small. But, probably, the very trifling difference which exists between them, or, in other words, the extreme smallness of the motive power, is very imperfectly comprehended; and will, perhaps, be regarded with some surprise, when its amount is shewn by exact computation.

(25.) In order to ascertain, without a long and troublesome calculation, what is the amount of motive power for any particular apparatus, the following Table has been constructed. An apparatus is assumed to be at work, having the temperature in the descending pipe 170°; and the difference of pressure upon the return pipe is calculated, supposing the water in the boiler to exceed this temperature by from 2° to 20°. This latter amount exceeds the difference that usually occurs in practice.

(26.) By referring to the annexed Table, it will be found that when the difference between the temperature of the ascending and the descending columns amounts to 8°, the difference in weight is 8·16 *grains* on each square inch of the section of the return pipe, supposing the height of the boiler A, fig. 2, to be 12 inches. This height, however, is only taken as a convenient standard from which to calculate; for, probably, the actual height will seldom be less than about 18 inches, and, in many cases, it will be considerably more.

Now, suppose, in such a form of apparatus as fig. 2, the boiler to be two feet high; the distance from the top of the upper pipe to the centre of the lower pipe to be 18 inches; and the pipe four inches diameter;—if the difference of temperature between the water in the boiler and in the descending pipe be 8°, the difference of pressure on the return pipe will be 153 *grains*, or about one-third part of an ounce weight: and this will be the amount of *motive power* of the apparatus, whatever be the length of pipe attached to it. If such an apparatus have 100 yards of pipe, four inches diameter, and the boiler contains, suppose 30 gallons,—there will be 190 gallons, or 1900 lbs. weight of water, kept in continual motion by a force only equal to one-third of an ounce.[1] This calculation of the amount of the motive power, in comparison with the weight moved, will vary under different circumstances; and in all cases the velocity of the circulation will vary simultaneously with it.

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[1] M. Dutrochet made some experiments on the influencing causes of the motion of currents in liquids. He found that a difference of temperature of 1-800th of a degree was sufficient to produce currents when aided by light, but the motions ceased on light being excluded. In the absence of light (except what was necessary to distinguish the object) the sound of a violoncello or of a bell produced circulation in the liquid. He therefore concluded that the most minute differences of temperature will produce motion among the particles of a fluid when aided by light or any other cause which produces feeble vibrations to the particles of the fluid. *Quart. Journal of Science*, vol. xxix. p. 194. It is not stated how this small excess of heat was ascertained. The effects of sound may possibly be in some way connected with a fact which Biot attempted to demonstrate by experiment,—that every vibration of a sonorous body in elastic media, is accompanied with a change of temperature. *Mémoires de la Société d'Arcueil*, 1809: and *Retrospect of Science*, vol. v. p. 429.

TABLE I.

Difference in Weight of Two Columns of Water, each One Foot high, at various Temperature.

Difference in Temperature of the Two Columns of Water: in Degrees of Fahrenheit's Scale.	Difference in Weight of Two Columns of Water contained in different sized Pipes.				Difference of a Column 1 foot high.
	1 in diam.	2 in diam.	3 in diam.	4 in diam.	per sq. in.
	grs. weight	grs. weight	grs. weight	grs. weight	grs. weight
2°	1·5	6·3	14·3	25·4	2·028
4°	3·1	12·7	28·8	51·1	4·068
6°	4·7	19·1	43·3	76·7	6·108
8°	6·4	25·6	57·9	102·5	8·160
10°	8·0	32·0	72·3	128·1	10·200
12°	9·6	38·5	87·0	154·1	12·264
14°	11·2	45·0	101·7	180·0	14·328
16°	12·8	51·4	116·3	205·9	16·392
18°	14·4	57·9	131·0	231·9	18·456
20°	16·1	64·5	145·7	258·0	20·532

⁂ The above Table has been calculated by the formula given with Table IV., in the Appendix, for ascertaining the specific gravity of Water at different temperatures. The assumed temperature is from 170° to 190°.

(27.) It will be observed in the foregoing Table, that the amount of motive power increases with the size of the pipe: for instance, the power is four times as great in a pipe of four inches diameter, as in one of two inches. The power, however, bears exactly the same relative proportion to the resistance or weight of water to be put in motion, in all the sizes alike; for although the motive power is four times as great in pipes of four inches diameter, as in those of two inches, the former contains four times as much water as the latter: the power and the resistance, therefore, are relatively the same.

(28.) As the motive power is so small, it is not at all surprising that, by an injudicious arrangement of the different parts of an apparatus, the resulting motion may frequently be impeded, and sometimes even totally destroyed: for the slower the circulation of the water, the more likely is it to be interrupted in its course. There are two ways by which the amount of the motive power may be increased: one, by allowing the water to cool a greater number of degrees between the time of its leaving the boiler and the period of its return through the descending pipe; the other, by increasing the vertical height of the ascending and descending columns of water. The effects produced by these two methods are precisely similar; for, by doubling the difference of temperature between the flow pipe and the return pipe, the same increase in power is obtained as by doubling the vertical height; and tripling the difference in temperature is the same as tripling the vertical height.[1] This can be ascertained by referring to the preceding table. Thus, suppose, when the difference of temperature is 8°, and the vertical height four feet, that the motive power is 32·6 *grains* per square inch: if the difference of temperature be increased to 16° while the height remains the same, or if the height be increased to eight feet while the temperature remains as at first,—the pressure, in either case, will be 65·2 *grains* per square inch, or twice the former amount. The same rule applies to other differences, both of height and temperature.

(29.) Almost the only two methods of increasing the difference of temperature between the ascending and the descending columns are, either by increasing the quantity of pipe, so as to allow the water to flow a greater distance before it returns to the boiler; or, by diminishing the diameter of the pipe, so as to

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[1] This is without reference to friction: the effect will therefore be a little modified by this cause. (See Art. 34 and 55.)

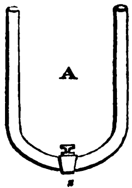
expose more surface in proportion to the quantity of water contained in it, and by this means to make it part with more heat in a given time. (See Art. 75.) The first of these two methods, however, is necessarily limited by the extent of the building that is to be heated, to which the quantity of pipe must be adjusted in order to obtain the required temperature: and as to the second, there are many objections against reducing the size of the pipes, which will be considered presently. The increase of motive power to be obtained by increasing the height of the ascending column of water is, therefore, what must principally be depended on, when additional power is required to overcome any unusual obstructions.

(30.) In all cases the rapidity of circulation is proportional to the motive power; and, in fact, the former is the index of the latter and the measure of its amount. For if, *while the resistance remains uniform*, the motive power be increased in any manner or in any degree, the rate of circulation will increase in a relative proportion. Now the motive power irrespective of retardation by friction may be augmented, as we have already seen, either by increasing the vertical height of the pipe; by reducing its diameter; or by increasing its length. If by any of these means the circulation be doubled in velocity, then, as the water will pass through the same length of pipe in half the time it did before, it will only lose half as much heat as in the former case; because the rate of cooling is not proportional to the distance through which the water circulates, but to the time of transit. If, then, by sufficiently increasing the vertical height, the difference between the temperature of the flow pipe and the return pipe be diminished one-half, it might be supposed that the motive power of the apparatus would remain the same, and no advantage would appear to be gained by this means. But this is not exactly the case. For although, whether we double the vertical height, or double the horizontal length, we shall, in either case (and omitting the question of friction), increase the velocity of motion; yet it will require a quadruple increase of vertical height, or a quadruple increase of horizontal length, to obtain double the original rate of circulation. (See Art. 33.) The increased velocity is therefore indicative of increased power; and, in a hot-water apparatus, it is the increased velocity of circulation which overcomes any obstructions of a greater amount than ordinary.

(31.) The velocity with which the water circulates in this kind of apparatus, although continually subject to variation, can nevertheless be calculated theoretically, when certain data are agreed upon, or are ascertained to exist.

(32.) When the two legs of an inverted syphon, A, fig. 6, are filled with liquids of unequal density, if the stop cock, *z*, be turned, so as to open the communication between them, the lighter liquid will move upwards with a force proportional to the difference of weight of the two columns, provided the bulk of the two liquids be equal. If one leg contains oil, and the other contains water, the relative weights will be about as nine to ten; therefore it will require 10 inches vertical height of oil, to balance 9 inches of water; and no motion will in that case take place. But when equal bulks of the two fluids are used, the velocity of motion with which the lighter fluid is forced upwards, is equal to the velocity which a solid body would acquire in falling, by its own gravity, through a space equal to the additional height which the lighter body would occupy in the syphon, supposing a similar *weight* of each fluid had been used. This velocity is easily calculated: — a gravitating body falls 16 feet in the first second of time of its

Fig. 6.



descent; 64 feet in two seconds, and so on; the velocity increasing as the square of the time: therefore, the relative velocities are, as the *square roots of the heights.* Now, in the case of the syphon, which we have supposed to contain a column of water and a column of oil, each 9 inches in height; as the oil ought to be 10 inches high to balance the 9 inches of water, the oil in the one leg will be forced upwards with a velocity equal to that which the water (or any other body) would acquire by falling through one inch of space; and this velocity, we shall find, is equal to 138 feet *per minute.*[1]

(33.) To estimate the velocity of motion of the water, in a hot-water apparatus, the same rule will apply. If the average temperature be 170°, the difference between the temperature of the ascending and the descending columns 8°, and the height 10 feet; when similar weights of water are placed in each column, the hottest will stand ·331 of an inch higher than the other;[2] and this will give a velocity equal to 79·2 feet *per minute.* If the height be

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[1] The velocity will be as the square root of 16 feet *per second,* to the square root of the additional height which an equal weight of the lighter liquid would occupy, reduced to the decimal of a foot. And as the acquired velocity of a body at the end of a given time is twice as much as the distance it passes through, in arriving at any given velocity by accelerated motion, or, in other words, as a body which falls through 16 feet of space, in one second, will proceed at the rate of 32 feet per second afterwards, without receiving any additional impulse; so the velocity found by this rule will be only half the real velocity; and the number thus obtained must be multiplied by 2. The velocity will, therefore, be found, by multiplying the *square root* of the difference between the height of the two columns in decimals of a foot, by the *square root* of 16; and then, multiplying that product by 2, will give the real velocity *per second.*

The discharge through a syphon, employed to empty casks and other vessels, can also be calculated by this rule: the velocity of motion will be equal to the difference in length of the two legs.

[2] The expansion of water by heat will be found in Table IV. Appendix.

five feet, the difference of temperature remaining as before, the velocity will be only 55·2 feet *per minute:* but if the difference of temperature in this last example had been double the amount stated,—that is, had the difference of temperature been 16°, and the vertical height of the pipe five feet,—then the velocity of motion would have been 79·2 feet *per minute*, the same as in the first example, where the vertical height was 10 feet, and the difference of temperature 8°. This, therefore, proves, in corroboration of what has been already stated (Art. 30), that reducing the temperature of the water, either by using smaller pipes, or by increasing the length through which it flows, has the same effect on the circulation as increasing the vertical height, leaving out of consideration the question of friction. The velocity for three feet of vertical height by the same rule will be 43·2 feet *per minute;* for two feet of vertical height, it will be 36 feet *per minute;* and for 18 inches of vertical height it will be 30·7 feet *per minute*, if the difference of temperature between the two columns be in each case 8°, the same as in the former examples. It must here be observed, however, that, although it appears by these calculations that increasing the vertical height of the pipe fourfold will produce a double velocity of circulation, as the water will then pass through the pipe in half the time, the difference between the temperature of the flow pipe and the return pipe will be lessened one half, and the velocity will at last become a mean rate: so that the mere quadruple increase of vertical height, without the horizontal length be at the same time increased, will only produce a rate of circulation about one and a half times the original velocity.

(34.) Such is the result of theory: but, although this is true in itself, we shall, in practice, find but few cases that in any way agree with these results, in consequence of other causes modifying the effects.

Even in an apparatus in which the length of pipe is not very considerable, where the pipes are of large diameter, and the angles few, a large deduction from the theoretical amount, must be made to represent, with tolerable accuracy, the true velocity. And in more complex apparatus, the velocity of circulation is so much reduced by friction, that it will sometimes require from 50 to 90 per cent. and upwards, to be deducted from the calculated velocity, in order to obtain the true rate of circulation.[1] The calculation of the friction of water passing through pipes, is alike complicated and unsatisfactory: though the question has been investigated by some of the most able philosophers and mathematicians, a simple and correct formula on this subject is still a desideratum; and in the present state of knowledge of the subject, it would be almost impossible to determine what would be the resulting velocity of circulation in a hot-water apparatus of complicated construction.[2]

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[1] It has been found by experiment (*Robison's Philosophy*, vol. ii. p. 336), that a smooth pipe 4½ inches diameter, and 500 yards long, yields but one-fifth of the quantity of water which it ought to do, independent of friction. And Mr. George Rennie found (*Philosophical Transactions*, 1831), that the velocity of a half-inch pipe was reduced nearly three-fourths (that is from 3·7 to 1) by increasing its length from 1 foot to 30 feet: that three semicircular bends reduced the velocity $\frac{1}{36}$ in a short pipe, and 14 such bends reduced it $\frac{1}{20}$ of its velocity: while 24 right-angled bends reduced the velocity nearly two-thirds. The results of M. Prony's experiments led him to adopt the formula $V = 26{\cdot}79\,\frac{\sqrt{DZ}}{L}$ for the discharge through straight pipes: D being the diameter of the pipe; Z the altitude of the head of water; L the length of the pipe in metres; and V the mean velocity. M. Dubuat's formula for diminution by flexure is $R = \frac{V^2 S^2 n}{3000}$; where R is the resistance; V the mean velocity; S the sine of the angle of incidence; n the number of equal rebounds. Dr. Young (*Philosophical Transactions*, 1808) objects to this theory, and gives a different one, which he considers more nearly to represent the true result.

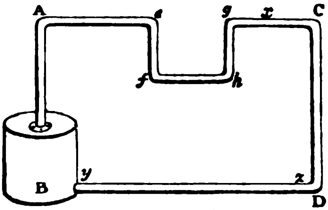
[2] In *Robison's Mechanical Philosophy*, vol. ii. pp. 261—627, will be found much information on this subject, with the results

(35.) In addition to these ordinary causes which impede the circulation, and which are common to all hydraulic experiments, there is another that is still more important, and is peculiar to the hot-water apparatus. The vertical angles in the pipe, or those angles which carry the pipe below the horizontal level, increase the resistance in this case to a very considerable extent; for they oppose not merely a passive resistance by friction, but they engender a force of their own, tending in an opposite direction to that of the prime moving power.

(36.) The motion of the heated particles of water is very different in passing through an ascending pipe, compared with that which takes place in a descending pipe. The heated particles rise upwards through an ascending pipe with great rapidity, and when the space occupied by the displaced particles is supplied by water from below, the motion becomes general, in one direction, being most rapid in the centre, and gradually decreasing towards the circumference, where, on account of the friction, it becomes comparatively slow. But in a descending pipe, the circumstances are very different, the motion being much more like that of a solid body. For as the heated particles are unable to force their way downwards through those which are colder and heavier than themselves, the only motion arises from the cold water flowing out at the bottom, its place being then supplied at the top by that which is warmer; the whole apparently moving together, instead of the molecular action which has been described as the proper motion in an ascending pipe.

of nearly all the experiments that have been made. Also see Dr. T. Young, *Philosophical Transactions*, 1831; *Nicholson's Journal*, vol. xxii. p. 104, and *Philosophical Magazine*, vol. xxxiii. p. 123; Mr. G. Rennie, *Philosophical Transactions*, 1831, and, *Reports Brit. Sci. Assoc.* vol. ii. p. 153, and vol. iii. p. 415. In these several works are given the experiments of Bossut, Prony, Dubuat, Eytelwein, Venturi, Borda, and others, which comprise nearly all that is known on this difficult subject.

Fig. 7.



(37.) In an apparatus constructed as fig. 7, the motion through the boiler and pipe A B and through the descending pipe C D, takes place according to the two methods here described. But it is evident that, on motion commencing in the return pipe *y z*, in consequence of the greater pressure of C D, than of A B, the water from A will be forced towards *e*, at the same time that the water in *e*, *f*, *g*, *h*, flows towards C. But when a very small quantity of hot water has passed from the pipe and boiler, A B, into the pipe *e f*, the column of water *g h*, will be heavier than the column *e f*, and therefore there will be a tendency for motion to take place along the upper pipe, *towards* the boiler instead of from it. This force, whatever be its amount, must be in opposition to that which occurs in the lower or return pipe, in consequence of the pressure of C D being greater than A B; and, unless, therefore, the force of motion in the descending pipe, C D, be sufficient to overcome this tendency to a retrograde motion, and leave a residual force sufficient to produce direct motion, no circulation of the water can take place.

(38.) An extremely feeble power, as we have already seen, will produce circulation of the water, in an apparatus where there are no unusual obstructions; but it is a necessary result of the motive power being so very small, that it is easily neutralized. I have known so trifling a circumstance as a thin shaving planed off a piece of wood, and accidentally getting into a pipe, effectually prevent the circulation in an apparatus otherwise perfect in all its parts.

(39.) It is not sufficient then, when such an obstruction as the vertical declination from the horizontal level, shewn by the last figure, has to be surmounted, merely to make the *direct* force of motion sufficient to overcome the antagonist force, and to leave the smallest possible residual amount for the purpose of causing circulation; because an amount which would be sufficient for this purpose, as an undivided force, would not be found sufficient as a residual force.

(40.) In estimating the additional height which it is necessary to give to the ascending column, in order to overcome such an obstruction as shewn in fig. 7, it will be necessary to take into account what is the length and diameter of the pipe through which the water passes between the time of its egress and regress; for on this depends the difference of temperature between the ascending and descending columns, which, we have seen, materially affects the amount of the motive power of the apparatus. If the length of pipe be considerable, a smaller increase of the vertical height of the ascending pipe will suffice; but if the length of pipe be short, a greater height must be allowed.[1] The temperature to which the air surrounding the pipes is to be raised, will also modify the result; for on this will depend the quantity

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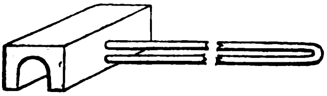
[1] This applies merely to the possibility of producing motion, and not to the resulting velocity of the circulation. For it must be borne in mind that, although in every case, by increasing the length of the pipe, or by reducing its diameter, we cause the water to assume a greater difference of temperature between the ascending and the descending columns, and thereby increase the circulation, still, in both these cases, we greatly increase the friction, which therefore considerably detracts from the advantages gained by this greater difference of temperature. For as the friction is a certain quantity, compounded of the square root of the length of the pipe directly and the diameter of the pipe inversely, it follows that the friction may become so great, by increasing the length and reducing the diameter, as completely to neutralize all beneficial effect; for unless the circulation is moderately active, the apparatus will be of such unequal temperature as to render it nearly useless. The utmost caution is therefore necessary, in order that the friction may not become so great as to interfere with the due circulation of the water.

of heat given out by the pipes *per minute*, which likewise affects the temperature of the descending pipe. (Art. 181.)

(41.) Under such a great diversity of circumstances, it would be difficult to form a rule for estimating what ought to be the height of the ascending pipe in such cases; because, not only are these circumstances different in each apparatus, but they likewise differ, in some respects, in the same apparatus, in the different stages of its working. The difficulty is also increased, by not being able to fix on an absolute minimum measurement, which is sufficient, under all circumstances, to cause a circulation of the water in the common form of the apparatus. There have been instances where apparatus have succeeded, though constructed on the very worst principles, in consequence of various circumstances having favoured the result. Thus in an apparatus, constructed as fig. 8, where the pipes were not more than three inches apart, the water circulated with perfect freedom; but in this case, not only was the pipe of considerable length, and without angles or turns, but the size of the pipe was only two inches diameter, so that the water cooled twice as fast as it would have done had pipes of four inches diameter been used (Art. 75). It is, however, quite certain that such a distance between the pipes, at their insertion into the boiler, as that which has just been described, is insufficient, under ordinary circumstances, to give a steady and good circulation. But when the two pipes are about 12 inches apart, at the place of their insertion into the boiler *x f*, fig. 3, which is 16 inches from centre to centre when the diameter of the pipe is four inches, it will be sufficient to produce a good circulation for almost any ordinary length of pipe, when it is not required to

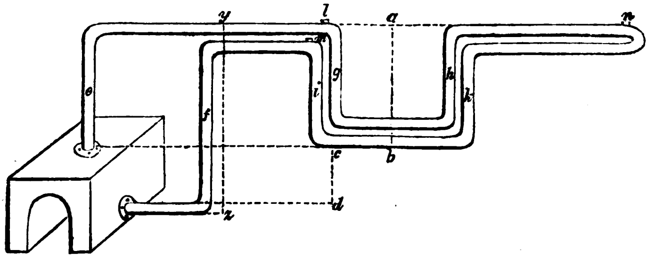
FIG. 8.



dip below the horizontal level. If this be considered as the minimum height, which, under ordinary circumstances, will obtain a good circulation when the pipes are not required to dip below the horizontal level, then an average height can be estimated for enabling any vertical declination of the pipes to be made.

(42.) In such cases the height of the ascending pipe should generally be just so much greater than the above dimensions, as the depth which the circulating pipe is required to dip below the horizontal level; bearing in mind the circumstances mentioned (Art. 40), which modify the general results.[1] Thus, suppose the depth of the dip, shewn by the dotted line *a b*, fig. 9, to be 24 inches; then the distance *y z*, ought to be 40 inches, if the pipes be four inches diameter; that is, 36 inches from centre to centre, or 40 inches from the top of the pipe *y* to the bottom of the pipe *z;* and, with these dimensions, as good a circulation will be obtained (excepting the

FIG. 9.



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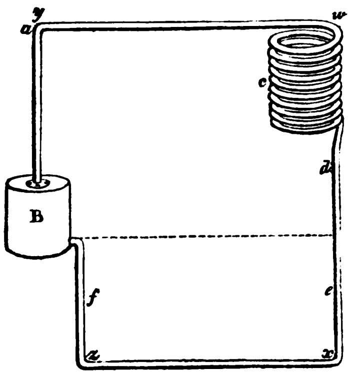
[1] So greatly, in fact, do these circumstances affect the general result, that it is very possible, in particular circumstances, to make the water descend below the bottom of the boiler to a considerable depth without stopping the circulation. It is therefore evident that the dimensions which are here given for the height of the ascending pipe relative to the dip, must not be taken as an absolute minimum, but simply as a general rule which will succeed in all cases. See Art. 44 and 45.

friction from the additional elbows) as when the distance between the top and bottom pipes is 16 inches from centre to centre, in the common form of the apparatus. It will be observed that, by this arrangement, the distance *c d*, from the under side of the flow-pipe to the upper side of the return-pipe, is just 12 inches, which is the same height that was stated to be necessary to insure a good circulation, on the ordinary plan, without a vertical dip. The reason why this height is sufficient in the present case, notwithstanding the increased friction of the angles, is because there must always be a greater difference between the temperature of *e* and *f*, than between either *g* and *h*, or between *i* and *k*, or even more than between both these together; therefore the tendency to *direct* motion is greater than towards retrograde motion, in proportion to this difference, and is sufficient to overcome the increased friction caused by the vertical declination: while the additional height of 12 inches beyond the height of the dip, possessed by the descending pipe *f*, is sufficient to produce circulation of the water. If *g* and *h*, and also *i* and *k*, were very wide apart, say 40 or 50 feet, instead of being, as usual, only about three or four feet, the balance of effect, though still in favour of *direct* motion, would not be so great as in the last supposed case; because there would be a greater difference in temperature between *g* and *h*, (that is, *h* would be heavier than *g* in a greater degree), which would give a greater tendency to retrograde motion. In many cases, therefore, it will be advisable to make the ascending pipe somewhat higher in proportion to the dip than is here stated, particularly when there are several such alterations required in the level of the pipes; and, in all cases, as has been before observed, the higher the ascending pipe is made, the more rapid will be the circulation, and, therefore, the more perfect the apparatus will become.

(43.) The remarks which have been made with respect to the height of the ascending pipe, relatively to the vertical declination or dip, below the level of the horizontal pipe, applies to all the usual forms which are given to the apparatus. But there are peculiar arrangements which may be adopted, that will allow the dip of the circulating pipe to be much greater than the proportion which has here been stated; for, in some cases, the dip pipes may even pass below the bottom of the boiler to a considerable depth, without destroying the circulation; and, from the very extensive use that is now made of the hot-water apparatus for heating buildings of every description, it is very desirable to examine this part of the subject at some length, as its application will, in many cases, entirely depend upon the possibility of making the pipes descend below the boiler.

(44.) In an arrangement of pipes, such as fig. 10, the circulation will depend entirely upon the quantity of heat given off by the coil *c*; for it is evident that, when the boiler B and pipe *a* are heated, the *direct* motion will arise in consequence of the greater weight of the water in the coil *c* and pipe *d*, above that which is in the boiler and pipe B *a*. But as the water in the pipe *e*, below the dotted line, will be lighter than that in the pipe *f*, the tendency in that part of the apparatus will be towards a retrograde motion. The result of these two forces will be, that if the water in the whole length of pipe *w x*, is heavier than that of the whole

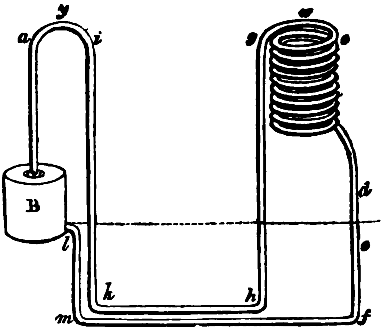
FIG. 10.



length, *y z*, in a sufficient degree to overcome the increased friction, circulation of the water will take place; and the velocity of motion will depend upon the amount of this difference in weight.

(45.) Another form, though somewhat more complicated, may be given to this arrangement of the apparatus. In fig. 11, B represents the boiler: and the effective or *direct* motion is, in this case, caused by the water in the coil and pipe *c d* being so much heavier than that in the boiler and pipe B *a*, that it overcomes the retrograde motion which is produced by all the other parts of the apparatus. Thus the water in *g h*, being *heavier* than that in *i k;* and that in *e f* (below the dotted line) being *lighter* than that in *l m*, has, in both cases, a tendency to retrogression; and this will be more considerable in proportion as the pipes *i k*, and *g h*, etc., are more distant from each other. The motive power, therefore, entirely depends upon the quantity of heat given off by the coil; for the water must be cooled down many degrees, in order to give it a sufficient preponderance over the water in B *a*, to cause a circulation; and the circulation must necessarily be very slow, and, therefore, the temperature very unequally diffused.

FIG. 11.

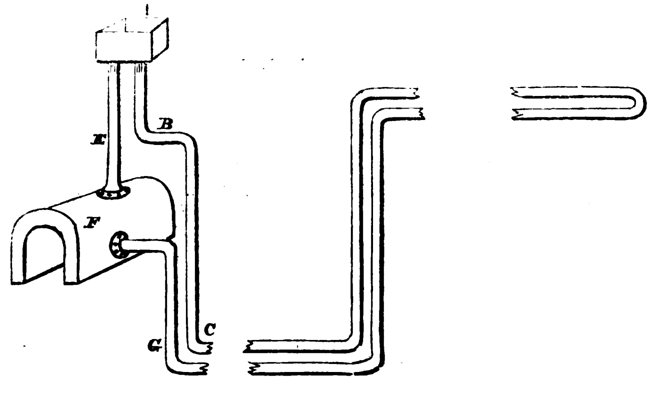


If the coil, in the last two figures, be placed in any lower position than is here shewn, the effect will be proportionally less in producing circulation; and if placed below the dotted lines, it would be scarcely possible to obtain any circulation at all. Nor would there be any circulation if the coil were omitted, because the mere descent of the water through a straight pipe would not cool it sufficiently to give the necessary preponderance to the descending column, unless some other contrivance, for the purpose of cooling the water to an equal extent, were adopted.

(46.) The principle which governs the circulation in these last-mentioned cases, is capable of many applications. And it must be remembered that, as a coil of pipes produces an enormous degree of friction in the fluid passing through it, which must be overcome before a circulation can be produced, a smaller difference of temperature between the ascending and descending columns would produce circulation, if the apparatus were contrived so as to cause less friction to the fluid passing through it.

In an apparatus constructed as fig. 12, the water rises directly from the boiler into an open cistern A, and it then descends through the pipe B, which communicates with the bottom or the side of this cistern. In cases of this kind it has been generally assumed, that the water will descend as far *below* the boiler, as the rising pipe and the cistern are *above* the boiler; and practically it is found that this is generally the

FIG. 12.



case, though the explanation of the fact must be sought for among a different class of phenomena, than those which merely regard the height of the ascending pipe.

(47.) The advantage of conveying the water into an elevated cistern, as shewn in the last figure, appears to be twofold. It allows the freest escape of air and of steam, either of which would prevent the circulation, if it lodged in the part of the apparatus *a*, *y*, *i*, in fig. 11; and which part is in fig. 12, occupied by the open cistern. This cistern also facilitates the circulation, by increasing both the actual as well as the relative weight of the descending column of water; because no part of the pipe B can possibly contain steam, as the water will remain in the cistern A until it has become colder than that in the pipe E and boiler F; and it is evident that by such an arrangement as fig. 12, this difference of temperature must constantly increase, after heat is applied to the boiler, until it becomes sufficient to give a preponderance to the water in B; and even if the heat were sufficient to raise steam in the pipe E, the effect would only be still further increased, instead of being diminished, or the circulation even wholly stopped, as would be the case with an apparatus like fig. 11 under similar circumstances.

(48.) Many other arrangements of the apparatus, answering the same purpose as these last three figures, might be contrived; but while these forms are advantageous when difficulties of adaptation have to be surmounted, it must not be imagined that they are recommended above the more simple forms shewn in figures 3, 7, and 9. And it requires great judgment in adopting some of these complicated arrangements, for many causes may interfere to prevent complete success; and it is sometimes so very difficult to detect the various causes of interference, and the impediments which arise are often, apparently, so insignificant in their extent, that even when ascertained they are frequently neglected. Those, however, who bear in mind how small is the amount of motive power in any apparatus of this description, will not consider as unimportant, any impediment, however small, which they may detect; but in the more complicated forms of the apparatus, so many causes become operative, that the reason of failure may sometimes elude the detection of even an experienced practitioner.

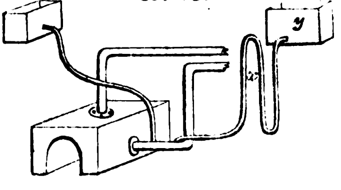
(49.) The necessity of making provision for the escape of the air from the pipes, has already been mentioned. It may be observed that, in such forms of the apparatus as described in the last four figures, the difficulty of its expulsion is much increased, as there are several points where it will collect and stop the circulation, unless proper means be taken to prevent this result. In the apparatus, fig. 9, the air will collect at three points *l*, *m*, and *n;* and the nature of the outlets provided for its escape will depend, in some measure, upon the plan adopted for supplying the apparatus with water. It frequently requires the greatest care and the closest attention to discover where the air is likely to lodge, as the most trifling alteration in the position of the pipes will entirely alter the arrangements with respect to the air vents. Want of attention to this has been the cause of many failures; and the discovery of the places where the air will accumulate is, occasionally, a matter of some difficulty. For although it be true, in a general sense, that the air will rise to the highest part of the apparatus, it will frequently be prevented getting to those parts by alterations in the level of the pipes, and by other causes. This is the case at *m*, fig. 9, where, it will be seen, the air which accumulates in that part of the apparatus is prevented from escaping to a higher level, by the vertical angle at *f* on the one side, and *i* on the other. In the apparatus, fig. 11, the air will accumulate at *y* and at *w*, and must be carried off by proper outlets; and in every case provision must be made for the air to pass either by a level pipe or by ascending gradients, for in no case can it be made to pass downwards (however small the extent) in its passage to the vent provided for its escape.

(50.) When a boiler is open at the top, or merely has a loose cover laid on it, no particular care is necessary repecting the supply of water. It can generally be poured in at the boiler, taking care not to fill it quite full, so as to allow for the expansion of the water when heated, as otherwise it will overflow. But when, as in figures, 7, 9, 10, 11, and 12, the boiler is close at the top, it is usual to place a supply cistern on a level with or above the highest part of the apparatus, so as to keep it always full of water. But as water expands about $\frac{1}{24}$ part of its bulk, when it is heated from 40° (the point of its greatest condensation) to 212°, it is indispensably necessary to provide for a part of the water returning back to the supply cistern when this expansion takes place. The cistern, however, needs not contain so much water as $\frac{1}{24}$ part of the whole contents of the apparatus; for it is found, in practice, that a much less quantity than this returns back into the cistern on the apparatus being heated. This arises from the fact of the water not reaching to so high a temperature as 212°, and also in consequence of its being generally at a higher temperature than 40° before it is heated, and by both these causes the expansion is considerably lessened; for if the water be raised from 50° to 180°, the expansion will only be about $\frac{1}{36}$ part of its bulk, and the expansion of the iron itself, by giving an increased capacity to the apparatus, will also tend still further to diminish the quantity of water returned back into the cistern. A very good proportion for general purposes is to make the supply cistern contain about

$\frac{1}{30}$ of the whole quantity of water in the pipes and boiler; though, as above stated, a smaller size will answer in many cases, where economy or convenience requires it to be reduced.

(51.) The usual plan for a supply cistern is shewn in fig. 13. The cistern is placed in some convenient situation, and then attached, by a small pipe, to any part of the apparatus—usually, to the lower pipe, as it is then less likely to allow of the escape of vapour, than if it were fastened to the top of the boiler. But a still better plan is to bend the pipe, attached to the cistern, into the form shewn by *x y*, which is a preventive to the escape of any heat or vapour at that part, as the legs of the syphon *x* generally remain quite cold.

FIG. 13.



(52.) One very important part of the subject of expansion is the necessity which exists for allowing sufficient room for the elongation of the pipes when they become hot. Want of attention to this has caused several accidents; for the expansive power of iron, when heated, is so great, that scarcely anything can withstand it. The linear expansion of cast iron, by raising its temperature from 32° to 212°, is ·0011111, or about $\frac{1}{900}$ part of its length, which is nearly equal to $1\frac{3}{8}$ inches in 100 feet. Therefore it is necessary to leave the pipes unconfined, so that they shall have free motion lengthways, to this extent at least; and instead of confining them, as sometimes has been done, facilities should be provided for their free expansion, by laying small rollers under them at various points: for as the contraction on cooling is always equal to the expansion on heating, unless they can readily return to their original position when they become cool, the joints are very likely to get loose, and to become leaky. These rollers may be made simply of a piece of rod iron about one-fourth or three-eighths of an inch diameter, which may be fixed in a frame to support the pipes, or they may lie loose on a stone or brick pier, the pipes being supported by this means at about every alternate joint.

CHAPTER III.

On the Resistance by Friction—Relative Size of Main Pipes and Branch Pipes—Vertical Main Pipes—Small connecting Pipes —Branch Pipes at different Levels—Stop Cocks and Valves —Their Use and proper Size—Their Place supplied by Cisterns—Inconvenience of them—Remedies.

(53.) When treating, in the preceding chapter, on the velocity of the circulation of water, it was observed that the theoretical velocity is always considerably reduced by friction. Although the calculation of the friction of water, in passing through pipes, is intricate,[1] the *relative* friction for different sizes of pipes is easily ascertained; and this appears to be nearly all that is necessary to be acquainted with, for the purpose of the present inquiry.

(54.) The friction occasioned by water passing through small pipes is very much greater than in those which are larger. This arises from two causes: the increased surface with which a given quantity of water comes into contact by passing through a small pipe; and the greater velocity with which the water circulates, in consequence of losing more heat per minute.[2]

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[1] See Art. 34.

[2] See Chap. IV. Art. 75. This latter remark of course only applies to water circulating in a hot-water apparatus: the former applies to all cases of hydraulics.

(55.) The relative friction for different sizes of pipes, when the velocity with which the water passes is the same in all, may be seen in the following Table:

Diameter of Pipes	½,	1,	2,	3,	4,	inches.
Friction . . .	8,	4,	2,	1·3,	1.	

Taking the friction, in pipes of four inches diameter, as unity,—that of a pipe two inches diameter is twice as much, and a one-inch pipe four times as much as the pipe of four inches; the friction being as the surface *directly*, and the whole quantity of water *inversely.*[1]

(56.) The friction which arises from increased velocity, is nearly *as the square of the velocity;* but this calculation is unnecessary to enter into here, because the velocity of circulation of the water, in a hot-water apparatus, is constantly subject to fluctuation: for as the friction increases with the velocity of circulation, so the velocity is checked by the increased friction; and it finally assumes a mean rate, proportioned to the friction on the one hand, and the theoretical velocity on the other, calculated according to the rule (Art. 33) in the preceding chapter.

(57.) Closely connected with the subject of friction, is the question of the proper size for leading or main pipes. It has been supposed by many persons that where two or more circulating pipes are attached to one main pipe, the area, or section of the main pipe, ought to be equal to the sum of the areas of all the branch pipes. This has led to the most inconvenient arrangements having been resorted to in particular cases. In some instances, pipes as large as nine inches diameter have been used for the main pipes, where those of four inches would have answered the purpose infinitely better; and other proportions equally erroneous have frequently been adopted.

(58.) It has been already explained (Art. 36), that

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[1] Dr. Young's Hydraulics, *Nicholson's Journal,* vol. iii. p. 31.

the motion of water is more rapid in an upright, than in a horizontal pipe. If four branch pipes be supplied by one upright main pipe, this latter needs be very little, if any, larger than the circulating pipe: but if only two or even three branches are to be supplied by one main pipe, it will be quite unnecessary in ordinary cases that the main pipe should be any larger than the branches, unless the length of the horizontal pipe be unusually great. If the branches exceed this number, it may be desirable to increase the diameter of the main pipe, in a moderate degree; but the motion of the water through it, however, will be just so much the more rapid, in proportion as there are more branches for it to discharge the water into. For it is evident that, if the outlet from the boiler be by a pipe four inches diameter, the flow of water will be more impeded, than if a pipe of six inches diameter were used; and the water will therefore become specifically lighter in the boiler than in the descending pipe, in a greater degree in the former case, than in the latter; and this will consequently cause a more rapid circulation through the apparatus. But, though the friction of the water will be greater in the ascending pipe by this arrangement, yet it will not be of much importance, except when very small pipes are used; for the friction is extremely small in a vertical pipe to an ascending current of water.

(59.) Another advantage will arise from this arrangement, in consequence of a small pipe, *under these circumstances*, losing less of its heat than a large one. For, suppose four branch pipes, four inches diameter, are to be supplied by one main pipe; one pipe of eight inches diameter would have the same sectional area as the four pipes of four inches diameter: but if, instead of being eight inches diameter, the main pipe be made only four inches diameter, then the water must travel four times faster through this pipe, than it would do through the one of eight inches diameter, in order to supply the same quantity of heat to the branch pipes. This it will do very nearly; and it may easily be deduced, that, under these circumstances, the water will only lose one-half as much heat by passing through the small pipe, as it would in passing through the larger one; for the loss of heat which the water sustains, is *directly* as the time and the surface conjointly.[1]

(60.) On the same principle it will frequently be found exceedingly convenient, when two rooms or buildings, somewhat distant from each other, are required to be warmed by one boiler, to make the connecting pipe between them much smaller than the pipe used for radiating the heat to warm the buildings. For, on the principle already mentioned, there will be a saving, as well of heat, as in the cost of the apparatus, by reducing the size of the pipe in that part which is not required to give off heat, but which is merely used to connect different parts together.[2] In this manner, a pipe of one inch may frequently be made to supply a pipe of four inches diameter; and it will sometimes be found convenient to connect pipes of large diameter with the boiler by this means, when the total length of pipe is not great.

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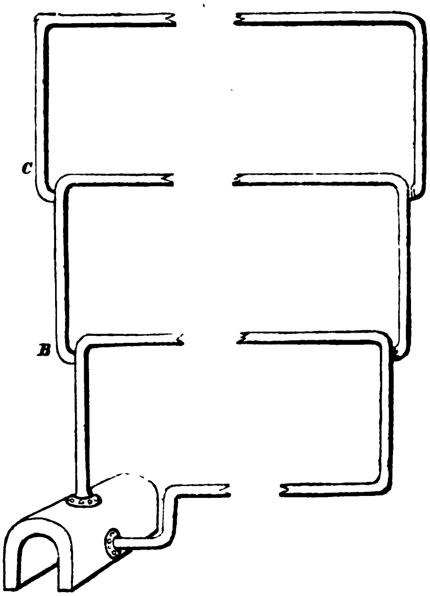
[1] See Chap. X. Art. 229.

[2] As all alterations in the size of the pipe, either by enlarging or contracting its diameter, materially alter the velocity of the circulation of the water, care should be taken that these alterations be not made capriciously and without some decided advantage appears to be attainable by so doing. Venturi found by experiment, that enlargements in a pipe reduced the velocity of discharge as follows:—When a given quantity of water was discharged through

A straight pipe in	109	seconds.
A pipe with one enlargement, required	147	„
„ three	192	„
„ five	240	„

(61.) Very important results frequently arise from errors with respect to main pipes which are placed vertically, in consequence of the great velocity with which the water circulates through such pipes. It frequently happens that the pipes which branch out from an upright main pipe, are required to circulate at very different heights; as, for instance, in warming the several floors of a warehouse or manufactory. In this case, two methods may be adopted: the pipe may either rise to the highest floor or level first, and after passing round such uppermost room, descend and circulate round that which is below it; then proceed to the next lowest, and so on, till it finally return again to the boiler: or each floor may have a separate range of pipes branching off from the main pipe, and finally returning, either together or separate, into the boiler. In the first of these cases it is obvious that the temperature will be very much greater in the higher floors than in the lower, unless the quantity of pipe, or other radiating surface, be very unequally distributed. For the water, by having passed through a great length of pipe before it reaches the lower rooms, will be much reduced in temperature, and the upper rooms will be heated long before the others become at all warm; and at all times the temperature will be very unequal. To obviate this, each floor should be warmed separately by its own range of pipes. But this requires particular management; for, if the several pipes merely branch out from the side of a vertical main pipe, the whole of the hot water will rise to the upper pipe, and leave all the lower lateral branches without causing any circulation of hot water through them. In order to avoid this, it is necessary either to have a separate pipe rising directly from the boiler, for each floor; or some means must be adopted to check the water in its upward course through the vertical main pipe when only one is used for several different floors. In fig. 14, it will be perceived that the water which passes up the pipe B, receives a check at B, and thereby, of course, facilitates the flow of water through the first horizontal pipe, which would otherwise have been left stagnant. The same occurs also at C for the same reason; and by this means a nearly equal flow of hot water may be obtained; while, had the supplying main from the boiler passed directly upwards in a perfectly straight line, all the hot water would have passed at once into the upper pipe, and the lower ones would have been left comparatively cold.

Fig. 14.



It is perfectly immaterial how many pipes lead out of or into the boiler: but it will generally much simplify the apparatus, if branch-pipes be used as in fig. 14, instead of making several separate outlets, and as many inlet-pipes to the boiler.

(62.) Very frequently it happens that several branch-pipes are required from the boiler, to circulate nearly at the same level; particularly in horticultural buildings, where two or three hot-houses are required to be warmed by one boiler. This seldom presents any difficulty, unless it be required occasionally to stop off certain of these houses, while the others are heated. In these cases, a complicated and expensive arrangement of cocks or valves becomes necessary. But here the rule, which has already been given (Art. 58 and 60), for connecting pipes, may likewise be followed, where stop-cocks are required occasionally to shut off the communication between different parts of an apparatus, so as only to warm one particular room or part of a building. The cocks used for this purpose need not be near so large as the bore of the pipes; for exactly in proportion as they are smaller, so much the more rapidly will the water pass through the obstruction.[1] Some judgment, however, must be exercised in all such cases: for, both with connecting pipes and cocks, if the size be very disproportionate, the free circulation of the water will of course be impeded. In most cases, a cock of two inches diameter, will be sufficiently large to use with pipes of four inches diameter; and a cock of one-and-a-half inch diameter, with pipes of three inches diameter: but for very small pipes, the relative proportions should perhaps be more nearly equal to the size of the pipes, on account of the increased friction.

(63.) When cocks or valves are used to stop off the circulation of a particular part of the apparatus, it is not sufficient merely to stop the upper, or flow pipe; but the corresponding pipe which returns the water to the boiler must also be stopped, otherwise the hot water will circulate backwards through the return-pipe, and pass into the flow-pipe; and thus the whole will become heated. This more particularly applies to those cases where the boiler is placed at any considerable depth below the circulating pipes; for then, as already stated, the circulating power will be much increased.

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[1] As this may at first appear doubtful, it should be borne in mind, that this kind of obstruction to the circulation will cause a greater difference between the temperature of the flow-pipe and the return-pipe; and, when this occurs, the velocity of the circulation must always be increased.

(64.) In order to avoid the expense of cocks or valves in these cases, an open cistern (as in fig. 12), has sometimes been used. From this cistern all the several flow-pipes are made to branch out; and then by driving a wood plug into any one or more of these pipes, the circulation will be stopped, until the water throughout the whole apparatus becomes heated, when it will generally flow back through the return-pipe as above mentioned. This inconvenience, however, may be prevented by such a contrivance as shewn in the return-pipe of fig. 15, which is simply an inverted syphon of a few inches in depth. This will not prevent the circulation when the flow-pipe remains open; but if that be closed by a plug in the cistern, then the hot water will not return back through the lower pipe. This inverted syphon, however, will in process of time be liable to be choked up with dirt, which will accumulate in the lower part of the bend; and for the purpose of removing this, it will be necessary to make a cap, or covering to the lower part of it, which can be removed at pleasure, for the purpose of clearing away any sediment that may accumulate. These cisterns, however, when thus used, are at best but a clumsy way of supplying the place of cocks or valves. The latter are sometimes made to stop off both the flow and return pipe at one operation; but in whatever way these are arranged, they are generally one of the most troublesome parts of the apparatus, as cocks and valves of all kinds are liable to get out of repair

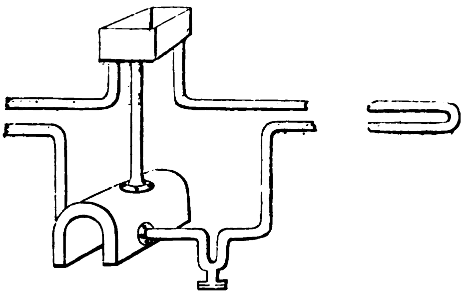

Fig. 15.

unless they are in the hands of those who perfectly understand them, and will keep them in proper order.

(65.) Though some of the propositions respecting the relative sizes of connecting pipes, main pipes, and cocks, may appear to be at variance with the laws of hydraulics, they will nevertheless be found correct; because several of the effects are to be referred either entirely to hydrostatic laws, or to a complicated result of hydrodynamics; and therefore they are not to be judged of by simple hydraulic principles. In fact, the correctness of the theories advanced in this treatise, which are of a practical character, and admit of verification, have been tested, more or less extensively, by actual experiment, and do not, therefore, rest merely on hypothetical reasoning.

CHAPTER IV.

Permanence of Temperature—Rates of Cooling for different sized Bodies—Proper Sizes for Pipes—Relative Size of Pipes and Boiler—Various Forms of Boilers and their Peculiarities—Objections against contracted Water-way in Boilers—Proper Size of Boilers for any given lengths of Pipe—What constitutes a good and efficient Boiler.

(66.) One of the greatest advantages which the plan of heating by the circulation of hot water possesses over all other inventions for distributing artificial heat, is, that a greater permanence of temperature can be obtained by it, than by any other method. The difference between an apparatus heated by hot water, and one where steam is made the medium of communicating heat, is no less remarkable in this particular, than in its superior economy of fuel.

(67.) It seldom happens that the pipes of a hot-water apparatus can be raised to so high a temperature as 212°; and in fact, it is not desirable to do so; because steam would then be formed, and would escape from the air vent, or safety pipe, without affording any useful heat. Steam pipes, on the contrary, must always be at 212° at the least, because, at a lower temperature, the steam will condense. A given length of steam pipe will therefore afford more heat than the same quantity of hot-water pipe: but if we consider the relative permanence of temperature of the two methods, we shall find a very remarkable difference in favour of pipes heated with hot water.

(68.) The weight of steam at the temperature of 212°, compared with the weight of water at 212°, is about, as 1 to 1694; so that a pipe which is filled with water at 212° contains 1694 times as much *matter* as one of equal size filled with steam. If the source of heat be withdrawn from the steam pipes, the temperature will soon fall below 212°, and the steam immediately in contact with the pipes will condense: but in condensing, the steam parts with its *latent heat;* and this heat, in passing from the latent to the sensible state, will again raise the temperature of the pipes. But as soon as they are a second time cooled down below 212°, a further portion of steam will condense, and a further quantity of latent heat will pass into the state of heat of temperature;[1] and so on, until the whole quantity of latent heat has been abstracted, and the whole of the steam condensed, in which state it will possess just as much heating power, as a similar bulk of water at the like temperature; that is, the same as a quantity of water occupying $\frac{1}{1694}$ part the space which the steam originally did.

(69.) The specific heat of uncondensed steam compared with water, is, for *equal weights*, as ·8470 to 1: but the latent heat[2] of steam being estimated at 1000°, we shall find the relative heat obtainable from *equal weights* of condensed steam, and of water, reducing both from the temperature of 212° to 60°, to be as 7·425 to 1; but for *equal bulks*, it will be as 1 to 228; that is, bulk for bulk, water will give out 228 times

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[1] The heat of temperature is that which is appreciable by the thermometer; and the term is used in contra-distinction to *latent* heat, which is not capable of being measured in a direct manner by any instrument whatever.

[2] The results of different experiments on the subject of the latent heat of steam, although somewhat various, are yet sufficiently near for all practical purposes. Watt's experiments gave 900° to 950°; Lavoisier and Laplace, 1000°; Mr. Southern, 945°; Dr. Ure, 967° to 1000°; and Count Rumford, 1000°.

as much heat as steam, on reducing both from the temperature of 212° to 60°. A given bulk of steam will therefore lose as much of its heat in one minute, as the same bulk of water will lose in three hours and three quarters.

(70.) When the water and the steam are both contained in iron pipes, the rate of cooling will, however, be very different from this ratio; in consequence of the much larger quantity of heat which is contained in the metal itself, than in the steam with which the pipe is filled.

(71.) The specific heat of cast-iron being nearly the same as water (see Table V., Appendix); if we take two similar pipes, four inches in diameter, and one quarter of an inch thick, one filled with water, and the other with steam, each at the temperature of 212°; the one which is filled with water will contain 4·68 times as much heat as that which is filled with steam: therefore if the steam pipe cools down to the temperature of 60° in one hour, the pipe containing water would require four hours and a half, under the same circumstances, before it reached the like temperature. But this is merely reckoning the effect of the pipe and of the fluid contained in it. In a steam apparatus this is all that is effective in giving out heat: but in a hot-water apparatus, there is likewise the heat from the water contained in the boiler, and even the heat from the brick-work around the boiler; which all tends to increase the effect of the pipes, in consequence of the circulation of the water continuing long after the fire is extinguished; in fact, so long as the water is of a higher temperature than the surrounding air of the room. From these causes, the difference in the rate of cooling, of the two kinds of apparatus, will be nearly double what is here stated: so that a building warmed by hot water will maintain its temperature, after the fire is extinguished, about six or eight times as long as it would do if it were heated with steam.

(72.) This is an important consideration wherever permanence of temperature is desirable; as, for instance, in hothouses, conversatories, and other buildings of a similar description: and even in the application of this invention to the warming of dwelling-houses, manufactories, etc., this property, which water possesses, of retaining its temperature for so long a time, and the very great amount of its specific heat, prevents the necessity for that constant attention to the fire, which has always been found so serious an objection to the general use of steam apparatus.

(73.) The velocity with which a pipe or any other vessel cools, when filled with a heated fluid, depends principally upon two circumstances—the quantity of fluid that it contains, relatively to its surface; and the temperature of the air by which it is surrounded; or, in other words, the excess of temperature of the heated body, above that of the surrounding medium. The subject of the radiation of heat, and the rate at which a heated body cools, under various circumstances, will be fully considered in another chapter. But for temperatures below the boiling point of water, and under such circumstances as we are now considering with regard to hot-water pipes, the velocity of cooling may be estimated simply in the ratio of the excess of heat, which the heated body possesses above the temperature of the surrounding air. The variation in the rate of cooling, arising from a difference of the superficies to the mass, is, for bodies of all shapes, *inversely*, *as the mass divided by the superficies.* Therefore, the relative ratios of cooling, for any two bodies of different shapes and temperatures, is the inverse numbers obtained by dividing the mass by the superficies, multiplied by the direct excess of heat above the surrounding air; provided the temperature of the heated bodies be below 212°. Thus suppose the relative ratio of cooling be required, for two cisterns filled with hot water, one a cube of 18 inches, at the temperature of 200°; the other a parallelopiped, 24 inches long, 15 inches wide, and 3 inches deep, at the temperature of 170°; the surrounding air in both cases being 60°. Then, as,

	INCHES.		INCHES.		
The cube contains	5832,	divided by	1944,	the superficies	= 3·0
The parallelopiped contains .	1080,	do.	954,	do.	= 1·13

The *inverse* of these numbers is, to call the cube 1·13, and the parallelopiped 3·0. Then multiply 1·13 by 140 (the direct excess of temperature of the cube), and the answer is 158·2: and multiply 3·0 by 110 (the direct excess of temperature of the parallelopiped), and the answer is, 330·0; therefore the parallelopiped will cool, in comparison with the cube, in the proportion of 330 to 158, or as 2·08 to 1: so that if it require two hours to cool the cube, a half, or a quarter, or any other proportional part of its excess of heat, the other vessel will lose the same proportional part of its excess of heat in one hour.

(74.) It is evident that these different velocities of cooling are quite independent of the effect that the respective bodies will produce in warming a given space; for as the cube contains upwards of six times as much water as the other vessel, so it would warm six times as much air, if both vessels were of the same temperature. But if six of the oblong vessels were used, they would heat just the same quantity of air as the cube; but the latter would require rather more than two hours and a half to do what the oblong vessels would accomplish in one hour, supposing the temperature to be the same in both cases. In the previous example, the temperatures are supposed to be different: otherwise the relative ratio of cooling, of the two vessels, would have been as two-and-a-half to one, instead of two to one as stated.

(75.) In estimating the cooling of round pipes, the relative ratio is very easily found; because the inverse number of *the mass divided by the superficies*, is exactly equal to the *inverse of the diameters*. Therefore, supposing the temperature to be alike in all,

If the diameter of the pipes be -	1,	2,	3,	4 inches.
The ratio of cooling will be - -	4,	2,	1·3	1.

That is, a pipe of one inch diameter will cool four times as fast as a pipe of four inches diameter; and so on with the other sizes. These ratios, multiplied by the excess of heat which the pipes possess above that of the air, will give the relative rate of cooling when their temperatures are different, supposing they are under 212° of Fahrenheit: but if the temperatures are alike in all, the simple ratios given above will shew their relative rate of cooling, without multiplying by the temperatures. When the pipes are much above 212°, as, for instance, with the High Pressure system of heating, the ratio of cooling must be calculated by the rules given in Chapter IX.

(76.) The unequal rate of cooling of the various sizes of pipes renders it necessary to consider the purpose to which any building is to be applied, that is required to be heated on this plan. If it be desired that the heat shall be retained for a great many hours after the fire is extinguished, then large pipes will be indispensable; but if the retention of heat be unimportant, then small pipes may be advantageously used. It may be taken as an invariable rule, that in no case should pipes of greater diameter than four inches be used, because, when they are of a larger size than this, the quantity of water they contain is so considerable, that it makes a great difference in the cost of fuel, in consequence of the increased length of time required to heat them. (See Art. 116.) For hothouses, greenhouses, conservatories, and such like buildings, pipes of four inches diameter will generally be found the best; though, occasionally, pipes of three inches diameter may be used for such purposes, but never any of a smaller size. In churches, dwelling-houses, manufactories, etc., pipes of either two or three inches diameter will, perhaps, upon the whole, be found the most advantageous; for they will retain their heat sufficiently long for ordinary purposes, and their temperature can be sooner raised, and to greater intensity, than larger pipes: and, on this account, a less number of superficial feet will suffice to warm a given space.

(77.) In adapting the boiler to a hot-water apparatus, it is not necessary, as is the case with a steam boiler, to have its capacity exactly proportional to that of the total quantity of pipe which is attached to it: on the contrary, it is sometimes desirable even to invert this order, and to attach a boiler of small capacity to pipes of large size. It is not, however, meant, in recommending a boiler of small capacity, to propose also that it shall be of small superficies; for it is indispensable that it should present a surface to the fire, proportional to the quantity of pipe it is required to heat; and in every case, the larger the surface on which the fire acts, the greater will be the economy in fuel, and the greater also will be the effect of the apparatus.

(78.) The sketches of the boilers, figs. 16 to 26, are several different forms which present various extents of surface in proportion to their capacity.

FIG. 16.

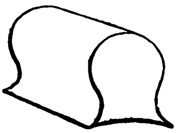


FIG. 17.

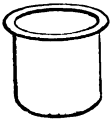


FIG. 18.

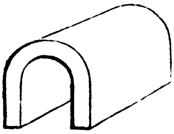


FIG. 19.

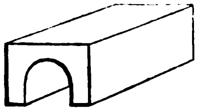


FIG. 20.

FIG. 21.

FIG. 22.

FIG. 23.

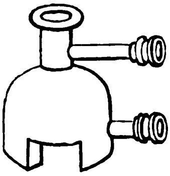


FIG. 24.

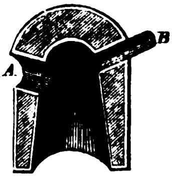


FIG. 25.

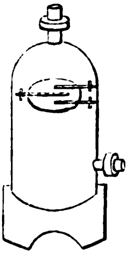
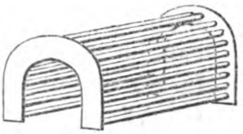


FIG. 26.



All except the first two, however, have but a small capacity, relatively to their superficies, compared with boilers which are used for steam. There is no advantage whatever gained by using a boiler which contains a large quantity of water; for, as the lower pipe brings in a fresh supply of water, as rapidly as the top pipe carries the hot water off, the boiler is always kept absolutely full. The only plausible reason which can be assigned for using a boiler of large capacity is, that as the apparatus then contains more water, it will retain its heat a proportionably longer time. This, though true in fact, is not a sufficient reason for using such boilers: for the same end can be accomplished, either by using larger pipes, or by having a tank connected with the apparatus, which can be so contrived, by being enclosed in brick or wood, or some other non-conductor, as to give off very little of its heat by radiation, and yet to be a reservoir of heat for the pipes after the fire has been extinguished. If this tank communicate with the rest of the apparatus by a stop-cock, the pipes can be made to produce their maximum effect in a much shorter time than if this additional quantity of water had been contained in the boiler; and a more economical and efficient apparatus will be obtained. The circulation will likewise be more rapid from a boiler which contains but a small quantity of water; because the fire will have greater effect upon it, and will render the water which is contained in it, relatively lighter than that which is in the descending or return pipe.

(79.) The boilers, fig. 16 and 17, are but seldom used for hot-water apparatus. Fig. 18 is an excellent form of boiler, and is generally made of wrought-iron. Fig. 19 is something similar, though decidedly inferior on account of the inconvenience of a flat top; which not only prevents the easy flow of the hot water to the ascending pipe (which ought always to be placed on the top), but also the flues do not act so efficiently on the flat top of this boiler. Fig. 20 is a good boiler; but is best for either very small or very large apparatus (and not for intermediate sizes), depending on the mode of setting; which subject will be described in the following chapter. Fig. 21 is only suitable for a very small apparatus. Fig. 22 and 23 (the former of which is a section, and the latter an elevation,) represent a cast-iron circular boiler of a very efficient construction, and suitable for either a large or small apparatus. This form, and that shewn by fig. 18, are decidedly the best boilers at present in use. Fig. 24 is a section of the boiler, known as Rogers's conical boiler; which is a circular boiler, externally resembling the fig. 25. The conical boiler has undergone much alteration of form since its first invention. It was first open at the top, and the fuel supplied there: this, however, is now supplied at A, and B is the smoke flue. Fig. 25 is a copper boiler nearly similar to the last, but contrived so as to be used without any brickwork. The radiation of heat from this boiler is of course considerable, and is generally entirely wasted: though when the boiler is placed inside the room or building to be warmed, this loss may be avoided, if the disagreeable smell from the heated copper does not render it objectionable. It is only suitable for very small apparatus. Fig. 26 is a boiler consisting of a double row of pipes (of which the external row alone is shewn), connected at each end by an arch, by which the water is supplied to the pipes forming the body of the boiler. This boiler heats rapidly, but is necessarily very wasteful of fuel, as no flues can be formed in setting it.

(80.) There are many other forms of boilers which have been proposed for the hot-water apparatus; and, in fact, the multiplication of them appears almost without limit. When strictly considered however, there is scarcely one that presents any real novelty, and generally they are mere colourable adaptations of some one of those which have been described; and the wonderful effects which sometimes are attributed to them, arise either from the parties being deceived in the results, or from their being unacquainted with what has previously been accomplished by others. The principles on which a boiler must be constructed in order to become efficient, are as fixed and immutable as the laws of nature; and the modes by which these principles are to be applied are all determinable by experience, and can be correctly judged of by certain rules, beyond the possibility of error. The mode of doing this will be pointed out in the present chapter, and may perhaps in some degree tend to prevent the erroneous notions which frequently prevail upon this subject.

(81.) The adoption of boilers of small capacity, having been recommended (Art. 78), it is necessary to accompany the recommendation with a caution against running into extremes; for this error has been the cause of failure, and of the inefficiency of the apparatus in many instances. The sketch, fig. 21, is an instance of this sort, in which an absurd extreme has occasionally been adopted. The contents of a boiler of this shape sometimes does not exceed a couple of gallons, even when applied to a very large furnace; and though this boiler presents a large surface to the fire, the space allowed for the water is so small, that the neutral salts and alkaline earths, deposited by the water which evaporates from the apparatus, contract the water-way, already far too small, and effectually impede the circulation, and also prevent the full force of the fire from acting on the water. In a very small apparatus, however, this form of boiler has occasionally been used with advantage, the fire being less intense.

But perhaps the more immediate cause of failure of this shaped boiler, arises from a different and very singular circumstance. The quantity of water which it contains being so very small, and the heat of the fire, therefore, when the furnace is large, being very intense upon it, a repulsion is caused between the iron and the water, and the latter does not receive the full quantity of heat. This extraordinary effect is not hypothetical: it has been proved to exist by the most satisfactory experiments; particularly some which were made by the Members of the Franklin Institution of Pennsylvania. The repulsion between heated metals and water, they ascertained to exist, to a certain extent, even at very moderate degrees of heat; being appreciably different at various temperatures below the boiling point of water. But, as the temperature rises, the repulsion increases with great rapidity; so that iron, when red hot, completely repels water, scarcely communicating to it any heat, except, perhaps, when under considerable pressure.[1]

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[1] Mr. Jacob Perkins brought this curious fact prominently forward, during his ingenious experiments on high-pressure steam. It has, however, long been known as a philosophical fact, and was first observed in 1756, by M. Leindenfrost. M. Klaproth subsequently investigated it, and published some experiments on the subject (*Nicholson's Journal,* vol. iv. p. 208). In the *Parliamentary Report* and evidence on the *Scotch Distilleries* for 1798 and 1799 (p. 610), there is a quotation from *Chaptal's Chemistry,* shewing that he was well acquainted with the fact; and also some

The boiler in question, however, seldom or never reaches the temperature of luminosity, though it is still sufficiently high to make a considerable difference in the heating of the water. Added to this, the form of it prevents the full effect of the heat being communicated to the pipes; for the extreme smallness of the water-way prevents the rapid communication between the various parts, and therefore the upright or flow pipe receives its principal supply of heat from that portion of the boiler which is immediately beneath where it is fixed, instead of that equable communication of heat from all parts, which is the ordinary process in boilers of good proportions. There is likewise a probability that steam would form in this boiler, which would still farther interfere with the circulation of the water. But were the water-way to be enlarged, all these inconveniences and probable causes of failure would proportionably decrease. Though all these causes of inefficient action may not exist simultaneously, yet they may act at different stages of the working of the apparatus. But they all apply equally to every boiler, in which the rational limits of the surface, relatively to the capacity or contents of the boiler, have given place to wild chimeras and fanciful notions, not based on sound principles of philosophy.

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experiments by M. Zeigler, by which he ascertained that a drop of water took 89 seconds to evaporate from metal heated to 520° Fahrenheit, but that it only required one second when the metal was at 300° Fahrenheit.

In the recent experiments "On the Explosion of Steam Boilers, by the Franklin Institution of Pennsylvania," a very thick iron ladle was perforated with a number of small holes, and then made red hot. When water was poured into this ladle, none of it escaped through the holes, until the ladle cooled down below redness; and the quantity which afterwards passed through, increased with every reduction of the temperature, the difference being quite appreciable even between the temperatures of 60° and 80° Fahrenheit.

(82.) It is obvious that the extent of surface which a boiler ought to expose to the fire, should be proportional to the quantity of pipe that is required to be heated by it: and it is not difficult to estimate these relative proportions with sufficient accuracy, notwithstanding the various circumstances which modify the effect.

(83.) It has been proved by experiments, that four square feet of surface of an iron boiler will evaporate one cubic foot of water per hour, when exposed to the *direct action* of a tolerably strong fire. This, however, requires free exposure to the radiant heat of the fire: for the heat communicated to the flue surfaces is only equal to one-third of that which is derived by the direct action of the fire, acting upon the bottom or sides of the boiler.[1] And it can be

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[1] Mr. Robert Stephenson's experiments on this subject clearly prove this proportion between the relative heating of flue surface and boiler surface to be correct. In his experiments the flues consisted of tubes passing through the water: and he found that while six square feet of boiler surface, evaporated six gallons of water in 38 minutes; the flue surface, consisting of 24½ square feet, had, in the same time, evaporated eight gallons. This will be found equal to evaporating one cubic foot of water per hour, from 3·7 square feet of the boiler surface exposed to the direct action of the fire; and the same quantity of water evaporated by 11·9 square feet of the flue surface; being in the proportion of 1 to 3. (See *Wood's Treatise on Railroads*, 3rd edition, p. 524.) In the best locomotive engines, the power of the boiler is equal to one cubic foot of water evaporated per hour by 1·7 square foot of boiler surface exposed to the direct action of the fire. This appears to be almost the greatest effect that can be produced at present. (*Experiments on Great Western Railway*, 1838.) In 1834, the Chevalier Pambour found the average of the engines on the Liverpool and Manchester Railway to be one cubic foot of water evaporated per hour, from 2·5 square feet of surface exposed to the direct action of the fire. The flue surface in all these experiments was calculated as equal to one-third that of the boiler surface. This high evaporating power can only be maintained when a very powerful draught is produced by mechanical means: and in all these cases there is a very great waste of fuel. In the original experiments of Watt, on steam boilers, he found that the

ascertained by calculation, that the same extent of heating surface which will evaporate one cubic foot of water per hour from the mean temperature of 52°, will be sufficient to supply the requisite heat to 232 feet of pipe four inches diameter, when the temperature of this pipe is to be kept at 140° above that of the surrounding air.[1] From this, then, it appears that one square foot of boiler surface *exposed to the direct action of the fire*, or three square feet of flue surface, will be sufficient in a hot-water apparatus to supply the necessary heat to about 58 superficial feet of pipe: or in round numbers, the proportion may be

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average of eight square feet of boiler surface was required to evaporate one cubic foot of water per hour. This proportion is still very generally used; and by employing a large heating surface, economy of fuel is always produced. This is strikingly exemplified in the Cornish engines; the boilers of which have a larger surface than any others, and the consumption of fuel (per horse's power of the engine) throughout Cornwall only averages one-fourth of that of the manufacturing districts of England. The whole of this saving, however, is not due to increased surface of the boilers; a large proportion of it is owing to the mode of using the steam expansively, which is there carried to the extreme.

Pambour has questioned the accuracy of the estimate for the proportionate effect of flue and boiler surfaces; which he considers do not differ so much in heating power as is generally supposed: but the doubt only applies to the boilers of locomotive engines where a very powerful blast is applied, and he agrees that, in other cases, the proportionate heating power of 3 to 1 for the boiler surface and flue surface, is nearly correct. (*Pambour's Treatise on Locomotive Engines*, 2d edition, p. 269.)

[1] It appears by calculation (Art. 107), that a four-inch pipe will lose ·851 of a degree of heat per minute, when the excess of its temperature above the circumambient air is 125°. If, therefore, this excess were 140°, the loss per minute would be ·953 of a degree of heat. Calculating, therefore, this loss to be 57·18 degrees per hour; and estimating also (the latent heat of steam being 1000°) that the cubic foot, or 1728 cubic inches of water evaporated, has received 1160° of heat; and that one foot in length of a four-inch pipe contains 150·7 cubic inches of water; we shall obtain $\frac{1728 \times 1160}{150{\cdot}7 \times 57{\cdot}18} = 232$ feet, as stated in the text.

stated as one foot of boiler to 50 feet of pipe. As this, however, is almost the maximum effect which can be produced (without mechanical means of producing draught), it is very desirable in all cases to allow an increased surface of the boiler; bearing in mind that not only will economy of fuel be thereby produced, but the apparatus will be much easier managed, and thus become more effective and certain in its operation. The following Table gives the *maximum* effect of a boiler for different proportions and sizes of pipes, calculated by the above rule.

TABLE II.

Surface of Boiler exposed to the direct action of the Fire,	4-in. Pipe.	3-in. Pipe.	2-in. Pipe.
4 square feet will heat	200 feet, or	266 feet, or	400 feet.
6	300	400	600
8	400	533	800
10	500	666	1000
14	700	933	1400
20	1000	1333	2000

A small apparatus ought always to have more surface of boiler, in proportion to the length of pipe, than a larger one; as the fire is less intense, and burns to less advantage in a small, than in a large furnace. The effect also depends greatly upon the quality of the coal, the height of the chimney, the rapidity of draught, the construction of the furnace, and many other particulars; but it will always be found more economical, as regards the consumption of fuel, to work with a larger surface of boiler at a moderate heat, than to keep the boiler at its maximum temperature.

(84.) But beside all these causes, that modify the effect, there is another, that will alter the proportions which may be employed. The data from which the calculation of the boiler surface is made, assumes the difference to be 140° between the temperature of the pipe and the air of the room which is heated; the pipe being 200°, and the air 60°. But if this difference of temperature be reduced, either by the air in the room being higher, or by the apparatus being worked below its maximum temperature; then, in either case, a given surface of boiler will suffice for a greater length of pipe. For if the difference of temperature between the water and the air be only 120° instead of 140°, the same surface of boiler will supply the requisite degree of heat to one-sixth more pipe; and if the difference be only 100°, the same boiler will supply above one-third more pipe than the quantity before stated. It will, therefore, sometimes occur in practice (where economy in construction is the primary object), that the quantity of pipe in proportion to a given surface of boiler may be even increased beyond the amount which is given in the preceding Table: because, in forcing-houses, for instance, the temperature of the air will always be above 60°; and in the warming of churches, workhouses, or other large buildings, the temperature of the water will generally be considerably below 200° —the pipe not being required to be worked at its greatest intensity,—and therefore, in both these instances, a larger proportion of pipe may be applied to a given sized boiler; but, as already observed, an increased consumption of fuel, and more attention in the management of the fire, will then be required. And therefore, it follows, that although a smaller boiler surface would really supply a sufficient quantity of heat, under strict management and constant attention, it will generally be better not to reduce the size of the boiler below what has here been stated; for not only will the apparatus need less attention, but also the required temperature of the building can be thus much sooner attained, as well as more easily continued. A very good proportion, suitable for nearly every purpose, is to allow about one foot of boiler surface (calculated, as already described, Art. 83) to about 40 superficial feet of pipe, or other radiating surface.

(85.) It may be desirable here to state what are the peculiar characteristics of a good boiler for this purpose; and how the qualifications of each particular shape are to be judged of. Some general rules also may be given, though a minute detail of the peculiarities of each of the various forms would scarcely be worth the space such a description would require. The principal recommendations of a boiler are, that it shall expose the largest surface to the fire in the smallest space; that it shall effectually absorb the heat given out from the fuel, so that as little heat as possible shall escape up the chimney; that it shall allow free circulation of the water throughout its entire extent; and that it shall not be liable to get out of order, nor rapidly deteriorate by continued use. The first of these qualifications is of itself a compound question. We have seen (Art. 83) that any surface exposed to the direct action of the fire, or in other words, to the *radiant heat*, receives, in a given space, *three times* as much heat as a similar surface exposed merely to the conducted heat, or that which is afforded by the products of combustion after they are thrown off from the burning fuel. Here then is a very important distinction in boilers; for as radiant heat passes in straight lines in every direction, it follows that the largest possible surface ought to be exposed immediately over the burning fuel, and that, too, at the least possible distance; because the effect of radiant heat decreases as the square of the distance between the radiating and the recipient bodies (Art. 194). It is no recommendation of a boiler, therefore, to say that it contains a certain number of square feet of heating surface in a given space; for unless this surface can be acted upon by the *radiant* heat of the furnace, a boiler of less than one-half the superficial measurement, if judiciously contrived for this object, may greatly exceed it in power.[1]

In this respect the boiler, figs. 22 and 23, appears to possess an advantage over most others. This boiler is of cast iron, and the part exposed to the fire is covered with a series of ribs two inches deep, and about one-fourth or three-eighths of an inch thick, radiating from the crown of the arch, at an average distance of two inches from each other. These ribs, it is evident, must increase the surface exposed to the fire to an enormous extent; and that, too, precisely where the effect is by far the greatest; being immediately over the burning fuel, and receiving the whole of the radiant heat from the fire.[2]

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[1] The most remarkable illustration of the effect of exposing a large surface to the direct action of the radiant heat, is afforded by the evidence given before the Committee of the House of Commons, in 1798, on the Distilleries of Scotland. Owing to the mode of levying the duty at that time, it became an object to work off the liquor from the still as rapidly as possible, irrespective of the cost of the apparatus or the expenditure of fuel. To such an extent was this carried, that the stills were actually charged, the wash distilled, and the refuse discharged, about 520 times in 24 hours, or 2¾ minutes for each charge of 16 gallons. There is no other instance known in the least approaching this extraordinary result, in which a small vessel of the measurement of 40 gallons could distil a charge of 16 gallons of wash in 1¾ minutes, half a minute more being required for charging the still, and the like time for discharging the refuse. This was accomplished by having the still exceedingly flat, so that the largest possible surface was exposed to the direct action of the radiant heat, and the flame acted intensely upon the whole bottom surface of the still, and then passed off at once into the chimney. The waste of fuel was, of course, immense, but the rapidity of action was fully accomplished.—*Report on Scotch Distilleries*, 1799, pp. 517-731.

[2] As early as the year 1828, the author adopted the plan of increasing the heating surface of these boilers by means of a great number of protuberances cast on the bottom, which protuberances were one inch long and seven-eighths of an inch diameter, and placed two inches apart from each other. Subsequently these pins, or protuberances, were still further extended, so as to form continuous bars or ribs, radiating from the centre of the boiler;

The form of this boiler being hemispherical, will also expose the largest surface in a given area.

(86.) The second qualification, that the boiler shall absorb the greatest quantity of heat from the fuel, is partly dependent on the cause already explained, and partly on the conducting power of the metal itself. In this respect the boiler (fig. 18) possesses an advantage over the other, in consequence of being made of wrought-iron, and therefore very much thinner. Were it made of copper, its effect would be still further increased, (see Art. 204); but the greater expense of copper is an objection.

(87.) The third recommendation of a boiler, that it shall allow of a free circulation of the water, is entirely dependent on its form; and on this subject some remarks have already been made (Art. 81.) And the last test of a good boiler, that it shall not be liable to get out of order, nor rapidly deteriorate, is one that depends partly on the goodness of the mate-

and they were made one inch-and-a-half deep and three-eighths of an inch thick; and they were then placed as well on the surface exposed to the water as that exposed to the fire. This plan of increasing the heating surface was, in the year 1835, patented by Mr. Sylvester, both for cast and wrought iron boilers; and in 1841, Mr. C. W. Williams patented the same plan for wrought iron steam boilers; the pins being, by his plan, screwed into the substance of the plate, instead of being formed by rolling, as proposed by Mr. Sylvester.

It has been generally supposed that all sharp protuberances inside a boiler, caused a more rapid ebullition of the water than a flat surface; and the author adopted this mode of increasing the water surface as well as the fire surface; and this plan was also followed both by Mr. Sylvester and Mr. Williams in their patents. Subsequent experiments, however, have convinced the author that it is unnecessary to increase the water surface by these means; and in particular, Mr. Josiah Parkes's experiments in 1840 (*vide* his published Report), on Mr. M. A. Perkins' patent steam boiler, proved that, owing to the great conducting power of water, the whole of the heat was abstracted from 117 superficial feet of iron exposed to the fire, by 44 superficial feet exposed to the water; or that the water will absorb the heat at least 2·6 times as fast from the iron, as the iron can receive it from the fire.

rials and workmanship, and partly on the mode of producing the combustion of the fuel. Some very important chemical effects appear to result occasionally, both from the fuel employed, as well as from the method of combustion. The effects on copper are the most destructive: and instances have occurred, where the bottoms of copper boilers have separated entirely from the sides as though cut through with a chisel, just at the part where the principal action of the fire occurs; and others have become entirely riddled throughout the surface exposed to the fire. These are very rare occurrences, and the cause appears somewhat obscure; but the subject will be better explained in a subsequent chapter (Chapter VI. Part II.)

CHAPTER V.

On the Construction of Furnaces—Combustion dependent on Size of Fire-bars—Furnace-doors, and other Parts of Furnace—Proportionate Area of Furnace-bars to the Fuel consumed—Confining the Heat within the Furnace—Directions for building the Furnace for different Boilers—Advantage of large Furnaces—Modes of firing.

(88.) The construction of the furnace for a hot-water apparatus, is a matter which requires some care: for although, from the small size of the boilers generally used, the furnace is by no means difficult to construct, it is a very common fault in building them, to allow of such a very easy exit for the flame and heated gaseous matter, that a large portion of the heat passes up the chimney, instead of being received by the water in the boiler. This arises principally from the shortness of the flues in these boilers, in comparison with those of steam-engine boilers; and in setting boilers for hot-water apparatus, it therefore requires great caution to prevent an unnecessary waste of fuel by erroneous principles in constructing the furnace.

In giving some general instructions on the subject of furnaces for hot-water apparatus, it is not intended minutely to describe the proper furnace for each different form of boiler; but the plan of building the furnaces for three or four different forms of boilers will be given, and the application of the principles to other forms must be left to the discretion of those who erect them.

(89.) The rate of combustion of the fuel in a furnace depends very little upon the total size of the furnace, but chiefly on the proportionate size of the furnace bars. A furnace which possesses, for instance, an area of 12 square feet, would not necessarily burn a much larger quantity of fuel per hour than one that had only an area of eight square feet; provided the area of the furnace bars was the same in both cases, and that no more air was admitted to the former than to the latter. But, by building the furnace of considerable dimensions, and with a moderately small area of fire bars, the fuel can be made to burn for a much longer period, without attention or renewal; and this is a very important object for this description of apparatus. For, as so intense a fire is not required, as is the case with a steam boiler,[1] an extremely small degree of attention is necessary for a furnace of this kind, which, when well constructed, ought to burn for ten or twelve hours without replenishing the fuel.

(90.) In all cases, a good and perfectly tight furnace door is requisite; for, if the door does not fit accurately, a large quantity of cold air enters, and passes between the fuel and the bottom of the boiler, and cools the boiler to a considerable extent.[2] The furnace-door should always be double;[3] and also a door to the ash-pit should be used, in order to shut off the excess of air when the fire is required to burn

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[1] In some steam boilers, particularly in the Cornish boilers, the fuel is burned with slow combustion; but the furnaces and boilers are very large in proportion to the work done by them, and great economy of fuel results from this plan of heating them (see Chapter VI. Part II.)

[2] In a subsequent chapter, the combustion of smoke will be discussed, and it will then be shewn that the admission of air, at or near the furnace-door, is sometimes desirable, but only in particular stages of the combustion.

[3] Count Rumford first introduced these double furnace-doors, of which many modifications have been since adopted.

slowly for a great length of time. Immediately within the furnace door, there should be a dumb plate; and the larger this is the better, provided it does not project the furnace-bars too far back, so as to cause the most active part of the combustion to take place at the posterior part of the furnace, instead of immediately under the boiler. The use of a large dumb plate in front of the furnace-bars, is to allow the fuel to be gradually coked, by placing it first on this dumb plate, and then, when well heated, pushing it forward upon the furnace-bars, where it enters into active combustion, and then a fresh charge of fuel is to be again laid on the dumb plate in order to undergo the same operation. By this plan of coking the coals on the dumb plate, nearly all the smoke from the furnace may be consumed; by which a considerable saving of fuel will be effected,[1] and a great nuisance prevented.

(91.) The size of the fire-grate, or furnace-bars, must be regulated by the quantity of pipe or other heating surface which the apparatus contains. The quantity of heat given off by a certain extent of iron pipe, or other heated surface, can be exactly ascertained, and will be shewn in the next chapter. From the data there given, we learn the quantity of coals required to be burned per hour, in order to maintain the required temperature. Having already given (Art. 83) the extent of boiler surface required to heat a given quantity of pipe, it will be desirable now to shew the area of the furnace-bars which will be required. It has already been stated (Art. 84), that the extent of boiler surface exposed to the fire, may with advantage be increased beyond the dimensions already given; and that economy of fuel will generally result from this increased surface. But the quantity of fuel that is burned ought not to be also increased in the same way: and therefore the size of

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[1] See Chapter VI. Part II., on the combustion of smoke.

the furnace bars, which alone regulates the quantity of fuel consumed, should be proportioned to the extent of the surface giving off heat to the building, rather than to the dimensions of the boiler.

With the average dimensions used for furnace bars, the spaces for the admission of air will generally vary from one-fourth to one-third of the total area of the space occupied by the furnace bars. In this case, one square foot of furnace bars will be sufficient to burn about 10 or 11 lbs. of coal per hour, under ordinary circumstances;[1] and on this calculation the following Table has been constructed,

TABLE III.

Area of Bars.			4-in. Pipe.	3-in. Pipe.	2-in. Pipe.
75	square inches	will supply	150 feet, or	200 feet, or	300 feet.
100	,,	,,	200 ,,	266 ,,	400 ,,
150	,,	,,	300 ,,	400 ,,	600 ,,
200	,,	,,	400 ,,	533 ,,	800 ,,
250	,,	,,	500 ,,	666 ,,	1000 ,,
300	,,	,,	600 ,,	800 ,,	1200 ,,
400	,,	,,	800 ,,	1066 ,,	1600 ,,
500	,,	,,	1000 ,,	1333 ,,	2000 ,,

Thus, suppose there are 600 feet of pipe, four inches in diameter, in an apparatus; then the area of the bars should be 300 square inches; so that 14 inches in width and 22 inches in length will give the requisite quantity of surface.[2] When it is

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[1] The consumption of fuel, on any given area of furnace bars, must depend upon the rapidity of the draught. In locomotive engines, with an artificial blast from the steam, the consumption of fuel is about 80 lbs. from each square foot of fire grate per hour. In some furnaces the consumption is not more than 6 lbs. per square foot, or about $\frac{1}{13}$ of the locomotive engine furnace; but the quantity given in the text is a mean rate.

[2] The proportions deducible from the above table, and those given Art. 83, for ascertaining the boiler surface, are very different to those generally used in steam-engine boilers. It will be observed, that by the rules here given, the area of the furnace bars is about one-sixth of the area of the boiler surface exposed to *the direct* action of the fire; whereas in steam boilers, the flue and boiler surfaces conjointly are usually in proportion to the surface of the

required to obtain the greatest heat in the shortest time, the area of the bars should be proportionably increased, so that a larger fire may be produced; and, on the contrary, when the object is to obtain slow combustion of the fuel, and when the rapidity with which the apparatus becomes heated is of little or no consequence, then the area of the bars may be reduced. The best method, however, will generally be found in using a sufficiently large surface of fire bars for the maximum effect required; and to regulate the draught by means of an ash-pit door, and a damper in the chimney; by which means almost any required rate of combustion can be obtained, with any ordinary degree of care.[1]

furnace bars, as 11 to 1, and sometimes even as 18 to 1 (*British Scientific Reports* for 1842, page 107). When this latter calculation, however, is reduced to the same standard as the other, viz., three feet of flue surface being equal to one foot of boiler surface exposed to the radiant heat,—the difference will not be near so great as it here appears. And it must also be considered that in large boilers the proportions must necessarily vary from those of the very small boilers required for a hot-water apparatus; for the effect of radiant heat decreases as the square of the distance between the recipient surface and the hot body; and therefore it is very easy to see how a considerable difference may arise between surfaces placed so differently in this respect, as they necessarily must be in large and in small boilers.

[1] When a rapid draught and quick combustion are required, the furnace bars may very advantageously be made very narrow and deep, so as to allow a larger proportionate space for the entrance of the air. Instead, therefore, of using furnace bars one-and-a-half, or one-and-three-quarters of an inch wide, with half an inch air space between the bars, they may be made about three-eighths or half an inch in width, and about four and a half or five inches deep, tapering at the lower edge to about one-eighth of an inch; and made with shoulders, as usual, to allow either half an inch or three quarters of an inch air spaces. Bars of this kind will have many advantages in particular cases. They will allow more than twice the quantity of air to pass through that the other bars will do, and therefore twice the quantity of coal can be burned on each square foot of the bars; and they will last longer than bars of the ordinary construction. The author, at the latter end of 1842, suggested the use of these bars

(92.) When the size of the furnace will allow of it, a dead plate should be placed beyond the bars at the back of the furnace, as well as in the front; but the very small size, both of the furnace and the boiler, for a hot-water apparatus, frequently renders this difficult or impossible to obtain. Where it can be done, it will be found advantageous to adopt it.

(93.) It is a matter of very great importance, that the heat should be confined within the furnace as much as possible, by contracting the farther end of it, at the part called the throat, so as to allow only a small space for the smoke and inflamed gases to pass out. The neglect of this, causes an enormous waste of fuel; for, in consequence of the shortness of the flues of these boilers, the heated gaseous matter passes too readily from the boiler, and escapes through the chimney at a very high temperature. The only entrance for the air should be through the bars of the grate,[1] and the heated gaseous matter will

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in locomotive engines, which is the most severe test they could be put to, and the result has been completely successful. Owing to the extreme thinness of the bars, the air passing between them keeps them always cool, which is impossible if the bars much exceed this thickness. The great depth of the bar gives the necessary stiffness; and the result of nearly twelve months trial, and with nearly twenty locomotive engines, is a very great increase in the durability of the furnace bars, in addition to the obvious advantage of admitting much more air into the furnace. Some of these bars, which have been used for ten months, and with which the engines have ran nearly 20,000 miles, are still perfectly good; and already they have done nearly four times the work of ordinary bars. The best size for this purpose is five and a half inches deep by half an inch thick, tapered to a quarter of an inch.

When the old form of furnace-bars is used, and they are required to bear a very intense heat, their durability is increased by making a longitudinal grove in the upper surface about three-eighths of an inch deep. This groove becomes filled with ashes, which, being a slow conductor of heat, preserves the bars from the intense heat of the fire.

[1] These observations apply exclusively to the small furnaces

then pass directly upwards to the bottom of the boiler, and should be there detained as long as possible by the contraction at the throat of the furnace; and if this part of the furnace be properly constructed (by not making the throat too near the crown of the boiler, and making it sufficiently small in proportion to the total quantity of gaseous matter required to pass through it), a reverbatory action of the flame and heated gases will take place, by which a far greater effect will be produced, than if too easy an exit were allowed into the flues and chimney.

(94.) The boiler, fig. 18, may be instanced as an illustration of this mode of constructing a furnace. The furnace-bars should lie level with the bottom of the boiler. Two large fire-bricks, or Welch lumps, are then to be so placed, at the farther end of the boiler, that the only exit for the flame and smoke shall be through an opening (varying from 3½ to 4½ inches, according to the size of the boiler,) left between these two bricks, exactly half-way between the crown of the arch and the level of the furnace bars. The flame must not be allowed to escape close to the top of the arch; for in that case no reverberation will take place, and the flame and gases escape from the furnace too soon to produce their full effect on the arched surface of the boiler, which, it has been already shewn, is three times as effective as the flue surface. The flue, after passing the throat of the furnace, diverges to the right and

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and boilers used for hot-water apparatus, and not to large furnaces for steam-boilers, or for other purposes. In the latter, air may very advantageously be introduced at or near the furnace-door, or in many other ways, as will be shewn in the chapter on the combustion of smoke. Even in these small furnaces, a limited quantity of air might in certain stages of the combustion be advantageously introduced; but this would require so much more attention than is usually given, or indeed required, for an apparatus of this kind, that the rule given in the text will be found most advisable for ordinary practice.

the left, and passes along the sides and then over the top of the boiler, before it finally escapes into the chimney.

(95.) The boiler, fig. 22 and 23, requires the same arrangement; but in this boiler the aperture for the escape of the flame and smoke is generally made a part of the boiler itself. The opening is also somewhat lower down towards the level of the furnace-bars, and the boiler being circular, the flue generally winds round the boiler, instead of passing separately on the right hand and on the left. The boiler, fig. 21, may be set in the same kind of furnace; or if the two legs or protuberances at the bottom be very short and close together, the fire may be made to act upon the whole under side (the bars being fixed at some distance below), and the flame returned through a flue along the top.

(96.) The boiler, fig. 20, may be set in two different ways. When the inside tube is sufficiently large, it is best to place the fire inside this tube, the furnace bars being placed at about one-third the diameter of the tube from the bottom. In this case the action of the furnace becomes very similar to that already described for the boiler, fig. 18; except that the water-way is continued below as well as above the fire. The throat of the furnace must be contracted, as already described for fig. 18; but in the present case the flues must first pass directly under the boiler, and then pass over the sides and top.

When this boiler is very small, the fire must be made entirely below the boiler; and it is then best in an oval or flattened shape, both externally and in the tube. The flame, in this case, passes from the furnace below, first through the tube, and then returns over the top of the boiler, and from thence the heated gases escape into the chimney.

(97.) The boiler, fig. 24, as originally constructed, had no external flue. It was chiefly used for very small apparatus, and it possessed the advantage, when a very slow draught was used (somewhat similar to that of the Arnott's stoves), of holding sufficient fuel to allow of the fire burning for a long time without attention, which is generally difficult to accomplish with very small boilers. The ingenious inventor of this boiler (Mr. Rogers) still prefers this plan, though many new modifications of the boiler have been introduced. It is now sometimes used with an external flue, in which case it becomes very similar in principle to the boiler, figs. 22 and 23, though less effective as to heating surface, as there is a less extent of surface exposed to the radiant heat. In the original form, without the external flue, the temperature is difficult to regulate: as the more the fuel burns away, the greater the heat becomes, in consequence of a larger surface of the boiler being then exposed to the radiant heat; and also because the fuel burns quicker, in consequence of the air meeting less obstruction in passing through it. In this case the greatest heat is produced when about two-thirds of the fuel has burnt away. When the boiler, however, has an external flue, the best mode of setting, is to make the flue proceed from openings left at the bottom of the boiler, and leaving a free space for the flue, around the boiler, of about two inches, or thereabouts. The draught of air meeting less obstruction in passing along the grate-bars and thence upwards through the external flue, than by passing through the large body of fuel contained in the body of the boiler, the whole external surface becomes available for receiving heat from the fire, instead of being entirely useless, as in the other mode of setting; and of course the same sized boiler will by this arrangement heat a larger quantity of pipe. This boiler, however, will, under any form, expose less surface to the radiant heat of the fire than the boiler, fig. 22; for its external surface will scarcely exceed the flue surface of this latter boiler, in its power of absorbing heat; and this flue surface, we have already seen, only possesses one-third the absorbent power which those surfaces have, that are exposed to the direct action of the radiant heat. The fire of this boiler, however, is readily managed, and burns with but little attention.

(98.) In the boiler, fig. 26, there is necessarily a considerable waste of fuel, in consequence of the flame escaping immediately into the chimney without passing through any flues—this form of boiler not admitting of any kind of flues being used. The flame passes between the several pipes which form the boiler, and of course can only act upon their under side. If the draught be rapid, a partial vacuum must be formed on the upper side of the pipes, the flame passing in straight lines upwards; and, therefore, a loss of heat by radiation would take place from the upper side of the pipes which form this boiler. The boiler, however, necessarily heats rapidly, as the consumption of fuel in the furnace, owing to the rapid draught, is very considerable.

(99.) The advantage of making the furnace to contain a large quantity of fuel has already been mentioned. But, independent of the smaller degree of attention required, when sufficient fuel to last for many hours is supplied at once, it is found practically that great economy results from this plan; and from experiments made on this subject, with steam-engine furnaces, it appears that the increased consumption of fuel always bears a direct proportion to the frequency with which it is supplied to the furnace; and that (in the experiments in question) the greatest economy resulted when the fuel was supplied only once a day.[1] When this plan, however, is followed,

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[1] Mr. Josiah Parkes on "*The Evaporation of Water from Steam Boilers,*" in the Transactions of the Institution of Civil Engineers, for 1838. This result, however, was obtained by a peculiar kind

the combustion is less intense than with more frequent firing; and, therefore, a larger boiler surface is always required in this case. Care also should be taken to prevent the ingress of an undue quantity of air, when the fuel burns away, and the furnace bars thus become unequally covered; for in this case, a large quantity of cold air will rush in and cool the boiler.

(100.) The rate of combustion materially depends also upon the thickness of fuel on the furnace bars, and its compact or its open state, as illustrated in the two cases of small coal and of large well burned coke. The quantity of air passing through the fire-grate or bars must be very different in these two cases, as the combustion wholly depends upon the quantity of air admitted to the fuel; and unless a sufficient quantity of air be admitted, to convert the whole of the carbon into carbonic acid gas, it will escape in the form of carbonic oxide, and a loss of effect will thereby arise (see Chap. VI. Part II., on the Combustion of Smoke).

(101.) The greatest economy of fuel is produced when the fires are kept thin and bright; the coal well coked, by means of a large dumb plate in the front of the furnace, and the damper kept as close as possible, consistent with allowing a sufficient draught. The Cornish engines, so celebrated for their economy of fuel, are thus worked. The thinner the fire, the less is the probability of the formation of carbonic oxide, which always causes a loss of heat; and when thick fires are used, this loss is frequently very considerable, unless (as in Mr. Parkes's experiments already mentioned) air is supplied above the fuel, as well as through the furnace bars.[2] In the small furnace

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of furnace, in which air was admitted at the bridge, as well as through the fire-bars.

[2] In locomotive engines, the fires are frequently as much as 17 inches thick; and the quantity of carbonic oxide, formed in con-

of a hot-water apparatus, it is frequently difficult, if not impossible, to adopt this plan of using a dumb plate sufficiently large to coke the whole of the fuel which is used; but the principle should be borne in mind in all cases, and applied as far as the circumstances will permit. The theory of combustion will be given in the chapter on the combustion of smoke.

sequence of this great thickness, is very considerable, and the loss of heat enormous. The thinner the fire, the more perfect must be the combustion; because the carbonic oxide is formed by the carbonic acid, which is the result of perfect combustion, passing through the red-hot coke, by which it imbibes an additional quantity of carbon, and is converted into carbonic oxide; and on all the carbonic acid that undergoes this change, there arises a loss of one-half the heat derived from its original conversion. The various methods of admitting air at the bridge, and at other places above the fuel, are all intended to obviate this loss, by reconverting the carbonic oxide into carbonic acid, by supplying it with an additional dose of oxygen.

CHAPTER VI.

Heat by Combustion—Quantity of Heat from Coal—Specific Heat of Air and Water—Measure of Effect for heated Iron Pipe—Cooling Power of Glass—Effect of Vapour—Quantity of Pipe required to warm a given Space—Time required to heat a Building—Facile Mode of calculating the Quantity of Pipe required in any Building—Quantity of Coal consumed.

(102.) Having in the preceding chapters investigated the fundamental principles of the hot-water apparatus, we proceed to consider some particulars which are necessary to be known, in order to apply the preceding remarks, and correctly to apportion the various parts of the apparatus, and calculate the effects which will be produced under various circumstances.

Very erroneous notions are entertained by many persons as to the absolute quantity of heat contained in different substances. This subject has already been mentioned; and, in the present chapter, we shall have occasion to apply this law of specific heat in several important calculations.

(103.) It will, however, be desirable first to ascertain the quantity of heat which can be obtained by the decomposition of combustible materials by fire; for in this also, it may be observed, very erroneous notions prevail. The quantity of heat obtainable by the combustion of any substance, is not, as many persons appear to consider, illimitable, but it is as fixed and determinate as any other of the laws of heat. The amount of heat by combustion depends on the chemical composition of the particular substance; but although this heat may be either wasted or successfully applied, according as the apparatus used for its combustion is imperfect or otherwise, still it must be remembered there is a maximum effect, which has been accurately ascertained, and which cannot be exceeded in any form of apparatus; though in no apparatus yet invented has it been possible absolutely to render available the whole of this heat.

Although every kind of fuel differs in the quantity of heat that it affords, it is unnecessary here to inquire into any other than the ordinary descriptions used for purposes similar to that we are now considering. The calculations therefore will be made with reference only to coal and coke of ordinary and average qualities.

(104.) It is stated by Watt that one pound of coal will raise the temperature of 45 lbs. of water from 55° to 212°. Rumford states the same quantity of coal will raise $36\frac{8}{10}$ lbs. of water from 32° to 212°; and Dr. Black has estimated that one pound of coal will make 48 lbs. of water boil, supposing it previously to be at a mean temperature. These quantities, when reduced to a common standard, vary but little from each other. Watt's experiment of 45 lbs. of water being heated from 55° to 212°, is equal to $39\frac{1}{4}$ lbs. only, if heated from 32° to 212°; and this nearly agrees with Count Rumford's calculation; at least the variation is not more than might be expected from a slight difference in the quality of the coal. Dr. Black's estimate is as much in excess over the experiments of Watt, as Rumford's is in defect; we may, therefore, take the average of these three experiments, which will give us a result, that 39 lbs. of water may be heated from 32° to 212° by one pound of coal.

The results of later experiments shew that, as an average effect, the above calculations are very accurate, when practically applied on a large scale. Mr. Parkes[1] found that the greatest effect he could produce by his improved mode of firing, was 10·3 lbs. of water, at the temperature of 212°, evaporated by one pound of coal; and that, by the ordinary methods of firing, the average obtained is only 7·5 lbs. of water, of the like temperature, evaporated by one pound of coal. The first of these is equal to 57·2 lbs. of water, heated from 32° to 212°, by one pound of coal; and the latter is equal to 41·6 lbs. of water heated to the like extent; and which very nearly agrees with the experiments of Watt, Rumford, and Black. In the Cornish engines, however, a much higher result is obtained, Mr. Parkes has given the results obtained in the "United Mines," during eight months, from which it appears the greatest evaporation is 15·3 lbs., and the average quantity 11·8 lbs. of water evaporated from the temperature of 212°, by one pound of coal. The former of these gives 85 lbs., and the latter 65½ lbs. of water, raised from 32° to 212°, by one pound of coal; which results appear to be the highest that are practically attainable, and are very much greater than can be produced with any other boilers, or qualities of coal, than those with which the experiments were made. In all the subsequent calculations, therefore, the average of the experiments of Watt, Rumford, and Black, will be adhered to, as being the most correct for ordinary practice; and we shall shortly have occasion to apply them, in elucidating that branch of the subject which is included in the present chapter.

(105.) In order to ascertain the effect which a certain quantity of hot water will produce in warming the air of a room, there appears to be no better method than that of computing from the specific heat of gases, compared with water.

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[1] Mr. Parkes "*On the Evaporation of Water from Steam Boilers,*" in the Transactions of the Institution of Civil Engineers, 1838.

(106.) Every substance, it is well known, has its own peculiar specific heat: that is, a given weight, or volume, of any particular substance at a certain temperature, contains a definite amount of heat, which, if imparted to any other substance, will produce upon this last a certain known effect, though it will be different for every different body or substance. Now, it is ascertained that one cubic foot of water, by losing one degree of its heat, will raise the temperature of 2990 cubic feet of air,[1] the like extent of one degree: and by losing 10° of its heat, it will raise the temperature of 2990 cubic feet of air 10°, or 29,900 cubic feet one degree, and so on.

(107.) But this calculation regards only the ultimate effect which will be produced, without reference to the time which will be required to obtain the result. To ascertain the time that is required to heat the air, which is a most essential element in every calculation connected with the subject under consideration,—recourse must be had to direct experiments; for the rate at which a given quantity of hot water will impart its heat to the surrounding air depends upon the nature and extent of surface of the body which contains it, as well as upon the degree of motion which the air possesses. The effect of the velocity of the air, however, is not necessary here to be considered; as it is only to a still atmosphere in

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[1] The specific heat of *equal weights* of water and air, by the experiments of Berard and Delaroche, is found to be as 1 to ·26669: but as the volume or bulk of an equal weight of atmospheric air is to water, as 827·437 to 1, we shall have ·26669: 1 : : 827·437 = 3102, which is the number of cubic feet of air that has the same specific heat as one cubic foot of water. This, however, appears to be rather too high a calculation: for Dr. Apjohn, in a memoir recently published (*Rept. Brit. Sci. Assoc.* vol. iv.), gives the result of a new mode of determining the specific heat of permanently elastic fluids, by which he makes the specific heat of atmospheric air ·2767, when that of water is represented by unity. Therefore ·2767 : 1 : : 827·437 = 2990, which is the number given in the text.

a building that these calculations are to be applied. But as the radiating and conducting powers of different substances vary considerably, it is necessary to make experiments with the same substance or material, as the pipes for which we wish to estimate the effect, before we can arrive at any conclusions as to the quantity of heated surface that will be required to produce any desired temperature in a building.

From the experiments made to determine this question, it appears that the water contained in an iron pipe of four inches diameter internally and four-and-a-half inches externally, loses ·851 of a degree of heat per minute, when the excess of its temperature is 125° above that of the circumambient air. Therefore (by Art. 106) one foot in length of pipe, four inches diameter, will heat 222 cubic feet of air one degree per minute, when the difference between the temperature of the pipe and the air is 125°.[1]

This calculation will serve as the basis by which we may estimate the quantity of heating surface for any building. But before we can apply it practically, we must know what quantity of heat the building will lose per minute, by the cooling power of the glass, by ventilation, radiation, and all other causes,

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[1] From the data given in Art. 229, Chapter X., it appears that 171·875 cubic inches of water, exposed to the cooling influence of the air by 287·177 square inches of surface of cast iron, loses ·8 of a degree of Fahrenheit per minute when the air is 79° colder than the pipe: therefore $\frac{125 \times \cdot 8}{79} = 1{\cdot}265^\circ$ will be the loss of heat per minute when the temperature of the pipe is 125° above that of the air. But this quantity of water, if exposed in a pipe of four inches diameter inside, and four-and-a-half inches outside, will only be surrounded by 193·435 square inches of radiating surface; therefore $\frac{193{\cdot}435 \times 1{\cdot}265}{287{\cdot}177} = \cdot 851^\circ$, will be the loss of heat per minute by a four-inch pipe, when the excess of temperature is 125° above the circumambient air. As all pipes are technically known by their internal diameter, this mode of measuring is here used, although the external measurement would be a more correct definition for these calculations.

which may tend to lower its temperature; for on these several causes must obviously depend the quantity of heat that is required to be added to it by the warming apparatus.

(108.) The quantity of air required for ventilation, and the method of ventilating buildings, are considered in subsequent chapters (Chapters III. and IV. Part II). It is unnecessary, therefore, in this place to pursue the subject further than to state, that, in all public buildings, and rooms of dwelling-houses, a quantity of air equal to from three-and-a-half to five cubic feet for each individual the room contains, must be changed per minute, in order to preserve the wholesomeness and purity of the atmosphere.

(109.) The loss of heat in all buildings having any great extent of glass, we shall find to be very considerable. It appears by experiment[1] that one square foot of glass will cool 1·279 cubic feet of air, as many degrees per minute, as the internal temperature of the room exceeds the temperature of the external air; that is, if the difference between the internal and the external temperature of the room be 30°, then 1·279 cubic feet of air will be cooled 30° by each square foot of glass, or, more correctly, as much heat as is equal to this will be given off by each square foot of glass; for, in reality, a very much larger quantity of air will be affected by the glass, but it will be cooled to a less extent. The real loss of heat from the room will therefore be what is here stated.

(110.) But though this amount is only calculated for a still atmosphere, intense cold is seldom or never accompanied with high winds,[2] and, therefore, no

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[1] Experiments on Cooling, Art. 230.

[2] That intense cold is rarely accompanied by high winds is matter of common experience. The obliquity of the sun's rays on the higher latitudes of the Northern hemisphere, when near the time of the winter solstice, prevents the atmosphere of those

additional allowance needs be made for this cause, provided we estimate sufficiently low for the external temperature. For the highest winds are generally about March and September; and the average temperature of the former month is 46°, and the latter 59½°. The greatest diurnal variation of the thermometer is 20° in March, and 18° in September, so that the average temperature of the nights will be 36° in March, and 50° in September.[1] But we shall presently find (Art. 114), that when the external atmosphere is at 36°, the quantity of pipe required to warm a building to 65°, is only about one-half of what would be necessary were the external air at 10°; therefore, if we calculate that the external temperature will be 10°, when we estimate the quantity of pipe required to warm a building which is to be used during the night, and that it will be 25° or 26° externally, in the case of such buildings as are only wanted to be warmed during the day, the required heat can then be maintained, even during the time of high winds.[2]

places which are distant from the Tropics from receiving any considerable quantity of heat; and, therefore, the air being all of nearly equal density, there is but little tendency to aerial currents in the lower strata.

[1] These temperatures are for the neighbourhood of London. In March, 1837, the night temperature, obtained by a register thermometer, only averaged 31·1°, which is nearly 5° lower than has been known for many years. Mr. L. Howard, in his "*Climate of London*," states that the average temperature ascertained by observations for ten years, is as follows:

		In London.	In the Country.
March . .	Mean highest temperature .	47·31°	48·46°
	Mean lowest temperature .	37·32°	34·57°
September	Mean highest temperature .	65·91°	65·42°
	Mean lowest temperature .	52·45°	47·03°

[2] By reckoning the external air at the above temperatures, the wind may have a velocity of from twenty to thirty miles an hour, without producing any diminution of the internal temperature; for it is probable that the cooling effect of wind on ordinary window glass, is not above one-half so much as appears by the experiments, Art. 230.

But in such situations as are very much exposed to high winds, it will be prudent to calculate the external temperature from *zero*, or even below that, according to circumstances; and, in very warm and sheltered situations, a less range in the temperature will be sufficient; a local knowledge of the situation will therefore be necessary to guide the judgment in particular cases.

(111.) The difference between the cooling effect of glass which is glazed in squares, and that which is lapped, is very trifling in those buildings where the air contains much moisture. This is the case in hothouses, where the plants are constantly steamed; and therefore, for such buildings, no farther allowance should be made on this account, for loss of heat.[1] But in skylights of dwelling-houses, in consequence of the greater dryness of the atmosphere, the heated air will escape through the laps of the glass in greater quantity, in proportion as less vapour is condensed on the surface. The height of the skylight will also make a considerable difference in the velocity of the escape of air through the laps, as it depends

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[1] The calculations of the specific heat of air, given in the note, Art. 106, are only for dry air. If the temperature be at 60° and the air saturated with moisture, then the same quantity of heat will only raise the temperature to 2967 cubic feet of this saturated air any given number of degrees, which would have raised 2990 cubic feet of dry air to the like temperature. This 2967 cubic feet of saturated air will contain 68 cubic inches of water; and this quantity of water will absorb as much heat during its conversion into vapour, as would raise the temperature of 117,507 cubic feet of air one degree. This is equal to the entire heat that 46 feet of pipe, four inches diameter, will give off in ten minutes, when the temperature is 140° above that of the air. The glass will, however, cool much less of this saturated air, than of dry air, for the mixture of air and vapour has greater *specific heat* than dry air. With lapped glass the loss of heat will be less with saturated than with dry air, because the vapour, when condensed upon the glass, will run down and nearly fill up the crevices between the laps, and effectually prevent the escape of the air, and thereby avoid the loss of heat.

upon the same principles which have been explained (Art. 33), as governing the motion of water; the increased velocity being relatively as the height and the difference of temperature between the internal and external air.[1]

(112.) In making an estimate of the quantity of glass contained in any particular building, the extent of surface of the wood-work must be carefully excluded from the calculation. This is particularly necessary in buildings used for horticultural purposes, where, from the smallness of the panes, the wood-work occupies a considerable space. The readiest way of calculating, and sufficiently accurate for ordinary purposes, is to take the square surface of the sashes, and then deduct one-eighth of the amount for the wood-work. In the generality of horticultural buildings, the wood-work fully amounts to this quantity; but in some expensively finished conservatories, etc., it is considerably less, and therefore the allowance must be made accordingly. When the frames and sashes are made of metal, the radiation of heat will be quite as great from the frame as from the glass; therefore, in such cases, no deduction must be made.[2]

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[1] See also Chapter V. Part II.

[2] Some persons have imagined that the loss of heat from a glass roof will vary greatly with the angle which the roof forms with the horizon. But this variation in the effect cannot be very considerable. It can only be that portion of the heat lost by conduction of the air, that can vary in this manner; and calculating the ordinary excess by which the temperature of the hothouse exceeds the temperature of the external air, this portion of the heat is only about three-sevenths of the whole (see Art. 186, etc.) But a small part only of this quantity will be affected by the angle of the glass. For the cooling effect of wind will be in proportion to the number of particles of air brought into contact in a given time; and with a horizontal wind this will be directly as the sine of the angle which the roof forms with the horizon. Supposing then the roof to be at an angle of 34°, as recommended by Mr. Knight (*Horticul. Trans.*, vol. i. p. 99),

Some loss of heat will likewise arise from imperfect fitting of doors and windows. In these cases the circumstances vary very considerably; but, in the majority of instances, no allowance is necessary for these sources of loss of heat, the external temperature of the air having been reckoned (Art. 110) sufficiently low to supersede the necessity of any farther deduction.

(113.) From the preceding calculations, the following corollary may be drawn:—the quantity of air

we shall find that the sine of the angle multiplied by the abovementioned portion of the heat affected by the conducting power of the air will give as a result that, at the angle of 34°, there will be about two-ninths more of the heat carried off by the conducting power of the air than would be the case if the glass were placed horizontally. But practically, this loss will be very materially lessened, by an effect which is not capable of being reduced to any exact calculation. When a stream of air strikes an upright surface of glass, it is not reflected back again upon itself, but glides along the surface, and by the increased heat will be directed upwards in a vertical line. (*Quetelet's Philosophy*, note 5, Appendix.) Passing, then, in this direction, it meets another stream of air proceeding in a line parallel to the original line of its motion; and it is by this again driven more closely in contact with the glass. But, having been warmed by the contact in the first instance, it will abstract less heat from the glass, and will thus prevent, to a considerable extent, the further loss of heat, until by the upward motion of the air it finally escapes into space. The same effect will be produced by a glass roof lying at any angle: but it is clear the heated particles will escape upwards more easily in proportion as the angle of the roof is smaller. Now, these effects are exactly the opposite of each other. The cooling effect of the wind *increases* with the angle of the roof, and is greatest on a vertical surface; while the counteracting influence, by the interference of the particles of air with each other, also increases in nearly the same proportion; and therefore the variation in the angle of the roof makes far less difference than might at first be expected in the cooling effect. The difference, however, between the cooling of a vertical pane of glass, and a perfectly horizontal one, is not inconsiderable in high winds: but the angle of a roof must be very small indeed, before it can escape the influences above described, and be brought to assimilate with a horizontal roof.

to be warmed *per minute*, in habitable rooms and public buildings, must be 3½ cubic feet for each person the room contains, and 1¼ cubic feet for each square foot of glass.[1] For conservatories, forcing-houses, and other buildings of this description, the quantity of air to be warmed *per minute*, must be 1¼ cubic feet for each square foot of glass which the building contains. When the quantity of air required to be heated has been thus ascertained, the length of pipe which will be necessary to heat the building may be found by the following

RULE:—Multiply 125 by the *difference* between the temperature at which the room is purposed to be kept, when at its maximum, and the temperature of the external air; and divide this product by the *difference* between the temperature of the pipes, and the proposed temperature of the room: then, the quotient thus obtained, when multiplied by the number of cubic feet of air to be warmed *per minute*, and this product divided by 222, will give the number of feet in length of pipe four inches diameter, which will produce the desired effect.[2]

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[1] As corrugated sheet-iron is coming much into use, it may be proper to observe that the loss of heat from this kind of material is exactly the same as from the like extent of glass (see *Experiments*, Chapter X.), and must be allowed for accordingly, wherever it is used.

[2] Let p be the temperature of the pipe, and t the temperature the room is required to be kept at; then $\frac{125}{p-t} = x$, which will represent the number of feet of pipe that will warm 222 cubic feet of air one degree per minute, when $p-t$ is different to the proportions given in Art. 107. If d represents the difference between the internal and the external temperature of the room, and c the number of cubic feet of air which are to be warmed per minute, then $x \,.\, \frac{d.c}{222} = \mathrm{F}$, will be the number of feet of pipe four inches diameter, which will warm any quantity of air per minute, according to the calculations, Art. 107.

The rule given in the text has been arranged in such a manner that it may be worked without decimals.

When the pipes which are to be used are three inches diameter, then the number of feet of four-inch pipe, obtained by this rule, must be multiplied by 1·33, which will give the length of three-inch pipe: or to obtain the quantity of two-inch pipe, the length of pipe four inches diameter, obtained by the rule, must be multiplied by two; the length required of three-inch pipe, being one-third more than four-inch, and the length of two-inch pipe being double that of the four-inch, when the temperatures are the same in all.

(114.) By the following Table, however, even the simple calculations given in this rule may be dispensed with. The Table shews the quantity of pipe four inches diameter, which is required to heat 1000 cubic feet of air *per minute*, any number of degrees. The temperature of the pipes is assumed to be 200° of Fahrenheit; this being the most usual temperature at which they can be easily maintained. But according to the length of pipe which is heated by one boiler, the temperature will sometimes be greater and sometimes less than this estimate, the temperature of the water being generally higher when only a small quantity of pipe is used. When the quantity of air to be warmed *per minute* is greater or less than 1000 cubic feet, the proper quantity of pipe will be found, by multiplying the length given in the Table, by the actual number of cubic feet of air to be warmed *per minute*, and dividing that product by 1000.

TABLE IV.

Table shewing the Quantity of Pipe, four inches diameter, which will heat 1000 Cubic Feet of Air per Minute, any required Number of Degrees: the Temperature of the Pipe being 200° Fahrenheit.

Temperature of external Air. Fahrenheit's Scale.	Temperature at which the Room is required to be kept.									
	45°	50°	55°	60°	65°	70°	75°	80°	85°	90°
10°	126	150	174	200	229	259	292	328	367	409
12°	119	142	166	192	220	251	283	318	357	399
14°	112	135	159	184	212	242	274	309	347	388
16°	105	127	151	176	204	233	265	300	337	378
18°	98	120	143	168	195	225	256	290	328	368
20°	91	112	135	160	187	216	247	281	318	358
22°	83	105	128	152	179	207	238	271	308	347
24°	76	97	120	144	170	199	229	262	298	337
26°	69	90	112	136	162	190	220	253	288	327
28°	61	82	104	128	154	181	211	243	279	317
30°	54	75	97	120	145	173	202	234	269	307
Freezing Point } 32°	47	67	89	112	137	164	193	225	259	296
34°	40	60	81	104	129	155	184	215	249	286
36°	32	52	73	96	120	147	175	206	239	276
38°	25	45	66	88	112	138	166	196	230	266
40°	18	37	58	80	104	129	157	187	220	255
42°	10	30	50	72	95	121	148	178	210	245
44°	3	22	42	64	87	112	139	168	200	235
46°		15	34	56	79	103	130	159	190	225
48°		7	27	48	70	95	121	150	181	214
50°			19	40	62	86	112	140	171	204
52°			11	32	54	77	103	131	161	194

⁂ To ascertain by the above Table the quantity of pipe which will heat 1000 cubic feet of air per minute;—find, in the first column, the temperature corresponding to that of the external air, and at the top of one of the other columns find the temperature at which the room is to be maintained: then, in this latter column, and on the line which corresponds with the external temperature, the required number of feet of pipe will be found.

(115.) If the building which it is designed to warm, is required to be used only during the day, the air, in this part of the country at least, is scarcely likely to be below 25°; but if—as for a forcing-house for instance—it is required to be heated both by day and by night, then, perhaps, 10° will not be too low to calculate from, or 22° below the freezing point. Suppose, now, we want to calculate the quantity of pipe required to heat a forcing-house to 75° in the coldest weather,—which we will assume to be 10° of Fahrenheit's scale, or 22° below freezing. We have already seen (Art. 109—113), that the quantity of heat required for horticultural buildings is merely so much as is necessary to replace the heat given off — or in other words, to compensate for the loss sustained—by the glass. The actual cubic measurement of the house signifies nothing in this case; it is the glass alone which gives off any appreciable heat; and therefore whatever quantity of pipe will compensate for this loss of heat by the glass, will also warm the house in the first instance, and maintain it at the required temperature afterwards; because, until the air of the house is heated to its maximum temperature, the glass will cool proportionally less air, the cooling power of the glass being obviously exactly proportional to the difference between the internal and external temperature. The pipe, therefore, gives off more heat to the air in the earlier stages of the operation than the glass transmits by radiation to the external atmosphere; and this difference in the effect is actually the rate at which the building becomes heated; and the increase of the temperature of the building continues, until the radiating power of the glass exactly balances the heat given off by the pipes: and the heat given off by the pipes, it may be observed, constantly *decreases*, while the cooling power of the glass *increases* with every addition to the temperature of the internal air. We see then that by knowing the surface of glass in such a building, we can estimate the quantity of pipe that will heat it. For suppose the house has 800 square feet of glass: we find (Art. 113), that every square foot of glass cools one and a quarter cubic feet of air *per minute*, as many degrees as the internal exceeds the external temperature. If therefore (as we have supposed in this case) the external temperature is 10°, and the internal temperature is required to be 75°, then 800 square feet of glass will cool 1000 cubic feet of air *per minute* from 75° down to 10°. By the Table then, in the *column* marked 75°, and on the *line* marked 10° for external temperature, we find the quantity 292; which is the number of feet in length of pipe four inches diameter, that are required to heat this 1000 cubic feet of air per minute, the required number of degrees; and this quantity of pipe, therefore, will heat a building having 800 square feet of glass, whatever the actual size of the building may be. And whenever the quantity of air to be heated per minute is either greater or less than 1000 cubic feet (or in other words, when the quantity of glass is greater or less than 800 square feet), then the proper quantity of pipe will be obtained by the rule of proportion, as already stated (Art. 114).

(116.) This rule will not, however, give the length of time required to heat any particular building. This will of course depend upon many circumstances; nevertheless, some approximation may be made to the average time required. Suppose the maximum temperature of the pipe to be 200°, the water being at 40° before lighting the fire; then the maximum temperature in horticultural buildings will be attained with

Four-inch Pipes, in about four and half hours.
Three-inch Pipes, in about three and a quarter hours.
Two-inch Pipes, in about two and a quarter hours.

But if a larger quantity of coal than that given by the Table, be used—if the surface of the boiler be much increased in proportion to the length of pipe—if the quantity of pipe used be excessive—or the temperature of the external air is higher than the estimated amount; then, in each of these cases, the time required for heating will be less. But if, on the contrary, the required temperature be not attained in the time given above, then, either too small a quantity of pipe, too small a surface of boiler, or too small a quantity of coal has been used.

It should, however, be observed, that although the *maximum* temperature will not be reached, at an average, in less time than is above stated, still, the required temperature will very often not take longer than half, or two-thirds of this time, to be attained: because the quantity of pipe being always apportioned to meet the case of extreme cold, when the external temperature is above that extreme limit, the pipe, by being superabundant, will warm the same space in a shorter time.

(117.) These calculations, however, will only apply to those cases where, in consequence of the cooling surfaces being very large, the proportion of pipe is considerable, relatively to the actual dimensions of the building. Wherever the cubical content of the building is large in proportion to its cooling surfaces, the time required to raise its temperature will be greater than is above stated; and this will be found to vary greatly in different descriptions of buildings. Churches and other large buildings (which only require a small heating surface relatively to their cubic contents) will generally require the longest time to heat; dwelling-houses will require a shorter time, and horticultural buildings the shortest of all. The length of time above estimated only applies to the latter description of buildings; for the other kinds of buildings the period will be very variable, and can scarcely be determined, except for each individual case.

(118.) Various circumstances may, however, interfere to diminish the effect of the apparatus; such, for instance, as damp walls,—particularly if the building is new—excess of ventilation, etc. The effect of damp walls in reducing the apparent power of an apparatus is very considerable, in consequence of the great quantity of heat which is necessary to evaporate the moisture. For it will require as much heat to vaporise one gallon of water from the walls of a building, as would raise the temperature of 47,840 cubic feet of air 10°. The true power of an apparatus can, therefore, never be ascertained, unless the building be perfectly dry. The same cause, though in a much less degree, becomes operative in buildings which are only occasionally warmed; and a longer time will always be necessary to heat such places, than those that are in constant use.

(119.) For estimating the quantity of pipe which is required to warm any building, rules of a much more facile character, though, at the same time, much more loose and inaccurate than those which have been already given, may easily be constructed; but they will answer sufficiently well in many common cases.[1] Thus, in churches and very large public rooms, which have only about an average number of doors and windows, and moderate ventilation, by taking the cubic measurement of the room, and dividing the number thus obtained by 200, the quotient will be *the number of feet in length*, *of pipe four inches diameter*, which will be required to obtain a temperature of about 55° to 58°.[2] For smaller

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[1] This rule must not be confounded with that already given. The former rule gave the result entirely from an estimate of the quantity of glass, *without any reference to the cubic contents of the building*: the present rule, on the contrary, is founded entirely on the cubic contents of the building, without direct reference to the quantity of glass. The results, however, of the two rules will be found to agree in most cases.

[2] Churches and other buildings for containing large assemblages

rooms, dwelling-houses, etc., the cubic measurement should be divided by 150, which will give the number of feet of four-inch pipe. For greenhouses, conservatories, and such like buildings, where the temperature is required to be kept at about 60°, dividing the cubic measurement of the building by 30, will give the required quantity of pipe; and for forcing-houses, where it is desired to keep the temperature in the coldest weather at 70° to 75°, we must divide the cubic measurement of the house by 20; but if the temperature be required as high as 75° to 80°, then we must divide by 18, to obtain the number of feet of four-inch pipe. If the pipes are to be three inches diameter, then we must add one-third to the quantity thus obtained; and if two-inch pipes are to be used, we must take double the length of four-inch pipe.

of people, ought never to be heated to a very high temperature, on account of the great quantity of animal heat given off in crowded congregations. It has been ascertained by calculations founded on the amount of oxygen consumed, that a man generates a quantity of heat in 24 hours sufficient to raise 63 lbs. of water from the freezing to the boiling point. Of this quantity, as much heat is expended in forming the vapour that passes off by perspiration and by transpiration from the lungs, as would heat about 36½ lbs. of water 180°; and the remainder of the heat, which is equal to raising the temperature of 26½ lbs. of water 180°, passes off by radiation from the body. (*Quetelet's Philosophy*, Art. *Heat.*) Now these results, if reduced to the same standard that has been adopted in the preceding calculations, will lead to the conclusion that as much heat is given off per minute from the body of an adult man, as would be produced by an iron pipe four inches diameter and three-and-a-half feet long, filled with water at 200°. This estimate however in practice would be found too high; for, on such occasions, there being generally no muscular exertion, less heat is produced, and also the increased temperature of the surrounding medium would prevent its free radiation. For, as all bodies only give off heat in proportion to their excess of temperature, the human body being constantly at the temperature of 98°, nearly twice as much heat would be given off (if the body were freely exposed) when the surrounding medium is at 50°, as would be the case if the latter were raised to 70°. It is found also, that on an average, women only consume about half as much oxygen as men, The quantity of pipe estimated in this way will only suit for such places as are built quite on the usual plan; but for others,—and indeed in all cases where it can be done,—the method given in the former part of this chapter should be employed. (Art. 113—115).

(120.) It should here be mentioned, that the calculations for the quantity of pipe required for horticultural buildings have been made with a view to the most economical mode of effecting the desired object. Some of the most successful horticulturists, however, have adopted the plan of using a much stronger heat in their forcing-houses, and allowing, at the same time, a much greater degree of ventilation than usual. This plan is stated to produce a finer fruitage; but it will only be obtained at an increased cost in the apparatus, and by a larger expenditure of fuel. Where economy is not required, it may perhaps be desirable to adopt this plan; and then the quantity of pipe which is used, must be proportionally increased above the estimates which are given in this chapter.

(121.) The quantity of coal necessary to supply any determinate length of pipe is easily ascertained, from the data given in Art. 229. After the water in the pipes is heated to its maximum, the quantity of coal consumed is, obviously, just what is required to supply the heat given off from the pipes. Now, by Art. 107, we find that when pipes four inches diameter are 146·8° hotter than the air of the room, the water contained in them loses exactly 1° per minute of its heat. By Art. 104, we find that 1 lb. of

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(*Combe's Principles of Physiology*, 4th edition, p. 222), and therefore they can only produce half as much heat; the consumption of oxygen always being proportional to the heat generated. From these facts it will appear that not only should buildings, such as those we are now considering, not be too highly heated, but that the pipes should be moderately small in diameter, in order to allow of the temperature being more easily lowered when the building is filled with people.

coal will raise the temperature of 39 lbs. of water 180°; therefore, as 100 feet in length of four-inch pipe contains 544 lbs. of water, it will require 13·9 lbs. of coal to raise the temperature of this quantity of water 180°. If, therefore, the water loses 1° of heat per minute, or 60° per hour, this quantity of coal will supply 100 feet in length of pipe, for three hours, if its temperature continue constant with regard to the air of the room. On this principle the following Table has been constructed. The temperature of the pipe is assumed to be 200°: then, knowing the temperature of the room, if we take the *difference* between the temperature of the pipe and that of the room,—by looking in the Table for the corresponding temperature, we shall find under it the number of pounds weight of coal which will be required per hour, for every 100 feet in length of pipe, in order to maintain the stated temperature. Thus, suppose the pipe to he four inches diameter, and its temperature 200°, while the room is at 75°; then, under the column headed 125° (which is the difference between these two temperatures), we find 3·9 lbs. as the quantity required per hour for every 100 feet of pipe. The quantities stated in the Table are given in pounds and tenths of a pound.

TABLE V.

Table of the Quantity of Coal used per Hour, to heat 100 Feet in length of Pipe of different Sizes.

Diameter of Pipe, in Inches.	Difference between the Temperature of the Pipe and the Room in Degrees of Fahrenheit.														
	150	145	140	135	130	125	120	115	110	105	100	95	90	85	80
4	4·7	4·5	4·4	4·2	4·1	3·9	3·7	3·6	3·4	3·2	3·1	2·9	2·8	2·6	2·5
3	3·5	3·4	3·3	3·1	3·0	2·9	2·8	2·7	2·5	2·4	2·3	2·2	2·1	2·0	1·8
2	2·3	2·2	2·2	2·1	2·0	1·9	1·8	1·8	1·7	1·6	1·5	1·4	1·4	1·3	1·2
1	1·1	1·1	1·1	1·0	1·0	·9	·9	·9	·8	·8	·7	·7	·7	·6	·6

(122.) It should be here observed, that an apparatus will not always consume the same quantity of coal; in fact, it will seldom require so much as the Table shews, because that is the calculation for the maximum effect. Suppose the quantity of pipe in a room has been accurately calculated, in order to maintain the temperature at 75° when the external air is at 30°; the consumption of coal for pipes of four inches diameter will then be 3·9 lbs. per hour for every 100 feet of pipe. But should the external temperature now rise to 40°, 77 feet of pipe would produce the same effect as 100 feet would in the former case; therefore the pipe must be heated to a lower temperature; and it will be found by calculation, that only 3 lbs. of coal would be used, instead of 3·9 lbs. As much coal, therefore, as would supply 77 feet of pipe at the maximum temperature, would suffice for 100 feet at this reduced temperature. The quantity of fuel which is consumed will, therefore, be continually subject to variation, as it will alter with the temperature of the external atmosphere; and, in general, the average quantity of coal required will be about one-third less than the amount given in the Table.

It is almost unnecessary to observe that, in calculating this Table, it has been assumed that the boiler and furnace are of a good construction; for on no other basis could an estimate be formed. Very great differences, however, exist in this respect; and for such cases no estimate whatever can possibly be made.

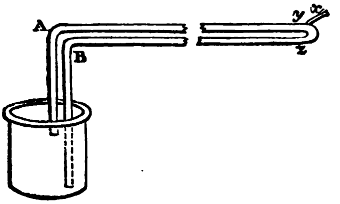
CHAPTER VII.

Various Modifications of the Hot-water Apparatus—Kewley's Syphon Principle—The High-Pressure System —Eckstein and Busby's Rotary Float Circulator—Fowler's Thermo-syphon—Price's improved Hot-water Boxes—Rendle's Tank System—Corbett's Trough System for Evaporation—Theory of Evaporation.

(123.) Under the common and generic term of "hot-water apparatus" various plans have been brought forward by different inventors, which, though essentially different in some of their features from those that have been already described, are, nevertheless, merely modifications of the general principles that have been explained. In the present chapter, some of these peculiar modifications of the invention will be investigated: and it will appear, that the original principles of all are the same, but that other of the fundamental laws of Nature are here brought into action conjointly with those that we have already examined, and give rise to an apparent diversity of operation.

(124.) The first notable invention of this sort which shall be mentioned, is Kewley's syphon principle. The sketch, fig. 27, shews this apparatus in its simplest form. The boiler is open at the top, and the two pipes dip into the water; the pipe A descending only a very short distance below the surface, and the pipe B reaching nearly to the

Fig. 27.



bottom of the boiler. A small flexible metal pipe *x*, is attached to the highest part of the pipes. To this an air pump is connected, and the air in the pipes being exhausted by this means, the atmospheric pressure forces the water up the pipes and fills them completely. This avoids the necessity of having a reservoir of water higher than the top of the boiler; for it is well known, that the usual atmospheric pressure is capable of raising a column of water in a vacuum to about 30 feet in height, varying, however, with the degree of pressure shewn by the barometer.

The water in the longer pipe B will acquire a preponderance of weight over that in the pipe A, even if it be at first of an equal temperature and density; because the pipe B only receives the particles of hot water which rise immediately under its base, while the other receives the heat from all parts of the bottom as well as the sides of the boiler; the water on the top being hotter than that at the bottom. But as soon as the water circulates through the pipes, it parts with its heat, and the whole length of the pipe B will then be colder than the pipe A, and the water will descend through B with greater force.

In consequence of the long pipe B being surrounded by the hot water in the boiler, the water, while descending through it, receives a small portion of heat, which lessens the difference of temperature of the two pipes, and reduces the velocity of the circulation. It appears probable, therefore, that additional velocity of circulation would be gained by placing the descending pipe B outside the boiler, and attaching it to the side in the same manner as the return-pipe in fig. 5. The principal inconvenience attending this would be the difficulty of stopping the ends of the two pipes A and B, which is now done by the simple contrivance of a plate screwed moveably to the base of each of the pipes, by means of an external rod passing over the pipes A and B, with a screw attached on the top; and by turning this the plate is drawn up into close contact with the end of the pipe. This completely stops the water when necessary,—the ends of the pipes being turned true to the plates, to make them water tight,—and by reversing the action of the pump, attached to the pipe *x*, the soundness of the joints can then be ascertained. A leaky joint is difficult of detection by any other means, as there is no emission of water from it in the usual way; and as the only immediate consequence of a leaky joint is the immission of air, it is not observable except by its stopping the circulation of the water, which occurs by the air accumulating and cutting off the connection of the water between the two pipes.

If this plan of having the return-pipe placed outside the boiler were found to increase the motive power of the apparatus, an advantage would be gained in all those cases where the pipes are required to pass under a doorway; because, in all such cases, the boiler for this apparatus must be set much further below the level of the floor than is required for the common hot-water apparatus. But by increasing the motive power, a less height would be sufficient: and it would therefore prevent the inconvenience sometimes found to attend this particular form of the apparatus, arising from the great depth the furnace is required to be sunk beneath the level of the pipes, in consequence of the very large size of the boiler which is generally used.

(125.) A singular fact is connected with this invention, which deserves notice, because it arises from a philosophical principle, which, in some other instances, has been applied in a most useful manner;[1] though, with this invention, it is rather disadvan-

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[1] The boiling of liquids *in vacuo* is well known, and has been most extensively applied in many cases. The boiling of sugar in vacuum pans is one of the most successful applications of science to the arts which modern times have produced.

tageous than otherwise. It is already been stated, that the height to which the water will rise in a vertical column, by the atmospheric pressure, is about 30 feet above the boiler. Supposing this to be the extreme limit to which the water will ascend in the pipes, the slightest elevation above this will cause a vacuum to be formed, similar to that at the top of a barometer, and the water at the top of the pipe will, in this case, be *without any pressure.* But if, instead of 30 feet, the pipe be continued upwards only 15 feet, then the pressure on the water, in the upper part of the pipe, will be 7½ lbs. on the square inch,—or half the usual atmospheric pressure;—and so on for other heights. Now, the boiling point of all liquids varies with the pressure. Water boils at 212°, under the mean pressure of 15 lbs. per square inch; but by reducing the pressure, it boils at a lower temperature; so that, at half the mean pressure of the atmosphere, it boils at about 186°. Suppose now that the pipes just described, rise 30 feet above the boiler, the water at the top will boil at the temperature of 161°, and will form steam in the upper part of the pipe; and this, by its great expansion, will force the water down and overflow the boiler or the supply cistern. For, at the ordinary pressure of the atmosphere, steam occupies about 1700 times as much space as the water from which it is formed, and still more at a diminished pressure; its expansion being inversely as the pressure. When the pipes rise to other heights above the boiler than that described above, the boiling points will be as follows:—

at 5 feet high, the boiling point will be	203°
10	195°
15	186°
20	178°
25	169°
30	161°

therefore the water in the boiler must always be kept below these temperatures, according to the height to which the pipes ascend.[1]

This peculiarity, which applies only to pipes on the syphon principle, is more a philosophical fact than a practical difficulty; for the water can generally be kept at a temperature sufficiently low for any ordinary height that is required. And, in fact, the boiling point will generally be higher than the temperatures here stated; because a small portion of air always remains in the pipes, which increases the pressure on the water, and makes the boiling point higher than the calculated amount.

This form of the apparatus answers the intended purpose extremely well, and has been extensively applied in practice; and it exhibits not only a considerable knowledge of the principles of science, but also great ingenuity in their application.

(126.) The next invention which we shall consider, is, the High Pressure hot-water apparatus.[2] This apparatus consists of a coil of small iron pipe, built into a furnace, the pipe being continued from the upper part of the coil, and passes round the room

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[1] These calculations are made by Wollaston's rule for his thermometric barometer. But this rule, although accurate at moderately small differences of pressure, becomes erroneous at considerable reductions of pressure. Professor Robison estimates the boiling point of water, *in vacuo*, at only 88°, instead of 161°, which the above calculation shews; and it is probable that the relative proportion between the pressure and the boiling point is in a logarithmic ratio, instead of the common arithmetical proportion of Wollaston's rule. This, in fact, is found to be the case at temperatures above 212°. But it is probable that, in the present case, Wollaston's rule will give a more accurate result than the other; because, as the vacuum in the pipes cannot be at all perfect, the boiling points will be much higher than the calculated temperature; perhaps even higher than stated in the text. See *Robison's Mechanical Philosophy*, vol. ii. pp. 22—37; and, Wollaston, on the *Thermometric Barometer*, *Philosophical Transactions*, 1817, p. 183.

[2] *Repertory of Arts*, etc., vol. xiii. (1832), p. 129.

or building which is to be warmed, forming a continuous pipe when again joined to the bottom of the coil. The diameter of this pipe is one inch externally, and half an inch internally. A large pipe, of about two-and-a-half inches diameter, is connected in some part of the circulation, either horizontally or vertically, with the small pipe, and is placed at the highest point of the apparatus. This large pipe, which is called "the expansion pipe," has an opening near to its lower extremity, by which the apparatus is filled with water, the aperture being afterwards secured by a strong screw; but the expansion pipe itself cannot be filled higher than the opening just named. After the water is introduced, the screws are all securely fastened, and the apparatus becomes then hermetically sealed. The expansion pipe, which is thus left empty, is calculated to hold about $\frac{1}{12}$ as much water as the whole of the small pipes; this being necessary in order to allow for the expansion that takes place in the volume of the water when heated, and which, otherwise, would inevitably burst the pipes, however strong they may be. For the expansive force of water is almost irrepressible, in consequence of its possessing but a very small degree of elasticity; and the increase which takes place in its volume, by raising the temperature from 39° (the point of greatest condensation) to 212°, is equal to about $\frac{1}{23}$ part of its bulk, and at higher temperatures the expansion proceeds still more rapidly.[1]

The temperature of these pipes, when thus arranged, can be raised to a very great extent; for being completely closed, and all communication cut off from the atmosphere, the heat is not limited, as usual, to the

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[1] See Table IV. Appendix. The force which would be exerted on the pipes by this expansion of $\frac{1}{23}$ of the volume of the water, would be equal to 14,121 lbs. per square inch, according to the experiments of Professor Œrstead. *Report, British Scientific Association*, vol. ii., p. 353.

point of 212°, because the steam which is formed is prevented from escaping, as it does in the common form of hot-water apparatus. The most important consideration respecting it, however, is the question as to its safety; for most persons are aware that steam, when confined beyond a certain point of tension, becomes extremely dangerous; and in this apparatus the boundary of what has hitherto been used in other cases is very far exceeded.

(127.) On the first introduction of this plan, it was usual to make the coil consist of one-fourth part of the total quantity of pipe which was used in the apparatus; and it was considered that, when this proportion was observed, the heat of the pipes could not be raised so high as to endanger them by bursting. But in practice this has not always proved a preventive to accident, even when the proportion which the coil bears to the radiating surface is much smaller than is here mentioned.[1]

The average temperature of these pipes is stated to be generally about 350° of Fahrenheit. But, a most material difference of temperature occurs in the several parts of the apparatus; the difference, amounting sometimes to as much as 200° or 300°. This arises from the great resistance which the water meets with, in consequence of the extremely small size of the pipes, and also from the great number of bends, or angles, that of necessity occur, in order to accumulate a sufficient quantity of pipe. In these angles, the bore of the pipe, already extremely small, is still farther reduced, which causes the water to flow so very slowly, that a great portion of its heat

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[1] The specification to the patent for this invention states that when the radiating surface is three times that of the coil the pipes cannot burst. It has, however, been found necessary greatly to increase the proportion of radiating surface, in order to prevent the bursting by excessive pressure; and the radiating surface is now frequently made ten times that of the coil in the furnace.

is given out long before it has circulated round the building which is to be warmed. The temperature of the coil, however, is what we must ascertain, if we wish to know the pressure this apparatus has to sustain, and thence to judge of its safety: for by the fundamental law of the equal pressure of fluids, whatever is the greatest amount of pressure on any part of the apparatus must also be the pressure on every other part.

Now the temperature of this apparatus is found to vary not only with the intensity of the heat of the furnace, but also with the proportion which the surface of the coil bears to the surface of the pipe which radiates the heat. In some apparatus, if that part of the pipe which is immediately above the furnace be filed bright, the iron will become of a straw colour, which proves the temperature to be about 450°.[1] In other instances it will become purple, which shews the temperature to be about 530°; while, in some cases, it will become of a full blue colour, which proves that the temperature is then 560°. By this means the pressure on the pipes may be known; for, as there is always steam in some part of the apparatus, the pressure may be calculated so soon as the temperature is ascertained. By referring to Table I. in the Appendix, we shall find that a temperature of 450° produces a pressure of 420 lbs. per square inch, while a temperature of 530° makes the pressure 900 lbs.; and when it reaches 560°, the pressure is then 1150 lbs. per square inch.

(128.) Those who are acquainted with the working of steam engines, are aware that a pressure of three or four atmospheres is considered as the maximum for high-pressure boilers: but we see that in this apparatus the pressure varies from ten times to twenty times that amount. And it will also be borne in mind, that, in consequence of the extremely small

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[1] See Table VI. Appendix.

quantity of water used in these pipes, the slightest increase in the heat of the furnace will cause an immediate increase in the pressure on the whole apparatus. For it appears, by a reference to the Table last mentioned, that if the temperature of the pipes be increased 50° above the amount before stated, the pressure will be raised to 1800lbs. per square inch; and by increasing the temperature 40° more, the pressure will be immediately raised to 2500lbs. per square inch; so that any accidental circumstance, which causes the furnace to burn more briskly than usual, may, at any moment, increase the pressure to an immense amount.[1]

(129.) The pipes which are used for this apparatus are stated to be proved with a pressure of 2800lbs. per square inch.[2] This is very probable: for as wrought iron, of the best quality, requires a longitudinal strain of 55,419lbs. to break a bar one inch square; so the force necessary to break a wrought iron pipe, of one-inch diameter externally, and half-an-inch diameter internally, would be 13,852lbs., which is equal to 8822lbs. per square inch on the internal diameter. But, on account of the strain on these pipes being transverse to the grain of the iron, and also in consequence of the welded joint of the pipe not being so strong as the solid metal, these pipes will not bear anything like the calculated amount of pressure. It is evident, however, that no ordinary force can burst them; but, as this casualty

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[1] This increased pressure is also extremely likely to occur in this apparatus when a portion of the pipe is occasionally shut off by means of cocks or valves. In this case the coil in the furnace becomes too powerful for the apparatus, and an explosion is then very likely to occur, unless the utmost caution be observed in regulating the fire. This source of danger is peculiar to the high-pressure system of heating, and does not at all apply to any of the other plans which have been described.

[2] As pipes are always proved when they are cold, this does not at all shew the strain they will bear when heated. On this subject see the following note.

does sometimes occur, this great strength of the materials proves the impossibility of regulating the temperature in hermetically sealed pipes, so as to keep the expansive force of the steam within even this immense limit.

(130.) Although this description of apparatus has been erected by many different individuals, possessing various degrees of mechanical knowledge, and severally performing their work with different degrees of excellence, much uniformity appears in the result, in those cases where failure has occurred. From a comparison of a number of cases where accidents have happened to apparatus erected on this system, more than one-half have arisen from the bursting of the coil, notwithstanding the increased size of the expansion-pipe renders this apparently the weakest part of the apparatus; the relative strength of pipes, with the same thickness of metal, being inversely as their diameters.

(131.) The cause of the explosions occurring principally in the coil is owing to the iron becoming weaker in proportion as its temperature is raised; so that, as the pressure increases, the iron decreases in strength to resist the strain.[1] Another circumstance also tends to produce the same effects. It is found, on breaking one of these pipes, after it has been used for some time in or near the fire, that the iron has lost its fibrous texture, and that it presents

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[1] The temperature of maximum strength for cast iron has been estimated at about 300°; but the "Committee on the Explosion of Steam Boilers," appointed by the Franklin Institution, consider that the maximum for wrought iron is higher than this, and that 572° may be considered as the temperature of maximum strength. After the temperature of maximum strength is once passed, the decrease in the strength of wrought iron is considerable: at a red heat, or about 800°, it loses about one-fifth of its strength. The maximum strength of copper, on the contrary, is at a very low temperature; for the strength increases with every reduction of temperature down to 32°, which is the lowest that has been tried. See Chapter IX. Art. 224 and 225.

a crystallized appearance, similar to what is known as "cold short iron." This singular change in the texture of iron has been noticed in other instances. Mr. Lowe (*Report, British Scientific Association*, 1834,) has found that wrought iron at a red heat, exposed to the steam of water for a considerable time, becomes crystallized; and in many other instances also, even without the presence of steam, the same effect has been observed. The cause of this phenomenon has not been clearly ascertained; but, whatever it may be, the effect undoubtedly is to weaken the tenacity and cohesive strength of the metal to a very great extent.[1]

But we shall find that, enormous as the pressure appears to be, with which these pipes are proved, it is not adequate to the working pressure which they sometimes have to resist. It has been ascertained, that the strength of wrought iron decreases considerably at temperatures above 572°, and as it also loses a great deal of its strength when it assumes the crystallized state, varying with the circumstances, and sometimes amounting to three-fourths of its original strength, it will appear that the proof pressure, when cold, for pipes which are to be used in this kind of

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[1] The author, in a paper which was read before the Institution of Civil Engineers (Minutes of the Institution, June, 1842), endeavoured to trace the cause of the extraordinary change which iron undergoes in these and some other circumstances. Percussion at certain high temperatures produces an instantaneous change; and at lower temperatures, longer continued percussion produces the same effect. Heating and rapid cooling likewise produce crystallization; and, in every case, magnetism appears to accompany the phenomena; but whether as cause, or effect, is not easy to determine. The subject is altogether of great interest, both in a practical and in a scientific point of view; and experiments on a large scale are in progress, in order to determine the question. Other metals besides iron are probably, to some extent, affected in a similar manner; and it is probable that, under certain circumstances, spontaneous change in the molecular structure of iron occurs, though far more slowly than by the action of percussion and heat.

apparatus ought, in fact, to be much greater than the amount to which they are actually proved; and hence the cause of these pipes bursting after they have been in use for some considerable time, if they happen accidentally to get heated to very high temperatures.

(132.) The question has sometimes been asked, What would be the effect on this apparatus, if the expansion-pipe were to be filled with water, as well as the small circulatory pipe? The almost immediate consequence would be the bursting of the pipes; for scarcely anything can resist the expansive power of water. The force necessary to resist its expansion, is equal to that which is required for its artificial condensation. Now, at the temperature of 386°, water expands rather more than $\frac{1}{12}$ of its bulk; and, to condense water this extent (note, Art. 19), requires a pressure of 27,104 lbs. per square inch: therefore, in an apparatus containing 800 feet of pipe, the bursting pressure, at this temperature, on the circulating and expansion pipe together,[1] would be 417,022,144 lbs.! But, as nothing could resist such a force as this, the apparatus would burst before it reached even a fractional part of this immense amount. For if the pipes were filled completely full of cold water, without allowing any room for expansion, and if they were then hermetically sealed, as before described, by increasing the temperature of the water only about 60°, the expansion of the water would cause a pressure of 2000 lbs. per square inch on every part of the apparatus, reckoned by the internal measurement.

(133.) The assertion has often been made, that the heated fluid contained in an apparatus constructed on this plan will not scald, even if the pipes should chance to burst, because *high-pressure steam*, it is

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[1] The strain being an expansive force from within, the pressure is only exerted on the inside measurement of the pipes.

well known, is not injurious in this respect. But this is quite a mistaken notion; for high-pressure hot-water will scald, though high-pressure steam will not, and the fluid which would issue through any fissure that might occur in these pipes could only be partially converted into steam, unless its temperature were at least 1200°. This is obviously impossible; but were it the case, the water would be all converted into steam the instant that it issued from the pipe. The reason that high-pressure steam does not scald, is in consequence of its capacity for *latent* heat being greatly increased by the high state of rarefaction it instantaneously assumes when suddenly liberated: this lowers its *sensible* temperature, and causes it to abstract heat from every thing that it comes in contact with. The scalding effect of high-pressure hot-water, on the contrary, when suddenly projected from a pipe or boiler by explosion, will always be the same, whatever its temperature may be, while confined within the pipe; for, the instant it is liberated, a portion of it is converted into steam, and the remainder sinks to the temperature of about 212°.

(134.) Among the advantages which have been supposed to arise from the use of this invention, it has been imagined that, in consequence of the quantity of water which the pipes contain being so small, the consumption of coal would be less with this than with any other description of hot-water apparatus. We have seen, however (Art. 121), that the quantity of coal which is used is in proportion to the heat that is given off in the room that is warmed; and a reference to the Table (Art. 121), will shew that the size of the pipe makes no difference in the consumption of coal per hour,—provided the same effect is required to be produced,—the only difference being in the length of time required to warm the water in the first instance. But there will, on the contrary, be a greater expenditure of fuel in this apparatus, in consequence of the coil affording less surface for the fire to impinge against, than would be obtained by using a boiler. In addition to this, the colder any surface may be when exposed to the action of a fire, the more heat will it receive in a given time; therefore, as the heat of these pipes is nearly three times as great as that of a boiler, there must be a considerable waste of fuel from this cause.

(135.) In consequence of the intense heat of these pipes, it is sometimes found that rooms which are heated by them, have the same disagreeable and unwholesome smell which results from the use of hot-air stoves and flues. In reality, the cause is the same in both cases; for it arises partly from the decomposition of the particles of animal and vegetable matter that continually float in the air, and partly from a change which atmospheric air undergoes by passing over intensely heated metallic surfaces.[1] From some experiments recorded in the *Philosophical Transactions* of the Royal Society,[2] made with a view of ascertaining the effect produced on the animal economy by breathing air which has passed through heated media, it appears that the air which has been heated by metallic surfaces of a high temperature must needs be exceedingly unwholesome. A curious circumstance is related in reference to these experiments, which is illustrative of this fact:—

" A quantity of air which had been made to pass through red-hot iron and brass tubes, was collected in a glass receiver, and allowed to cool. A large cat was then plunged into this factitious air, and immediately she fell into convulsions, which, in a minute, appeared to leave her without any signs of

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[1] The exact nature of this change which the air undergoes has not been ascertained; but whatever be the chemical alteration which occurs, a physical change undoubtedly takes place, by which its electrical condition is altered.

[2] *Philosophical Transactions,* vol. xxvii. p. 199.

life. She was, however, quickly taken out and placed in the fresh air, when, after some time, she began to move her eyes, and, after giving two or three hideous squalls, appeared slowly to recover. But on any person approaching her, she made the most violent efforts her exhausted strength would allow, to fly at them, insomuch that in a short time no one could approach her. In about half an hour she recovered, and then became as tame as before."

The high temperature of these pipes, and the intensity at which the heat is radiated from them, have sometimes been urged as an objection against this invention, when applied to horticultural purposes; because any plants which are placed within a certain distance of them are destroyed. Although, no doubt, this effect really takes place, it can be easily avoided with proper care; for, as radiated heat decreases in intensity *as the square of the distance*, it only requires that the plants should be placed farther off from these pipes than from those which are of a lower temperature. In comparing the effect of two different pipes, if one be *four* times the heat of the other,—deducting the temperature of the air in both cases,—the plants must be placed *twice* as far off from the one as from the other, in order to receive the same intensity of heat from each. The only inconvenience, therefore, is the loss of room, which, in some cases, may not be of much importance. But a more serious objection by far appears to lie in the inequality of temperature which any building heated by these pipes must have, in consequence of their being so very much hotter in one part than in another. This difference of temperature between various parts of the same apparatus has already been stated to amount, in some cases, to as much as 200° or 300°, varying, of course, with the length of pipe through which the water passes. From what has been stated in Chapter IV. it will also be observed that, owing to the smallness of these pipes, this kind of apparatus cools so rapidly when the fire slackens in intensity, that the heat of a building which is warmed in this manner will be materially affected by the least alteration in the force of the fire, instead of maintaining that permanence of temperature which is so peculiarly the characteristic of the hot-water apparatus with large pipes.

These inconveniences and objections against this apparatus, however, are of but secondary importance in comparison with the question which exists respecting its security. But as there are no means of regulating the temperature in hermetically sealed pipes, so there can be none for limiting the pressure which they sustain; and it is only by methods far too refined for general use, that the real amount of the expansive force can be ascertained. An apparatus which to all appearance, therefore, is perfectly safe at any given time of inspection, may in a few minutes afterwards have the pressure so much increased by adventitious circumstances, as to render it extremely dangerous, particularly if its management be confided to unskilful hands; and each day that it is used must add to its insecurity, in consequence of the pipes which form the coil continually becoming thinner by the action of the fire. The high temperature of these pipes has also frequently caused inflammable materials to take fire, and repeated accidents have occurred in this way.

This invention undoubtedly exhibits great ingenuity; and could it be rendered safe, and its temperature be kept within a moderate limit, it would be an acquisition in many cases, in consequence of its facile mode of adaptation. Its safety would perhaps be best accomplished by placing a valve in the expansion-pipe, which, from its large size, would be less likely to fail of performance than one which was inserted in the smaller pipe. If this valve were so contrived as to press with a weight of 135 lbs. per square inch, the temperature of the pipes would not exceed 350° in any part: the pressure would then be nine atmospheres, which is a limit more than sufficient for any working apparatus, where safety is a matter of importance.

(136.) A modification of this apparatus was proposed, and a patent taken out, in 1832, by Mr. Holmes, for using oil instead of water.[1] As fixed oils boil only at very high temperatures, it was supposed there would be no liability to bursting the apparatus, as the temperature could not be raised sufficiently high to produce any pressure similar to that from steam. The temperature proposed to be employed was about 400°; but the plan entirely failed, in consequence of oil, when exposed to very high temperatures for any considerable length of time, becoming thick and viscid; and, finally, it entirely loses its fluidity, and becomes a gelatinous mass. Of course, under these circumstances, no circulation of the oil could be produced so as to render the apparatus practically useful.

(137.) An apparatus of a totally different character from the preceding follows next to be described. It is an invention which, at first, appears to be singularly at variance with the general principles that have been laid down in this treatise; but, however its mode of action may at first appear to differ from the principles which have been explained, it is certain that, if these principles are derived from the laws of Nature, they must act equally at all times and under all circumstances; for the operation of the physical laws can never be suspended, though they may be occasionally neutralized by a superior antagonist force. In the case of two opposing forces, the resulting action is proportional to their difference of power; but when the antagonist force is removed, each will act according to its own peculiar laws.

This is the case with the invention now to be

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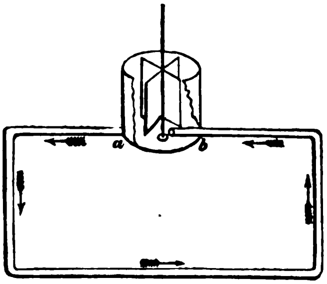
[1] *Repertory of Arts*, etc., vol. xv. (1833), p. 79.

described. By it, hot water is made to *descend* to any required depth below the boiler,—apparently in opposition to the law of gravity,—while the cold water will *ascend*, though of greater specific weight.

(138.) Eckstein and Busby's Patent Circulator, or Rotary Float, is an invention by which *centrifugal force* is made to overcome the *force of gravity*, in the circulation of hot water.[1] The boiler, which is either open or closed at the top, has a pipe, *a*, attached to its circumference, which is carried in any direction, either downwards or around the room to be warmed, and finally returns into the boiler, and ends exactly in its centre, as shewn at *b* in the annexed figure.

FIG. 28.



The float, or circulator, has motion given to it by means of a fly, similar to a smoke-jack, which is placed in the chimney, and is turned by the smoke of the fire that is used to heat the boiler,—the float being fixed on centres, and revolving freely in the boiler. The centrifugal force imparted to the water by the rapid rotation of this float causes it to rise higher at the periphery than in the centre of the boiler; and the velocity with which the float moves determines the extent of this deviation from the level. The end of the pipe *b*, being in the centre, is then under a less pressure or head of water, than the pipe *a*—the former being, by its position, removed from the greater pressure at the sides, which is caused by the centrifugal force imparted to the water by the float, which acts on the pipe *a* placed at the circumference.

Suppose now the velocity of rotation to be such

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[1] *Repertory of Arts*, etc., vol. xiv. (1832), p. 137.

as to impart a centrifugal force sufficient to raise the water *one inch* higher at the circumference than in the centre, there will then be a pressure of 246½ grains per square inch upon the pipe *a*, more than upon the pipe *b*, supposing the temperature of the water to be about 180°. This additional pressure will allow the water in the pipe *a* to descend 42 feet below the boiler, if it does not lose more than 6° of heat before it returns back again to the boiler through the pipe *b*: if it lose 10°, then it will only descend 25½ feet, and so on for other temperatures. Now, as a pipe four inches diameter loses ·817 of a degree of heat per minute, when its temperature is 120° above that of the room (Art. 229); this pipe may be of as great a length as the distance through which the water will flow in seven minutes and a half, in the first case, or twelve minutes in second.

(139.) The length of pipe through which the water will circulate in the abovementioned times, will depend upon the depth to which it descends below the boiler. In this apparatus, the shorter the distance through which the water flows, the greater is the rapidity of circulation,—an effect which is the reverse of what occurs in the common form of hot-water apparatus. In general, the circulation is here very rapid; but the distance through which the water will travel is more limited than with the common plan of circulation. For, suppose the water to be raised, by the centrifugal force, one inch higher at the periphery than at the centre of the boiler, and that it descends 42 feet; if the water in the pipe lose six degrees of heat during its transit, the circulation will then be extremely slow; because, by the Table (Art. 26,) we find that the difference of weight between two columns of water 42 feet high, and six degrees difference of temperature, is 242 grains per square inch on the area of the pipe, which is within four grains of the weight of the one-inch additional height of the water in the boiler. But if the difference between the temperature of the two pipes be only four degrees, then the difference between the weight of the two columns will be 160 grains per square inch of the area of the pipe; and (by Art. 33,) we shall find that this will give a velocity of 81 feet per minute, so that the pipe may in this case be about 400 feet long. But if the water only lose three degrees of heat during its transit through the pipes, then (by Art. 33) its velocity will be 100 feet per minute, provided it descends only 42 feet below the boiler; and, therefore, the pipe may be about 350 feet in length. If the depth of the descent below the boiler be only one half the amount above mentioned,—or 21 feet instead of 42,—then the length of pipe through which the water will circulate, will be just double the amount that has been stated for the several differences of temperature.[1]

These calculations are all made for pipes of four inches diameter; but if smaller pipes be used, the distance through which the water will circulate will be less; because, as the quantity of heat lost in a given time by different sized pipes is *as the inverse of their diameters*, so also will be the distance that the water will flow, if the velocity of its motion be the same.[2]

If greater velocity be given to the fly-wheel and float, the centrifugal force and the height of the water at the circumference of the boiler will both be

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[1] This being exclusive of friction, the actual length of pipe will be less than is here calculated.

[2] It will be observed from what has been stated respecting the common plan of circulation, that the whole of these effects are exactly the reverse of what there occurs. In that, the greater the difference of temperature between the pipes, the more rapid the circulation: in this, the circulation is more rapid in proportion as the pipes are nearer to the same temperature. In the former, the circulation is more rapid when the pipes are moderately small; in the latter, the larger the pipe, the greater the velocity of circulation.

increased; and the distances to which the pipes can be carried, may then likewise be extended.

(140.) By using a close boiler instead of an open one, a range of pipes may be taken upwards which will act on the common plan of circulation, while another range of pipes may proceed from the bottom, and act on the principle which has here been explained. In this case, the centrifugal force, of which the additional height at the circumference of the boiler is merely the index or measure of effect, will still be of equal power, provided the velocity of the float continues the same; and the water will therefore descend to the same extent as before. The spindle of the float must, in this latter case, pass through a stuffing-box on the top of the boiler, or some other contrivance to answer the same purpose must be adopted.

This invention, which is a happy application of dynamical principles to overcome one of the most constant of Nature's laws, by the development of an antagonist force, has hitherto been but little used. It is, however, clearly capable of being efficiently applied in those cases where the same object cannot be accomplished by any of the more simple means which have been previously described.

(141.) A plan proposed by Mr. Edward Weeks for circulating water at different heights was some years since made the subject of a patent, but it is not necessary here to be described, as it has long since been superseded by more efficient means. A boiler also of his invention is described in Art. 98; and the mode of circulating water below the boiler described Art. 46, was also first used by Mr. Weeks.

(142.) Mr. Thomas Fowler, of Great Torrington, in 1828, took out a patent for an apparatus which he called a Thermo-syphon.[1] It was, however, wholly inapplicable to the purposes intended, in consequence

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[1] *Repertory of Arts*, etc., vol. ix. (1830), p. 393.

of the complication of valves and cocks required to work it; the whole of which complication is overcome by the invention of Mr. Kewley, described in Art. 124.

(143.) An apparatus was invented by Mr. H. C. Price, and patented in 1829, which was designed principally to alter the form of the radiating surfaces.[1] These surfaces, instead of being composed of pipes, are formed of flat close vessels about three feet square and 2½ inches deep, placed edgeways (or vertically), so that when several of them are fixed together, a thin stratum of air passes upwards between them, and becomes heated in its passage. A main pipe connects all these vessels together at the bottom, another similar pipe is fixed at the top; and these main pipes lead to and from the boiler, thus keeping up the circulation of water in all these flat vessels at the same time. This is often a very convenient mode of applying a large extent of heating surface in a moderately small space; but the principle of the circulation is in no way different from the ordinary hot-water apparatus. The vessels containing the hot water are usually placed in a vault or chamber below the room or building to be warmed; and the air when heated ascends to the room above through ventilators in the floor, or other similar contrivances.

For large buildings this plan answers exceedingly well, and many extensive apparatus have been erected with perfect success, as it is always combined with a system of ventilation, which is too often neglected in other methods of heating buildings.

(144.) A plan has lately been proposed by Mr. Rendle, of Plymouth, as a novel mode of heating horticultural buildings, and which he has denominated the "Tank System." The principal object proposed, is to afford bottom heat to plants, without the use of

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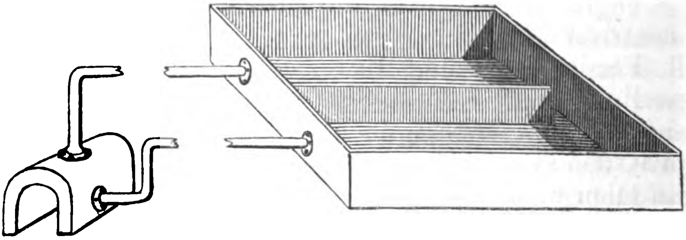
[1] *Repertory of Arts*, etc., vol. x. (1830), p. 65.

bark, tan, dung, or other expensive and troublesome materials. The plan recommended is to construct a tank, either of brick, wood, slate, stone, or metal, immediately below the beds of the hothouse: the tank being the full width of the bed, and about four or five inches deep. A partition divides this tank up the centre, except about two or three inches at the further end; and then, by connecting two pipes to the end of the tank nearest to the boiler, one leading from the flow-pipe of the boiler and the other from the return-pipe, and placing these on the opposide sides of the before-mentioned partition, a circulation of water is produced, the hot water passing up one side of the tank and returning back along the other side, the partition merely separating the two currents. The tank is first covered with large and strong slates, and then a layer of loose stones is laid, and subsequently layers of sand and earth; and the sides of the tank are so constructed as to rise sufficiently high to make a convenient receptacle for these several layers of materials, through which the heat ascends to the plants placed in the earth on the top.

This form of apparatus is represented in fig. 29,

Fig. 29.



which shews the tank without the cover, and also without the sides which support the layers of stones and earth. The tank, if made of brick, requires to be well stuccoed, in order to make it hold the water without percolation through the bricks; but the expansion caused by the heat renders it difficult to keep the tank perfect. Wood tanks are also liable to become leaky; and when used, require to be made in the most substantial manner.

(145.) The plan of affording bottom heat in this manner possesses but small claims to novelty, except as regards the form of the vessel which contains the heated water. In 1788, steam was first used for giving a bottom heat to plants by T. Wakefield, Esq. of Northwich. His experiments were continued for several years with considerable success, and in 1792 the plan was adopted at Lord Derby's gardens, at Knowsley, apparently on the model of Mr. Wakefield's, and was attended with perfect success.[1] From 1801 to 1806 the use of hot water, flowing through leaden pipes placed about nine inches below the surface of the mould, was employed by T. N. Parker, Esq., of Sweeney Hall, Oswestry, for giving bottom heat for melon pits, the water circulating through a single pipe only, which was attached to a small copper boiler. Mr. Weston, of Leicester, in 1800, employed for the same purpose leaden pipes three inches diameter, filled with hot water, which, from the slow conducting power of the metal, retained the heat for a great length of time.[2] In 1826, Mr. MacMurtie, gardener to Lord Anson, described a method of giving bottom heat jointly by flues and steam, which he had successfully employed for a period of twelve years;[3] and in 1831, the author applied the circulation of hot water, on the common plan, through iron pipes of four inches diameter, for producing bottom heat in forcing pits, without the use of dung.

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[1] A long account of these experiments will be found in the *Repertory of Arts*, vol. xiv. (1st Series,) p. 235, et seq.; and also in the *Transactions of the Society of Arts and Manufactures*, etc.

[2] *Repertory of Arts*, vol. xiii. p. 238 (1st Series).

[3] *Horticultural Transactions*, vol. vi.; and *Quarterly Journal of Science*, vol. xxii. p. 341.

All these plans have been successful to a considerable extent; but they all have one defect in common with Mr. Rendle's system. It is difficult to regulate the quantity of moisture; and by some of these plans—particularly those where steam was allowed to evaporate in large quantities—there was too much damp for the plants, and by others they were too dry. Mr. Rendle's tanks are liable to the same objections. And it is probable that the most efficient way of applying hot-water circulation, for producing bottom heat, would be by passing large iron pipes of four inches diameter through troughs made water-tight, placed beneath the bed required to be heated, and filled with small loose stones. These stones when once heated, will retain their temperature for a great length of time, and by pouring water into the trough, vapour can be raised to any extent that may be required, the quantity being much or little as circumstances may render desirable, or the heat may be continued without any vapour, whenever a dry heat is required. The pipes need not be placed very close together; about 12 or 18 inches apart from each other would probably be a good distance when four-inch pipes are used, depending principally upon the quantity of vapour which is required to be raised.

(146.) Mr. Rendle proposes to make his tanks supply sufficient heat to warm the air of the house, as well as to produce a bottom heat for the plants. Those who adopt this plan will soon find that it can only be used as an adjunct to any other method, and that it cannot supersede the ordinary modes of heating horticultural buildings. The chief merit of this plan consists in bringing into action a large reservoir of hot water, contained in slow conducting materials; by which (when the tank is connected with the pipes that heat the air of the house in the usual way) greater equality of temperature can be maintained in a hothouse, than by any other method which comprises only a smaller body of hot water. This, however, does not appear to form any part of Mr. Rendle's system. In a small pamphlet, published by him, the apparatus is described as intended both to heat the air of the house, as well as to give bottom heat to the plants; and when the tank is made of brick, according to his recommendation, the quantity of heat radiated from the exterior surface must necessarily be so small that sufficient heat to warm the air of the house in cold weather, cannot possibly be obtained. Iron tanks, instead of brick, have been proposed by other parties; by which this latter objection would be overcome: but by the greater radiating power of the iron, the advantages contemplated by Mr. Rendle would not be obtained; and there must be many objections to the employment of this kind of iron tank. The brick tank, when used only for bottom heat, and as an addition to the usual arrangement of pipes for warming the air, may frequently form a very useful apparatus; but it will probably give way to some better arrangement, by which the vapour can be regulated with more certainty than this form of apparatus appears capable of doing.

(147.) A patent was obtained in 1838, by Mr. Corbett, of Plymouth, for heating buildings by hot water circulating in open troughs, instead of pipes of the usual form.[1] The objection to this plan is the difficulty of regulating the quantity of vapour given off by the open troughs, to suit the varying requirements of the plants. The inventor proposes to do this by means of moveable covers to be placed on the troughs, which would prevent the vapour rising so rapidly. But all the advantages of this plan appear to have been anticipated several years previous, by the use of pipes with troughs of about three inches deep cast on the top, and extending nearly the whole length of the pipe. The trough,

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[1] *Repertory of Arts*, etc. vol. xi. (1839), p. 346.

being formed by the surface of the pipe itself, is always kept hot; and any quantity of vapour can be obtained, up to the actual saturation of the atmosphere of the house, by filling these troughs partially or wholly, as the case may require.

(148.) The last two inventions which have been described, appear to be founded on a very imperfect knowledge of the physical laws which they call into action. The tank system, when used as the inventor of it recommends, must necessarily fail to afford sufficient heat to the air, as a very slight acquaintance with the laws of radiant heat will shew; and the use of open troughs, to supersede the previous method of pipes with troughs cast on them, is founded on a misconception of the laws of vaporization.

(149.) Mr. Corbett states, in the specification to his patent, that the quantity of vapour which is given off from the troughs depends upon the temperature of the air and the depth of the troughs. This last circumstance (inasmuch as by increasing the depth, the radiating surface must be enlarged, and the temperature of the water thereby lowered,) will certainly somewhat alter the rate of evaporation, though not necessarily its final quantity; but the temperature of the air in no way influences either the quantity or the rate of evaporation, unless it be so cold as to condense the vapour.

(150.) Dr. Dalton[1] has shewn that the only circumstances which affect the vaporization of water in atmospheric air, are—"First, the quantity evaporated is in direct proportion to the surface exposed, all other circumstances being alike. Second, an increase in the temperature of the liquid is attended with an increase of evaporation not directly proportionate. Third, evaporation is greater where there is a stream of air, than where the air is stagnant. Fourth, the

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[1] *Memoirs of the Philosophical Society of Manchester*, vol. v. p. 576, et seq.

evaporation from water is greater, the less the humidity previously existing in the atmosphere, all other circumstances being alike." The rate of evaporation therefore, from. water under 212° of Fahrenheit, is directly as the surface of water exposed, and as *the evaporating force;* which latter is the name that has been given to the difference in the elasticity of the vapour which rises from the water at the given temperature, and that of the vapour already existing in the air. And Dr. Dalton found that "the same quantity is evaporated with *the same evaporating force*, whatever be the temperature of the air."

(151.) This theory of evaporation is here more particularly dwelt upon, because many persons have adopted the notion that any quantity of vapour, without limitation, can be produced by means of open troughs, such as have been described. Nothing, however, can be more erroneous. When once the air is saturated, the *evaporating force* ceases;[1] until either a portion of the vapour it contained be condensed, or the temperature of the evaporating fluid be increased, when of course a new state of circumstances obtains, and the condition of equilibrium ends. Practically, however, evaporation never ceases when the evaporating liquid is kept at a high temperature; because the air being at a much lower temperature, the vapour contained in it must always have less elasticity than that given off from the water: the result will be that the water evaporated will be condensed by the air, and will be precipitated; while, at the same time, the latent heat of the vapour will be rendered sensible, and will raise the temperature of the air.[2] If the air were confined in a place where

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[1] These remarks apply to the case of fluids under the temperature of 212°. A different state of things obtains when the vapour formed exceeds the total atmospheric pressure.

[2] The quantity of heat given out by the condensation of vapour is very considerable. By the note to Art. 106, it will be seen

it could not again lose any portion of this acquired heat, this process would ultimately stop the evaporation; but in horticultural buildings, the loss of heat from the large surface of glass is so considerable, that this result cannot follow.

(152.) As the quantity of vapour given off to the air depends, as we have here shewn, on the surface and the temperature of the water exposed, it follows that no possible advantage can be obtained from a large quantity of water in an open gutter, over the same surface of water obtained by the old method of troughs fixed or cast on the top of the pipes; while the latter are more easily regulated to suit the requirements of different plants and different seasons, and are also free from several practical difficulties, which attend the application of the other method.[1]

(153.) The preceding remarks are descriptive of the principal modifications which have hitherto been introduced into the hot-water apparatus, though many deviations of a minor character have been proposed, several of them indeed being introduced apparently for the sake of novelty. The advantage, however, which may be derived from these peculiar forms or modifications of the apparatus must depend upon the purpose for which it is required. Thus, in places where a long continuance of heat and uniformity of temperature are required, the form of the pipes, tanks, vessels, and other radiating surfaces, should be such

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that a cubic foot of water will heat 2990 cubic feet of air as many degrees as the water itself loses. As the latent heat of vapour is about 1000°, it follows that every *cubic inch* of water which is evaporated, and then again condensed from vapour as abovementioned, will communicate 5° of heat to 346 *cubic feet* of air.

[1] Those who wish to follow further the subject of spontaneous evaporation may, with advantage, consult the *Memoirs of the Manchester Philosophical Society*, already quoted; also *Nicholson's Journal*, vol. xxvii. p. 17; *Journal de Physique*, vol. lxv. p. 446; *Quarterly Journal of Science*, vol. xvii. p. 46; and *Philosophical Transactions*, vol. lxxxii. p. 400.

as to afford only a small surface, while they contain a large quantity of water. This may be obtained by using pipes of large diameter, or tanks of a large cubical content, and approaching in form either to the sphere or the cube; while, on the contrary, where the heat is required to be quickly raised, and permanence of temperature is unimportant, the radiating surfaces may be greatly increased, in proportion to the actual quantity of water contained in the apparatus. In this case, therefore, pipes of small diameter, or tanks which are very flat in form, may advantageously be used; and many varieties of the apparatus will necessarily be adopted amongst ingenious persons who practically apply this invention to the vast number of useful purposes to which it is applicable. Many of the purposes to which it is extremely suitable have not hitherto had it applied; and its advantage in other cases, has not even yet been sufficiently appreciated. Such are the uses to which it may be adapted in various manufactories—in paper-making, calico-printing, dyeing, and starch-making; and also for druggists, seedsmen, and numerous other purposes of general utility; and for drying-rooms for every purpose where a mild and equable heat is desirable. For many of these purposes it is exceedingly convenient, as the form of the heating surface can be made to suit the peculiar object to which it is to be applied; and the inconveniences that arise from unequal degrees of heat, consequent on most other methods of warming, are, by this means, entirely avoided.

CHAPTER VIII.

General Summary of the Subject—Points requiring particular attention—Abstraction of Air from the Pipes—Vertical Alteration of Level—Effect of Elbows in compensating unequal Expansions of the Pipe—Different Floors heated by one main Pipe from the Boiler—Reduced Effect from Pipes laid in Trenches—Cements for Joints—Sediment in Boilers—Use of Salt in Pipes to prevent freezing—Deposition of Vapour in inhabited Rooms, and necessity for Ventilation—Construction of Drying-Rooms.

(154.) Having, in the preceding chapters, arranged, under distinct heads, the various remarks on the principles of warming by the circulation of hot water, it may here be desirable to bring under general review the principal facts which it has been the object of this work to explain. There are, besides, many minor points connected with the invention, that could not conveniently be brought under notice in any of the foregoing divisions, under which the subject has been treated, but which, nevertheless, may be found very useful to those who are investigating its principles, or adapting it to practice.

(155.) A correct knowledge of the cause of circulation of the water, it has already been observed, is absolutely necessary to the successful application of this invention in many of its more complicated arrangements. Some estimate must be formed of the amount of the motive power possessed by an apparatus of this sort, otherwise it will be impossible to ascertain what will be the result of any particular position, or determinate length of the pipes, in many peculiar cases; as, for instance, in such forms of apparatus as figures 10, 11, and 28. It is also necessary, in order to make provision for the escape of the air from an apparatus of this kind, to have some knowledge of the laws which regulate the motion of fluids, in order to ascertain where the air will lodge, and why it should accumulate in one place rather than another. No circumstance connected with the subject requires greater caution than this. In every part of the apparatus where an alteration of the level occurs, a vent for the air must be provided; because, from the extreme levity of air compared with water (Art. 13), it is impossible that the air can ever descend, so as to pass an obstruction lower than the place where it is confined. Thus, in fig. 7, if the air accumulate in the pipe between A and *e*, it is evident that a vent at C, although it would take off the air from *g h* and from C D, could not receive any portion of that which is confined between A *e*, or between *e f*, because, in that case, it must *descend* through the pipe *e f*, before it could escape. The principle is the same in all cases, however large, or however small, the descent may be: and the accidental misplacing of a pipe in the fixing, by which one end may be made a little higher than the other, will as effectually prevent the escape of air through a vent placed at the lower end, as though the deviation from the level were as many *feet*, as it may, perhaps, be *inches*. It is, however, impossible to give multiplied examples of this part of the subject, for probably no two instances precisely similar may occur; but it deserves the most serious attention in following out its practical consequences, for many failures have arisen from its neglect.

(156.) When any particular obstructions are required to be overcome, in consequence of numerous alterations in the level of the pipes; when the pipes are required to descend below the boiler; or, in short, when any other variation from what may be considered as the usual form and arrangement of the apparatus, may be desirable, it is essentially necessary to have some data on which to found a calculation as to what will be the practical result of the required deviation; for no partial experiment of a tentative character, nor even the effect shewn by a miniature model, will give anything like an accurate idea of what will be the result, when the experiment is made on a large scale. The reason of this is obvious. It has been shewn that the greater the distance through which the water flows, the greater does the motive power become, in consequence of the water being colder in the return-pipe relatively to the flow-pipe, while at the same time the friction is increased, though not always in an equal degree. This will, therefore, prevent partial experiments—that is, working models exhibiting only a particular portion of the whole apparatus—from being conclusive; and with a miniature model, although the decreased time and distance of transit are compensated by the reduced size of the pipe exerting a greater cooling power on the water, the friction being much greater in small than in large pipes, the velocity will be reduced in a very sensible degree, and the results rendered wholly inconclusive. In general, the successful working of a miniature model will be conclusive that the experiment on a larger scale will perform still better; but the failure of the model will be no proof that the larger apparatus will not be successful.

Calculations on this subject possessing any claims to accuracy are extremely difficult; and exact results, indeed, are perhaps impossible in the present state of our knowledge on this difficult branch of hydraulics, notwithstanding the many eminent and learned men who have both written and experimented on the motion and resistance of water moving in pipes.[1] Notwithstanding this acknowledged difficulty, the remarks made in the preceding chapters will enable an approximate estimate to be formed as to the general effect, which may be expected from any particular arrangement of the apparatus, and whether the motive power will be increased or diminished by the arrangement proposed. And, by following out in detail the rules which have been given, a tolerably accurate judgment may be formed as to the result that may be expected, under almost every form of the apparatus that may be adopted.

(157.) In the diagrams which have been given in the first and second chapters, the simplest possible arrangement of the pipes has been shewn. To give the various forms in which the pipes and heating surfaces may be laid would obviously be impossible; it must be left to the ingenuity of the adapters of the apparatus to deduce, from the general rules which have been given, the form of apparatus best suited to the particular case; and, while bearing in mind the causes which produce and increase the circulation, it will not be difficult to contrive an almost infinite variety of arrangements for accomplishing the desired result.

(158.) In the simple form of the apparatus, as generally used in hothouses, there is seldom much difficulty, except when the pipes are required to dip below the doorways. When the boiler is placed sufficiently low (Art. 42), the difficulty of taking off the air from the pipes is principally to be attended to. It has sometimes been the practice to place an *open* upright pedestal on the top of the pipe at *l*, fig. 9, for the supposed purpose of adding by the weight of its column of water to the downward pressure at that part, and by this means to increase the

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[1] See Chapter II., Art. 34.

circulation. But the real effect of such a column of water pressing on the pipe must be to increase the pressure on every part of the apparatus alike, and not on this part in particular; and therefore it is probable that any real effect obtained by this means is attributable to a more easy escape being provided for the air. For any air accumulating at this part must be particularly prejudicial, by occupying a portion of the space which ought to be filled with water, and by thus much diminishing the pressure on the descending column. A very small accumulation of air at this part of the apparatus might seriously retard, or even totally obstruct, the circulation, and therefore a ready escape for the air at this point is particularly desirable. The same effect is no doubt, to some extent, produced by the open cistern A, fig. 12 (Art. 46); for, although its effect may sometimes be beneficial, it is difficult to account for it on the ground of increased pressure; while it is obviously quite possible that benefit may arise from the air having so easy an escape.[1]

(159.) It will be apparent from these remarks, how essential it is to free the pipes from any accumulation of air, when such difficult cases of circulation are attempted as those described in Art. 44—48, or any of an analogous character. It is probable that many failures have arisen entirely from this cause, which a very slight alteration would have prevented;

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[1] It has been supposed that, although this increased pressure by a vertical column of water undoubtedly extends to every part of the apparatus, an advantage must arise in consequence of the bubbles of steam and hot water (which rise continually upwards from the bottom of the boiler, strongly acted on by the fire,) being relatively lighter than the rest of the water, when the latter is thus condensed by the increased vertical height. This, however, must needs be erroneous; because steam produced under pressure is of greater density exactly in proportion to this pressure, and therefore the relative proportions between the densities of the steam bubbles and the water must be preserved, however much the pressure may be increased.

and attention to this point in the construction of all hot-water apparatus can hardly be urged too strongly.

(160.) When the pipes dip below the doorways of hothouses, it is sometimes very difficult to allow sufficient depth for two pipes of large diameter below the step of the door, when placed as shewn in fig. 9. When this is the case, a smaller pipe may be used at this particular part; and, just at the dip, the large iron pipe may be suddenly reduced to one of small diameter, and again increased when it rises from below the door. The circulation will by this means always be reduced to some extent (Art. 60), and it is by no means advisable to adopt it whenever it can be avoided; but this plan will succeed tolerably well when an iron or common leaden pipe of one-inch bore is used for passing under the doorway, and attached at each side of the doorway to an iron pipe of three or four inches diameter. All unnecessary variations in the size of the pipe ought however to be avoided; and when adopted they are better to be gradual than sudden, as there will be less obstruction to the water passing through a trumpet-shaped pipe, either from a large to a small pipe, or from a small pipe to a larger, than when these changes are made abruptly.

Inconvenient as these vertical dips in the pipe frequently are, they, as well as the horizontal bends, are sometimes useful in counteracting an inconvenience which otherwise might occur from the expansion of the pipe in its horizontal length. When there is a very long length of perfectly straight pipe passing along the side of a building, and returning again in the same direction, it often happens that the expansion of one of these lengths of pipe is so much greater than the other, owing to its higher temperature (and this particularly happens when the circulation is slow), that some of the joints become loose, and a leakage occurs. This inconvenience is more likely to occur when three or four pipes are placed one above the other; in which case the upper pipes always become heated first, and thence become more expanded in length: and so great is the force of this expansion, that unless there is some degree of elasticity given to the pipes, either by elbows intervening, or by some other means, a leakage is almost certain to occur; and generally it happens at the extreme end of the pipes farthest from the boiler. When steam-pipes were used for heating buildings, this cause of leakage was very inconvenient; and Count Rumford introduced an ingenious mode of counteracting it, by attaching both the upper and lower pipe to a copper drum, which, being more pliable than the cast-iron, corrected the evil. In all cases where there is a great length of pipe running in a straight line, it is necessary to bear in mind the certainty of expansion occurring, and to provide for its effects: for serious accidents have occurred to buildings by neglecting this precaution, as the expansion cannot be prevented under any circumstances, and its power is immense against anything that resists it.

(161.) In all cases where pipes are placed at various elevations above the boiler, for the purpose of warming different floors of a building, or where from any other cause the pipes descend by steps or gradations from a high elevation to a lower, before the water returns to the boiler, it is necessary that the water should be made to ascend at once from the boiler to the highest elevation. By this means the best possible circulation is always insured, as there will then be the greatest difference between the weight of the ascending and descending columns. It will, however, often be found convenient, when different floors of a building are required to be heated by one apparatus, to have a separate pipe leading from the boiler to each floor; as it but seldom happens that horizontal branch pipes are effective when leading out at different elevations from a general main pipe rising vertically from the boiler. This arises from the extremely rapid motion of the water in vertical pipes; by which means the whole of the heated water passes directly to the highest level, without delivering any to the lower horizontal branches. This plan of having separate pipes for each floor is better than having one pipe gradually descending through them all, as the shorter the circulation is, the more equal will be the effect, in consequence of greater equality in the temperature of the pipes (Art. 61).

(162.) In the fourth and fifth chapters the construction of boilers and furnaces has been so fully treated on, that it is not necessary here to offer any additional remarks. As regards the shape of the radiating surfaces that are employed to heat the buildings, it may be observed that a judicious selection in this respect is a matter of considerable consequence, and the remarks already made (Art. 73—77) will explain the principal points which must be considered in determining the form and dimensions of these surfaces. The rules for calculating the extent of these surfaces, required for any description of buildings, have been given in the sixth chapter; and the proper proportions of any apparatus may be calculated by these rules and those given in the fourth and fifth chapters.

It may be observed, however, that in those cases where the radiating surfaces are not placed actually in the room or building which is to be heated, but which produce their effect by heating successive portions of air, which then pass into the room that is required to be warmed, there will always be some loss of heat, which will therefore need some correction to be made in the calculations already given. This applies also to those cases where the pipes are placed in drains or trenches below the floor, with trellis gratings or ventilators in the floor to cover the pipes and to emit the heat. The proportion of heat lost by this means will depend upon various circumstances. When the pipes freely radiate their heat into the room to be warmed, about one-fifth of the total effect is produced by radiation, and the rest by contact of the air with the heated surface (Art. 186, et seq.): but that portion of the heat obtained by radiation will be considerably reduced by placing the pipes in a trench. For the interior surface of the trench will become considerably heated; and as the heat given off by radiation depends in a great degree upon the difference of temperature between the heated body and the medium by which it is surrounded, it follows that the hotter the trench becomes the less radiant heat will be given off by the pipes. The loss of effect by this means would be considerable were it not for the circumstance of the heated surface of the trench itself giving out heat by conduction to the air; the effect therefore becomes a very complicated one, but it may probably be assumed as a tolerably correct result, that the loss of heat by placing the pipes in a trench which is well covered for nearly its whole length with trellis gratings, will vary from five per cent. to ten per cent. according to circumstances. When the trench is only partially covered with trellis gratings, the loss of heat will be more; and therefore when this plan of placing the pipes is adopted, at least two-thirds of the entire trench ought to be covered with the trellis grating, and the freest possible escape must be allowed for the heated air. The trench also should not be made too large; and the best size will be, to have it large enough to hold the pipes, and to allow the workmen easily to fix them; and all the space beyond that will only tend to diminish the effect of the apparatus.[1]

[1] It is often very desirable to make the bottom and sides of these

The same remarks will of course apply to all cases where the pipes or other radiating surfaces are placed in vaults or chambers below the rooms intended to be heated; and, in all cases of this kind, some allowance must be made for the loss of effect arising from the causes here described.

(163.) In the seventh chapter, some of the principal modifications of the hot-water apparatus have been described, and their peculiarities pointed out, in order to ascertain how far they accomplish the objects proposed. Many of these inventions are highly ingenious, and well deserve attention, for the purpose of ascertaining under what particular circumstances their peculiarities can be most advantageously applied for accomplishing the intended object.

(164.) The mechanical operation of fitting together the pipes is a subject known to most good workmen who are acquainted with iron-work. The usual and best kind of pipes for the purpose are those with socket joints; those with flange joints having long ceased to be employed for hot-water apparatus. And even for steam, where flange joints were formerly invariably used, the socket joints are now very frequently employed, as they make a much neater and at the same time an equally strong joint. In fact, when the joints of socket pipes are well made, the pipes themselves will break before the joints will yield, or before the faucet end of one pipe can be drawn out of the socket of the other. The joints require to be well caulked with spun yarn, and then filled up with the cement which is well known to engineers under the name of iron cement. This forms the strongest joint that can be made; but other cements are frequently used, the principal of which

trenches full of holes, for the purpose of admitting fresh air into the building. Some remarks on this subject will be found under the head of "Ventilation," in a subsequent chapter (Art. 312).

are a mixture of white and red lead, which makes a very good cement; and a cement made of quick lime mixed into a paste with boiled linseed oil[1] has occasionally been employed with considerable success.

(165.) It may be desirable to make a few observations on the water that is to be used in this kind of apparatus. Sometimes the foulest and most filthy water is used in a hot-water apparatus, by which a thick coating of mud is deposited, and which must, necessarily, not only much reduce the effect of the apparatus, but also injure the boiler. But a far more general, and, in fact, an extremely common error lies in using hard water, which contains a large quantity of earthy salts. Rain water ought always to be used when it can possibly be obtained, because all hard waters are impregnated with saline matter, which forms the sediment or incrustation so common in those vessels in which water is boiled. This incrustation always accumulates in the boiler of a hot-water apparatus in which hard water is used, and forms a coating, varying in substance from the thinnest lamina to two or three inches in thickness. When this deposit of saline matter occurs in a boiler, not only is less heat received by the water, in consequence of the conducting power being lessened by the interposed substance, but the boiler will be much injured by the increased heat of its external surface, and more fuel will be consumed.

The quantity of sediment formed in a hot-water apparatus, however, bears no comparison in ordinary cases with that of steam-boilers. In the latter, the quantity is so large as sometimes to require its removal at least once in every three or four days,

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[1] This composition is very liable to spontaneous combustion, and should therefore be used with caution, particularly by mixing it apart from anything likely to ignite by the heating of the materials.

and sometimes even oftener. But, as there is scarcely any evaporation from a hot-water boiler under ordinary circumstances, the quantity of sediment is so small, if the water is good, that the boiler does not require cleaning out even after many years use. This remark, however, will not apply to such forms of apparatus as Mr. Rendle's or Mr. Corbett's (Art. 144 and 147); for, in these, the evaporation of the water is so great that the sediment in the boiler must necessarily be very considerable; and, without proper care, it may become a most serious evil. Owing to the extreme smallness of the boilers used for hot-water apparatus, it is very difficult to clean them from sediment, and with the majority of them it is impossible. When, therefore, such boilers are applied to an apparatus on the tank system, or to Mr. Corbett's open troughs, they will probably fail in a comparatively short time, unless the use of rain water be strictly adhered to. The plan of open troughs cast on the pipes (Art. 147), is not of course liable to the same objection; for, however large the evaporation may be, the boiler cannot be affected by it, as the sediment will necessarily remain in the troughs, and can easily be removed.

(166.) This kind of sediment can only be removed from a boiler with great difficulty. It consists, principally, of carbonate of lime and sulphate of lime, together with the sulphates of soda and magnesia, and several other salts, varying considerably in different localities. A weak solution of muriatic acid (one part of acid by measure to 20 or 30 parts of water) will generally reduce this concreted sediment into a substance of less tenacity, which may then be removed with slight mechanical force. By using rain water the inconvenience arising from these deposits will, however, be entirely avoided, and the apparatus will both last longer and be more efficient.

(167.) Some inconvenience has occasionally been experienced when a hot-water apparatus has been left for a long time without being used, and exposed to considerable degrees of cold, by the water becoming frozen in the pipes; for it is not only difficult in such cases to thaw the water, but sometimes also the pipes crack. To prevent the pipes from cracking it will generally be sufficient to draw off a portion of the water, so that the horizontal pipes shall not be quite full; for the cracking of the pipes arises from the sudden expansion which takes place in the water, at the moment of its passing into the solid state of ice. But when the apparatus is not likely to be used for a considerable time, it would be much better, if the weather be very cold, to empty the pipes entirely of water; for it is always troublesome to thaw the water when once frozen in the pipes.[1] But in an apparatus used in a building of which the temperature is always above 32°, this is obviously unnecessary, as the water cannot then be frozen. A plan, however, may be adopted which will effectually prevent the water freezing with any ordinary degree of cold, namely, by using salt water in the apparatus, instead of fresh water. This plan would certainly be somewhat injurious to the apparatus, on account of the action of the salt on the iron; but the injury would not be extensive, and would be very slow in its operation. Perhaps in this country such a plan is unnecessary; but should this kind of apparatus be adopted in colder climates, the suggestion might be useful. The larger the quantity of salt which a given portion of water contains, the greater is the degree of cold necessary to congeal it. Thus, the quantity of salt contained

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[1] It is a fact not generally known, that water which has been boiled freezes sooner than that which has not been boiled. This circumstance was observed by Dr. Black, in 1775 (*Philosophical Transactions*, vol. lxv. p. 124). But it has since been remarked, that Aristotle, Pliny, and others of the ancients, have noticed the same fact in their writings (*Memoirs of the Manchester Philosophical Society*, vol. i. p. 261).

in sea water is about three per cent.;[1] this requires, according to Dr. Marcet, a temperature of about 28° to freeze it: but if the quantity of salt be increased to 4·3 per cent., the water will not freeze until the cold be reduced to 27½° of Fahrenheit, or 4½° below the ordinary freezing point of fresh water. When the water contains 6·6 per cent. of salt, it will not freeze until the temperature be reduced to 25½° of Fahrenheit; and if it contains 11·1 per cent., the temperature must reach as low as 21½° before the water will congeal.[2]

The effect which would be produced on cast-iron pipes and boilers, by any of these quantities of salt, would not be of much importance; although, in process of time, it would certainly, in some degree, corrode the apparatus.[3] When the apparatus has been once filled with salt water, the waste which occurs in the water, by evaporation, should only be supplied with fresh water; for as the salt does not evaporate, the same quantity of salt will remain in the apparatus, and will combine with the fresh water when added.

(168.) As water at a medium temperature can hold in solution nearly 36 per cent. of common salt (chloride of sodium), and nearly 40 per cent. at the

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[1] This quantity varies considerably in different localities. In the English Channel the quantity is as above stated; but on the coast of Spain it contains about six per cent., while the water of the Baltic only contains about 1½ per cent. Between the Tropics the quantity is very large;—as much as 10 per cent. is stated to exist in some of the tropical seas and oceans (*Ure's Chemical Dictionary*, art. *Muriatic Acid*).

[2] *Ure's Chemical Dictionary*, art. *Caloric;* and *Blagden's Experiments, Philosophical Transactions*, vol. lxxviii. p. 279.

[3] A remarkable difference obtains in the rate at which oxydation acts on cast and on wrought iron. Hard cast iron will resist oxydation about three times as long as wrought iron; and, according to the experiments of Mr. Daniell, the same difference exists in the length of time requisite to produce a given effect by acids. The effect on soft cast iron will approach nearer to that of wrought iron, varying with its hardness.

boiling temperature, there is no fear of any deposit forming in the boiler from this cause.[1] The reason of a deposit forming in boilers where hard water is used, is, because the water leaves behind, on evaporation, the saline compounds which it held in solution; and as the water which is added to supply the place of that which has evaporated likewise contains the same extraneous matter, the quantity presently becomes larger than the water can hold in solution, and the residue is precipitated and hardened by the heat of the fire. All the salts of lime, which are usually contained in hard water, are likewise soluble in this fluid only in a very limited degree. For instance, sulphate of lime, one of the most common ingredients in hard water, is soluble in it only to the extent of one-fifth of one per cent., and carbonate of lime in a still smaller proportion; therefore the precipitation begins to take place so soon as the quantity exceeds this small amount.

(169.) In the 9th and 10th chapters, some of the most important of the laws of heat, which are applicable to the general subject of this treatise, are described; and also the experimental data on which are founded several of the calculations given in the preceding chapters. Those who are desirous of investigating for themselves the accuracy of the various rules which have been given, will thus be enabled to judge of the subject in its more scientific bearings.

(170.) Before concluding these remarks, however, it may be proper to observe that this method of heating buildings by hot water always requires to be accompanied by an efficient mode of ventilation: for, even though the air may not be injured by the apparatus employed to heat it, the air of all inhabited rooms must necessarily be deteriorated by the respiration of the inmates. This remark would

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[1] *Ure's Chemical Dictionary*, art. *Salt.*

have been superfluous, were it not that cases have occurred where the evils that have arisen from defective ventilation have been erroneously attributed to this plan of warming by hot water; and the vapour which is given off from the lungs of the inmates of a room, and, under these circumstances, is condensed upon the windows, has been supposed to arise from the water in the apparatus being converted into steam, and escaping through the joints of the pipes. If this were a solitary opinion, it might, like many others equally erroneous, be passed over in silence; but as this has been seriously objected against the invention by many who ought to know better, it may be worth while to state the cause more at length.

(171.) The quantity of vapour given off from the lungs, and also by exhalation from the skin, has been estimated at from twelve to thirteen grains per minute. If, in consequence of imperfect ventilation of inhabited rooms, the air cannot escape after it has received this additional quantity of vapour exhaled from the body, it must, as soon as it has acquired a larger quantity of moisture than the temperature of the *external* air will support in the form of vapour (Art. 289), deposit a portion of it upon the glass; because, the glass being nearly of the same temperature as the external air, whatever quantity of the internal air comes in contact with it, its temperature is immediately lowered, and the excess of its vapour is condensed upon the surface of the glass. Thus, suppose the temperature of the air in a room to be 65°, and the dew point 55°, then, if the temperature of the external air be only 35°, as much of the air in the room as comes in contact with the glass will deposit whatever vapour it contains above the quantity that a temperature of 35° will enable it to sustain. Under these circumstances, the amount deposited on the glass will be (Art. 289) about two grains for each cubic foot of air that is cooled by the glass; and the same effect, though in a less degree, will take place on all the other cold surfaces in the room. As each square foot of glass will cool one and a quarter cubic feet of air per minute, from the internal to the external temperature (Art. 109), we shall find that, under the circumstances we have supposed,—which is purposely taken as an extreme case,—the quantity of vapour deposited in this manner will amount to two and a half grains per minute on each square foot of glass.

(172.) We need be at no loss, then, to discover the cause of this accumulation of vapour on the windows and walls of rooms which are badly ventilated; and whenever the quantity of moisture thus condensed appears to be considerable, it may be taken as good evidence that the ventilation of the room is imperfect. That the same amount of condensation does not result from the use of hot-air and cockle stoves, is in consequence of a portion of the vapour being decomposed by the intense heat; but when this method of avoiding the inconvenience is adopted, a worse evil is produced than that which is attempted to be removed, although, perhaps, it is not so obvious to the sight.

(173.) A similar error is very frequently committed in the construction of drying closets and rooms intended for drying various articles in manufactures and the arts. It is frequently supposed that a sufficient degree of heat is alone what is required for this purpose; and the amount of ventilation is considered quite an unimportant matter. It needs scarcely be observed that the reverse of this is the proper course; and that ventilation is, in these cases, of far more importance than the degree of heat maintained in the room.

(174.) The experiments of Dr. Dalton long since demonstrated that evaporation was independent of the air; that the vapour arising from any liquid depends upon its temperature; and that the air retards the velocity of the discharge by its *vis inertiæ*.[1] If the air were wholly removed from the surface of water, the vapour proper to the particular temperature would be discharged instantaneously, instead of rising gradually, as when the water is exposed to the atmosphere. The *quantity* of evaporation is not affected by these causes. If water be placed under the receiver of an air-pump and the air exhausted, the full quantity of vapour which can be formed at that particular temperature will rise instantaneously; but if the air be allowed to fill the receiver, the same quantity of vapour will rise, and it will have slowly to filter its way and disperse itself through the air which fills the receiver. In these cases, we of course suppose that the vapour is not removed; but that, when once formed, it is allowed to remain in the receiver, and that the temperature is kept constantly the same. But when the vapour is allowed to escape, or to condense, the rate of its formation is very different in air and in vacuo; for Mr. Daniell's experiments proved that, in the same time, the quantity of vapour raised from a constant surface of water, in vacuo, and in air of atmospheric density, was as 90 to 1; and that at all intermediate pressures the quantity of vapour was inversely proportional to the elasticity of the incumbent air.[2]

When, however, the air possesses motion, its effect on the quantity of vapour emitted from the surface of water over which it passes will be very different. The effect is, then, to drive off the vapour from the surface of the evaporating body as fast as it is formed; and this Dr. Dalton found to be proportional to the velocity of the air.[3] This latter case is precisely that

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[1] *Memoirs of the Manchester Philosophical Society*, vol. v. p. 575, and *Philosophical Magazine*, vol. xvi. p. 346.

[2] *Quarterly Journal of Science*, vol. xvii. p. 52.

[3] *Memoirs of the Manchester Philosophical Society*, vol. v. p. 576.

with which we are concerned, while considering the effect of ventilation, and more particularly in the ventilation of drying-rooms.

(175.) It is quite a mistaken notion to suppose that a better effect will be produced by preventing too rapid a motion of the air through drying-rooms, for the purpose of allowing the air to imbibe more of the moisture by this means. The infiltration of moisture into the air, or the absorption of moisture, as it is generally called, is extremely slow, as the experiments of Daniell and of Leslie have proved: and therefore it is by the brisk motion of the air driving off the vapour as fast as it is formed, that the principal effect is produced in the ventilation of drying-rooms.[1] The quantity of air which really becomes humid by such means, is extremely small; and Leslie has estimated that, in a case of ordinary evaporation, where the air possessed but small velocity, only the 184th part of the air that passed over the wet surface became saturated.[2]

(176.) It is extremely difficult to estimate the quantity of heating surface that is required for a drying-room; for not only will the temperature vary greatly with the nature of the substances to be dried, but also with the degree of dampness they possess, and also with the amount of ventilation. The same quantity of heating surface that would raise the temperature of a drying-room to 80° or 90° with an imperfect ventilation, might possibly not heat it above 60° or 70° if the ventilation were perfect; and yet in the latter case, probably, the drying effect would be greater than in the former. This, however, is not

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[1] The drier the air the more rapidly will it absorb the moisture exhaled into it; but, under any condition of dryness, the absorption of moisture will be much less rapid by the air than its discharge from the vaporising body, when the pressure and resistance of the air is removed.

[2] *Leslie, on Heat and Moisture,* p. 86.

without certain limitations in its operation. Whenever the ventilation is sufficient to carry off the vapour as fast as it is formed, anything beyond this must be injurious, as it will lower the temperature of the room, without promoting the dispersion of the vapour; and we have already seen that the quantity of vapour raised depends, in the first instance, upon the temperature of the vaporising body. When, however, an atmosphere of vapour exists immediately around the body emitting the vapour, the emission is enormously reduced, and sometimes even wholly stopped; and this will occur, however high the temperature of the vaporising body and of the air may be. In this case, therefore, even a very much lower temperature, accompanied by a brisk motion of the air, would be far more effectual than a high temperature with defective ventilation.

(177.) Calculations have been made on the quantity of heated surface required for drying-rooms, for different purposes;[1] but there are so many contingencies to be taken into the estimate, that it is necessary to make a distinct calculation for each particular case that occurs, and particularly it is necessary to know the quantity of water to be evaporated in a given time. A large amount of heating surface is absolutely indispensable; but attention to the perfect ventilation of the room is even of more importance than its actual temperature, as it has been the object of these remarks to prove, and as the drying effects of high winds, even when accompanied with a very moderate temperature, constantly exhibit.

(178.) The physiological effects resulting from particular modes of warming and ventilating inhabited rooms, form a most interesting subject of inquiry; and are not only interesting as matters of scientific research, but they closely concern every individual member of the community. It is a question which

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[1] *Tredgold, on Heating Buildings by Steam,* p. 241.

affects not merely the personal comfort of individuals, but, according to the opinion of the ablest pathologists, it influences the health, and effects the duration of life. In a subsequent chapter we shall endeavour to trace some of the physiological effects of various methods of artificial heat, and the most important consequences will be found to result from the use of some of these different inventions.

CHAPTER IX.

ON THE LAWS AND PHENOMENA OF HEAT.

Radiation and Conduction — General Law of cooling Bodies in Air and other Gases—Different Law for Conduction and for Radiation—Effect by the Incidence of the Rays—Effects of Surface on Radiation—Effects of Colour—Effects of Roughness—Absorptive Power of Bodies for Heat—Conducting Power of Metals—Conducting Power of Wood—Conducting Power of Liquids—Cooling Influence of Water and Air—Reflective Powers of Bodies—Specific Heat of Bodies—Latent Heat—Spontaneous Evaporation—Heat and Cold by Condensation and Rarefaction of the Air—Motion of Liquids influenced by Heat—Effect of Heat on Strength of Materials.

(179.) However various are the methods by which artificial heat is distributed in the warming of buildings, they are all reducible to certain rules, which constitute the primary laws of heat. These laws are very numerous, and some of them extremely complicated; but they possess a very high degree of philosophic interest. They are far too extensive, however, to allow in this work, even a bare outline of all the various phenomena to be given, which this branch of science exhibits. But in the present chapter, such of the laws of heat as relate to the subject more immediately before us, shall be stated, in order to afford a more ready and convenient reference to those who wish to study the scientific principles of warming buildings by artificial heat.

(180.) There are four distinct properties of heat, which all bodies possess in a greater or less degree, which we shall first consider. These are, *radiation*, *absorption*, *conduction*, and *reflection*. There are also others, which will be subsequently mentioned, such as the specific heat of bodies, their change of state, and other subjects connected with their chemical constitution.

(181.) Heated bodies give off their caloric by two distinct modes,—radiation and conduction. These are governed by different laws: but the rate of cooling by both modes increases considerably in proportion as the heated body is of a greater temperature above the surrounding medium. This variation was long supposed to be exactly proportional to the simple ratio of the excess of heat; that is to say, supposing any quantity of heat given off in a certain time at a specified difference of temperature, at double that difference, twice the quantity of heat would be given off in the same time. This law was originally proposed by Newton, in the *Principia*, and although rejected as erroneous by some philosophers, it was followed by Richmann, Kraft, Dalton, Leslie, and many others, and was usually considered to be nearly accurate, until the masterly and elaborate experiments of MM. Petit and Dulong, proved that, although approximately correct for low temperatures, it becomes extremely inaccurate at the higher degrees of heat.

(182.) The cooling of a heated body, under ordinary circumstances, is evidently by the combined effects of radiation and conduction. The conductive power of the air is principally owing to the extreme mobility of its particles; for otherwise it is one of the worst conductors we are acquainted with, so that, when confined in such a manner as to prevent its freedom of motion, it is a most useful non-conductor.

(183.) The proportions which radiation and conduction bear to each other, have, in general, been very erroneously estimated. Count Rumford considered the united effect, compared with radiation alone, was as five to three; and Franklin supposed it to be as five to two. Dr. Murray also considered a certain relation existed between radiating and conducting powers.

No such general law, however, can be deduced; for the relative proportions vary with the temperature, and with the peculiar substance or surface of the heated body. For, while *the cooling effect of the air by conduction is the same on all substances, and in all states of the surface of those substances*, radiation varies materially, according to the nature of the surface.

(184.) The elaborate experiments of Petit and Dulong have placed on record a vast amount of most valuable information on this subject;[1] and, by their researches, some of the most important of the laws of heat have been deduced. The following abstract will give such of their deductions as are most applicable to the subject under inquiry.

(185.) The influence of the air by its power of conduction varies with its elasticity or barometric pressure. The greater the elastic force, the greater also is its cooling power, according to the following law:—*When the elasticity of the air varies in a geometrical progression, whose ratio is* 2, *its cooling power changes likewise in a geometrical progression, whose ratio is* 1·366.

The same law holds with all gases, as well as with atmospheric air; but the ratio of the progression varies for each gas.

(186.) To shew the relative velocities of cooling, at different temperatures, the following Table, constructed from the experiments of Petit and Dulong, is given. The first column shews the excess of

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[1] *Ann. de Chimie*, vol. vii. p. 113, et seq., and *Annals of Philosophy*, vol. xiii. p. 112, et seq.

temperature[1] of the heated body above the surrounding air;[2] the second column shews the rate of cooling of a thermometer with a plain bulb; and the third column gives the rate of cooling when the bulb was covered with silver leaf. The fourth column shews the amount due to the cooling of the air *alone;* and, by deducting this from the second and third columns respectively, we shall find what is the amount of

TABLE VI.

Excess of Temperature of the Thermometer above that of the Air; Centigrade Scale.	Total Velocity of cooling of the naked Bulb.	Total Velocity of cooling of Bulb covered with Silver Leaf.	Amount of cooling due to Conduction of the Air alone.
260°	24·42	10·96	8·10
240°	21·12	9·82	7·41
220°	17·92	8·59	6·61
200°	15·30	7·57	5·92
180°	13·04	6·57	5·19
160°	10·70	5·59	4·50
140°	8·75	4·61	3·73
120°	6·82	3·80	3·11
100°	5·57	3·06	2·53
80°	4·15	2·32	1·93
60°	2·86	1·60	1·33
40°	1·74	·96	·80
20°	·77	·42	·34
10°	·37	·19	·14

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[1] The temperatures in all these experiments of Petit and Dulong are expressed in degrees of the Centigrade thermometer. As the zero of this thermometer is the freezing point of water, and from that to the boiling point of the same fluid is 100°,—in order to find the number of degrees of *Fahrenheit's* scale, which answers to any given temperature of the *Centigrade*, multiply the number of degrees of *Centigrade* by nine, and divide the product by five; add 32 to the quotient thus obtained, and this sum will be the number of degrees of *Fahrenheit* required. As, however, in the above Table, the temperatures given are only the *excess*, and not the absolute temperatures, the 32° to be added by this rule must be omitted.

[2] In these experiments the temperature of the air was at 0° Centigrade, therefore these temperatures are both the excess and also the absolute temperatures.

radiation, under the two *different states of surface*, noticed at the top of the second and third columns.

(187.) Some very remarkable effects may be perceived by an inspection of the above Table. It appears that the ratio of heat lost by contact of the air alone, is constant at all temperatures; that is, whatever is the ratio between 40° and 80°, for instance, is also the ratio between 80° and 160°, or between 100° and 200°. This law is expressed by the formula—

$$v = n \, . \, t^{1\cdot 233}$$

where t represents the excess of temperature, and n a number which varies with the size of the heated body. In the case represented in the foregoing Table $n = 0\cdot 00857$.

(188.) Another remarkable law is, that *the cooling effect of the air is the same for the like excess of heat on all bodies, without regard to the particular state or nature of their surface.* This was ascertained by Petit and Dulong, in a series of experiments not necessary here to detail, but which abundantly prove the accuracy of the deduction.[1]

(189.) By comparing the second and third columns in the preceding Table, it will be immediately perceived that the loss of heat by *radiation* (deducting the cooling by conduction of the air, given in the fourth column) varies greatly with the nature of the radiating surface; though, whatever be the nature of the surface, *the loss of heat follows the same law in all cases, though in a different ratio.*

It should be observed that, in this Table, the second, third, and fourth columns shew the number of degrees of heat which were lost per minute, by the body which was the subject of experiment; and, therefore, these numbers represent the *velocity* of cooling.

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[1] *Annals of Philosophy*, vol. xiii.

When the numbers in the last column are deducted from those in the second and third columns, the difference will shew the loss of heat by *radiation*, for the plain and silvered bulb respectively; the fourth column being the loss by conduction of the air, which is the same for all surfaces. It will immediately be perceived, therefore, that the loss of heat by conduction and by radiation, bear no constant ratio to each other. But, while *conduction proceeds by a regular geometrical progression*, radiation follows another law, viz., *when a body cools in vacuo, surrounded by a medium whose temperature is constant, the velocity of cooling, for excess of temperature in arithmetical progression, increases as the terms of a geometrical progression, diminished by a constant quantity.* This law is represented by the formula—

$$V = m.\, a^{\theta}\, (a^{t} - 1)$$

where a is a constant quantity for all bodies $= 1{\cdot}0077$; t the excess of temperature of the radiating body; θ the temperature of the surrounding medium; and m a co-efficient, which varies with the size and nature of the radiating body, to be determined for each particular case. It will likewise appear that, when we compare the *total cooling* of two different surfaces, the law is more rapid at low temperatures, and less rapid at high temperatures, for the body which *radiates the least*, in comparison with that which radiates with greater power.

(190.) But the cooling of a body by conduction of the air differs from the effect of radiation in a remarkable manner in this particular;—that, while *the ratio of loss by conduction continues the same, for the same excess of temperature, whatever be the absolute temperatures of the air and heated body,—radiation increases in velocity, for like excess of temperature, when the absolute temperatures of the air and heated* *body increase.* The following Table shews the law of *cooling by radiation,* for the same body, at different temperatures:

TABLE VII.

Excess of Temperature of the Thermometer	Velocity of Cooling when the surrounding Medium is at the undermentioned Temperatures.			
	0°	20°	40°	60°
220°	8·81	10·41	11·98	—
200°	7·40	8·58	10·01	11·64
180°	6·10	7·04	8·20	9·55
160°	4·89	5.67	6·61	7·68
140°	3·88	4·57	5·32	6·14
120°	3.02	3·56	4·15	4·84
100°	2·30	2·74	3·16	3·68

It will be observed in this Table, that, when the absolute temperatures of the surrounding medium and radiating body are increased 20° of Centigrade, *the difference between their temperatures continuing the same,* the velocity of cooling is multiplied by 1·165, which is the mean of all the ratios in the above Table, experimentally determined.

(191.) The total cooling of a body by radiation and conduction, then, we shall find to be represented, under all circumstances, by this formula—

$$m \, . \, a^{\theta} \, (a^{t} — 1) + n \, . \, t^{b}$$

The quantities a and b are constant for all bodies and under all circumstances; the first being $= 1·0077$ and the latter $= 1·233$. The co-efficient m will depend on the size and nature of the heated surface, as well as upon the nature of the surrounding medium. The co-efficient n is independent of the absolute temperature, as well as of the nature of the surface of the body; but will vary with the elasticity and nature of the gas in which the body is plunged; t is the excess of temperature of the heated body, and θ the temperature of the surrounding medium.

(192.) The fact, already adverted to, that the ratio of cooling of those bodies that radiate least, is more rapid at low temperatures, and less rapid at high temperatures, than those bodies that radiate most, is perhaps one of the most remarkable of the laws of cooling. It was first deduced experimentally by Petit and Dulong, and it may be mathematically proved from their formulæ.[1] It appears, however, that, when the total cooling of two bodies is compared, the law is more rapid at low temperatures, for the body which radiates least, and less rapid, for the same body, at high temperatures; though separately for conduction and for radiation, the law of cooling is, for the former, irrespective of the nature of the body, and for the latter, that all bodies preserve, at every difference of temperature, a constant ratio in their radiating power.

(193.) To revert to the first Table in this chapter. We find the total cooling at 60° and 120° (of Centigrade), to be about as 3 to 7; at 60° and 180°, as 3 to 13; and at 60° and 240°, as 3 to 21: whereas, according to the old theory of Newton, they should have been respectively as 3 to 6; as 3 to 9; and as 3 to 12. But we find that the deviation increases greatly with the increase of temperature, and that when the *excess* of temperature of the heated body, above the surrounding air, is as high as 240° of Centigrade (432° of Fahrenheit), the real velocity of cooling is nearly double what it would appear to be by the old and imperfect theory, varying, however, with the nature of the surface.

(194.) But radiant heat is subject to other laws besides those we have yet considered. Rays of heat diverge in straight lines from every part of a heated

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[1] *Annals of Philosophy*, vol. xiii. p. 335.

surface, and likewise from extremely minute depths below the surface of hot bodies, being subject to the laws of refraction, the same as light. The intensity of these rays *decreases as the square of the distance*, and the emission of the rays is greatest in a line perpendicular to the surface. The same law obtains here also, as with light,—that the effect of the ray is *as the sine of the angle* which it forms with the surface from which it emanates.[1] This *law of the sines*, first discovered experimentally by Leslie, suggests a practical caution connected with the subject before us, namely, that the shape of the pipes used to warm a building, is not wholly unimportant; for, if flat pipes be used, and they be laid horizontally, the major part of the *radiated* heat from the upper surface will be received on the ceiling, and therefore will produce but little beneficial effect. The loss sustained in this way will be greater in proportion to the higher temperature of the pipes; for it will be seen by the Table at the beginning of this chapter, that the relative proportion which radiation bears to conduction, increases with the temperature: at the ordinary temperature of hot-water pipes, about one-fourth the total cooling is due to radiation.

(195.) The radiation of heat, we have already seen, is greatly either increased or diminished, according to the nature of the surface of the radiating body. Professor Leslie has given the following as the relative powers of radiation by different substances:[2]

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[1] This law is thus stated by Fourier:—" The rays of heat which issue under different angles from the same point of the surface of any body, have an intensity which decreases proportionally to the sine of the angle formed by their direction with the plane tangential to the surface at the point of emission."—*London and Edinburgh Philosophical Magazine*, vol. ii. p. 104; also *Report, British Scientific Association*, vol. iv. (1835), p. 22.

[2] *Leslie, on Heat*, pp. 81—110.

Table VIII.

Lamp Black	100
Water (by estimate)	100
Writing Paper	98
Resin	96
Sealing Wax	95
Crown Glass	90
China Ink	88
Ice	85
Read Lead	80
Isinglass	80
Plumbago	75
Thick Film of Oil	59
Film of Jelly	54
Thinner Film of Oil	51
Tarnished Lead	45
Thin Film of Jelly (one quarter of former)	38
Tin scratched with Sand-Paper	22
Mercury	20
Clean Lead	19
Iron, polished	15
Tin Plate	12
Gold, Silver, and Copper	12
Thin Laminæ of Gold, Silver, or Copper Leaf, on Glass	12

(196.) It is very generally supposed that *colour* has a considerable influence on radiant heat, and also upon the absorption of heat—the two effects being similar and equal. Sir Humphry Davy, by exposing surfaces of various colours to the heat of the sun, proved experimentally[1] that the absorbing power of different colours was in this order;—black, blue, green, red, yellow, and white: black being the best, and white the worst absorbent. In this order, then, we should expect to find the radiating powers of different colours, and that by painting a body with a dark colour, we should increase its power of radiation. This, however, is not the case: and there are the strongest reasons for supposing that the absorption and radiation of *simple heat*,—that is, heat without light, or heat from bodies below luminosity,—are wholly irrespective of colour, and depend upon the nature of the surface.

(197.) By comparing the results given in the above Table, it will appear that the radiation of heat bears no relation to colour, when the radiating body is below the temperature of boiling water. By the

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[1] *Beddoe's Contributions*, p. 44.

Table it appears that lamp-black and white paper are nearly equal in power; while Indian ink is much less, and black-lead still lower in the scale; though as far as colour only is concerned, these last are nearly the same as lamp-black. Professor Powell considers, as also did Leslie, that *softness* may probably tend to increase the radiation of *simple* heat;[1] and the former found that a thermometer-bulb coated with a paste of chalk was affected (by this kind of heat) even more than a similar one coated with Indian ink; but the same result does not occur with luminous hot bodies.[2] Professor Bache has likewise made an extensive series of experiments on this subject, which confirm this result.[3] The experiments of Leslie proved that radiation proceeds not only from the surface of bodies, but also from small depths below the surface; and therefore the thickness of coating of any good radiating substance, materially affects the results, as may be observed by the above Table.[4] The thickness which produces the greatest effect, however, probably varies with different substances; and it is therefore necessary to separate this effect from anything merely resulting from the colour of the heated body. Professor Powell, after an elaborate examination of all the phenomena attending the heat received from the sun, is of opinion that there is no *simple radiant heat* received by us from the sun's rays; and that the simple radiant heat, which no doubt is initially radiated from the sun, is absorbed by the atmosphere of that luminary, some

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[1] It is necessary to distinguish particularly between *simple heat* from bodies of a limited temperature, and that which is given off from *luminous* hot bodies. From these latter, the experiments of Nobili and Melloni prove the existence of two distinct kinds of heating rays given off at the same time from the same body.

[2] *Professor Powell's Report on Heat, British Scientific Association,* vol. i. p. 279.

[3] *Ibid.*, vol. ix. (1840), p. 18.

[4] *Leslie, on Heat,* pp. 106—110.

small portion, perhaps, which escapes, being stopped in the higher regions of our own atmosphere.[1] The experiment of Sir H. Davy, on the absorption and radiation of *solar* heat, by different colours, is therefore not applicable to the case of *simple heat*, or such heat as is given out by bodies below luminosity. And in conformity with this view is the experiment of Scheele; in which he found that if two thermometers filled with alcohol, one red and the other colourless, were exposed to the sun's rays, the coloured one would rise in temperature much more rapidly than the other; but if they were both plunged into the same vessel of hot water, they rose equally in equal times.

(198.) We are fully justified then, from these and other analogous experiments, in drawing the conclusion, that *the radiation of* SIMPLE HEAT *is not influenced by the colour of the heated body.* Any difference which appears to obtain in this respect, is, therefore, solely referrible to the *nature* of the colouring substance.

(199.) The effect of roughness of the surface was also investigated by Sir J. Leslie; and he found that either tarnished surfaces, or such as are roughened by emery, by the file, or by drawing streaks or lines with a graving tool, always had their power of radiation considerably increased.[2] The accuracy of this deduction had not been questioned until some recent experiments of M. Melloni; by which it has been ascertained that this increased effect from roughened surfaces is not a general law, but is only a particular result, for which another explanation must be sought. M. Melloni, experimented with four plates of silver, two of which, when cast, were left in their natural state without hammering, and the other two were planished to a high degree under the hammer. All

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[1] *Report of the British Scientific Association*, vol. i. p. 290.

[2] *Leslie, on Heat*, p. 81, etc.

the plates were then finely polished with pumice-stone and charcoal; and after this, one of each of the pairs of plates was roughened by rubbing with coarse emery paper in one direction. The quantity of heat radiated from these plates was as follows:—

Hammered and polished plate	10°
,, and roughened ,, ...	18°
Cast and polished plate	13·7°
,, and roughened ,, ,, ...	11·3°

In comparing these effects, it appears that the hard hammered plate increased in radiating power four-fifths by roughening its surface; while the soft cast plate lost nearly one-fifth of its power by the same process. M. Melloni, therefore, draws the conclusion that the roughness of the surface merely acts by altering the superficial density, and that this will vary according as the body is of a greater or less density previous to the alteration of its surface by roughening.[1]

(200.) It was deduced from experiments by Leslie, that the *absorptive* power of bodies for heat was very nearly proportional to the *radiative* power:[2] and Dr. Ritchie has subsequently proved that these effects are precisely equal to each other.[3]

(201.) The velocity with which heat enters into and quits any body, is supposed to be equal; though this velocity is different for each different body. On this property of bodies with regard to heat, many of the experiments have been founded which constitute the laws of heat. It has also been established by the experiments of MM. Melloni and Nobili, that *the radiating powers of surfaces, for simple heat, are in the inverse order of their conducting powers.* It

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[1] *Melloni, on Emissive Power of Bodies*, etc., *Comptes rendus de l'Academie des Sciences*, and *Edinburgh Philosophical Journal*, 1838.

[2] *Leslie, on Heat*, etc., pp. 19—98.

[3] *Journal of the Royal Institution*, vol. v. p. 305.

follows, therefore, that neither the radiating powers, nor the conducting powers of bodies, will discover their actual rate of cooling comparatively with any other body.

(202.) We might be led to conclude, from all that precedes, that those metals which are the worst conductors would be the most proper for vessels or pipes for radiating heat; because we find that the heat lost by contact of the air is the same for all bodies, while those which *radiate most*, or are the worst conductors, give out more heat in the same time, than those bodies which *radiate least*, or are good conductors. Such would be the case if the vessels were *infinitely* thin; but as this is not possible, the slow conducting power of the metal opposes an insuperable obstacle to the rapid cooling of any liquid contained within it, by preventing the exterior surface from reaching so high a temperature, as would that of a more perfectly conducting metal, under similar circumstances; thus preventing the loss of heat, both by contact of the air and by radiation, the effect of both being proportional to the excess of heat of the *exterior* surface of the heated body. If a leaden vessel were *infinitely* thin, the liquid contained in it would cool sooner than in a similar vessel of copper, brass, or iron: but the greater the thickness of the metal, the more apparent becomes the deviation from this rule; and, as the vessels for containing water must always have some considerable thickness, those metals which are the worst conductors will oppose the greatest resistance to the cooling of the contained liquid, although apparently in opposition to the result of the preceding experiments.

It is difficult on these grounds to account for the effect which lead paint has in preventing the free radiation of caloric from bodies coated with it; because, in this case, the lead must be extremely thin, and ought, therefore, to increase the amount of radiation. The effect probably arises from the total change of state which the lead undergoes by its chemical combination with the carbonic acid, in the process of making it into white lead. Practically, it is found to have an injurious tendency on the free radiation of heat from most bodies; varying, however, with their radiating powers. On a good radiator, its effect is the most injurious, on a bad one, less so: but its use should be avoided as much as possible, in all cases where the free radiation of heat is the object in view.

(203). Various experiments have been made by Richmann, Ingenhausz, and Dr. Ure, to ascertain the conducting power of metals. Dr. Ure's results, which differ but little from the others, place the metals in the following order as regards their conducting power, namely—silver he found by far the best conductor; next copper; and then brass, tin, and wrought iron, nearly equal; then cast-iron and zinc; and lead he found by far the worse of all.[1]

(204.) The only accurate experiments, however, which have been made on this subject, are those by M. Despretz,[2] which give the following results:—

TABLE IX.

Gold	100·0	Tin	30·39
Platina	98·10	Lead	17·96
Silver	97·30	Marble	23·60
Copper	89·82	Porcelain	12·20
Iron	37·43	Fire Brick	11·40
Zinc	36·30		

This Table gives a very useful practical enunciation of the value of different substances as conductors of heat. But to ascertain the absolute conducting power of the various substances is extremely difficult; the preceding Table obviously only shews their

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[1] *Ure's Dictionary of Chemistry*, art. *Caloric*.

[2] *Despretz, Traité de Physique*, p. 201; and *Quarterly Journal of Science*, vol. xxv. p. 220.

relative conducting powers. Experiments, however, have been made on the absolute conducting powers of some substances, which are of considerable practical value, although they leave much yet to be desired.

(205.) M. Biot ascertained the conducting power of a bar of iron, by plunging one end of it into a bowl of mercury heated to 102½° Centigrade (216½ Fahrenheit), and ranging along the bar eight thermometers at various distances from each other. The observations were made after the temperature became permanent; the air during the experiment was 16¼° Centigrade (61 Fahrenheit), and the results were as follow:

TABLE X.

No. of Thermometer.	Distance from Mercury, Decimeters.	Excess of Temperature above the Air, Centigrade.	Distance from Mercury, Inches.	Excess of Temperature above the Air, Fahrenheit.
0	0	86·25°	0	155°
1	2·115	29·375	8·326	53
2	3·115	17·5	12·263	31½
3	4·009	11·25	15.783	20
4	4·970	7·1875	19·566	13
5	5·902	4·6875	23·236	8
6	7·777	2·1875	30·618	4
7	9·671	1·25	38·074	2
8	11·556	Insensible.	45·495	Insensible.

In this Table, the first column gives the numbers of the thermometers in their regular order; the second column gives the distance of each thermometer from the source of heat, viz., the bowl of mercury; and the third column gives the excess of temperature of the thermometers above that of the atmosphere, measured by the Centigrade scale. The fourth and fifth columns are the same as the second and third, only the measures are given according to the English scales, instead of the French.

(206). A similar experiment,[1] in which the source of heat was melted lead, is given in the following Table. The temperature of the air was 18·125° Centigrade (64½° Fahrenheit), and that of the iron bar was not taken until it had been exposed to the heat of the lead for several hours, in order to insure permanence of temperature.

TABLE XI.

No. of Thermometer.	Distance from Extremity, Decimeters.	Excess of Temperature above the Air, Centigrade.	Distance from Extremity, Inches.	Excess of Temperature above the Air, Fahrenheit.
1	2·230	76·875	8·78	138·37
2	3·230	47·187	12·71	84·93
3	4·120	29·375	16·22	52·87
4	5·081	17·812	20·00	32·06
5	6·028	10·625	23·73	19·12
6	7·899	3·750	31·09	6.75
7	9.783	1·562	38·51	2·73

(207.) A third experiment, also by M. Biot, was made with a bar of copper, plunged at one extremity into melted lead. It had fourteen thermometers ranged along it, of which, however, only eleven were available. The unit of distance was 101 milliometers,[2] and the temperature of the air was 15·75° Centigrade (60½° Fahrenheit.)

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[1] For these experiments, see Biot's *Traité de Physique*, tome iv. p. 670, et seq. Also, *Reports, British Scientific Association*, vol. x. (1841), p. 15, et seq.

[2] The milliometer is ·03937 of an inch English measure, and therefore the 101 milliometers are equal to 3·97637 inches.

TABLE XII.

No. of Thermometer.	Distance from Extremity.	Excess of Temperature above the Air, Centigrade.	Distance from Extremity, Inches.	Excess of Temperature above the Air, Fahrenheit.
4	5·25	80·50°	20·87	144·9°
5	6·25	65·75	24·85	118·3
6	7·25	53·75	28·82	96·7
7	8·25	43·75	32·80	78·7
8	9·25	35·50	36·77	63·9
9	11·25	24·00	44·73	43·2
10	13·25	15·70	52·68	28·2
11	15·25	11·00	60·63	19·8
12	17·25	7·50	68·58	13·5
13	19·25	5·25	76·53	9·4
14	21·25	3·75	84·49	6·7

(208.) Some experiments by M. Despretz,[1] similar to the preceding, and extending also to other substances, are contained in the following table. In these experiments the distance between each of the consecutive thermometers was 10 centimeters (3·937 inches English), and the temperatures are given by the Centigrade scale.

TABLE XIII.

Excess of Temperature above the Air, Centigrade Scale.	No. of the Thermometers.						Temperature of the Air, Centigrade.
	1	2	3	4	5	6	
Copper . .	66·36	46·28	32·62	24·32	18·63	16·18	17·08
Iron . . .	62·9	36·69	20·52	12·32	8·19	6·61	17·34
Pewter . .	63·41	35·17	21·52	15·52	—	—	17·34
Zinc . . .	64·17	38·02	25·43	17·93	—	—	5·62
Lead . . .	65·13	29·42	14·93	9·99	—	—	17·12
Marble . .	63·91	6·08	1·95	1·47	—	—	17·15

In all these experiments the substances were exposed to the cooling influence of the air. In

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[1] *Traité de Physique*, par M. Despretz.

Mr. Kelland's *Report on the Laws of Conduction of Heat*, made to the British Scientific Association (vol. x.), the mathematical formulæ of MM. Fourier, Libri, Poisson, and others, are given at considerable length, for estimating the conducting powers for heat; but they are not suitable for insertion here.

(209.) Experiments on the same plan as the preceding were made by MM. Delarive and Condolle on the conducting power of wood: the results are given in the following Table.[1] They shew the difference in conducting power, according to the direction of the fibre. The bars of wood were about five inches long, one-and-a-half inch broad, and one inch thick. The first thermometer was three centimeters (one and one-eighth inch English) from the end; and the others were two centimeters (three-quarters of an inch English) apart from each other. The temperatures given are the excess above the atmosphere, at the respective distances from the heated end.

TABLE XIV.

Names of the Woods.		No. of Thermometers, Centigrade Scale.				
		1	2	3	4	5
Walnut . .	Longitudinal direction of the fibre.	80·13	43·0	19·63	9·19	5·13
Oak . . .		81·7	41·2	17·5	7·2	3·7
Fir . . .		84·0	39·25	20·6	8·5	3·7
Poplar . .		79·8	34·2	14·2	6·2	2·8
Walnut . .	Transverse direction of the fibre.	99·5	37·43	13·9	6·0	3·25
Oak . . .		79·3	22·75	7·5	3·6	2·4
Fir . . .		70·9	13·8	4·5	2·5	1·9
Poplar . .		78·5	13·75	3·44	1·56	1·0

(210.) Fluids, both in the liquid and aeriform state, are bad conductors of heat, unless they have perfect

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[1] *Ann. de Chimie*, vol. xl. p. 91; and *Quarterly Journal of Science*, vol. xxvii. p. 188.

freedom of motion, in which case they become far better conductors than solids, on account of the extreme mobility of their particles.[1] Water, under these circumstances, is a far better conductor of heat than any of the metals (except mercury); and air, particularly when charged with moisture, is also an excellent conductor, under like circumstances. Count Rumford made some experiments to ascertain the cooling power of different fluids, based upon the principle that their conducting power and absorbing power are equal.[2] The mode of operating was to enclose a thermometer in a glass-balloon filled with the particular substance of which the conducting power was to be ascertained; and to place it first in freezing water, and then plunge it into boiling water. The respective times required to raise the thermometer from 0° to 70° Reaumur, were supposed to indicate the conducting powers of the different substances, which would therefore be their cooling powers upon any heated body placed in them. The following Table shews the results of these experiments, the times being given in minutes and seconds.

TABLE XV.

Substances.	Times of Cooling.	Ratio of Conducting Power.
Mercury	0·36″	1000
Moist Air	1·51″	330
Water	1·57″	313
Common Air	7·36″	80·41
Rarefied Air, density $\frac{1}{4}$.	7·37″	80·23
Do. do. $\frac{1}{24}$.	7·51″	78
Torrecellian Vacuum . .	10·53″	55

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[1] In aeriform fluids radiant heat is transmitted with extreme rapidity without any visible motion of the particles; but this is a very different case to that stated in the text.

[2] *Rumford's Essays*, vol. ii. p. 425.

These experiments, however, are by no means conclusive; and there is every reason to believe that, by varying the method of the experiment, a vast difference would be found in the results. The glass balloon which surrounded the thermometer was only one inch and a half diameter, the thermometer itself being half an inch diameter. This space was far too small to allow a free and rapid motion among the particles of the various media which were the subject of experiment; and therefore the conducting powers of the liquids, which have less facility of motion among their particles than the aeriform fluids, appear far less than they really are. Dr. Osborne ascertained the refrigerating power of water compared with air of the same temperature to be as 14 to 1,[1] while Rumford's experiments shew it to be less than four to one: but there is reason to believe that when due provision is made for allowing perfect mobility among the particles of water, the cooling power of water will be very much greater than the amount even which is stated by Dr. Osborne;[2] and Leslie states that water at the boiling point conducts

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[1] *Reports of the British Scientific Association*, vol. iv. (1835), p. 96.

[2] Some experiments of the author led him to conclude that the conducting power of boiling water compared with air was fully double the amount stated by Dr. Osborne; and these agreed so well with the experiments of Mr. Parkes, already quoted (Art. 85, note), that the author was induced to adopt the proportion of 28 to 1 as the cooling power of water and air, in an extensive and peculiar apparatus which required the cooling powers of these media to be properly adjusted. The result has proved that the cooling power of water is fully equal to this estimate; but it is probable that the relative conducting power varies with the temperature of the heated body. For unless the temperature be sufficiently high to give free motion to the particles of water, the cooling power will be reduced; while the same difference can scarcely occur in air, in consequence of the extreme mobility of the particles. The diminished adhesion of liquids by increased temperature has been experimentally determined by Dr. Ure. (See Art. 223.)

heat five times more rapidly than the same fluid when near the freezing point.[1]

(211.) The power of *reflection* in all bodies is inversely as their radiating power, as was experimentally determined by Leslie.[2] The following Table shews the reflective power of different substances:—

TABLE XVI.

Brass	100	Lead	60
Silver	90	Tinfoil, softened by Mercury	10
Tinfoil	85	Glass	10
Block Tin	80	Glass coated with Wax	5
Steel	70		

(212.) The *specific heat* of different substances is a subject of considerable importance, as connected with the heating of buildings; for on the theory of specific heat is based many of the calculations for ascertaining the proportions of the various apparatus employed.

(213.) Every substance contains a certain distinctive quantity of heat, called the specific heat of that particular body, which can be ascertained by mixing together (with proper precautions) known quantities of different substances. Thus, if a certain weight of quicksilver, one pound for instance, of the temperature of 40°, be mixed with the same weight of water, of the temperature of 156°, the resulting temperature will be 152·3°; so that the water will lose 3·7° of temperature, and the quicksilver will be raised 112·3°. Or, if a pound of water at 100° be mixed with a pound of oil at 50°, the resulting temperature will be 83·5° and not 75°, which would be the mean temperature of the two. Thus it appears that the same quantity of heat that will raise a pound of water 1°, will raise the temperature of a pound of

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[1] *Leslie, on Heat and Moisture*, p. 17.

[2] *Leslie, on Heat*, pp. 20 and 98.

oil 2°, or a pound of mercury 23°; and so of other substances, which all possess a capacity for caloric, each peculiar to itself. The following Table shews the specific heat of some of the principal substances which have been ascertained, chiefly from the experiments of Berard and Delaroche, and Petit and Dulong. They are all referred to water, as the standard, and are supposed to be the quantity of heat contained in equal weights of the several substances.[1]

TABLE XVII.

Water	1·0000	Oxygen	0·2361
Aqueous vapour	0·8470	Carbonic Acid	0·2210
Alcohol	0·7000	Carbonic Oxide	0·2884
Ether	0·6600	Charcoal	0·2631
Oil	0·5200	Sulphur	0·1850
Air	0·2669	Iron (wrought)	0·1100
Hydrogen	3·2936	Mercury	0·0330
Azote	0·2754	Platinum	0·0314
Oxide of Azote	0·2369	Gold	0·0298

(214.) It has, however, been much questioned whether the several substances possess the same capacity for heat at all temperatures; and MM. Petit and Dulong, as also Dr. Dalton, appear to have established the fact that the capacity for heat of every substance increases with the temperature; or, in other words, that the quantity of heat given out by any body in cooling a given number of degrees, is greater at high temperatures than at low temperatures. The following Table exhibits the specific heat of several bodies between the temperatures of 0° and 100°, and also between 0° and 300° of Centigrade.

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[1] A further list will be found in Table V. Appendix.

TABLE XVIII.

Substance.	Mean Capacity between 0° and 100° Centigrade.	Mean Capacity between 0° and 300° Centigrade.
Iron	·1098	·1218
Mercury	·0330	·0350
Zinc	·0927	·1015
Antimony	·0507	·0549
Silver	·0557	·0611
Copper	·0949	·1013
Platinum	·0335	·0355
Glass	·1770	·1900

(215.) But independent of the sensible heat of bodies as ascertained by direct measurement, when any change of state occurs, as from the solid to the liquid and from the liquid to the æriform, or *vice versa*, certain quantities of heat enter into or quit the respective substances, which, not being directly measurable by the thermometer, have been termed *latent heat.* Ice at 32° requires 140° of heat to enter into combination with it, before it assumes the liquid state; and it then becomes water, though still only at the temperature of 32°. And water at 212° requires 1000° of heat to enter into combination with it before it assumes the state of steam, though in the latter state it still only shews a thermometric temperature of 212°. The following Table gives the quantity of heat rendered latent when certain solids assume the liquid state and certain liquids assume the state of vapours: the degrees are those of Fahrenheit's thermometer.

TABLE XIX.

TABLE OF LATENT HEAT.[1]

Of Liquids: by Dr. Irvine.		Of Vapours: by Dr. Ure.		
Water	140°	Vapour of Water at 212°,		1000°
Sulphur	143·7	„	Alcohol	457
Spermaceti	145	„	Ether	312·9
Lead	162	„	Oil of Turp.	183·8
Bees' Wax	175	„	Nitric Acid	550
Zinc	493	„	Ammonia	865·9
Tin	500	„	Vinegar	903
Bismuth	550	„	Petroleum	183·8

(216.) Many important facts arise from the theory of latent heat. One of the most important in regard to the arts, is the peculiar properties of steam. But without entering at any length into this important and extensive subject, it may be observed that experiments have clearly proved that at all temperatures and pressures steam contains exactly the same absolute quantity of heat. For, while under increased pressure, steam can be made to exhibit almost any thermometric temperature, the latent heat of high-pressure steam always decreases exactly in the same ratio as its sensible heat increases, so that its latent and sensible heat together always amount to 1180° above the freezing point of water. Thus, a certain weight of steam at 212°, when condensed into water at 32°, gives out

Sensible Heat	180°
Latent Heat	1000
	1180

And the same weight at 400°, when condensed into water at 32°, gives out

Sensible Heat	368°
Latent Heat	812
	1180

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[1] *Dr. Ure's Dictionary of Chemistry,* art. *Caloric.*

The same holds good with steam at all other temperatures, and extends from 212° to the highest range of steam pressures.

(217.) The phenomena of spontaneous evaporation present some important facts connected with the subjects of our present inquiry. To Dr. Dalton we owe much of the knowledge which we possess of the laws that govern the vaporization of liquids; and his numerous experiments on the subject rank among the most valuable contributions to science. Evaporation is distinguished from ebullition by this circumstance;—that, during the latter phenomenon, the liquid which is converted into vapour maintains an invariable temperature, provided the pressure upon it do not change; while, with the former, the temperature is constantly subject to change, the quantity of liquid evaporated being proportional to the temperature and to the surface exposed. Evaporation is wholly independent of the pressure of the air, and is the same in a vacuum, in the natural atmosphere, or in a condensed medium: but this is only true as regards the absolute quantity which can exist in a given space, for the air is found greatly to impede evaporation by its inertia opposing a mechanical obstruction, and thereby retarding the time required for the operation, when such obstruction does not exist. In a vacuum, the evaporation is almost instantaneous; but, in a space containing air, the time required for the evaporation of the maximum quantity of vapour is longer in proportion to the density of the air, though ultimately the quantity is the same.[1]

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[1] Professor Daniell made some experiments on this subject, by which he was led to conclude that "the amount of evaporation is *cæteris paribus* in exact inverse proportion to the elasticity of the incumbent air."—(*Quarterly Journal of Science*, vol. xvii. p. 52). This remark, however, applies only to the rate of evaporation, and not to the quantity which can exist in a given space. Even from ice, the evaporation is very considerable; and some

(218.) The quantity of liquid discharged into free space, by spontaneous evaporation, is, under these circumstances, much influenced by the motion of the air, which thus carries off the successive strata of vapour that rise from the liquid, a very strong wind causing about twice as much vapour to be discharged as a still atmosphere. Dr. Dalton's experiments enable us to estimate the evaporating force under all circumstances. He ascertained that from a circular vessel of six inches diameter, kept at the temperature of 212°, the quantity of water evaporated was 120 grains per minute in a still atmosphere, 154 grains per minute with gentle motion of the air, and 189 grains per minute with a brisk motion of the air. The temperature of the air does not influence the evaporation; and he found that, at any other temperature of the water, the evaporation was exactly proportional to the elastic force of the vapour at that temperature.

The following Table was contructed by Dr. Dalton from his experiments:

Table XX.

Shewing the force of Vapour and the full Evaporating Force for every Temperature, from 20° to 212° Fahrenheit, expressed in grains of water, that would be raised *per minute* from a vessel six inches in diameter, supposing there were no vapour already in the atmosphere.

Temperature. Fahrenheit.	Force of Vapour.	Evaporating Force in Grains.			Temperature. Fahrenheit.	Force of Vapour.	Evaporating Force in Grains.		
		Still.	Gentle.	Brisk.			Still.	Gentle.	Brisk.
20°	·129	·52	·67	·82	28	·174	·70	·90	1·10
22	·139	·56	·71	·88	30	·186	·74	·95	1·17
24	·150	·60	·77	·94	32	·200	·80	1·03	1·26
26	·162	·65	·82	1·02	34	·214	·86	1·11	1·35

experiments of M. Schuebler shew that, during the very coldest weather, the spontaneous evaporation of ice in the open air is sometimes nearly 1-40th of an inch in depth from each square foot of surface every 24 hours.—*Quarterly Journal of Science*, vol. xxvii. p. 187.

TABLE XX—*continued.*

Temperature. Fahrenheit.	Force of Vapour.	Evaporating Force in Grains.			Temperature. Fahrenheit.	Force of Vapour.	Evaporating Force in Grains.		
		Still.	Gentle.	Brisk.			Still.	Gentle.	Brisk.
36	·229	·92	1·18	1·45	76	·880	3·52	4·52	5·53
38	·245	·98	1·26	1·54	78	·940	3·76	4·83	5·91
40	·263	1·05	1·35	1·65	80	1·000	4·00	5·14	6·29
42	·283	1·13	1·45	1·78	82	1·07	4·28	5·50	6·73
44	·305	1·22	1·57	1·92	85	1·17	4·68	6·07	7·46
46	·327	1·31	1·68	2·06	90	1·36	5·44	6·98	8·56
48	·351	1·40	1·80	2·20	95	1.58	6·32	8·11	9·95
50	·375	1·50	1·92	2·36	100	1·86	7·44	9·54	11·71
52	·401	1·60	2·06	2·51	110	2·53	10·12	12·98	15·93
54	·429	1·71	2·20	2·69	120	3·33	13·32	17·09	20·97
56	·458	1·83	2·35	2·88	130	4·34	17·36	22·27	27·34
58	·490	1·96	2·52	3·08	140	5·74	22·96	29·46	36·16
60	·524	2·10	2·70	3·30	150	7·42	29·68	38·08	46·74
62	·560	2·24	2·88	3·52	160	9·46	37·84	48·56	59·59
64	·597	2·39	3·07	3·76	170	12·13	48·52	62·26	76·41
66	·635	2·54	3·27	3·99	180	15·15	60·60	77·77	95·44
68	·676	2·70	3·47	4·24	190	19·00	76·00	97·53	119·7
70	·721	2·88	3·70	4·53	200	23·64	94·56	121·35	148·9
72	·770	3·08	3·96	4·84	210	28·84	115·36	148·04	181·6
74	·823	3·29	4·23	5·17	212	30·	120·	154·	189·

In this Table,[1] the first column gives the temperature of the water; the second, the elastic force of the vapour at that temperature; and the third, fourth, and fifth columns shew the number of grains weight of water, evaporated per minute, from a vessel six inches diameter (or 28·274 square inches, equal to ·196 of a square foot), when the air is still, or in gentle or in brisk motion respectively.

(219.) In order to know exactly the quantity of vapour that will be evaporated per minute, we must know the quantity which already exists in the atmosphere. For this purpose we must find the dew point of the air,—that is, the temperature at which the vapour in the air just begins to condense.[2] By

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[1] See Dr. Dalton's experiments, *Memoirs of the Manchester Philosophical Society*, vol. v. p. 579, et seq. The Table given by Dr. Dalton only extends to the temperature of 85°; the temperatures above that are calculated from his data.

[2] Dr. Dalton used for this purpose a very thin glass vessel, into

referring to the table we shall then find the quantity of vapour in the air at that time; and this, deducted from the quantity shewn by the table to be given off at the ascertained temperature of the evaporating liquid, will give the exact quantity of water that will be evaporated per minute. Thus, suppose the dew point of the air to be 48°, and the temperature of the air and of the evaporating liquid to be 70°, with a still atmosphere: the vapour in the air, as shewn by the table, at the temperature of 48°, is 1·4 grains; which subtracted from that at 70°, viz., 2·88 grains, gives 1·48 grains per minute for the quantity of vapour given off from a surface six inches diameter.

It will be observed that, if the temperature of the air be lower than the temperature of the evaporating fluid, the vapour will again condense; but the rapidity of this condensation will depend upon the relative temperatures, and the quantity of moisture contained in the air.

(220.) The heat and cold caused by the condensation and rarefaction of the air, produce important effects, both in natural phenomena, and in the mechanical application of this agent in the arts. When the air is partially exhausted in a receiver enclosing a thermometer, the temperature sinks very considerably; but if the air be again suddenly admitted to the original pressure, the temperature rises considerably higher than in the first instance. The reverse of this occurs when the air is first condensed, and then allowed to resume the original pressure; in which case the

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which he poured cold water, and noted the temperature. If the vapour was instantly condensed, he poured out this water and applied some a little warmer, and so on, until he obtained the proper temperature at which he could just perceive a slight dew deposited on the glass. This temperature then was the dew point. Daniell's Hygrometer is a much more elegant instrument, but more difficult to manage.

temperature sinks considerably lower on the original pressure being restored, than the thermometer indicated before the condensation.[1]

This result, however, appears to be produced by an unavoidable imperfection in the experiment. For the vessel that contains the air communicates its heat in the one case, and abstracts it in the other, which causes the apparent difference; and this difference is therefore dependent upon the rapidity of the operation, thereby allowing more or less time for the interchange of heat between the air and the vessel containing it.

In Dr. Dalton's experiments,[2] the thermometer which sunk 2° on rarefying the air, rose 4° on again allowing it suddenly to resume its original pressure. When the air was first condensed and then suddenly allowed to resume its original pressure, the thermometer rose 2° on the condensation, and then sank $3\frac{1}{2}$° on diminishing the pressure suddenly to its original amount. These inequalities, however, although an accompaniment of the experiment, are not due to the mechanical expansion or condensation of the air; and the results will vary with every alteration in the condition of the containing vessel, and of the quantity of air.

(221.) Professor Leslie investigated this subject, both experimentally and theoretically, and he found that the quantity of heat evolved under these circumstances was very great; but, as the specific heat of air increases as its density diminishes, only a small portion of the heat thus produced becomes appreciable. When air of the following densities is restored to its original pressure, represented by 1, the heat evolved is as follows:—

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[1] *Manchester Memoirs,* vol. v. p. 515; and *Nicholson's Journal,* vol. iii. p. 160.

[2] *Ibid.*

TABLE XXI.

Density of the Air.	Heat Evolved. Fahrenheit.	Density of the Air.	Heat Evolved. Fahrenheit.
1·0	0°	0·4	94·5
0·8	20·6	0·2	216·
0·6	48·	0·0003	13500·

This evolution of heat, he considered to be owing to the diminution of the specific heat of the air by condensation. When air was condensed so as to double its density, the mathematical formula which he constructed from his experiments, shewed that the sensible heat which would be evolved would be equal to 67·5° Fahrenheit.[1]

(222.) Mr. Ivory also investigated the mathematical law of the heat produced under these circumstances;[2] and he found "that the heat extricated from air, when it undergoes a given condensation, is equal to three-eighths of the diminution of temperature required to produce the same condensation, the pressure being constant." Air, under a constant pressure, diminishes 1-480th of its volume for every degree of depression of Fahrenheit's scale; and therefore 1° of heat will be extricated from air when it undergoes a condensation equal to $\frac{1}{480} \times \frac{3}{8} = \frac{1}{180}$. If a mass of air were suddenly reduced to half its bulk, the heat evolved would be $\frac{1}{2} \div \frac{1}{180} = 90°$.[3] M. Despretz made some experiments to ascertain whether water evolved heat when subjected to great pressure; and he found that a compressive force equal to 20 atmospheres caused the disengagement of only one sixty-sixth part of a degree of heat.[4] This result might reasonably be expected from the

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[1] *Dr. Thomson, on Heat and Electricity*, p. 126, et seq.

[2] *Philosophical Magazine* (Second Series), vol. i. p. 89; and *Quarterly Journal of Science*, vol. xxiii. p. 228.

[3] *Ibid.*

[4] *Quarterly Journal of Science*, vol. xxiv. p. 20.

small degree of compression to which water can be subjected.

(223.) Dr. Ure instituted some experiments to ascertain the influence which heat had in increasing the fluency of various liquids; and he found in all cases a great increase in the velocity of their efflux through a given aperture, by raising their temperature. In some liquids of a viscid nature, the increase appears to be very great. Such, for instance, is the case with some kinds of oil, which, by raising their temperature from 65° to 254°, had their velocity of efflux increased nearly six times. With those which were less viscid, the increase was less. Water, by having its temperature raised from 60° to 164°, had its velocity increased about one-sixth.[1] These results are wholly independent of any effect from alterations of pressure, but appear to arise from the particles of the fluids possessing less adhesiveness among themselves by the increased temperature.

(224.) The effects of heat in producing variations in the strength of materials, is a subject which has received but little attention; and with the exception of some experiments made by the Franklin Institute of Pennsylvania, on the strength of iron and copper, little appears to be known. By these experiments[2] the maximum strength of wrought iron, estimated by its resistance to a longitudinal strain, was obtained by heating the iron to 572° Fahrenheit; at which temperature the strength is 15·17 per cent. greater than at the ordinary mean temperature of the air. The rule deduced for the strength of iron at high temperatures is, that "the thirteenth power of the temperature above 80° Fahrenheit is proportionate to the fifth power of the diminution from the maximum tenacity." And it appears that, at the temperature

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[1] *Reports of the British Scientific Association*, vol. viii. p. 23. (See also Art. 210).

[2] *Report on the Explosion of Steam Boilers, by a Committee of the Institute: Journal of the Franklin Institute*, vols. xix. and xx.

of about 1050°, iron loses about one-half of its maximum strength; at 1240° it loses about two-thirds; and at 1317° seven-tenths of its maximum tenacity is overcome.

The following Table shews the diminution of tenacity at various temperatures. The maximum tenacity of the fourth column is a calculated amount, obtained by adding 15·17 per cent. to the strength of the metal when tried cold. The seventh column shews that the mean irregularity of structure is 10 per cent. of the strength when tried cold.

TABLE XXII.

No. of the Experiment.	Temperature observed (Fahrenheit).	Tenacity observed. In lbs.	Maximum Tenacity at the Point of Fracture. In lbs.	Manner of obtaining the Maximum.	Diminution by Heat, in parts of the Maximum Tenacity.	Irregularity of the Metal in parts of the original Strength.
1	520°	58451	63267	experiment	·0761	·0992
2	570	60398	66146	—	·0869	·1125
3	596	57682	63386	calculation	·0899	·2401
4	600	56938	63086	—	·0964	·2401
5	630	60010	67033	experiment	·1047	·1440
6	662	58182	65785	—	·1155	·0644
7	722	54442	64483	calculation	·1436	·0507
8	732	53378	62736	experiment	·1491	·1310
9	734	57903	68407	calculation	·1535	·0644
10	766	54819	65176	experiment	·1589	·1563
11	770	54781	65445	calculation	·1627	·0234
12	824	55892	70080	—	·2010	·0413
13	932	45531	68202	—	·3324	·0413
14	947	42401	66193	experiment	·3593	·0446
15	1030	37587	68071	calculation	·4478	·0460
16	1111	27603	61531	—	·5514	·0330
17	1155	21967	54992	—	·6000	·0330
18	1159	25620	64234	—	·6011	·1102
19	1187	21913	60102	—	·6352	·0330
20	1237	21298	63065	—	·6622	·1147
21	1245	20703	63065	—	·6715	·0347
22	1317	18913	63065	—	·7001	·1147

(225.) In the experiments made with copper, at various temperatures, the Committee found that, unlike iron, the maximum strength of copper was at a very low temperature; and that it increased in strength at every reduction of temperature down to 32°, which was the lowest at which they could try it. The mean strength of copper at ordinary temperatures was found to be 32,146 lbs. per square inch; and the following Table exhibits the diminution of strength at high temperatures. To obtain the actual temperature of each experiment 32° must be added to the temperatures given in the second column.

TABLE XXIII.

Number of the Experiment.	Temperature above 32° of Fahrenheit.	Diminution from the Strength at 32°.
1	90°	·0175
2	180°	·0540
3	270°	·0926
4	360°	·1513
5	450°	·2046
6	460°	·2133
7	513°	·2446
8	529°	·2558
9	660°	·3425
10	769°	·4398
11	812°	·4944
12	880°	·5581
13	984°	·6691
14	1000°	·6741

(226.) The strength of cast iron at high temperatures has not been ascertained with the same accuracy. It has, however, been estimated that its maximum strength is at the temperature of about 300° Fahrenheit, which is considerably below that of wrought iron.

(227.) The effects of heat, which have here been mentioned, are a few of the laws and phenomena of this important branch of science. They appear to be those which are most closely connected with the subject of the present inquiry: but it must not be supposed that they are given as an epitome of the general laws of heat, as the subject would be far too extensive for the present work. Many most important and interesting phenomena have therefore been entirely omitted; but those which are here mentioned, and others that are alluded to and interspersed in various parts of this treatise, appear to be all that are requisite for the illustration of the subject now before us, and will afford useful suggestions to those who wish to investigate the principles of heating buildings theoretically and scientifically, as well as to learn the mere practical details.

CHAPTER X.

EXPERIMENTS ON COOLING.

(228.) From what has been stated in the preceding chapter, it is evident that the velocity with which a heated body cools depends upon various circumstances; and experiments are necessary, in order to obtain data for the calculations which the known laws of heat enable us afterwards to apply to the subject now under investigation.

No experiments on cooling are extant, that appear to be suitable to the present purpose, except some that were made by Tredgold, and these are erroneous in the application he has made of them. For he has neglected all considerations of the thickness of the body on which he experimented, and has therefore estimated that the rate of cooling of a very thin sheet-iron vessel, containing a heated fluid, is the same only as a cast-iron pipe, though the latter is fully six or eight times the thickness of the former. The same error also occurs in his experiments on the cooling of glass; and, consequently, his conclusions on the dispersion of heat, as applied to the warming of buildings, are erroneous to a considerable extent. Another source of error lies in his having estimated the quantity of water which the vessels contained at rather too large an amount, in allowing for the specific heat of the vessels; which latter could not possibly have had quite the same temperature as the water, owing to loss by imperfect conduction, and to the cooling influence to which it was exposed. The effect of each of these errors is to make the rate of dispersion appear more rapid than the true velocity; and the result is, that in some of the calculations founded on these experiments the errors amount to upwards of 16 per cent.

(229.) To ascertain the velocity of cooling for a surface of cast-iron, a pipe thirty inches long, two inches and a half diameter internally, and three inches diameter externally, was used in the following experiments. The ends of the pipe were closed by corks which entered into the pipe one inch and a half at each end; and the bulb of a thermometer was inserted into the water about three inches from one end, the temperature of the water being the same in every part of the pipe. The exposed surface of the pipe (including the surface exposed by the thickness of the metal at the ends) was 287·177 square inches. The quantity of water contained in it was 132·534 cubic inches; and the equivalent to be added to this for the specific heat of the pipe, is 39·341 cubic inches; making the estimated quantity of water 171·875 cubic inches.[1] The rates of cooling were tried with different states of the surface: first, when it was in the usual state of cast-iron pipes covered with the brown surface of protoxide of iron; next, it

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[1] In estimating the equivalent of water which was required to represent the specific heat of the pipe, the difference between the external and internal temperatures necessarily required an allowance to be made on account of the thickness of the pipe being considerable. This diminution of specific heat was estimated to be equal to a superficies of the pipe one-sixteenth of an inch thick. The total equivalent of water which would represent the specific heat of the pipe, supposing it to be exactly of the same temperature as the water contained in it, would be 52·455 cubic inches: from this must be deducted 13·114 cubic inches as above stated, leaving the equivalent specific heat of the pipe equal to 39·341 cubic inches of water, as stated in the text.

was varnished black; and finally, the varnish was scraped off, and the pipe was painted white with two coats of lead paint. The following Table shews the observed time of cooling, corrected and reduced to the same excess of temperature above the circumambient air.

TABLE XXIV.

TABLE OF THE COOLING OF IRON.

Temperature of Room 67°. Maximum Temperature of Thermometer 152°.

Thermometer cooled		Rusty Surface.		Black Varnished Surface.		White Surface.	
from	to	Observed Time.	Calculated Time.	Observed Time.	Calculated Time.	Observed Time.	Calculated Time.
152°	150°	2′ 30″	2′ 21″	2′ 16″	2′ 16″	2, 19″	2′ 24″
152	148	5 0	4 44	4 38	4 36	4 53	4 51
152	146	7 45	7 12	7 28	7 3	7 28	7 22
152	144	10 15	9 44	9 45	9 27	10 13	9 57
152	142	12 45	12 15	12 2	11 54	12 57	12 36
152	140	15 0	15 0	14 32	14 32	15 22	15 22

		Minutes.
The ratios of Cooling 1° are therefore,	Black Varnished Surface . .	1·21
	Iron Surface	1·25
	White Painted Surface . . .	1·28[1]

These ratios are in the proportion of 100, 103·3, and 105·7; but as the relative heating effect is the inverse of the time of cooling, we shall find that 100 feet of varnished pipe, $103\frac{1}{4}$ feet of plain iron pipe, or $105\frac{3}{4}$ feet of iron pipe painted white, will each produce an equal effect.

In these experiments, it might have been expected

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[1] These ratios of cooling, it will be observed, are for pipes of three inches diameter; but the cooling of any other size can be calculated from the data here given.

to find greater differences between the effects of the various states of the surface, than appears really to obtain. The greatest difference only amounts to about 5¾ per cent., but it would probably be greater in proportion, with an increased thickness of the coating of paint.

(230.) To ascertain the effect of glass windows in cooling the air of a room, the following experiments were made, with a vessel as nearly as possible of the same thickness as ordinary window-glass. The temperature of the room, in these experiments, was 65°; the thickness of the glass was ·0825 of an inch; the surface of the vessel measured 34·296 square inches, and it contained 9·794 cubic inches of water, including the equivalent for the specific heat of the glass. The time in which this vessel cooled, when filled with hot water, is shewn as follows:

TABLE XXV.

TABLE OF THE COOLING OF GLASS.

Thermometer Cooled		Observed Time of Cooling.	Calculated Time of Cooling.	Average Rate of the Observed Time of Cooling.
from	to			
150°	140°	6′ 40″	6′ 54″	1·176° per minute, at an excess of 65° above the Temperature of the air.
150	130	14 15	14 43	
150	120	23 30	23 40	
150	110	34 0	34 0	

From the average rate of cooling which is here given, the effect of glass in cooling the air of a room may easily be calculated. As the specific heat of equal volumes of air and water[1] is as 1 to 2990, the above average will shew that each square foot of glass will cool 1·279 cubic feet of air 1° per

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[1] See Art. 106.

minute, when the temperature of the glass is 1° above that of the external air.

But by this we shall only find the effect of glass in a still atmosphere; and therefore, to ascertain the cooling effect of external windows, when exposed to the action of winds, farther experiments are necessary.

(231.) In some researches of Leslie's, on the cooling power of wind, he used a bright metallic ball filled with hot water, and noted the time of cooling when it was exposed to wind at different velocities. The result he obtained was, that the cooling effect on the ball was very nearly in a direct ratio with the velocity. But it will be obvious, by referring to the experiments of Petit and Dulong, in the preceding chapter, that the relative cooling of heated bodies, when exposed to air moving at different velocities, must depend upon the nature of the surfaces. For while the quantity of heat which is abducted by the air, is proportional to the number of particles of air which pass over the heated body in a given time, the heat that is lost by radiation is not only independent of this effect, but the relative proportion of heat lost by radiation differs for each particular substance. As the bright metal ball that Leslie employed in his experiments would lose only an extremely small proportion of its heat by radiation, it might naturally be concluded that the rate of cooling would be nearly in a direct ratio with the velocity of the air. But with a surface of glass, the result must be very different, because the radiation is then very considerable; and, therefore, the total cooling will be much slower than the simple ratio of the velocity. For while a surface of glass of the temperature of 120°, and at an excess of 52° above the surrounding medium, loses about two-thirds of its heat by radiation, a bright metallic surface of the same temperature will only lose one-eleventh part of its heat by the same cause.

(232.) In the following experiments it appears that the cooling effect of wind, at different velocities, on a thin surface of glass, is very nearly as the square root of the velocity. In these experiments, the velocity of the air was measured by the revolution of the vanes of a fan; the temperature of the air was 68°; the time required to cool the thermometer 20° was noted for every different velocity, and the maximum temperature of the thermometer, in each experiment, was 120°. In still air it required 5′ 45″ to cool the thermometer this extent; and the following Table shews the time of cooling by air in motion.

Table XXVI.

TABLE OF THE COOLING OF GLASS BY WIND.

Velocity of the Wind, in Miles, per Hour.	Times of Cooling the Thermometer 20°. From 120° to 100° of Fahrenheit.		
	Observed Time of Cooling.	Time reduced to Decimals of a Minute.	Corrected Time; being the Inverse of the Square Root of the Velocities; in Decimals of a Minute.
3·26	2′ 35″	2·58	2·58
5·18	2 10	2·16	2·04
6·54	1 55	1·91	1·82
8·86	1 40	1·66	1·56
10·90	1 30	1·50	1·41
13·36	1 15	1·25	1·27
17·97	1 5	1·08	1·10
20·45	1 0	1·0	1·03
24·54	0 55	·91	·94
27·27	0 48	·81	·88

(233). In consequence of the large quantity of glass in buildings used for horticultural purposes, the cooling effect of wind is of considerable importance. We see, however, that with an increased velocity the cooling effect is considerably less, in proportion, on glass than on metal. And it will be very much less on window-glass than even what is here stated; for, as glass is an extremely bad conductor of heat, the increased thickness which window-glass possesses over that which composes the bulb of a thermometer will make a material difference in the quantity of heat that is lost by the abduction of the air, as there will be, in this case, a greater difference between the temperature of the external and the internal surface. The cooling effect of wind is therefore not near so considerable on glass as is generally supposed; and it will probably be nearly one-half less on window-glass than what is shewn by the preceding experiments. Exact experiments on this subject, however, are extremely difficult, owing to the unequal action of the air on different parts of the surface. Thus, if a cylindrical or spherical vessel be employed, the action of the wind will be such that the particles of air striking the surface in front will cause a vacuum at the back part of the vessel, from which latter part the heat will be given off by radiation alone. It thus becomes impossible to ascertain accurately what would be the effect, if the whole of the surface could be acted upon by the wind; and the same remark will apply to most other forms of surface which could be employed experimentally.

(234.) The following Table shews the results of Tredgold's experiments on cooling, already referred to. They are here given, principally, to shew the cooling power which thin sheet-iron will have in any building in which it is used; and they may therefore be useful now that corrugated iron is so frequently employed in many descriptions of buildings. In these experiments the specific heat of the vessels was added to the quantity of water they contained. The vessels were always cooled from 180° down to 150° of Fahrenheit; the time required for this cooling, and the other particulars of the experiments, being noted in the table.

TABLE XXVII.

Nature of Surface.	Surface exposed. Square Inches.	Equivalent Quantity of Water. Cubic Inches.	Temperature of the Room. Fahrenheit.	Time of Cooling. Minutes.	Average Excess of Temperature. Fahrenheit.	Loss of Heat per Minute. Fahrenheit.
Tinned Plate	79	62·28	55½°	46	124½°	·759
Sheet Iron .	76·7	61·7	57	29	123	1·18
Glass . .	71	61·2	56½	31½	123½	1·075

In these experiments, as already stated, the cooling of the sheet-iron will not afford a fair criterion for the effect of cast-iron pipes; but it will be perceived that thin sheet-iron has, in a still atmosphere, the same cooling power as glass; and therefore its effect in cooling the air of any building in which it is used will be very great, and in high winds it will produce a far greater cooling power than the same extent of glass (Art. 231), as its cooling power will be nearly in the direct ratio of the velocity of the wind.

These remarks on the cooling power of different substances when employed in buildings, must of course be understood merely to apply to those cases in which the interior temperature of the building is higher than that of the external temperature. When these conditions are reversed, the effects must necessarily also be altered.

PART SECOND:

ON THE VARIOUS METHODS OF WARMING AND VENTILATING BUILDINGS, THE COMBUSTION OF FUEL, ETC.

CHAPTER I.

Early Methods of Warming Buildings—The Romans—their Stoves—Baths—Flues—Mode of Preparing their Firewood The Persian Method—Chinese Method of Flues—Method of the Ancient Britons—Invention of Chimneys—Burning of Coals in England—Early Writers on the subject—Improvements in the Form and Construction of Stoves and Fire-Places.[1]

(235.) The various methods of warming buildings have consisted, in all countries and in all ages, until a very recent period, of the rudest appliances and the most inartificial inventions. At a very early period, it is true, the Romans were acquainted with the method of heating rooms and buildings by flues; and these were elaborate in their construction, and complicated in their arrangements. But they were so expensive in their construction, and so wasteful in their expenditure of fuel, that this method of warming buildings could only be adopted by very few of even

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[1] In this and the following chapters, the articles on "Stoves" and "Ventilation," written by the author, and published in the *Encyclopædia Metropolitana*, have been incorporated with such further observations as the want of space prevented him from making in the work in question.

that rich and luxurious nation. The comparatively late invention of chimneys fully accounts for the immense size and peculiar construction of the flues used by the ancients; for unless a large space were provided for the combustion of the fuel and the entrance of the air, the heat could not have been conducted through the flues, owing to the absence of the necessary draught produced by the use of a high chimney. The *hypocaustum* of the Romans was this plan of flues. It appears to have consisted of a long furnace; and a number of narrow arches (*testudines alvei*) received the fire of the hypocaustum, and conducted it along and underneath the floor of the room to be warmed.[1] The whole of the hypocaustum was immediately below the room which was to be heated. Sometimes a great number of short columns or pillars supported the floor instead of these arches. They were set in four rows very close together, and the flame of the furnace passed between them, as appears by some very perfect specimens which have been discovered.[2] Pliny the younger, in his letter to Gallus, giving the description of his villa Laurentinum, mentions that his bedchamber was warmed by a small hypocaustum:[3] and this plan was generally adopted in heating the baths.[4] For this latter purpose, however, an improved method was adopted when the Thermæ of Rome were built, and which has been described by Seneca.[5] The water of the bath was heated by passing it through the fire in a brass pipe of a serpentine form, thence called *Draco*. The most approved mode was to employ the *Miliarium*,[6] which appears to have been a leaden vessel of large

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[1] *Castell's Illustrations of the Villas of the Ancients,* pp. 8, 9.

[2] *Philosophical Transactions,* vol. xxv. p. 2225 and vol. xli. p. 855.

[3] *Castell's Illustrations,* p. 13.

[4] *Ibid.* p. 9.

[5] *Seneca Nat. Quæst.* lib. 3. cap. 24.

[6] *Palladius,* lib. i. tit. 40.

circumference, the middle part being open for the spiral pipe, and for the draught of the fire to pass through. This vessel of water that surrounded the flame was also placed upon part of the same fire, and for that reason the bottom was obliged to be made of brass, as were also the pipes.

(236.) But the method of warming by the hypocaustum was far too expensive for general use. The Romans used portable furnaces, containing embers and burning coals, to warm the different apartments of their houses, which were placed in the middle of the room.[1] These were sometimes made to contain water, which was heated by the fuel of the furnace, and probably they were also used for cooking. One of these boilers and furnaces, found at Herculaneum, was in the shape of a castle with four towers.[2] The usual kind of stoves, however, were nearly on the plan of our braziers. They were mostly elegant bronze tripods, supported by satyrs and sphinxes, with a round dish above for the fire, and a small vase below to hold perfumes, which were thrown into the brazier to correct the smell of the coals. A square stove of bronze, of the size of a moderate table, found at Herculaneum, rested on lions' paws, and was ornamented upon the border with foliage. The bottom was a strong iron grating, walled up with bricks above and below, so that the fire could not touch the sides of the stove, nor fall through the bottom. It was similar to those still used in large rooms in Italy.[3] But the smoke from these stoves was so considerable, that the furniture of the winter rooms was different from the summer rooms; and Vitruvius expressly states that these winter apartments had plain cornices, and were without carved work or mouldings, in order to allow the soot to be

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[1] *Adams's Roman Antiquities*, p. 454.

[2] *Fosbroke's Archæology*, 4to. vol. i. p. 233.

[3] *Ibid.*, vol. i. p. 237.

easily and frequently cleaned away.[1] At great entertainments it was usual to have watchmen stationed to be ready to extinguish any fire which might happen; the smoke issuing from the kitchen windows being so great on these occasions, that it was common to speak of this great smoke as synonymous with a great entertainment.[2] The utmost care, however, was taken to prevent the smoke as much as possible, and to procure wood, which gave the smallest quantity of smoke in combustion. A great deal of the firewood used by the Romans was procured from Africa.[3] The bark of the wood was peeled off, the wood was then suffered to lie a long time in water, and afterwards dried and anointed with the lees of oil, which was considered the most effectual way to prevent it from smoking.[4]

(237.) In the time of Seneca (A. D. 64), another method of heating buildings was adopted; which consisted of pipes built in the walls, that conveyed the heat from a furnace, constructed in the earth under the edifice. These pipes or flues were conducted to the different rooms; and the upper end was often ornamented with the representation of a lion's or a dolphin's head, or any other figure, and it could be opened or shut at pleasure. These pipes, however, were liable to become full of soot; and as they were very likely to catch fire by being over-heated, laws were made forbidding them to be brought too near to the wall of a neighbouring house.[5]

(238.) The Persians used a stove consisting of an iron vessel sunk in the earth in the centre of the apartment. After a fire had been kindled and had

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[1] *Vitruvius,* lib. vii. cap. 3. *Beckmann's History of Inventions,* vol. ii. p. 74.

[2] *Beckmann,* vol. ii. p. 71.

[3] *Ibid.* vol. ii. p. 300.

[4] *Adams's Roman Antiquities,* p. 454. *Beckmann,* vol. ii. p. 79.

[5] *Beckmann,* vol. ii. p. 90.

well warmed the place, a wooden top, like a small low table, was placed over the hole in the floor which contained the stove, and this top was then spread with a large coverlet quilted with cotton, which hung down on all sides to the floor. Those people who were not very cold, only put their feet under the table or covering; but those who required more heat, put their hands under it also, or crept under it altogether.[1] The Jews likewise used such stoves in their houses, and the priests had them also in the temple:[2] in fact, throughout the East, this mode of warming apartments appears to have been commonly adopted.

(239.) In China, a very elaborate system of flues has been long in use, by which the floors of the rooms are heated by a furnace constructed below, with a moderate expenditure of fuel. A very equable temperature appears to be maintained by this means, notwithstanding the winter temperature of some parts of China is so low that the thermometer nearly reaches the zero of Fahrenheit's scale. Father Gramont described this mode of heating in 1771,[3] but the date of its introduction does not appear to be known.

(240.) Although the Romans must have introduced their methods of warming buildings into England at a very early period, as appears by various remains which have been excavated in recent times,[4] the inhabitants of Britain long contented themselves with contrivances of the rudest and simplest character. Among the Ancient Britons, in each dwelling there was only one place for a fire, which was merely a hole in the centre of the floor. In the time of the Anglo-Saxons, the ordinary plan was to place the ignited fuel on the hearth in the middle of the floor,

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[1] *Beckmann,* vol. ii. p. 83.

[2] *Ibid.* vol. ii. p. 85.

[3] *Philosophical Transactions,* 1771, p. 61.

[4] *Philosophical Transactions,* vols. xxv. and xli.

and an opening in the roof, immediately above the hearth, permitted the escape of the smoke. In the better class of buildings, an ornamented turret was erected in the centre of the roof for carrying off the smoke, while in ordinary houses the opening in the roof was merely defended from the weather by louvre boards, in the manner now practised in many of our commonest buildings used for manufactories.

(241.) The invention of chimneys necessarily made a great alteration in the mode of heating buildings. The date of their introduction has been much debated: but there appears to be no positive evidence of their existence before the middle of the fourteenth century; the earliest record being, that an earthquake at Venice in 1347 threw down a great many chimneys.[1] Twenty years after this they appear to have been unknown at Rome; for in that year Francesco da Carraro, lord of Padua, came to Rome, and finding no chimneys at the inn where he lodged, he caused two chimneys to be built by workmen whom he had brought with him; and over these chimneys, the first ever seen at Rome, he caused his arms to be affixed.[2] This slow communication of such an important invention, so closely connected with health and comfort, contrasts most strangely with the rapid promulgation of every discovery and improvement of the present time.

The introduction of chimneys into England appears to have been in the reign of Richard II.; and one of the first is supposed to have been at Bolton Castle built in this reign.[3] It was long before they came into general use; but in the reign of Elizabeth most rooms in respectable houses were furnished with them, and apologies were made to visiters if they

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[1] *Beckmann's History of Inventions*, vol. ii. p. 98.

[2] *Ibid.* p. 99.

[3] *Fosbroke's Archæology*, vol. i. p. 113.

could not be accommodated with rooms with chimneys.[1]

(242.) It is uncertain at what time stove-grates were first used, though probably they were not invented till coals became the ordinary fuel. For though coals were known to the Britons before the arrival of the Romans, their use was barely tolerated in England till the seventeenth century, as it was supposed that the air was rendered unwholesome by their use.[2]

After the improved method of burning fuel under open chimneys was introduced, they were used not only as the receptacle for the fire, but they also became the ordinary place of resort for conversation and conviviality for all the inmates of the house. The chimney-corner was the post of honour; and the custom of the whole family sitting under the chimney-breast is not even yet exploded in some of our rural districts.

(243.) The earliest writers who endeavoured to improve the construction of stoves were Keslar of Frankfort, in 1614; Savot, in 1625; Glauber, in 1669; and Delesme, in 1686. In 1713 (or perhaps even in 1709) the Cardinal de Polignac, under the assumed name of M. Gauger, published a most excellent treatise on the construction of fireplaces, which in 1715 was translated and published in this country by Dr. Desaguliers.[3] This treatise, which is now

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[1] *Fosbroke's Archæology*, vol. i. p. 112.

[2] See Chapter VI. Art. 341.

[3] Dr. Desaguliers, in his *Experimental Philosophy*, vol. ii. p. 557, published in 1744, mentions this book, and states that the author concealed his name, but that he knew him to be Monsieur Gauger of Paris: and he mentions a curious circumstance of a Frenchman coming over to this country, who, although so ignorant that he could scarcely read three pages of the book, professed himself its author, and applied to the king to grant him a patent free of expense, on account of the great value of the stoves described in the book, and that he was too poor to pay for the patent.

scarce, contains a most lucid explanation of the methods of economizing fuel, based on the soundest principles of philosophy. It was the first attempt which had been made to apply the known laws of heat to the construction of fireplaces; and though, in consequence of wood being the fuel universally used in France at that period, and this fuel being always burned upon the hearth, the author made no mention of *stoves*, but merely of *fireplaces*, the translator, Dr. Desaguliers, added a chapter on the *stoves* to be used in these improved fireplaces; and the work in that new form was a complete epitome of all those principles which Franklin, and after him, Count Rumford, so successfully brought under the public notice, and which, if strictly carried out, would form, even at the present day, the best guide to the proper construction of stoves and fireplaces. An epitome of this little work would be, in fact, a recapitulation of all the most approved methods of constructing fireplaces, stoves, and chimneys; but most of these principles are now too well known to require explanation, and others which are less so, will be touched upon in another form in the course of this treatise.

(244). The word *stove* is used in this treatise to signify either a close or an open fire-grate to burn fuel in; and, in general, this is what the word is now supposed to mean. In horticulture, the building itself, which is heated, and not the place which holds the fire, is called a stove, and this expression is employed by many old writers. Anciently, however, the term *hothouse*, which we now use to signify a building for horticultural purposes, was descriptive of a sudorific bath, the use of hothouses for the purposes of horticulture being an invention of comparatively a recent date. At the beginning of the seventeenth century, hothouses were used for the cultivation of orange trees, and were considered a mark of royal magnificence.[1]

(245.) The various elegant forms given to the stove grates of the present day are quite a modern invention. Formerly they were called "cradles of iron for burning sea-coal,"[2] from which we should suppose them to be very different in construction to ours; and even those described in Dr. Desagulier's work, as late as the beginning of the eighteenth century, are nothing more than a few bars bent into a semicircle and fastened into the back. How far the utility of stove-grates has been affected by the modern alterations of form, we shall endeavour to shew in the following chapter; and subsequently we shall inquire into the physiological effects produced by some of the modern methods of distributing artificial heat.

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[1] *Fosbroke's Archæology*, vol. i. p. 275.

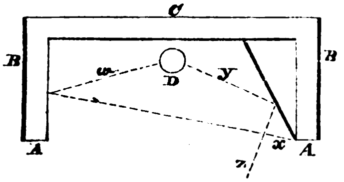
[2] *Ibid.*, vol. i. p. 268.

CHAPTER II.

Forms of Fireplaces and Chimneys—should be made to reflect Heat—Contraction of Chimney Breast—Hollow Hearths and Backs for Fireplaces—Rumford's Principles of Construction—Errors in the Construction of Stoves—Register-Stove in a case—Jeffrey's Stove—Franklin's Pennsylvania Stove—Cutler's Torch Stove—Sylvester's Radiating Stove—Russian and Swedish Stoves—German Stoves—Hot-air Stoves—Cockle Stoves—Dr. Nott's Stove—Dr. Arnott's Stove—Franklin's Vase Stove—Gas Stoves—Joyce's Stoves—Beaumont's Stove.

(246.) Previous to the publication of M. Gauger's treatise (already alluded to), chimney fireplaces were generally made in the form of a large square recess, and the breast of the chimney was of the same size as the recess itself. The error of this construction was pointed out, in the work of M. Gauger, by a reference to the known laws of heat. Radiant heat is subject to the same law as light,—that the angle of reflection is equal to the angle of incidence. Hence it follows that a ray of heat, falling perpendicularly on the flat sides of the chimney recess, will be reflected back upon itself: if the ray forms an angle vertically with the side, it must be reflected up the chimney; and if the ray forms an angle horizontally with the flat side of the chimney, this angle must necessarily be so small that it cannot be reflected forwards beyond the jambs of the mantelpiece. On these considerations M. Gauger recommended that the back of the recess should be contracted, so that the sides should incline outwards at a considerable angle, by which means the radiant heat would be reflected into the room, and much more effect produced. The fig. 30 will explain this: it is supposed to be the ground-plan of a fireplace, with straight sides: A B C are the jambs, sides, and back of the fireplace, and D the body which radiates heat. If now a ray *w* falls on the side, it will be reflected at the same angle, and fall just within the jamb at *x;* but if the side be inclined, as shewn by the line *f*, then a ray *y* falling upon it, will be reflected into the room in the direction of *z*, and of course a vast difference in the effect will be experienced.

Fig. 30.



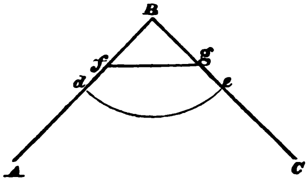
But this author likewise recommended other improvements. He advised a considerable contraction of the breast of the chimney by which less heat would escape through the funnel or shaft of the chimney, while, at the same time, he proved that the smoke would escape with equal facility as before. Another improvement which he suggested was in making the hearth and back of the fireplace hollow, by means of metal plates, so that by having these hollow spaces to communicate with the external atmosphere, the air in passing through them would be warmed before it entered the room, and would prevent the cold currents of air which otherwise would enter through the crevices of the doors and windows. This construction of fireplaces was intended for the burning of wood, and as the fire was therefore merely laid on the hearth, the effect of these hollow spaces, and particularly the hollow hearth, would of course be very considerable, by warming a large quantity of air.

(247.) Subsequent inventors have been much indebted to this work by M. Gauger. Franklin acknowledged the great assistance he had derived from it; and the methods of economizing fuel, afterwards so successfully introduced by Count Rumford, in his improved stoves, are all similar in principle to the plans recommended by the French author.

(248.) In the year 1796, Count Rumford published his *Essays on the Management of Fire and the Economy of Fuel;* and he there described those improvements which have ever since that time been followed in the construction of stove-grates. The error shewn by M. Gauger to exist in the construction of fireplaces, by making the sides parallel to each other, was, at the time that Rumford wrote his treatise, still continued. In pointing out the error of this mode of construction, he shewed that, in order to obtain the greatest effect from the fuel, the sides of the fireplace ought to be placed at an angle of of 135° with the back of the grate, or (which is the same thing) at an angle of 45° with a line drawn across the front of the fireplace. This angle must necessarily reflect the greatest number of rays into the room; the difference of effect between this mode of construction and that of the parallel sides being very great. The reduction in the size of the throat of the chimney was likewise another improvement which he effected, though this also had been recommended by M. Gauger nearly a century previous. The angular covings for the sides of the fireplaces, Rumford considered should not be formed of iron, but of some non-conducting substance, such as fire-clay, in order that more heat might be reflected from them into the room. A circular form for these sides, or covings, he considered produced eddies or currents, which would be likely to cause the chimney to smoke; and he likewise objected to the old form of registers or metal covers to the breast of the chimney for the same reason, and because by their sloping upwards towards the back of the fireplace, they caused the warm air from the room to be drawn up the chimney, and thus impeded the passage of the smoke. These registers are now made so as to be lower at the back than at the front of the stove; but, in general, they are placed far too high up. And the very same reasons which decide the angle of greatest effect for the cheeks or sides of the fireplace to be 45°, also apply to this case; and a large quantity of heat now lost by the ordinary register-stoves would be saved if the register top were placed at this angle, and sufficiently low down to allow it to reflect the heat from the fire into the room. The dimensions of the fire-grate itself Count Rumford recommended to be much less than formerly; and the best proportions for the chimney recess he stated, were, that the width of the back should be equal to the depth from front to back, and the width of the front, or the opening between the jambs, should be three times the width of the back.

(249.) Although the best form for register-stoves has now for several years past been adopted, the desire for novelty has caused the true principles of construction to be frequently departed from; and we accordingly find, in the most modern stoves, considerable deviations from these principles. Fig. 31 is a section of a register-stove constructed on the best possible plan for diffusing heat into the room. The sides are a right angle of 90° A B C; and the bars *d e* describe a quadrant of a circle whose radius is just half the length of the side A B. If now we wish to follow Rumford's rule of making the back one-third the width of the front, we obtain this by taking one-third of the length A B, which will give B *f*; and then if we draw the line *f g*, we shall obtain exactly the required dimensions.

FIG. 31.



By this arrangement it will be perceived that the sides of the stove form an angle of 135° with the back; and all the rays of heat which fall upon these sloping sides, will therefore be reflected into the room, directly in front of the stove, in right lines. The falling cover, or register top, should also form an angle of 135° with the back, by which a large portion of heat will be radiated downwards into the room. These proportions, however, cannot well be adopted in stoves of a very large size, as they will be found to throw the stove rather too far back; but for all moderate sized stoves no form can be adopted which will produce so good an effect.

(250.) Various methods have been contrived to render available some further portion of the heat which is given off by the fuel during combustion in these stoves, in addition to that which is obtained by radiation. These contrivances are nearly all of them mere modifications of that pointed out by M. Gauger, by means of the double back and hearth of his improved fireplaces. Notwithstanding this invention is at least 130 years old, it has, during the last 30 years, been repeatedly brought forward, and more than once patented, by different persons, as a new invention. The principle has been the same in all the different cases, with but very little difference in the mode of applying it. A current of air is brought from the external atmosphere, and is made to pass through a small box at the back of the stove; the back of the stove itself forming one side of the box; and in order to prevent the air from escaping into the room before it is sufficiently warmed, the box is divided by several partitions so as to check the passage of the air, which is carried successively through them all before it escapes into the room. This mode of warming the air is exceedingly useful, and is capable of various modifications; and it is not only economical in fuel, but frequently is very efficacious in remedying smoky chimneys, and in preventing those cold draughts from doors and windows which are so exceedingly unpleasant and unhealthy.

(251.) A most efficient mode of applying this principle is to enclose the whole of the register-stove in an ornamental case. In this way the stove stands forward in the room a few inches, and the case forms an air-chamber entirely round the back and sides of the stove, by which a very large heating surface is obtained, which moderately warms the air, while the whole effect of the radiant heat is obtained from the open fire, the same as in an ordinary register-stove. When the air-chamber communicates with the external air, this forms a very excellent stove, and the atmosphere is purer than when the air of the room only is made to pass over the heated surface.

(252.) A stove invented by Mr. Jeffrey (the inventor of the well known instrument called the Respirator) accomplishes the same object in a somewhat different manner. This stove stands extremely prominent in the room, without being at all sunk in the wall as fireplaces usually are. The entire back of the stove above the fire, consists of a series of flat tubes, one inch wide, and about nine inches deep from back to front, which are placed edgeways, one inch apart from each other, so as to present alternately a close and an open space of one inch in width. These tubes are about eighteen inches long, and reach quite to the top of the stove, and pass just through the mantelpiece. The only way by which the smoke can escape into the chimney is by passing through the openings left between these flat tubes, which are so connected at the top as to prevent the smoke passing into the room. The lower end of these tubes opens into a small air-chamber which communicates with the external atmosphere, and the air therefore passes from this chamber through the flat tubes, and escapes at rather an elevated temperature into the room from the upper part of the tubes; having been warmed in its passage through the tubes by the heat which has been abstracted from the smoke by their surface. Nothing new in principle is obtained by this arrangement; the only difference between this plan and that of the many previous contrivances for the same purpose, is that the heat which warms the air is derived from the smoke, in the others it is obtained by bringing the air into contact with the surface that is heated directly by the fuel contained in the stove itself. The method employed by Mr. Jeffrey appears very likely to cause the chimney to smoke, unless the draught is particularly good; for the smoke must have so large a portion of its heat abstracted by passing between the flat tubes, that its power of ascending must necessarily be very much reduced. The stove also presents some practical difficulties in removing the soot from the chimney; for which purpose a part of the jamb has to be removed.

(253.) Dr. Franklin, in 1744, introduced a stove for burning wood, which he called the Pennsylvania stove; in which he introduced the principle of heating the air very much in the manner first recommended by M. Gauger, by means of a double or hollow back. This stove[1] was in the form of an oblong box with the front removed. At about three or four inches from the back of this box, a flat close chamber was fixed, three inches deep, the whole width of the stove, and reaching to within about four inches of the top. The smoke escaped over the top of this flat chamber, and passed downwards between it and the real back of the stove, and thence passed into the chimney. This hollow chamber communicated underneath the stove with a tube opening into the external atmosphere, and a considerable quantity of air thus passed

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[1] *Franklin's Works*, vol. ii. p. 225, et seq.

through the flat chamber, and escaped into the room through small holes left at the sides, after traversing the length of the chamber three or four times by means of divisions placed across it for that purpose. The heated surface of the stove itself also warmed the air of the room, and a large quantity of radiant heat was also given off from the burning fuel. This stove is very economical, and it was a good deal used in America, and some of them have been used in England, in those parts of the country where wood is abundant.

(254.) An ingenious stove was proposed some years since by Mr. Cutler, and called the torch stove. It possessed an open fire, exactly like an ordinary register-stove, but it was made to consume its own smoke on a very ingenious principle. Below the bars of the grate there was a deep box which sank down into the hearth, and which contained the fuel. The fire was lighted at the top, and as the fuel burned away, the box was wound up by a chain passing over a rack and pinion, placed out of sight, in the interior of the stove. By this means the fuel burned only at the top; and the quantity of heat could be regulated at pleasure, according to the height to which the fuel was supplied from the box below. For as the sides of the box were solid, and therefore no air could pass through the fuel it contained, the combustion took place only in that part of the fuel which was raised up to the level of the fire-bars; and as this part of the fuel always burned clear, the raw coal below was gradually and slowly heated, and the gaseous parts were consumed while passing slowly through the ignited fuel at the top. This stove was rather cumbrous in appearance, and there was an inconvenience attending its use arising from the trouble of relighting the fire and filling the box with fuel, when the latter did not contain a sufficient quantity to last the entire day. The principle however of lighting the fire at the top, and supplying fresh fuel from below, is undoubtedly good, as it affords the most perfect control over the intensity of the fire, and consumes nearly the whole of the smoke.

(255.) Another modification of the register-stove is the invention of Mr. Sylvester. In this stove the hearth consists of a great number of hollow bars fitted into an appropriate frame. The hollow bars not only form the hearth, but at their extreme end the fuel is placed, and the bars thus form the grating on which the fuel is burned. The air to support the combustion passes through the hollow bars, and also through the front of the fire. The ends of these bars on which the fire is placed become hot; and the remaining part of the bars also becoming heated by the conducting power of the metal, a radiation of heat into the room is produced by the bars which form the hearth. The fire being placed as it were on the hearth, the cheeks or sides of the stove are of much greater length than usual, and a larger quantity of heat is radiated into the room. The smoke escapes through openings in the back, which are placed something like louvre boards. The ashes from the stove fall into a box below the hearth, which requires to be occasionally emptied by removing the loose bars forming the hearth.

(256.) The stoves which come now to be mentioned are of a different character, and form that class (the only one known in many parts of Europe), which heat the air by contact with their surfaces, and not by radiation directly from the burning fuel itself. In most of these stoves the fire is wholly concealed from view; while in a few, of modern invention, a part of the fire is dimly seen through talc placed in the front.

(257.) In the North of Europe, close stoves are alone used for heating buildings. In Russia and

Sweden, the stove is generally made of brick, tiles, or stone; and it occupies a large space at one end of the room. It is usually either square or oblong, and is divided by partitions into different compartments, so as to increase the surface over which the smoke and heated gases pass before they finally escape into the chimney. The materials which compose the stove being slow conductors of heat, they retain the heat for a long time when once warmed; and these stoves seldom require replenishing with fuel more than once a day. They usually burn wood for fuel, and are supplied by a fire-door exterior to the room intended to be warmed. M. Guyton endeavoured to introduce these stoves into France at the close of the last century, and paid much attention to the best form of construction, and the comparative cost of fuel, the results of which were published in the *Annales de Chimie.*[1]

(258.) In Germany, iron stoves are used, which heat the air by contact with their surfaces. A very superior stove is also used, made of glazed earthenware, which is very similar to the Swedish stoves last described, and which gives a mild and agreeable heat. This stove necessarily occupies much room; but it is decidedly the best construction for a close stove, as the quality of the air is less injured by it than by the heated metal from ordinary close stoves. With all these close stoves it is usual to employ a vase of water to supply moisture to the air, to prevent the unpleasant effects which would otherwise be experienced, and which will be noticed in the following chapter.

(259.) In this country, hot-air stoves constructed of iron have been usually employed for warming large buildings, until the introduction of the plan of warming by steam and by hot water.

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[1] See also *Repertory of Arts*, vol. xvi. p. 254, et seq.

The hot-air stove is too well known to need description. It may be observed, however, that the great defect of these stoves being that they heat the air too highly, and thereby render it unwholesome, whatever plan of construction tends to increase the heated surface exposed to the fire without increasing the size of the fire-box itself, will of course lower the temperature of the surface which heats the air, and thereby render the stove less objectionable. This has been accomplished in a very ingenious manner by Mr. Sylvester, by means of covering the cast-iron case, which receives the heat from the fire with iron ribs projecting three or four inches beyond the surface of the case. These ribs greatly increase the surface, and thereby reduce the temperature, which is the great desideratum in these stoves.

(260.) The method of heating by cockle stoves is but little more than a modification of the ordinary hot-air stoves adapted to a larger scale. Mr. Strutt, of Belper, in Debyshire, appears to have been the first person to introduce an improved method of heating by cockle stoves; and from the year 1792, when he first warmed his large cotton factories in this manner, various improvements have been made in these stoves, which, without at all altering their principles, have rendered their application more general.

The cockle stove consists of a very thick iron case, which forms the top and sides of the furnace. This case, or cockle, is enclosed in another case of brick or stone, placed so as to allow a space of three or four inches, or more, between them in every part; and appropriate openings are left for the admission of cold air at the bottom, and for the emission of the hot air at the top, which is from thence conveyed through channels or pipes to any place which is required to be warmed. A vast number of ingenious contrivances have been proposed for the improvement of this apparatus, and for many years it was the principal method of warming all the large buildings in England. It has been sometimes called the Belper stove, after the name of the residence of the inventor. The unwholesome effects of these stoves, however, have caused them to be now nearly superseded by the use of hot-water pipes, which, from their lower temperature, are free from the injurious tendency which the hot-air stoves have always been found to exhibit.

(261.) A stove invented by Dr. Nott of Philadelphia, has been found to produce very considerable effect with but a small expenditure of fuel, and requiring very little attention. This stove is usually something of a pyramidical form. The lower part, which forms the fire-box, is lined with fire-bricks, and the stove is divided vertically into two compartments. The fuel is put into this stove through an opening near the top, which forms a reservoir for the fuel and occupies the front part of the stove, and the smoke passes downwards through a grating placed at the bottom, and then escapes through the back part of the stove into the chimney. The air for the support of the combustion enters the stove principally on the top of the fuel, and a small portion also enters below. As the fuel burns but slowly in consequence of the small quantity of air admitted, the fire-box and reservoir, when once filled, will supply fuel for several hours, and give a very great heat. In fact, the heat is generally so considerable, and the air is thereby rendered so arid, that it is extremely unpleasant and unwholesome to those who are exposed to its influence.

(262.) One of the most economical stoves as regards the consumption of fuel, that has yet been invented, is that which has been introduced by Dr. Arnott. This invention is an improvement (in some respects) upon Dr. Nott's stove above described, the principal difference being the limiting the admission of air by which the combustion is regulated, and by separating the burning fuel more perfectly from actual contact with the heating surface of the stove, by which means the excessive heat of Dr. Nott's stove is in a great measure avoided. The plan for regulating the admission of air was, long previous to its application by Dr. Arnott, employed for limiting the intensity of the heat of furnaces; for which invention, Dr. Ure, some years since obtained a patent. Dr. Arnott's stove consists of an external case of iron, of any shape that fancy may dictate: within this case a fire-clay box, to contain the fuel, is placed, having a grating at the bottom, and a space is left between the fire-box and the exterior case, so as to prevent, as much as possible, the communication of too much heat to the exterior case. The pedestal of the stove forms the ash-pit, and there is no communication between the stove and the ash-pit, except through the grating at the bottom of the fire-box. A small external hole in the ash-pit, covered by a valve, admits the air to the fire, and according as this valve is more or less open, the vividness of the combustion is increased or diminished, and thence the greater or less heat produced by the stove. The quantity of air admitted by this valve is governed by a self-regulating apparatus, either by the expansion and contraction of air confined by mercury in a tube, or by the unequal expansion of two bars of different metals riveted together, on the plan proposed by Dr. Ure.[1] The

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[1] This ingenious and simple invention consists of two thin narrow bars, one of brass or copper and the other of iron, about eighteen inches or more in length, riveted together at each end. On subjecting this compound bar to heat, the brass expands considerably more than the iron, and the elongation of the bars causes them to open in the centre and recede from each other (forming a bow) in consequence of their being riveted together at both ends. The greater the heat, the more the centre of the bars recede from each other, or the greater the arc of the bow becomes; and

smoke escapes through a pipe at the back of the stove; very little smoke however is eliminated from these stoves, the fuel being always either coke or anthracite coal. By adjusting the regulator so as to admit only a small quantity of air, the temperature of the stove is kept within the required limits; and owing to the slow conducting power of the fire-clay, of which the fire-box is formed, the heat of the fuel is concentrated within the fire-box, and the fuel burns with less air, and therefore more slowly than it would otherwise do. This slow combustion of the fuel, however, produces a large quantity of carbonic oxide, which is liable to escape into the room, and being a strong narcotic poison, is attended with considerable danger to those who breathe it. The escape of this gas from these stoves has been experimentally ascertained by Dr. Ure, by attaching to the ash-pit of a stove a glass vessel containing a solution of subacetate of lead, which was speedily acted upon by the carbonic gas, and formed into the insoluble carbonate of lead.[1] Carburetted hydrogen gas is also frequently formed in these stoves, and many dangerous explosions have in consequence occurred, and many calamitous fires have been produced by these stoves, which require, therefore, to be used with the utmost caution. The endeavours to prevent these explosions have hitherto been unsuccessful; and so long as the principle of the extreme slow combustion and small admission of air is preserved, it will probably be impossible to prevent them occasionally taking place. They appear to arise from the inflammable gases generated during the combustion of the fuel, being detained in the stove and in the chimney, by the want of sufficient

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by combining together a series of these bars, almost any extent of motion may be obtained, for the purpose of opening or closing valves or air-passages of furnaces or ovens.

[1] *Ure's Dictionary of Arts, etc.*, art. *Stove.*

draught; and they are particularly liable to occur when the chimney is very large, or, if it consists merely of an iron pipe, and is much exposed to the cooling influence of the atmosphere. In such cases the heat which escapes into the chimney is insufficient to cause the ascent of the liberated gases; they therefore form in the stove, or in the chimney, explosive compounds, the effects of which become visible whenever the air and the gases mix together in certain proportions. The compound thus formed is similar to the gas known in mines by the name of fire-damp; and this mixture will explode whenever the carburetted hydrogen is not less than one-twelfth and not more than one-sixth of the whole mass. The explosion of carbonic oxide only takes place under particular circumstances; but red-hot charcoal will cause it to explode when mixed in the proportion of two measures of oxide to one of atmospheric air;[1] and Dr. Dalton has remarked other circumstances under which this gas may explode when mixed with atmospheric air, the carbonic oxide being not less than one-fifth and the oxygen not less than one-thirteenth of the whole mixture.[2] Many plans to remedy these evils have been proposed, principally by the admission of air above the fuel as well as through the ash-pit in the usual manner; but occasionally this only increases the evil, during certain stages of the combustion, though generally the effect is to increase the temperature of the stove so much as to render it extremely unpleasant, and liable to all the objections which exist against the old hot-air stoves. The immense number of serious accidents which have occurred from these stoves, ought to render those persons who use them extremely careful. The great source of danger arises from their fancied security; and this erroneous notion has caused them

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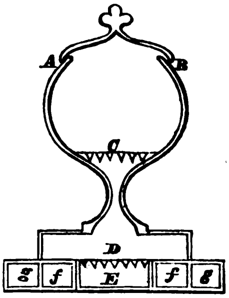
[1] *Dr. Henry's Chemistry*, vol. ii. p. 347.

[2] *Dr. Dalton's Chemical Philosophy*, p. 373.

to be placed in situations not sufficiently protected; and either by explosions, or by the stoves, from accidental causes, becoming red-hot, many buildings have been set on fire, and most serious damage sustained.[1]

(263.) A very excellent contrivance for a stove, which burns coal, and at the same time consumes its own smoke, was invented by Dr. Franklin, in the year 1771. Nearly a century previous to that time, M. Delesme, a French engineer, described an exceedingly rude contrivance on a similar principle, which was afterwards mentioned by Dr. Leutmann in a work on stoves, published by him in Germany, in 1723. Dr. Franklin expressly acknowledged that this stove of Delesme gave rise to his own invention. This stove is in the shape of a large vase, of which fig. 32 is a section, and it is fully described in Dr. Franklin's works.[2] Near the bottom of the body of the vase a grating C is placed, on which the fuel rests, and the top A B opens for the purpose of supplying the fuel. D is a square box forming the pedestal of the stove, at the bottom of which another grate is fixed to allow the ashes to fall into the box E. This latter box is open at the back, and communicates

Fig. 32.



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[1] The author is in possession of an extensive list of accidents caused by these stoves, some involving total destruction of the buildings, and many more of serious damage. In one of the former three lives were lost; and among buildings totally destroyed is to be reckoned Okehampton Church, and (almost beyond a doubt) the Armoury at the Tower of London. Howth Castle, near Dublin; Larkfield House, Sussex; and a vast number of other private and public buildings have had narrow escapes from destruction from this cause. And wherever these stoves are used the utmost caution ought to be observed to keep them insulated from every thing of an inflammable nature.

[2] *Franklin's Works*, vol. ii. pp. 296—300.

with the hot-air passages *f f* and *g g*, through which the heated gaseous matter given off from the fuel passes before it enters the chimney. It will be perceived that the draught of this stove is *downwards;* that is, the air enters at a small hole, about one-and-a-half inch diameter, at the top of the stove, passes through the fuel in the vase, and escapes, together with the gaseous products of the fuel, through the pedestal D, the box E, and the hot-air passages *f f* and *g g*. That portion of the fuel which lies on the grate C is always red hot; and the smoke from any fresh fuel having to pass through this heated medium, is consumed, and the gases pass off in a clear and almost invisible state, so that no smoke lodges in the air passages or in the chimney. Like all stoves with a downward draught, the fire is troublesome to light in the first instance; but when once lighted, it can be made to burn for almost any length of time without attention, by merely adjusting the opening at the top for the admission of air, and the consumption of fuel is extremely small.

This stove, with some slight alterations, has been brought before the public on more than one occasion since Franklin's time, as a new invention; and within the last four or five years it has been again brought forward with arrangements very decidedly inferior to those proposed by Franklin. As designed by him, this stove is the best and most economical of its class, superior to Dr. Arnott's stove in its equality of temperature, economy of fuel, and permanence of action; though like the latter, and all others of the same general character, the want of ventilation, and the peculiar effects produced on atmospheric air by highly heated iron, render it undesirable for constant use in rooms for ordinary and domestic occupation.

(264.) The application of a method of burning carburetted hydrogen or coal gas, for the production of artificial heat for warming buildings, is an invention of rather recent date. The apparatus in which this is effected is very simple. A metallic ring, pierced on its upper side with a great number of holes of very small size, is connected with a pipe communinicating with the gas main, and is placed within a double drum or cylinder of iron, raised an inch or two from the floor on small legs. This double drum is so made that there is a space between the inner and outer cylinder of about two inches; and in this space, near to the bottom, the ring pierced with holes is fixed. A stop-cock in the pipe connecting the pierced ring with the gas-main, shuts off the supply of gas when the stove is not in use. On opening this cock, and applying a light to the pierced ring, a brilliant ring of flame is immediately produced, which soon warms both the inner and the outer case of the stove by the heat generated during the combustion of the carburetted hydrogen gas. The top of the drum is covered with a large open ventilator, by which the heated air that passes through the inner cylinder is allowed to escape into the room; but the products of the combustion, having no means of escape, pass downwards from the bottom of the stove into the room. This having been found exceedingly unwholesome, a plan has been contrived by which a considerable portion of the products of the combustion are carried off by a pipe inserted between the two cylinders, which conveys away the gaseous products into the open air.

A moderate-sized stove of this description burns from 12 to 15 cubic feet of carburetted hydrogen gas per hour; and this is converted into two new compounds—water and carbonic acid gas. The quantity of water formed will be 2·6 cubic inches for each cubic foot of carburetted hydrogen, or about a pint to a pint and a quarter of water per hour; and from 12 to 15 cubic feet of carbonic acid gas, and *eight* times that quantity of nitrogen, will be the constant products of the combustion, and produce the most serious deterioration in the quality of the air. But when these gaseous products are carried off by a chimney, the loss sustained will be very nearly one-half the total heat which is produced by the burning of the gas.

(265.) Dr. Dalton's experiments have proved that the combustion of one pound in weight of carburetted hydrogen generated sufficient heat to melt 85lbs. of ice. A cubic foot of this gas weighs 292·89 grains; and a stove burning 15 cubic feet an hour, for 15 hours a day, will consume 225 cubic feet, or 9·41 lbs. of gas, which therefore would melt 799 lbs. of ice; and the cost of this quantity of gas, at the usual average price, would be two shillings and threepence. The latent heat of water being 140°, the same quantity of heat that would melt 799 lbs. of ice, would heat 179·2 cubic feet of water 10°. And as one cubic foot of water will raise the temperature of 2990 cubic feet of air as many degrees as the water loses (Art. 106), the combustion of 225 cubic feet of carburetted hydrogen gas would raise the temperature of 535,808 cubic feet of air 10°. This then will be the total effect of a stove of this kind. But we find (Art. 104), that 15·91 lbs. of coal will produce exactly the same quantity of heat, the cost of which will be only about threepence, or, to allow for waste and imperfect combustion, say the coal will cost fivepence; it therefore appears that the cost of fuel for a gas stove without a flue will be more than five times as much as a hot-air stove that burns coal, and about ten times as much as for coal, if the gas stove has a flue for carrying off the products of the combustion. Sir John Robison, who did much to improve the gas stoves, and particularly in applying them to the purposes of cooking, in a paper read before the Society of Arts for Scotland, after describing some of his improvements, concluded by stating, that, "on the whole, it may be assumed that this mode of heating apartments is the most expensive, the least efficient, and, excepting that by Joyce's charcoal stove, the most insalubrious that can be resorted to."[1]

(266.) The stove invented by Mr. Joyce, for burning charcoal, has been so universally admitted as too unwholesome for use, that it would be almost unnecessary to describe it, were it not for the vast interest it excited on its first announcement to the public. The stove consists of a thin metal case, generally in the form of an urn or vase. Through the bottom of this, there is a small pipe which rises for two or three inches into the body of the stove, and terminates about the centre in a conical-shaped funnel, closed at the top, and pierced full of holes. This pipe conveys air to the fuel; and at the top of the stove there is a valve or regulator, by which the rate of combustion can be controlled; for no more air will enter the lower pipe than is sufficient to replace the volume of gas given off from the valve at the top of the stove. A small quantity of ignited charcoal being placed in the stove, the remaining space is filled up with charcoal not ignited; and the combustion is slowly carried on by the air which enters at the lower pipe, and can be continued for a vast number of hours without any attention. The whole of the charcoal is converted into carbonic acid gas, the effects of which are fatal to animal life. Little or no smell is emitted by these stoves; the charcoal being deprived of its usual pungent quality, by reburning it thoroughly in a close oven, and quenching it while hot with an alkaline solution. Independent of all other considerations, these stoves are a most expensive mode of producing heat, owing to the high price which charcoal always bears in this country.

These stoves are remarkable chiefly for the ex-

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[1] *Mechanic's Magazine,* vol. xxxii. p. 292.

traordinary interest they excited on their first introduction to public notice. Before the specification for the patent was enrolled, one of these stoves was publicly exhibited for several weeks; and probably no invention ever excited so much attention in so short a time; as the nature of the fuel and plan of combustion were strictly kept secret, and it was supposed a new era in the production of artificial heat was about to commence. No sooner did the stoves come into use, however, than their deleterious effects were apparent. Several persons were suffocated by using them; and the high anticipations, which at first were entertained of them, were quickly dissipated, and their use reduced within very narrow limits.

(267.) An immense number of stoves have been brought before the public during the last two years, of which the novelty consists in nothing but their names. To describe them would be useless. Like other ephemeral productions, they will mostly sink into oblivion, and probably be succeeded by others as devoid of originality. There is still room, however, for great improvements in the production of stove heat; but, until the salubrity of the open fire grate can be combined with the greater economy of the close stove, there does not appear much probability of satisfying the required conditions, as all which have hitherto been invented are deficient in one or other of these particulars.

(268.) The same objections also, to a greater or less extent, apply to all the methods of heating by flues. The extremely unequal temperature of the flues causes an insurmountable objection to their general adoption, even if their great expense and difficulty of adaptation to dwelling-houses or public buildings did not operate against them. One of the best systems of flues was proposed a few years since, by Mr. Alfred Beaumont, in which the principal novelty consisted in the furnace being built *above* the flue, and having a downward draught. By this means the smoke from the fire was nearly or quite consumed, and a very great evil of common flues thereby prevented; as the surface of the flues being by this means free from soot, which is a non-conductor of heat, a more free distribution of heat took place than by the old flues, and the fire was also much more under control. The principle, already described, for downward draughts, applies equally to this plan. The furnace (in some cases) was merely a circular hole sunk in the floor, about two or three feet deep. The bottom, when in use, was a solid plate; which was moveable, to take away the ashes. About three inches from the bottom there was an entrance into the flue; through this the flame and the products of combustion passed to the flues, and the fire being always bright at the bottom, the combustible gases from the fresh fuel, by passing through this, were converted into other products, which did not deposit smoke. In other cases, a stove made of fire-clay was raised on the floor; and the flame and heated gases passed into the flues, which formed the stone flooring of the room to be heated. In all these cases, the principle was the same; and several public buildings were heated on this plan, which is probably the best of any system of flues.

CHAPTER III.

ON THE CHANGES PRODUCED IN ATMOSPHERIC AIR, BY HEAT, COMBUSTION, AND RESPIRATION.

Necessity for Ventilation — Constitution of the Atmosphere — Ventilation first proposed in Sixteenth Century—subsequent Inventions for Ventilating—Effects of contaminated Air on the Human Frame—Effects of Climate on Health and Longevity —Cause of Miasmata — Effects of excessive Moisture and excessive Dryness of the Atmosphere—Respiration, its Products and Effects—Impure Air—Carbonic-acid Gas—Vapour from the Body—Effect of Diminished Pressure—Electric Condition of the Air—Decomposition of extraneous Matter in the Air—Effects of Hydrogen, Carburetted Hydrogen, and Carbonic Oxide—Quantity of Air required for Ventilation— Importance of the Air to Animal and Vegetable Life.

(269.) Probably no subject connected with the health and vigour of the mind and body deserves more and receives less attention, than the condition of the internal atmosphere of our houses and apartments. Attempts are indeed occasionally made to introduce some system of ventilation in public buildings, but they are far more frequently unsuccessful than otherwise, in consequence of the arrangements not having formed any part of the original plan, and being mere additions of a very imperfect character. In private dwellings, however, ventilation appears never to be considered as at all necessary: but if the contaminations and impurities that are frequently contained in the air which forms the *pabulum vitæ* of human beings, could be seen by the eye, in the same way as contaminations or impurities in ordinary alimentary food, the evil would not be endured for even the smallest period of time.

(270.) The real constitution of the atmosphere has been known, comparatively, but a short time; the experiments of Priestley, Scheele, and Lavoisier, in the latter part of the last century, having first made known its true nature. More than twenty centuries previously, however, Hippocrates wrote so justly on the immense importance of breathing pure air, of the great influence which it exerted on health and longevity, and laid down such just rules upon the subject, that few writers, even of the present day, appear to have more correct notions of the vast and important effects which the air produces on the human frame, than were possessed by this great father of medicine.[1] Agricola, however, in the sixteenth century, appears to have been the first writer on artificial ventilation; he having recommended the ventilation of mines by producing a current of air by fire, much in the same manner as has been practised in mines ever since his time. Nothing of any considerable importance occurred after this, until Desaguliers, in 1727, proposed a ventilating pump,[2] which some years afterwards Dr. Hales[3] applied in a better manner and to a considerable extent, in the ventilation of ships, hospitals, prisons, and other places which were found to be unwholesome by confined air. In 1734, Desaguliers invented a centrifugal ventilating wheel or fan; and in 1739, Sutton proposed a plan of ventilating ships, which consisted in drawing the air required for the combustion of the fuel in the ship's cooking apparatus, through pipes leading from the hold, and other confined places,[4] precisely on the

[1] *Hippocrates*, lib. *de Acre, Aquis, et Locis.*

[2] *Philosophical Transactions*, 1727, vol. xxxv. p. 353.

[3] *Ibid.*, 1743; and *Dr. Hales on Ventilators*, London, 1743.

[4] *Philosophical Transactions*, 1742, vol. xlii. p. 42.

same plan that has been repeatedly adopted since his time, and has also been applied to the present Houses of Parliament. Since the time of Hales, many plans have been proposed for ventilating buildings, but they are mostly modifications of one or the other of the methods here described, and, if properly applied, are amply sufficient to accomplish all that is required.

(271.) Few persons have any notion of the vast consequences which result from impure air; and how seriously the duration of human life is affected by want of proper attention to this important subject. Dr. James Johnson,[1] speaking of the effects of impure air, says, "that ague and fever, two of the most prominent features of the malarious influence, are *as a drop of water in the ocean*, when compared with the other less obtrusive but more dangerous maladies that silently disorganise the vital structure of the human fabric, under the influence of this deleterious and invisible poison;" and experience proves that multitudes shorten their lives by breathing impure air, and many more lay the foundation of diseases, accompanied by years of pain and sorrow, by neglecting to avail themselves of the bountiful provision of nature, which spontaneously affords to all who choose it, an unlimited supply of this important element, and requiring merely an unrestricted and free passage to diffuse itself abundantly in every direction.

(272.) The powerful effects which are produced on the animal functions by certain deleterious gases are very imperfectly known, as they are generally found in so diluted a state as to render their action slow and almost imperceptible. But to be aware of their real nature and influence, we should see their effects in a more concentrated form. Dr. Christison, in his work on Poisons, quotes from Hallé a descrip-

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[1] *Diary of a Philosopher.*

tion on the effects of the gases from the *fosse d'Aisance* of Paris, on those who inhale them; and Dr. Kay gives the following account of them in his work on Asphyxia.[1] "Often the individual exposed to them perishes in a moment, his head and arms falling, and the trunk being doubled up from the instantaneous loss of muscular power. If death does not immediately occur, the victim, when he recovers from the first effects of this exposure, is affected with pains in the head, nausea, fainting fits, severe pains in the stomach and limbs, and constriction of the throat. Sometimes he utters involuntary cries, or lapses into dilirium, accompanied with the sardonic laugh and convulsions, or tetanus ensues. The face is pale; the pupil dilated and motionless; the mouth filled with a white or bloody froth; respiration convulsive; the pulsation of the heart irregular; the skin cold; until at length complete Asphyxia and death terminate the scene of suffering." The gases which produce these effects are combinations ~~of~~ ammonia, sulphuretted hydrogen, and nitrogen; and all these gases are occasionally to be found in the contaminated air of close ill-ventilated rooms, though of course in smaller quantities. The effects of climate are of the same kind. The impurity of the air in certain localities produces the most frightful results. Cretinism, although its cause is not positively ascertained, is ascribed by medical writers to confined air and other agencies;[2] and so frightful and revolting is this state of degeneracy of both body and mind, that Dr. James Johnson's description of the disease fully realises the character which he has given it, that "Goitre (or the enlarged neck), on such a scale as we see in the Vallais, is bad enough; but Cretinism is a cure for the pride of man, and may here be studied by the philosopher and physician on

[illegible]
Carb acid

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[1] *Dr. Kay's Physiology and Treatment of Asphyxia,* p. 326.

[2] *Dr. Hawkins's Medical Statistics,* p. 198.

a large scale, and in its most frightful colours."[1] The picture is almost too frightful to copy, and is only second to his description of another scourge, Pellagra, arising from the same cause, which afflicts nearly one-seventh of the inhabitants of the Lombardo-Venetian Plains,[2] and the wretched victims of which rot away in a state so painful and disgusting, that the description absolutely sickens the reader, and prepares him for the announcement, that multitudes of these wretched beings end their state of hopeless misery by committing suicide, which they generally do by drowning.

(273.) The statistical reports laid before Parliament by the War Office, on the sickness and mortality of the troops of the United Kingdom stationed in different parts of the world, prove most clearly the immense effect upon human life produced by small and almost inappreciable differences in the quality of the atmosphere. For on the same class of persons performing the same duties, and placed as nearly as possible in the same circumstances, the average mortality varies in different parts of the world, from 1·37 per cent. per annum to 66·83 per cent. per annum; or the mortality is nearly forty-nine times as great in some localities as in others.[3] The morbific

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[1] *Dr. James Johnson's Change of Air, or the Pursuit of Health,* etc. p. 56.

[2] *Ibid.*, p. 75.

[3] These reports present the result of twenty years observation, and were laid before Parliament in the years 1838, 1839 and 1840, being respectively for "The West Indies,"—"The United Kingdom, the Mediterranean, and British America,"—and "Western Africa, the Mauritius, etc." The following list is extracted from these reports, and gives the mortality *per cent. per annum,* among white troops only, exclusive of native troops:—

	Per cent.		Per cent.
British Guiana	8·4	St. Vincents	5·49
Trinidad	10·63	Barbadoes	5·85
Tobago	15·28	St. Lucia	12·28
Grenada	6·18	Dominica	13·74

influence of certain gaseous emanations from the earth, in various parts of the globe, is well known. "The banks of the Nile about Sennaar," says Bruce, "resemble the pleasantest part of Holland in the summer season; but soon after, when the rains cease, and the sun exerts his utmost influence, the dora begins to ripen, the leaves to turn yellow and to rot, the lakes to putrify, smell, and be full of vermin, and all this beauty suddenly disappears—bare-scorched Nubia returns; and all its terrors of poisonous winds and moving sands, glowing and ventilated with sultry blasts, which are followed by a troop of terrible attendants — epilepsies, apoplexies, violent fevers, obstinate agues, and lingering and painful dysenteries, still more obstinate and mortal."[1] So pestilential is this spot, that "no horse, mule, ass, or any beast of burden, will breed or even live at Sennaar, or many miles round it. Poultry does not live there. Neither dog nor cat, sheep nor bullock, can be preserved a season there. They must all go every half-year to the sands."[2] Dr. James Johnson's graphic account of the Campagna di Roma,[3] and its poisonous exha-

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	Per cent.		Per cent.
Antigua, etc.	4·06	Cape of Good Hope, Frontiers	0·98
St. Kitts	7·10	Mauritius	2·74
Jamaica	12·13	Ionian Islands	2·52
Sierra Leone	48·3	New Brunswick	1·47
Cape Coast Castle	66·83	United Kingdom	1·4
St. Helena	3·3	Canada	1·61
Cape of Good Hope	1·37		

These interesting reports give many particulars relating to the climate of each place. The principal characteristic of Sierra Leone and Cape Coast Castle is the extreme humidity of the atmosphere. In the year 1828, upwards of 313 inches of rain fell in three months at the former place; and in the following year, the quantity was 144½ inches in six months, but owing to the registers being imperfect the annual mean quantity has not been exactly ascertained.

[1] *Bruce's Travels*, vol. vi. p. 387.

[2] *Ibid.*, p. 381.

[3] *Dr. James Johnson's Change of Air*, etc., pp. 117 and 219.

lations, and Signor Gaetano Giorgini's account of some other pestiferous localities,[1] give a sufficient idea of the effects of apparently small corruptions of the atmosphere. And these accounts, to which vast numbers of others might be added, all prove how very small an alteration in the constitution of the atmosphere materially affects the health of all who expose themselves to its influence. Professor Daniell has lately ascertained some facts, which render it probable that many of the localities desolated by malaria owe their unwholesomeness to small quantities of sulphuretted hydrogen, produced by decomposition of the sulphates contained in sea-water by decayed vegetable matter.[2]

(274.) We have seen the effect of climate on the military, by the returns from the War Office, already alluded to. The duration of life among the inhabitants of different countries is not less remarkable. The average deaths annually, throughout England and Wales, are in the proportion of one for every sixty inhabitants; and they vary in every country,[3] being nearly three times more numerous in some

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[1] *Ann. de Chimie*, vol. xxix.; also *London and Edinburgh Phil. Magazine*, vol. xix. p. 15.

[2] *Daniell, on Sulphuretted Hydrogen*, etc., *London and Edinburgh Phil. Magazine*, vol. xix. pp. 1—19.

[3] Dr. Hawkins, in his *Medical Statistics*, pp. 30—74, gives the following average of the *annual* deaths in different localities.

England	1 in 60	Naples	1 in 28
Pays de Vaud	1 in 49	Leghorn	1 in 35
Sweden	1 in 48	London	1 in 40
Holland	1 in 48	Manchester	1 in 74
France	1 in 40	Birmingham	1 in 43
Prussia	1 in 35	Paris and Lyons	1 in 32
Kingdom of Naples	1 in 35	Strasburg & Barcelona	1 in 32
Wirtemberg	1 in 33	Berlin	1 in 34
Russia	1 in 41	Madrid	1 in 29
Venetian Provinces	1 in 28	Rome	1 in 25
United States	1 in 40	Amsterdam	1 in 24
Nice	1 in 31	Vienna	1 in 22½

This average for England, which is stated to extend to the year parts of Europe, than in England. Very remarkable differences occur also in localities differing but very little from each other. M. Quetelet, in his celebrated work on Man, states, in reference to the effects of climate on the duration of life, that the deaths annually in the different localities are as follow:—

Departement de l'Orne .	1	death in every	52·4	inhabitants.
„ de Finisterre	1	„	30·4	„
Province of Namur . .	1	„	51·8	„
„ of Zealand (Netherlands) .	1	„	28·5	„

This great excess of mortality in the last-named place, M. Quetelet attributes to the extreme and constant humidity of the atmosphere, which produces an immense number of fevers and other maladies.[1] The observations of M. Bossi also confirm this opinion; for, by dividing the *Departement de l'Ain* into four districts, he found the deaths annually to be as follow:[2]—

In the Mountainous Parts .	1	death in every	38·3	inhabitants
On the Banks of Rivers . .	1	„	26·6	„
On the level Parts sown with Corn	1	„	24·6	„
In Parts interspersed with Ponds and Marshes .	1	„	20·8	„

And it can be shewn that, in England also, the rate of mortality follows nearly the same ratio, from the same causes: and in the reports on the mortality among troops already alluded to, the excessive unwholesomeness of some particular districts, is attributed entirely to the excessive moisture of the atmosphere, particularly when accompanied by high temperature. All physiologists have agreed as to the injurious

1821, does not quite agree with more recent calculations, founded on the Report of the Registrar-General, and the difference probably arises from some variations in the mode of taking the averages.

[1] *Quetelet, sur l'Homme, et le Développement de ses Facultés,* etc., and *London Statistical Journal,* vol. i. p. 176.

[2] *London Statistical Journal,* vol. i. p. 177.

effects of a heated atmosphere saturated with moisture. Hippocrates, by a comparison of the prevailing diseases with the state of the weather, and particularly as respected the moisture of the air, drew conclusions, which the observations of succeeding ages have fully confirmed. Excessive dryness, however, not less than an extraordinary degree of moisture, equally destroys the salubrity of the air; though the diseases produced by these opposite states are, as might be imagined, of a very different character.[1] The monsoon, or rainy season of India, the campsin, or southerly wind of Egypt, and the simoom, or hot wind of the Asiatic continent, more rapidly destructive than either of the others, are some among the numerous instances which might be adduced to prove the effects of various excessive degrees of heat, moisture, and dryness of the air.

(275.) The effects produced on the hygrometric condition of the air by various modes of artificial heat are of much importance. Dr. Ure has described[2] the result of his examination into the effects produced upon a great number of the gentlemen in the Long Room of the Custom House, London, arising from the use of the powerful hot-air or cockle stoves, used for heating that establishment. He found they were all affected with the same sensations and complaints; tension or fulness of the head, flushings of the countenance, frequent confusion of ideas, remarkable coldness and langour in their extremities, feeble pulse and other sensations of an unpleasant character. The stoves he found were frequently red hot, and the air in passing over them was sometimes heated to 110°, and was thereby rendered intensely dry. The animal and vegetable matters floating in the air were decomposed, and imparted a disagreeable smell to

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[1] *Dr. Arbuthnot, on the Effects of Air on Human Bodies;* and Dr. Paris, *Pharmacologia*, vol. i. p. 197, 325, etc.

[2] *Philosophical Transactions*, June, 1836.

the atmosphere. This apparatus was found to be so pernicious that it was removed, and a different mode of heating adopted. But these effects, described by Dr. Ure, are by no means uncommon. The author examined a school heated in the same manner; and it was found to be so pernicious to the health of the children, that they occasionally dropped off their seats in fainting fits; and when this did not occur, they suffered so much by the debilitating effects of the intensely heated atmosphere that they constantly required the relief of going for a few minutes into the fresh air. The usher of the school, a strong healthy young man, also suffered in the same way; and on one occasion he fainted away in the school-room, and it was with difficulty that animation was restored. These pernicious effects, though generally in a somewhat less degree, always result from the use of intensely heated metallic surfaces. They are, however, much modified by tempering the air by the evaporation of water. In Russia and Sweden, the Apennines, and other places, where close stoves are used, an earthen vessel of water is always placed on the stove for this purpose, and greatly mitigates the oppressive effects which would otherwise be experienced. The desiccating power of the air increases with its temperature, to a very great extent. Air at 32° contains, when saturated with moisture, $\frac{1}{160}$th of its weight of water; at 59°, it contains $\frac{1}{80}$th; at 86°, it contains $\frac{1}{40}$th; its capacity for moisture being doubled by each increase of 27° of Fahrenheit.[1] But when air is heated artificially without being in contact with water, it is prevented from acquiring this additional quantity of vapour, and it then possesses a harsh and arid feel, the effects of which we have already seen. And this extreme aridity of the air causes it rapidly to absorb moisture from the skin

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[1] *Leslie, on Heat and Moisture*, p. 123.

and lungs of persons exposed to its influence; and the evaporation, by its refrigerating effect, contracts the blood-vessels at the surface, while other parts, not being exposed to this influence, become in consequence surcharged with the fluids which are repelled from the extremities.[1]

(276.) A comparison of the dew point of the air, made at those seasons of the year which are the most salubrious and agreeable, shews that, in rooms artificially heated, the most healthy state of the atmosphere will be obtained when the dew point of the air is not less than 10°, nor more than 20° Fahrenheit, lower than the temperature of the room. When these limits are exceeded, the air will be either too dry or too damp for healthy and agreeable respiration; and attention to the hygrometric condition of the air would, perhaps, tend more to the amelioration of that numerous class of pulmonary complaints which so peculiarly distinguish the inhabitants of this country, than any other remedial measure.

(277.) The decreased consumption of oxygen, when a highly heated atmosphere is breathed, is also another circumstance which exerts considerable influence on health. The experiments of Seguin, Crawford, and De la Roche,[2] on this subject, shew that, under these circumstances, the blood is not so thoroughly decarbonised, as when a colder atmosphere is breathed; and this, as we shall presently have occasion to shew, quickly operates on the nervous system, affecting the animal functions as well as the mental faculties. In winter fully one-eighth more oxygen is consumed, than in the summer during the same period.[3]

(278.) The contamination of the air, produced by respiration and by artificial heat and combustion, is

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[1] *Ure, on Ventilation, etc., Philosophical Transactions,* 1836.

[2] *Murray's Chemistry,* vol. iv. p. 480.

[3] *Liebig's Animal Chemistry,* pp. 16, 17.

very considerable. Wide spreading as are the consequences of the malarious influences of climate, the effects produced by the contaminations of the air, by the causes now to be described, are scarcely less extensive, though less capable of being numerically determined; and as the progress of civilization causes larger numbers of persons to congregate together, the necessity for attending to these effects becomes continually of greater importance.

(279.) Respiration is a never ceasing and most extensive source of contamination of the air, and the theory of its operation has long engaged the attention and divided the opinions of physiologists. The opinion held by some of the most eminent, is that *inspiration* is involuntary, being caused by the pressure of the air on the lungs; while *expiration* is the effort of the lungs to discharge the air after it has been changed in its nature, and become hurtful to them.[1] The effects produced by breathing over again a portion of this mephitic air, depends upon the constitution of the individual who is exposed to its influence, and upon the amount of the contamination which the air has sustained. Considerable differences exist in the experiments which have been made upon the changes produced by respiration on atmospheric air: but this is unavoidable, on account of the very different capacity of the lungs of different individuals, and also in consequence of the mephitis itself differing in the same individual during the various stages of digestion, exertion, or repose, and according to the nature of the ingesta which he receives.

The contamination of the air is produced not only by respiration but by animal exhalations, which are given off by both the lungs and the skin. That which is produced by respiration is chiefly by the formation of carbonic acid gas, and by the vapour

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[1] *Blumenbach's Institutes of Physiology*, by Eliotson, p. 84.

which is exhaled from the lungs. The proportion of both the vapour and the carbonic acid gas has been variously estimated by different experimentalists. Dr. Prout[1] has collected together the results of the different experimenters on the quantity of carbonic acid given off in respiration. His own experiments give a mean of about three-and-a-half per cent. as the quantity expired by himself, and four-and-a-half per cent. when his experiments were made on another person. Sir Humphry Davy's estimate is about four per cent.; Menzies, five per cent.; Dr. Murray, six per cent.; Allen and Pepys, eight per cent.; Dr. Fife, eight-and-a-half per cent.; Goodwin, and also M. Jurin, ten per cent. But Dr. Prout has shewn that the quantity varies greatly at different periods of the day, and that the maximum quantity is given off about noon, up to which period it gradually increases from the beginning of twilight; and after noon it as gradually decreases till evening, and is at its minimum during the night.[2] Some recent and extensive experiments have confirmed these results generally; but it appears the times of maxima and minima depend principally on the state of digestion and the periods of taking food.[3]

The quantity of vapour given off from the lungs has also been very variously estimated. Dr. Menzies calculated it at six ounces; Mr. Abernethy, nine ounces; Sanctorious, eight ounces; and Dr. Hales, twenty ounces in twenty-four hours;[4] and the average is supposed to be about three grains per minute. The amount of vapour given off from the skin was found by Thenard to vary from nine to twenty-six grains per minute. Keil found it to amount to thirty-

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[1] *Annals of Philosophy*, vol. ii. p. 336.

[2] *Ibid.*, p. 330.

[3] *London and Edinburgh Philosophical Magazine*, vol. xiv. p. 401.

[4] *Dr. Paris's Medical Chemistry*, p. 316.

one ounces in twenty-four hours, or ten and a half grains per minute. Seguin ascertained that it varied from eight to twenty-four grains per minute; and it is generally considered that the average quantity is about ten grains per minute, which agrees with the experiments of Lavoisier.

(280.) It is also found that the quantity of oxygen consumed in respiration varies with the state of exertion or repose. Lavoisier found that by a man, while engaged in strong muscular exertion, compared with the same individual while in a state of repose, the consumption of oxygen was as 32 to 14. It is also ascertained that the quantity of oxygen consumed in respiration exceeds the bulk of carbonic acid gas which is expired from the lungs; the remainder unites with the hydrogen derived from the food, and forms the vapour given off from the lungs and skin: and these proportions differ so greatly with the nature of the food, that while some animals expire a quantity of carbonic acid equal to that of the oxygen consumed, others do not expire more than half as much carbonic acid as the oxygen consumed would produce.[1]

(281.) Notwithstanding these differences of opinion among physiologists respecting various points connected with respiration, there are certain fundamental facts which are agreed upon, that we shall find amply sufficient for the illustration of the subject before us.

(282.) The quantity of air admitted into the lungs varies in different individuals, and even in the same individual at different times, being greatly influenced, as already stated, by the relative amount of exertion or repose. Some experimentalists have estimated that as much as 800 cubic inches of air enters the lungs per minute; but it is more generally supposed to be about 330 cubic inches per minute under

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[1] *Liebig's Animal Chemistry*, p. 26.

ordinary circumstances:[1] and this air, after passing through the lungs, returns charged with carbonic acid gas and vapour of water, as already stated.

(283.) Whenever the same portion of air is breathed a second time, a great sensation of uneasiness is experienced. This arises from several causes. The quantity of oxygen contained in the air, when in its natural state, varies from 20·58 to 21·12 per cent.;[2] but it is found impossible to separate the whole of this oxygen by respiration, on account of the affinity which exists between the gases; and, however often the air is breathed, only about one-half of this quantity of oxygen can be separated from it. If therefore the process of respiration consumes (in forming the carbonic acid and the vapour) a quantity of oxygen, varying from six to eight per cent., by merely passing the air once into the lungs, it is evident that but very little can be afterwards abstracted by any further process of respiration.[3] Carbonic acid gas contains its own volume of oxygen; therefore, when any deficiency of oxygen occurs, the proper quantity of carbon cannot be given off from the lungs—a process which is absolutely indispensable for the preservation of life.

(284.) The physiological effects of a deficiency of oxygen are very remarkable. When the lungs are not sufficiently supplied with oxygen, sanguification ceases to be performed; and the arterial blood retain-

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[1] Menzies and Goodwyn estimate the quantity of air taken into the lungs, at each inspiration, at 12 cubic inches; Jurin, at 20; Cuvier, at 16 or 17; Davy, at 15; and Thomson, at 33.—(*Dr. Kay on Asphyxia*, p. 123). The number of inspirations in a minute, Haller considers to be about 20; Menzies, 14; Davy, 26 or 27; Dr. Thomson, 19; and Majendie, 15.—(*Dr. Paris's Medical Chemistry*, p. 315.)

[2] *Dalton, on the Atmosphere, London and Edinburgh Philosophical Magazine*, vol. xii. p. 402.

[3] See the experiments of Messrs. Allen and Pepy's *Philosophical Transactions*, 1808, and *Nicholson's Journal*, vol. xxii. p. 204.

ing the dark colour of venous blood, circulates in this state through the system. Bichât proved by experiments,[1] that when venous or dark-coloured blood is injected into the vessels of the brain through the carotid artery, the functions of the brain are immediately disturbed, and in a very short time cease entirely; the heart instantly loses its motion, and death speedily follows. Bichât considers the effect of the venous blood circulating through the brain to be similar to the action of a narcotic poison; and this takes place when the air is impure and does not perfectly oxygenate the blood. When the lungs receive impure air, imperfectly oxygenated blood is circulated through the brain, producing a cessation of the functions of that organ, by which respiration is immediately affected, and the heart ultimately ceases to act. Sir B. Brodie also found by experiments made with various active poisons,[2] that when the action of the brain is impeded by other causes than that produced by the blood, a similar result obtains: for the instant the brain loses its action, respiration stops, the heart gradually fails of its power of contracting and propelling forward the blood, and death speedily ensues. But it has been found that, after the brain has ceased to act, if an artificial respiration of pure air be produced, and continued for a short time, the functions of the brain will be restored, and the animal ultimately recovers.

(285.) The effects so speedily experienced by some persons in close and ill-ventilated rooms are by these experiments easily accounted for. Headache is usually the first sensation of uneasiness which is experienced; and the succeeding symptoms of langour, uneasy respiration, faintness, and syncope, are all clearly referrible to the same cause as that which produced in Bichât's experiments the cessation of the

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[1] *Bichât, Recherches Physiologique sur la Vie et la Mort.*

[2] *Philosophical Transactions,* 1811; pp. 36 and 178, et seq.

vital functions. These effects always result from breathing air containing any considerable quantity of carbonic acid gas. When the quantity of this gas is very considerable, it produces such a painful irritation of the epiglottis, as immediately causes it to close spasmodically on the glottis, and thus prevents the entrance of the gas into the lungs; but this also prevents the entrance of the atmospheric air, and thus produces immediate suffocation.

(286.) Physiologists are divided in opinion as to the precise nature of the action on the human frame, exerted by carbonic acid gas. Sir Humphry Davy, Dr. Christison, Dr. Bird, and Dr. Paris, appear to consider that it acts as a strong narcotic poison. Dr. Thomson, and some others, entertain a different opinion, and think it only acts on the animal economy by preventing the proper quantity of oxygen from entering the lungs, and thence producing suffocation.

(287.) The greatest proportion of carbonic acid gas which may be breathed with impunity, has not been exactly determined, and opinions respecting it are very various. But it is evident that a given quantity of the gas produced by respiration or combustion will reduce the proportion of oxygen in atmospheric air to a much greater extent than the same quantity of carbonic acid gas added by simple mechanical mixture. For, in the formation of a given quantity of carbonic acid gas, either by combustion or respiration, exactly the like volume of oxygen is consumed—carbonic acid gas being a compound of one volume of gaseous carbon united to one volume of oxygen; therefore, by these modes of forming carbonic acid gas, we both reduce the quantity of oxygen, and increase the quantity of carbonic acid; and it has been estimated that two per cent. of carbonic acid gas produced by combustion, deteriorates the air as much as 10 per cent.

added mechanically by simple mixture.[1] But in ill-ventilated rooms this is by no means the only cause of the oppression and inconvenience which are experienced. The vapour given off from the lungs and from the skin forms a very important source of contamination; and, being charged with animal effluvia, its effects in contaminating the air are very considerable. The baneful effects of the mephitic exhalations from animal respiration are not confined to the human frame. The glanders of horses; the pip, of fowls; and a peculiar disease to which sheep are subject, all arise from the bad air generated by their being too closely crowded together;[2] and in no case can animals be confined in a vitiated air for any length of time, without serious injury resulting, although the effects may be shewn in various ways. In ordinary cases the contamination is insufficient to produce these violent and fatal effects; but the slow and insidious effects of a less deteriorated atmosphere are matters of far more importance than most persons believe;[3] and we have already seen, by the unerring evidence of statistical facts, how fearfully human life is shortened by even the smallest conceivable differences in atmospheric and climatic influences.

(288.) The quantity of vapour given off from the body (which we have already seen averages about 12 or 14 grains per minute) is greatly influenced, not only by the different degrees of muscular exertion and repose, but also under the ever changing hygrometric condition of the atmosphere: for the greater the quantity of vapour which the air contains, the less will the air be able to carry off from the human body. For the air possesses a desiccating power

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[1] *The Lancet*, for December, 1838.

[2] *Paris, Medical Chemistry*, p. 309.

[3] Some most excellent observations on this subject may be found in *Dr. Combe's Principles of Physiology*, 4th edition, pp. 236—238, and 244—248.

on the human body; but, of course, that power is lessened in proportion as it is nearer to the point of saturation.

(289.) The *hygrometric* condition of the atmosphere is ascertained by the *dew point.*[1] The lower is the dew point, the more moisture will be carried off from the lungs by the air in respiration; and therefore less will be given off by perspiration from the skin, than when the dew point is higher. This is often the case in very cold weather, when a large quantity of vapour is carried off from the lungs, and but little by perspiration. When air is respired from the lungs it is nearly of the temperature of the blood, which is 98° Fahrenheit; and it is then charged with a large quantity of vapour. If we ascertain the quantity of vapour which the air contains when expired, and deduct what it possessed before it was inhaled, we shall learn the amount given off by the lungs; the quantity of air breathed per minute being known. Now, suppose the temperature of the air, before it is inhaled, to be 40°, and the dew point 30°; as 330 cubic inches of air is the average quantity breathed per minute, $\frac{43}{100}$ of a grain[2] of vapour will be received into the lungs with the air per minute. But when the air is again expired, the temperature will be 98°, and the dew point is always found to be 94°; it will then contain 3·07 grains of vapour in the 330 cubic inches; so that upwards of two and a half

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[1] The dew point is that thermometric temperature of the atmosphere at which vapour is condensed. By exposing a cold body to the air, a fine dew is deposited on its surface, and, by observing the temperature of this cold body, we know the exact quantity of vapour contained in the air at that time. Warm air contains a larger quantity of vapour than that which is colder; for air has the property of taking up water in solution in a quantity proportional to its temperature. The Table II. Appendix, shews the quantity of vapour that the air contains when the dew point is obtained in this manner.

[2] See Table II. Appendix.

grains per minute are given off from the lungs under these circumstances. But if the dew point of the air, before it is breathed, be 50°, which is frequently the case in damp or warm weather, then a less quantity of vapour will be given off in the same time. Dr. Dalton states that, in the torrid zone, the dew point sometimes rises to 80°, and that even in this country it occasionally reaches to 60°, while, in winter, it is sometimes below zero. This easily accounts for the variable quantity of moisture which is exhaled from the body and lungs at different times.

(290.) The atmosphere, during damp weather, when it is frequently nearly in a state of saturation, is unable to carry off the full quantity of vapour from the body. This causes the oppressive sensation that is so often experienced under such circumstances; and the slightest exertion causes the perspiration to condense upon the surface of the body, and a degree of heat is experienced much greater than the simple thermometric temperature would occasion.

(291.) Although the carbonic acid gas given off from the lungs, is rather more than 37 per cent. heavier than the oxygen which is consumed, still, in consequence of the dilatation of its volume by the increased heat, and the greater levity of the vapour given off from the lungs, the air is specifically lighter at the moment of its expiration than at its inspiration. For 800 cubic inches of pure air at the temperature of 60°, and the dew point 40°, will weigh 243·395 grains; but 800 cubic inches of air at 95°, containing eight-and-a-half per cent. of carbonic acid gas,[1] and

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[1] The quantity of carbon given off from the lungs being so considerable, we cannot wonder that the subject of its origin has been a deeply disputed question. Supposing 26 cubic inches of carbonic acid gas to be given off from the lungs per minute, on an average, that quantity will contain 3·3 grains of pure carbon, which in 24 hours will amount to 11 ounces. Besides this, if the quantity of vapour from perspiration and pulmonary transpiration

5·6 grains of vapour, with the dew point 85°, will only weigh 232·450 grains; being nearly five per cent. lighter. Hence air, when expired from the lungs, always rises upwards, and will flow through ventilators in the ceiling, or the upper part of the walls of a room, if such be provided for its escape; but, otherwise, the vapour condenses, and the volume of the air collapses as it cools; it then becomes heavier than the substrata of air, and sinks to the lower part of the room contaminated with impurities.

(292.) The sensation of uneasiness produced by breathing impure air is an indication of the injurious

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be taken at 10 grains per minute for the former, and three grains for the latter, they will amount to 42 ounces in 24 hours, making the vapour and carbon together amount to nearly 3·3 lbs., besides other excrementitious matter from the body. Some other source, then, besides the food, must exist for obtaining the matter which supports vitality, and this probably is the air. Liebig has shewn (*Animal Chemistry*, p. 287), that a man takes in with his food, about 13·9 ounces of solid carbon daily; and that the more food he consumes, the greater quantity of oxygen he inspires. It has been ascertained by Dr. Prout, that a vegetable diet diminishes the quantity of carbonic acid gas given off, and, of course, reduces the quantity of oxygen consumed; because carbonic acid gas contains exactly its own bulk of oxygen, united to the given weight of pure carbon. The accuracy of Dr. Prout's experiments has been confirmed by divers, and persons making use of the diving bell. In all hot climates also, where, from the rarified state of the air, less oxygen is received at each inspiration than in the higher latitudes, the inhabitants feel but little desire for animal food, and use, principally, a vegetable diet; while, on the contrary, the inhabitants of the Arctic regions use animal food almost exclusively. Dr. Richardson, who accompanied Capt. Franklyn on his voyage of discovery to the Polar seas, says, that himself and the other individuals who composed the expedition, never felt the slightest wish for vegetable diet, but desired the most stimulating animal food, and in much larger quantities than they had ever before been accustomed to. In such a climate, in consequence of the coldness and density of the atmosphere, the quantity of oxygen inhaled is much greater than in warmer regions, and therefore allows the larger quantity of carbon to be carried off, which the dieting on animal food produces. These results, therefore, accord with Dr. Prout's experiments.

effects that result from it, which are too often neglected. When the air is not sufficiently pure to effect the complete decarbonization of the blood, we have seen that the result is the circulation of venous blood through the brain; the respiration then becomes impeded, and the nervous system deranged; the extent of these effects, of course, varying with the amount of the exciting cause and with the peculiar constitutions of the individuals exposed to their influence. Dr. Harwood remarks on this subject, "the want of wholesome air, however, does not manifest itself on the system so unequivocally, or imperatively; no urgent sensation being produced, like that of hunger, and hence the greater danger of mistaking its indications. The effects of its absence are only slowly and insidiously produced, and thus, too frequently, are overlooked until the constitution is generally impaired and the body equally enfeebled."[1]

(293.) The diminished pressure of the air in inhabited rooms, caused by rarefaction, by chimney-draughts, or by exhaustion of the air by mechanical means for the purpose of ventilation, has been supposed by some physiologists to produce considerable effects on the health of persons exposed to its influence. It cannot, indeed, be doubted that a diminished pressure of any considerable extent would be productive of great inconvenience, and cause considerable derangement of the animal economy. But the diminution of pressure from these causes seldom exceeds a quantity equal to about $\frac{1}{100}$ of an inch of the common mercurial barometer, and generally it does not reach $\frac{1}{200}$ of an inch. The ordinary fluctuations of the barometer produced by meteorological causes amounts to upwards of two inches and a half in the altitude of the mercurial column; and this

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[1] *Harwood's Curative Influence of the Southern Coast of England*, p. 282.

difference is not found generally to produce any remarkable effects on the animal functions,—a difference of pressure so very far exceeding anything which can occur in consequence of the rarefaction of the air in an ordinary room, that it cannot be conceived possible that this is the cause of the pathological effects which are experienced by persons much confined within doors.

The extremely small differences of pressure which occur by the rarefaction of the air in inhabited rooms by heat and ventilation, can only be detected by experiments with the differential barometer. But the natural differences of pressure which occur in many parts of the world are very great. At Mont Louis, in Roussillon, of the Pyrenees, one of the highest of the inhabited parts of Europe, the mean height of the barometer is only 24·65 inches,[1] which is more than five inches below the standard mean height in London; and many other places might be named where the pressure of the atmosphere is much reduced below our own standard. Some physiologists, indeed, have been of opinion that the inhabitants of places and districts, of which the height above the level of the sea is such as to cause a pressure considerably less than ours, are subject to peculiar diseases arising from this cause. Even the comparatively small differences which occur in the several parts of our own island, have been supposed to produce very marked pathological effects. Dr. Harwood has written at large on this subject;[2] and Drs. Wells, Darwin, Beddoes, and Cullen, and also Mr. Mansfield, have given similar opinions. From the facts they have collected, it appears that the inhabitants of high situations, where the atmospheric pressure is, of course, reduced, are more liable to

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[1] *Kirwan, on Temperature,* p. 89.

[2] *Harwood, on the Curative Influence of the Southern Coast of England.*

pulmonary consumption than those residing in low and even in marshy districts. But whether these effects are attributable or not to a diminished atmospheric pressure, the small difference which is caused by rarefaction and ventilation, wholly inappreciable as it is by any ordinary test by the barometer, can scarcely be supposed capable of producing any important results: while we possess the most ample evidence, that in the vitiated atmosphere, and altered hygrometric condition of the air, there exists abundant cause for the langour and deficiency of vital energy which are so frequently experienced by persons exposed to their influence.

(294.) Another cause, however, exists, which probably exerts far greater influence than that arising from altered pressure; a more accurate knowledge of which would enable us to account for frequent apparent anomalies in the sensations experienced in buildings which are artificially heated. The electric condition of the air, and its influence on the nervous system, are subjects apparently of the highest importance; but unfortunately our knowledge at the present time is so imperfect on this interesting and important branch of science, and almost daily experience of new discoveries convinces us we have still so much to learn respecting it, that it is difficult at present to assign to this agent its due place among the operative causes, which undoubtedly combine to render many methods of artificial heat peculiarly prejudicial to the animal economy.

(295.) Experiments of a very extensive character have shewn that the electric state of the atmosphere, when no peculiar disturbance takes place, is always of that kind which is known by the name of *positive* or *vitreous* electricity. The quantity of electricity contained in the air appears to be far greater than is generally supposed, as the experiments of Mr. Crosse, Mr. Sturgeon, and Mr. Weekes, clearly shew.[1] The quantity undergoes diurnal variations, there being two maxima and two minima in twenty-four hours;[2] the greatest quantities being a few hours after sunrise, and after sunset; and the smallest quantities being just before sunrise, and again a few hours before sunset,—or, as some suppose, about midday and midnight.

(296.) The experiments which have been made on the electric state of the air of close and ill-ventilated rooms, have shewn that in these cases the electric condition of the air is reversed, and that instead of being *positively* electric, the electricity of the air is of that kind which is called *negative* or *resinous* electricity. This subject has generally excited so little attention, that but few experiments have been made upon it; and the causes of interference are so numerous, that it requires much delicacy both in the instruments and in the manipulation to arrive at satisfactory conclusions. The similarity of the effects produced on the human frame under these circumstances, compared with the effects which are frequently experienced during the passage of thunder clouds, when the air is generally negatively electric, or else in a constant state of oscillation between the positive and negative, also leads to the conclusion that the electric state of the air of close rooms, performs a very important part in the production of those unpleasant effects which are generally experienced in such cases. In the natural state of the atmosphere, the earth is always found to be *negatively* electric with respect to the air, and of course all conducting bodies in communication with the earth are in a similar electric state. But when the air also becomes *negatively* electric, the earth still

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[1] *Noad's Electricity*, pp. 89—102.

[2] *Ibid.*, p. 99; *Daniell's Chemical Philosophy*, p. 253; *Schubler's Researches, Quarterly Journal of Science*, vol. ii. p. 416.

retains its original condition, and the human body thus becomes charged with electricity; the air in this condition being unable to carry off the electricity, as would be the case with a moderately moist atmosphere *positively* electric. The body in this case receives a charge of electricity similar to what is called the electric bath, produced by placing the person on a glass stool, and communicating a charge from an electric machine. The effects of the electric bath, when it is continued for a considerable time, are similar to those which result from the atmosphere of close rooms—headache and nervousness. Drowsiness, which is another frequent consequence of close rooms, is produced by a different cause, arising from the imperfect arterialization of the blood circulating through the brain, as we have already seen (Art. 284). Whatever therefore increases the *positive* electricity of the air, also relieves to a considerable extent the unpleasant effects of close, ill-ventilated, and highly-heated rooms. Evaporation of water, and, at certain periods of the day, vegetation, both tend to relieve the oppressive effects of close rooms; and both are known to produce *positive* electricity of the air.[1] So greatly does evaporation affect the electric condition of the air, that the diurnal variation in the quantity of electricity follows nearly the same course as the exhalation of moisture, and evaporation is considered to be the principal source of atmospheric electricity.[2] But evaporation, by adding to the moisture of the air, also renders it a good conductor of electricity; while dry air, on the contrary, is an extremely bad conductor: and hence it follows, that evaporation of water in a highly-heated and desiccated atmosphere must produce salutary effects, in relieving the unpleasant effects experienced in close rooms. It must not however be understood, that adding moisture to

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[1] *Thomson, on Heat and Electricity,* pp. 440 and 502.

[2] *Noad's Electricity,* pp. 92 and 100.

the air is at all times desirable. Sometimes the air may be deteriorated by any additional moisture, and the proper quantity of moisture is a question of great importance on health, as the fluids from the body cannot be carried off if the air be too moist; while, on the other hand, the electric condition of the body will be disturbed if the air be too dry.

(297.) The disturbance of the electric condition of the air certainly adds another link to the chain of causes which produce the unwholesome and depressing effects of ill-ventilated rooms. Dr. Faraday[1] considers that the deterioration of the air under these circumstances "depends as much or more on matters communicated to the air by the living system, as by any direct injury to the air due to the deficiency of oxygen or presence of carbonic acid;" and as electricity is produced by every change of state, both respiration and the vaporization of the fluids of the body must produce considerable effect upon the electric condition of the atmosphere of rooms, where large numbers of persons are congregated together.

(298.) The preceding remarks will enable us to estimate the comparative wholesomeness of various methods of distributing artificial heat. Many of these methods are highly injurious to the animal economy, and cannot be persevered in without permanent derangement of the health of those who are exposed to their influence.

(299.) There are always suspended in the air myriads of particles of animal and vegetable matter; but these almost unheeded atoms possess a high philosophical importance, however they may, generally, be disregarded. They are the evidences of the unceasing changes which the material world is continually undergoing—the irrefragable proofs that the visible matter of the universe is slowly and almost

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[1] *Report of Select Committee on Ventilation of Houses of Parliament*, p. 21.

imperceptibly passing through a series of transmutations, which affect both organic and inorganic nature. Many of these particles are easily decomposed by heat, and are then resolved into the various gases, either in their elementary or mixed state. Hence, many of the methods of producing artificial heat are materially affected, as regards their wholesomeness, by the fact of their being able or not to decompose or chemically alter these floating particles of matter. To this cause is mainly attributable the unpleasant smell produced by several modes of warming buildings by highly-heated metallic surfaces; and we have already seen that the hygrometric and electric condition of the air is also altered by the same means. All the different descriptions of hot-air stoves are more or less liable to these objections; as also the high-pressure system of hot-water apparatus, and still more the cockle or hot-air furnaces. Dr. Nott's stoves, and also the Russian and German stoves, are subject to this inconvenience. But the cockle or hot-air furnace is particularly liable to these objections; for not only will it act powerfully in decomposing the floating particles of extraneous matter contained in the air, resolving them into sulphuretted, phosphuretted, and carburetted hydrogen, with various compounds of nitrogen and carbon, but it will likewise decompose a portion of the vapour contained in the air, absorbing the oxygen and liberating the hydrogen.

(300.) These various gases thus exhaled into the air cannot be breathed without considerable inconvenience. Signor Cardone made some experiments on breathing hydrogen gas. He inhaled 30 cubic inches, which is about one-ninth part of the total quantity of air contained in the lungs; and the almost immediate effects he experienced were an oppressive difficulty of breathing, and painful constriction at the superior orifice of the stomach, followed by abundant perspiration, tremor of the body, heat, nausea, and violent headache; his vision became indistinct, and a deep murmur confused his hearing. Some of these symptoms lasted a considerable time, and were with difficulty got rid of.[1] Sir Humphry Davy tried the effect of inhaling carburetted hydrogen. He made three inspirations of the gas. "The first inspiration produced a sort of numbness and loss of feeling in the chest and about the pectoral muscles. After the second inspiration he lost all power of perceiving external things, and had no distinct sensation, except a terrible oppression on the chest. During the third expiration this feeling disappeared, and he seemed sinking into annihilation, and had just power enough to drop the mouth-piece from his unclosed lips." The effects of this experiment lasted for several hours, producing excessive pain, extreme weakness, nausea, loss of memory, and deficient sensation.[2] Carbonic oxide is still more prejudicial in its action on the animal system. Sir Humphry Davy, on trying the effects of inhaling a small quantity of it, was seized with a temporary loss of sensation, succeeded by giddiness, sickness, and acute pains in different parts of his body; and it was some days before he entirely recovered: but Mr. Witter, of Dublin, who tried to repeat the experiments, was immediately affected with apoplexy, and was restored with difficulty.[3]

This last-mentioned gas is generated by all stoves which are constructed so as to burn with a very slow draught; and Dr. Arnott's stove has been found peculiarly liable to produce this deleterious gas, which escapes into the room through the ventilator in the ash-pit, and is extremely unwholesome in

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[1] *Annals of Science*, vol. xxviii. p. 149.

[2] *Davy's Researches on Nitrous Oxide;* also *Paris, on Diet*, p. 296.

[3] *Ure's Dictionary of Chemistry*, art. *Carbonic Oxide.*

small close rooms. The carburetted hydrogen is abundantly produced by the gas stoves, in consequence of a portion of the gas escaping unburned from the stove; and this gas, and the large quantity of vapour produced by them, as already described (Art. 264), render these stoves peculiarly unwholesome. All these causes of deterioration of the air affect different persons in very different degrees; but wherever the causes exist, the result will necessarily be derangement of the animal system, however robust the persons may be who are exposed to their influence; but of course the sensations will be soonest experienced by the delicate and the valetudinarian.

(301.) It remains to estimate the quantity of air which is required to be changed by ventilation, in order to preserve the purity of the air when deteriorated by respiration and the exhalations from the human body.

(302.) The quantity of air necessary for respiration is very much less than is required to absorb the vapour given off from the skin and from the lungs. The amount of vapour from this cause, we have already seen, is about 12 grains per minute, when the individual is not making any particular muscular exertions. If the temperature of the room be 60°, the air will absorb 5·8 grains of vapour per cubic foot; but the average dew point being about 45°, the air will previously contain 3·5 grains; so that each cubic foot of air will be able to absorb only 2¼ grains of vapour. Under these circumstances the perspiration from the body will saturate 5¼ cubic feet of air per minute. But, in estimating the quantity of air which is to be warmed in order to allow of sufficient ventilation, this amount may be considerably reduced; because, as 45° is the average dew point for the whole year,[1] it will be much lower in winter and higher

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[1] This is for the neighbourhood of London. It varies of course

in summer, and probably will not exceed 20° or 25° on an average, during the time that artificial heat is required. Every cubic foot of air will then absorb an additional quantity of about 3½ to 4 grains of vapour; and we may therefore estimate the quantity of air which is requisite to carry off the insensible perspiration, at 3¼ cubic feet, and for the pulmonary supply a quarter of a cubic foot per minute, for each individual.

This calculation is sufficient for estimating the quantity of air which in winter is required to be warmed per minute, as explained (Art. 113). But for the purpose of summer ventilation a larger allowance should be made. As the dew point is much higher in summer, the air will absorb less moisture from the body, while at the same time, the exhalations from the body are considerably greater in summer than in winter. For summer ventilation, therefore, at least five cubic feet of air per minute, for each person, ought to be changed, in order to maintain the purity of the room.

(303.) Other causes of deterioration of the quality of the air exist, such as the consumption of oxygen, and the elimination of extraneous gases by the burning of fires, candles, lamps, etc.; but as all gases are capable of absorbing equal quantities of vapour, it follows that, when air has been deteriorated by these causes, so as to be less fit for respiration, it is

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in different places, and is much influenced by the prevailing winds. An easterly wind travelling to us from the Continent of Europe, and across the dry and arid countries of the Asiatic Continent, must necessarily part with much of its moisture, acquired from the Pacific Ocean, before it reaches us; and, therefore, it will be to us a dry wind: while, on the contrary, a westerly wind is always charged with a large quantity of moisture, absorbed during its passage from the American Continent, across the Atlantic. Its passage over this ocean—a distance of 3000 miles—occupies a period varying from 3 to 10 days; during which time it is constantly imbibing moisture from the ocean.

still just as capable of carrying off the vapour from the surface of the body as pure air; and therefore no allowance needs be made for these causes of vitiation.

(304.) Some persons have calculated the quantity of air which is required for ventilation at a much greater amount than is here stated. Dr. Reid considers that ten feet per minute ought to be allowed for each individual; and in some of his experiments, at the House of Commons, he states that 30 cubic feet, and sometimes even 60 cubic feet, per minute, has been allowed.[1] Such cases of extreme ventilation are by no means necessary; and although in the House of Commons, where these experiments were made, a larger proportionate amount of ventilation is requisite than in almost any other case, it is very difficult, if not impossible, to avoid the effect of draughts when such excessive ventilation is produced. In all ordinary cases also, the expense of providing such a great amount of ventilation would be an insuperable objection; though, in such buildings as the Houses of Parliament, the expense is perfectly unimportant, provided the desired object of an improved atmosphere be obtained.

(305.) The important changes in the chemical constitution of the atmosphere, which we have seen result from respiration, heat, and combustion, imperatively demand a constant change in the air, in order to maintain its purity, and to enable it to support organic life. It would be difficult to describe this fact in more forcible language than that which formed the concluding lecture, at the *Ecole de Médicine*, by M. Dumas, on "The Chemical Statics of Organized Beings." From this most interesting lecture some very short extracts can alone be given; but those who have the means of consulting the

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[1] *Reports of the British Scientific Association*, vol. vii. p. 131.

document at large, will derive both pleasure and instruction from its perusal.[1]

"We have proved, in fact," says M. Dumas, "that animals constitute, in a chemical point of view, a real apparatus for combustion, by means of which burnt carbon incessantly returns to the atmosphere under the form of carbonic acid; in which hydrogen, burnt without ceasing, on its part continually engenders water; whence, in fine, free azote is incessantly exhaled by respiration, and azote in the state of oxide of ammonium by the urine. Thus from the animal kingdom, considered collectively, constantly escape corbonic acid, water in the state of vapour, azote, and oxide of ammonium; simple substances, and few in number, the formation of which is strictly connected with the history of the air itself. Have we not, on the other hand, proved that plants, in their normal life, decompose carbonic acid for the purposes of fixing its carbon and of disengaging its oxygen; that they decompose water to combine with its hydrogen, and to disengage also its oxygen; that, in fine, they sometimes borrow azote directly from the air, and sometimes indirectly from the oxide of ammonium or from nitric acid, thus working, in every case, in a manner the inverse of that which is peculiar to animals? If the animal kingdom constitutes an immense apparatus for combustion, the vegetable kingdom in its turn constitutes an immense apparatus for reduction; in which reduced carbonic acid yields its carbon, reduced water its hydrogen, and in which also reduced oxide of ammonium and nitric acid yield their ammonium or their azote.

"If animals, then, continually produce carbonic acid, water, azote, oxide of ammonium—plants incessantly consume oxide of ammonium, azote, water, carbonic acid. What the one class of beings gives

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[1] Translated in the *London and Edinburgh Philosophical Magazine*, vol. xix. p. 338, et seq.

to the air, the others take back from it; so that, to take these facts at the loftiest point of view of terrestrial physics, we must say that *as to their truly organic elements*, plants and animals spring from air —are nothing but condensed air."

These views have been beautifully investigated and explained in the lecture of M. Dumas, here alluded to, and also by M. Liebig, in his excellent works on animal and vegetable chemistry. The effects of animal respiration, we have already examined at some length. The respiration of plants is a subject of much interest to the horticulturalist, although several points connected with it are still undecided, and remain matters of dispute even among men of the first rank in science.

(306.) The effects of a factitious atmosphere are less injurious to vegetable than to animal life. Vegetables appear to have a power of accommodating their functions, in some degree, to the nature of the gaseous elements by which they are surrounded. That solar light has a powerful effect on vegetables has long been acknowledged; and under this influence they exhale large portions of oxygen and moisture. Dr. Daubeny has ascertained that the same action is produced in the absorption of moisture by the roots, and the exhalation of it by the leaves of plants, whether they are exposed to a strong light, or with a smaller degree of light they receive a considerable portion of radiant heat.[1] So powerful, indeed, is the action of light, that M. Condolle has found that plants, during the day; and when exposed to the light, are wholly uninjured by the action of gases which quickly destroy them at night; and even the application of chlorine and other deleterious substances to the roots of plants is innocuous during the day, though they are presently destroyed by similar treatment at night. Sulphuretted hydrogen, nitrous

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[1] *Reports of the British Scientific Association*, vol. iv. p. 73.

acid gas, muriatic acid gas, and chlorine, were severally tried in this manner, with similar results in each case.[1]

It has been generally supposed that plants exhale carbonic acid gas during the night; but this, by Dr. Dalton's experiments, appears doubtful: for he states that, by numerous analyses of the air of hot-houses, he has always found it to contain during the day, as well as during the night, the same proportions of carbonic acid gas.[2]

The action of fruits on the air has been stated by M. Berard in his Essay, which received the prize from the French Academy of Sciences, to produce a constant elimination of carbon, under all circumstances.[3] This opinion has been controverted, and, as it is supposed, successfully by M. de Saussure, who states that green fruit has the same influence on the air as the leaves have—the action of the former being rather less intense; but, in proportion as the fruit ripens, its power to decompose carbonic acid gas becomes feebler.[4]

Although it would appear that the purity of the air is not of so much importance to vegetation as it is to the animal economy, still, as many of the gases which are innocuous to plants during the day are deleterious to them in the night, it is necessary to prevent any considerable deterioriation of the air, in order to preserve them in a healthy state. Hence it becomes an important matter, when it is an object to obtain fruits and flowers of the finest descriptions, to employ only such means of producing artificial heat as do not eliminate extraneous gases to the air; and

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[1] *London and Edinburgh Philosophical Magazine*, vol. iv. p. 316.

[2] *Reports of the British Scientific Association*, vol. vi. p. 58.

[3] *Annales de Chimie*, vol. xvi. p. 152; and *Quarterly Journal of Science*, vol. xi. p. 395.

[4] *Quarterly Journal of Science*, vol. xiii. p. 152.

experience has proved that, since the general introduction of the plan of heating buildings by hot water, horticulturists have found their plants to be more healthy and productive than with the old methods of warming buildings.

The general principles of physiology, which have here been discussed, will enable a correct opinion to be drawn as to the effects on organic life of any method of producing artificial heat. It is not to any particular invention that these remarks apply, they equally affect all; and when any new plans for heating buildings are brought under the public notice, it will be well for those who value their health to test the merits of these inventions by the general principles which have here been explained.

CHAPTER IV.

ON THE VARIOUS METHODS OF PRODUCING VENTILATION.

Spontaneous and Mechanical Methods of Ventilation—Cause of Motion in Spontaneous Ventilation—Velocity of Discharge—Effects of unequal height of Discharge Pipes—Defects in Ventilation of Churches—Proportions of Induction and Abduction Tubes—Quantity of Air discharged through Ventilators—Ventilation by Heat and by Chimney Draughts—Mechanical Ventilation by Fans, Bellows, and Pumps—Quantity of Air discharged by these Means—Calculation of Power expended.

(307.) The different modes of producing ventilation may all be classed under two general heads—the natural and the mechanical. All the methods of spontaneous effusion, produced by the unequal density of two columns of air, whether caused by chimney draughts or otherwise, belong to the former class while the various methods of ventilating by fans, bellows, pumps, and other similar contrivances, belong to the latter class. Of these different modes, the mechanical is the most effective; the natural generally, but not always, the most economical.

(308.) The primary force which produces motion in spontaneous ventilation, is the difference of specific gravity of the two columns of air. If a column of air contained in a tube or chimney be heated, it expands according to an ascertained law, applicable to all gaseous bodies; namely, that the expansion is equal to $\frac{1}{480}$ of its volume for each degree of Fahrenheit that the temperature is raised from 32° to 212°. If this column of air be 10 feet high, and have its temperature raised 20°, then it will expand $\frac{20}{480}$, or $\frac{1}{24}$ of its bulk; so that its specific gravity would be diminished, and it would require a column of air 10 feet 5 inches high to balance a column of the external air 10 feet high, when the temperature of the latter is 20° lower than that of the former. But as the height of the heated column is limited by the height of the tube or chimney, which we suppose to be only 10 feet high, the colder column presses it upwards with a force proportionate to this difference in weight, and with a velocity equal to that acquired by a body falling through a space equal to the difference in height that two columns of equal *weight* would occupy, which in this case is five inches. Now the law of gravitation is this:—that the velocity of descent is relatively as the square root of the distance through which the body falls; and as a body falls $16\frac{1}{12}$ feet in a second, (or 16 feet neglecting the fraction,) the velocity will be, agreeable to the well known law of gravitation, equal to eight times the square root of the height of descent, in decimals of a foot; or $2\sqrt{g.h}$; where g is the distance through which a falling body descends in one second of time, namely, 16·09 feet, and h the height of the descent.[1]

In the case we have supposed, five inches is the height of the effective descent of the heavy column of air. This fall of five inches is equal to ·416 of a foot; therefore, by the rule $2\sqrt{16{\cdot}09 \times {\cdot}416}$ $=5{\cdot}174$ feet per second, or 310 feet per minute, will be the velocity with which the heated column of air would be forced through the tube or chimney under the circumstances we have supposed. If, therefore, the tube were one foot square, there would pass out

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[1] See Chapter V. Part II.

310 cubic feet of air per minute. This rate of efflux, however, is subject to certain corrections, on account of the contaminations which increase the specific gravity of the escaping air, and also in consequence of friction, arising from various causes; but more particularly in consequence of angular deviations in the tubes. In straight tubes the friction is found to be in all cases directly as the length of the tube, and inversely as the diameter. In general practice a deduction of from one-fourth to one-third of the initial velocity is necessary to compensate for these several effects, and to represent the true rate of efflux. The velocity of discharge per second through ventilating tubes, or chimneys, will therefore be found (after the difference in height of the two columns of air has been calculated in the manner already stated) to be equal to eight times the square root of the difference in height of the two columns of air in decimals of a foot: this number reduced one-fourth, to allow for friction, and the remainder multiplied by 60, will give the true velocity of efflux *per minute;* and the area of the tube in feet, or decimals of a foot, multiplied by this latter number, will give the number of cubic feet of air discharged per minute.

(309.) In calculating the rate of efflux of the air from any room or building, it is not merely the height of the room which must be considered, but the total height of the column of heated air. Thus, if the ventilating tube passes through another room or loft over the room to be ventilated, before it discharges the vitiated air into the atmosphere, the total vertical height from the floor of the room to the top of the tube is the effective height of the column of heated air. If the tube in its course passes horizontally, the additional length may be neglected in the calculation in all ordinary cases, as it makes no other difference in the result except that of increasing the friction by so much additional length. The vertical height is that which alone governs the rate of the discharge, and the horizontal length of the tube is merely one of the fortuitous circumstances which slightly modify the result.[1]

(310.) As the vertical height of the column of heated air governs the velocity of discharge, in the ratio of the square root of the height of the column, it is necessary, if more than one ventilating tube or opening for the escape of the heated and vitiated air be made, that they shall all be similar in height; otherwise the highest vent will prevent the efficient acting of the lower one, and the discharge may even be less through the two tubes than it would be with the upper one alone. The cause of this apparently paradoxical effect is not difficult of explanation. If we suppose a tube, open at both ends, to be filled with heated air, it is evident the velocity of the ascent will be proportional to the height of the tube and the excess of temperature of the air which it contains, the weight of the external air pressing the lighter column upwards as already explained. But if another opening be made at the side of the tube, at one half the total height, then this opening at the side will not emit any portion of the heated air, but will on the contrary admit a quantity of cold air; and the velocity of its admission will be, like that of the cold air at the bottom of the tube, in proportion to the height of the heated column of air in the tube above the opening. Now, as the column of air above this opening is only one half the height of that above the former opening at the bottom of the tube, the velocity with which the air enters it will be, compared to the velocity with which it enters the opening at the bottom, as the square root of the height of the

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[1] This remark must be taken with its proper limitation, for cases may arise, where the friction, caused by the horizontal tube, may become a very important element in reducing the velocity of the discharge.

heated column of air above the respective openings. Both these openings will therefore admit cold air at the same time; but, by the admission of the cold air at the middle of the tube, the temperature of the superincumbent atmosphere above the lower opening will be reduced, and the velocity with which the air enters the lower opening will therefore be diminished; the excess of temperature of the air in the tube being the *primum mobile* of the efflux. The interference of the different currents will likewise reduce the quantity of air discharged; and the total result will be that somewhat less air would be discharged under these circumstances, than if the whole of the air had entered at the bottom.

(311.) Precisely the same effects as here described take place in the ventilating of rooms by openings at any height above the level of the floor. The highest opening alone will act as the abduction tube, and all openings below this will act as induction tubes, reducing the discharge by lowering the temperature of the air in the upper part of the room, and also by causing in it counter currents. Some modifications of this result will, however, occasionally occur, as, for instance, when the abduction tube is too small; in which case, the next lowest opening will also act in carrying off the heated air. On the other hand, when the openings for the admission of cold air are too small in proportion to those for the egress of the hot air, then the current of cold air will descend through part of the hot-air tube, and the hot air will ascend through the other part of the same tube.

These effects are frequently very sensibly felt in churches and other buildings, where part of the ventilation is effected by means of the windows. The cold air entering at these windows generally descends upon the heads of those who are placed near them. The effect of this entering current is to lower the temperature of the vitiated air, which parts with a portion of its heat to the fresh air entering the building, and the vitiated air being heavier than fresh air of the same temperature, it falls by its greater specific gravity, and is again breathed by the persons assembled, instead of the pure air which they would have received, had the openings for the admission of the fresh air been at or near the floor of the building.

No plan of ventilation can be worse than that just described, which, however, is the method adopted in a very great majority of churches and other large buildings. Notwithstanding this plan has obtained such extensive adoption, it is certain that it is opposed to every sound principle of science, and has had its rise in the most perfect ignorance of the physical laws; and no better proof than this needs be adduced, to shew how very little the true principles of ventilation have been studied, and how erroneous any conclusions on this subject are likely to prove, that are not based on the known laws which govern the motions of fluids.

(312.) In all the methods of ventilation, it is advisable to make the aggregate area of the openings that admit the fresh air, larger than the aggregate openings for the efflux of the vitiated air. This becomes necessary notwithstanding the increase of volume which takes place in the heated and vitiated air. If the opposite course be adopted, and the abduction tubes be larger than the eduction, then a counter current takes place in the hot-air or ventilating tubes, and the cold air descends through them; but by making the induction tubes numerous, and of a large total area, the velocity of the entering current is reduced, and unpleasant draughts are avoided. It is also expedient to divide the entering current as much as possible; for by so doing it prevents the dangerous effects of cold draughts, when the entering current is colder than the air of the room; and when it is hotter than the air of the room, it prevents the air from rising too rapidly towards the ceiling, and therefore distributes it more equally throughout the apartment. Provided the aggregate openings for the admission of cold air be not less than those for the emission of the heated air, the quantity of air which enters a room depends less upon the size or number of the openings which admit the fresh air, than upon the size of those by which the vitiated air is carried off. This will be evident when it is considered that, the room being always absolutely full of air, no more air can enter until a portion of that already in the room be removed. But as soon as a portion of the air which previously occupied the room is removed, a similar quantity of fresh air rushes in to supply its place; the quantity entering being exactly equal to that which escapes.[1] The only exception which occurs to this rule, is the slow interchange among the particles of air, which takes place according to the laws of gaseous diffusion, through the lower as well as the upper openings of the room; and which continues so long as any inequality exists either in the specific gravity or in the composition of the gaseous matter.

(313.) The following Table will shew the discharge *per minute* through a ventilator one foot square, for various heights and differences of temperature,—the allowance which has already been stated (Art. 308) having here been made. The discharge through a ventilator of any other size may easily be calculated; because, as the area is here 144 square inches, we have only to multiply the number of feet found by the Table, by the number of square inches in the

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[1] This description, perhaps, scarcely gives the exact circumstances of the case; for in spontaneous ventilation a small portion of the cold air will enter before any discharge takes place from the room; for it is the compression produced by the fresh air entering, which causes the heated air to flow out.

area of the proposed ventilator, and then, by dividing that number by 144, the quotient will be the quantity sought, which will represent the number of cubic feet of air that will be discharged per minute by the proposed ventilator.

TABLE XXVIII.

Table of the Quantity of Air, in Cubic Feet, discharged per Minute, through a Ventilator of which the Area is one Square Foot.

Height of Ventilator, in Feet.	Difference between Temperature of Room and External Air.					
	5°	10°	15°	20°	25°	30°
10	116	164	200	235	260	284
15	142	202	245	284	318	348
20	164	232	285	330	368	404
25	184	260	318	368	410	450
30	201	284	347	403	450	493
35	218	306	376	436	486	531
40	235	329	403	465	518	570
45	248	348	427	493	551	605
50	260	367	450	518	579	635

⁂ The above Table shews the discharge through a ventilator of any height, and for any difference of temperature. Thus, suppose the height of the ventilator, from the floor of the room to the extreme point of discharge, to be 30 feet, and the difference between the temperature of the room and of the external air to be 15°, then the discharge through a ventilator one foot square will be 347 cubic feet *per minute*. If the height be 40 feet, and the difference of temperature 20°, then the discharge will be 465 cubic feet *per minute*.

(314.) As the discharge through any given height and size of ventilator is less in proportion as the difference between the external and internal temperature is smaller, it follows that it will be most difficult to obtain ventilation in hot weather. In summer, either the number or the dimensions of the ventilators should be increased; otherwise a room which is well ventilated in winter will be extremely uncomfortable in summer. The increase in size can be effected by having moveable ventilators, which can be contracted at pleasure; and the actual size of the trunk or channel which conveys the air away should be sufficiently large to carry off the largest quantity of air required for summer ventilation.

(315.) The method of spontaneous ventilation which has been described, requires, in every case, that the air of the room to be ventilated shall be of a higher temperature than the external air. In very hot weather, and with crowded assemblies, this method is generally insufficient to secure a wholesome and comfortable state of the atmosphere. But artificial means have long been in use for increasing this effect. This is accomplished in two ways;—either by heating the air in the upper part of the ventilating tube, which causes it to ascend with greater rapidity, and thereby to draw it out of the room or building; or by causing the air of the building to pass through a furnace, from which all other supply of air is excluded. Both these plans have been extensively used, and both answer the intended purpose. The principal theatres in London are ventilated by the former method, advantage being taken of the heat of a large chandelier placed near the ceiling in the centre of the house. The heat of this chandelier causes a great rarefaction of the air and increases the draught; and it thence passes out through tubes into the open atmosphere, the building being supplied with fresh air from below. The method of ventilating by causing the vitiated air to pass through a furnace has also been long and extensively employed.[1] In

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[1] In 1739, Mr. Sutton proposed this plan of ventilation; but, Dr. Desaguliers, in 1723, appears to have adopted a plan somewhat similar for ventilating the House of Commons (*Desagulier's*

many manufactories, this method is economically applied, where fire-heat is used either for steam-engines or other purposes. All that is necessary is to conduct the air from the rooms requiring ventilation, through tubes, into the ash-pit of the furnace, all other supply of air to the ash-pit being prevented; and the draught of the fire causes a rapid abstraction of air from the building, which is immediately supplied by fresh air, and produces a thorough ventilation.

(316.) The most extensive application yet made of this principle has been by Dr. Reid, for the ventilation of the present temporary Houses of Parliament. For this purpose a large chimney has been erected with a furnace of proportionate size, and the air is drawn off from the ceilings of the buildings with great rapidity, passing through a tunnel into the bottom of the furnace, and thence through the fire. The quantity of air thus withdrawn is governed by the force of the fire. In this case it is very great, for by means of this furnace the whole air in the House of Commons can be changed in a very few minutes.

(317.) The ventilation of the late House of Commons was, for many years, a subject of complaint, and it engaged the attention of many practical and scientific men. The apparatus which has been erected for this purpose, in the present House of Commons, appears, however, to be a most expensive and cumbrous contrivance, for accomplishing an object obtainable by far easier means. The thorough ventilation of such a building as this can only be procured by two methods, — draught by heat, or mechanical ventilation by a fan: but the latter of these methods

Experimental Philosophy, vol. ii. p. 560); though in reality the invention of applying fire-heat to produce a draught of air was long prior to either of these dates, and was first proposed by Agricola, in the sixteenth century (see Chapter III.)

possesses so many advantages over the former, that it appears surprising it should, for so many years, have been neglected; and that, of all the numerous plans which have been tried for ventilating the late House of Commons, the draught by heat, though applied in various ways, has been the principle of them all. Dr. Ure has written a useful memoir on the subject of ventilation, in which he compares the advantages of these two methods; and he estimates the relative cost of ventilating by a fan, compared with that by chimney draught, as about 1 to 38. In his calculations on this subject, however, he has apparently been led into an error. His experiments on the consumption of fuel, to produce a given effect by chimney draught, were all made on furnaces used either for steam boilers, or for brewers' coppers. But, as it could only be the residual heat of the furnace which became available in his experiments, after the principal part of the heat given off by the coal had been absorbed by the boiler, it is certain that any calculation, founded on the effect produced in this manner, must be considerably below the truth. But although the relative cost of fuel will not be so greatly different as Dr. Ure supposes, under any circumstances the difference between the two methods must be very considerable.

(318.) The efficiency of the mechanical method of ventilation by a fan, turned by machinery, has been proved so extensively in some of the largest manufactories in the kingdom, that it appears singular Dr. Reid should have adopted so cumbrous and expensive a contrivance as that which he has erected at the present House of Commons. Whether or not this method of ventilation be adopted in the new Houses of Parliament, there can be but little doubt that, ultimately, the more simple, efficient, and economical plan of ventilating by a fan will be resorted to.

(319.) The Marquis de Chabannes, about the year 1816, extensively applied the other mode of ventilation which has been alluded to, by artificially heating the air by means of stoves after it has passed through the ceiling, and by which means the draught is greatly increased. This plan was applied to several very large buildings, and, among others, to the Houses of Parliament. It has been fully described by the Marquis, in a pamphlet published by him; but it appears now entirely to have fallen into disuse: and although, perhaps, on a very small scale, it might occasionally be beneficially employed, it is neither economical nor particularly efficient for large buildings.

(320.) The mechanical method of ventilation appears to possess many advantages. It is of course only suitable for extensive buildings, on account of the cost of erection and maintenance of the apparatus being too great in any case, except where a large quantity of air is required to be withdrawn. The usual plan is either to employ a rotary fan to draw out and discharge the air, or a pump or bellows, which answers the same purpose. A rotary fan was used as long ago as the year 1734, by Dr. Desaguliers, for ventilating hospitals, prisons, and other buildings;[1] though the plan he recommended appears to have been but little used for that purpose. In fact, although the principle was good, it failed in consequence of the trouble attending its use. About the year 1741, Dr. Hales introduced his method of ventilating by bellows; and it was applied in many cases with great success. Several of the prisons, hospitals, and other buildings of the metropolis, as well as nearly all the ships in the navy, were successfully ventilated by this apparatus, which was extremely simple in its construction and operation.[2] It consisted of a large

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[1] *Philosophical Transactions*, 1735, vol. xxxix. p. 41.

[2] *Dr. Hales, on Ventilators.* London, 1743.

box with valves opening inwards, and other valves opening outwards, which alternately admitted and discharged the air, when an internal diaphragm fixed by leather hinges to the centre of the box, was moved up and down by a handle passing through the upper part of the box. One defect, however, was common both to this apparatus and that of Dr. Desaguliers; they were both made dependent for their operation on manual labour, and therefore their use was limited both in duration and extent. For however efficacious the operation might be, the trouble attending it, when the whole effect was produced by manual exertion, rendered it inconvenient, expensive, and uncertain. The extensive introduction of machinery throughout every department of manufactures has again, after a lapse of many years, brought into use both these methods of ventilating buildings. The ventilating fan of Dr. Desaguliers, with some improvements suggested by modern discoveries and experiments, is now extensively used in the manufacturing districts of England; the fan being turned by the steam power employed in the manufactories. The bellows of Dr. Hales, slightly altered in their form, have also again been recently brought into use. The late Mr. Oldham, the engineer to the Bank of England, applied this principle of ventilation to a part of that establishment with complete success. This apparatus differs, however, slightly from that of Dr. Hales, particularly in being fitted with a piston instead of a moveable diaphragm, which gives it more of the character of a pump, though the difference in its construction is very inconsiderable. In this case also the motive power is steam; the powerful machinery constantly in use at the Bank, being employed to work the pump which ventilates the building. Both these methods of ventilating, when thus applied, are unerring in their operation, and appear to accomplish all that is necessary or desirable on this important subject. For the quantity of air discharged can, by both methods, be either increased or diminished at pleasure, by the mere shifting of the band which drives the pulley.

(321.) By these methods of ventilation, the rarefaction or diminished pressure of the air can be effectually prevented. In the method adopted at the Bank of England, instead of the vitiated air being drawn from the building by the apparatus, the operation consists in forcing in fresh air, which, in cold weather, is warmed by passing through a steam chamber; and the vitiated air escapes from the room in consequence of its greater levity,—the quantity which escapes being equal to that which is forced in by the pump. By this means no diminution of pressure can arise; but from what has already been stated, it may be questioned whether the small diminution of pressure which occurs under ordinary circumstances, is a matter of any importance.

(322.) The fans that were used by Dr. Desaguliers were seven feet in diameter and one foot wide. They revolved in a concentric case, close in every part, except an opening at the centre, which communicated by a pipe with the room to be ventilated, and another pipe at the circumference, by which the foul air that was drawn in at the centre was thrown out with considerable force by the rotating leaves of the fan. This construction, however, has been found objectionable. Considerable loss of power accrues from employing a fan moving concentric with the case, on account of a large quantity of air being carried round by the leaves of the fan, instead of passing out through the discharge pipe at the circumference. The most advantageous form is when the case is eccentric to the revolving leaves of the fan, the discharge pipe being placed at that part of the circumference of the case where the eccentricity is the greatest; the air being admitted at the centre in the same manner as before stated. In this form there is comparatively little loss of power; but owing to the inertia of the air, some loss must always occur between the calculated and the actual discharge; the difference being always greater in proportion to the greater speed with which the fan revolves.

(323.) The mode of calculating the quantity of air discharged by any mechanical method, as also the power expended in discharging it, is necessary to be known, in order to apportion an apparatus of a proper size to any particular building. Both these subjects have been investigated by Dr. Ure,[1] who has made various experiments connected with this branch of inquiry. The mean velocity of the portion of the vanes of the fan by which the air is discharged, is about seven-eighths of the velocity of the extremities of the leaves: but owing to the inertia of the air, there will be a further loss in the velocity of the issuing current, increasing with the greater velocity of the vanes; so that, under ordinary circumstances, the current will be discharged with a velocity equal to about three-fourths of the velocity of the extremities of the leaves. This velocity, in feet per second, multiplied by the area of the discharge pipe in square feet, will give the number of cubic feet of air discharged per second. To estimate the force necessary to cause the rotation of the fan, the following method of calculation, founded on the ordinary mode of estimating steam power, will be found sufficiently accurate. Suppose the effective velocity of the vanes of the fan to be 70 feet per second, and the sectional area of the eduction tube to be 3 square feet, then $70 \times 3 = 210$ cubic feet will be the quantity of air discharged per second; and this number, multiplied by 60, will give the quantity per minute. As a cubic foot of air weighs 527 grains, there will be about 13

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[1] *Philosophical Transactions*, 1836.

cubic feet of air to a pound; therefore $\frac{210 \times 60}{13} =$ 969 lbs. is the weight of air put in motion per minute, with a velocity of 70 feet per second. The height from which a gravitating body must fall, in order to acquire a velocity of 70 feet per second, is $\frac{70^2}{8^2} = 76{\cdot}5$ feet; which, multiplied by the number of pounds weight, moved per minute, will give the power necessary to be expended, in order to discharge this quantity of air at the stated velocity; and this product divided by 33,000 (the number of pounds weight that one horse will raise one foot high per minute), will give the amount of steam power required. Therefore $\frac{76{\cdot}5 \times 969}{33{,}000} = 2{\cdot}24$, or nearly $2\frac{1}{4}$ horses power, will be necessary to discharge the given quantity of air at the velocity stated.

The quantity of air discharged by bellows is easily calculated. The cubic contents of the box (or that portion of it which is filled and emptied at each alternation of the handle) multiplied by the number of strokes per minute, will of course give the quantity of air discharged; making such deduction from this amount as may be necessary for imperfect fitting of the diaphragm. The ventilating pump differs from the bellows simply in making the whole diaphragm move up and down, instead of one end being fixed. The force requisite for discharging the same quantity of air by either of these methods, is the same as with a fan. For suppose a ventilating pump three feet square and five feet high; and that the piston makes 25 double strokes per minute, each four and a half feet long; in this case 2025 cubic feet of air per minute will be discharged, and if the valve for its discharge be 10 inches square, the velocity of its discharge will be equal to 48·6 feet per second. This quantity of air reduced into weight, will be $\frac{2025}{13} = 155$ lbs., put into motion every minute at the rate of 48·6 feet per second; and therefore we shall have $\frac{48{\cdot}6^2}{8^2} = 36{\cdot}9$ feet, as the height from which a gravitating body must fall to obtain the velocity of 48·6 feet per second; and $\frac{155 \times 36{\cdot}9}{33{,}000} = {\cdot}17$, or one-sixth of a horse's power, as the necessary force to discharge this quantity of air at the stated velocity.

(324.) The Archimedian screw has recently been proposed for the ventilation of buildings, and its application to this purpose has been secured by a patent. In comparison with a fan, it appears to be every way inferior; for neither in quantity nor in velocity can it at all approach the performance of the fan in discharging air from buildings. By the fan almost any velocity of the discharged current may be obtained; but by the Archimedian screw, the velocity of the discharged air must be comparatively small. The friction between the air and the threads or spirals of the revolving screw must be the power which produces the discharge: but so soon as the pressure or condensation of the air between the spirals equals the friction existing between the air and the surface of the spirals, any further increase in the amount of the discharge ceases; and the screw might revolve with any increased velocity without increasing the quantity of air discharged, and a loss of power in turning the screw would then necessarily occur. The plan, therefore, appears to be only suitable for discharging comparatively small quantities of air, and at a moderate velocity.

(325.) Considering the great importance of ventilation, it is much to be regretted that so little attention has generally been devoted to the subject by scientific men. The treatises which have been written upon it are extremely few, and those generally but too indefinite and inconclusive. In the year 1835, a Committee of the House of Commons was appointed to report upon the best plan of ventilating the Houses of Parliament; but the various scientific men who were then examined, were unable to point out any public building of which the ventilation was at all deserving of the consideration of the committee, as a model for adoption. In fact, it is not merely the method, but the amount of ventilation which is desirable, that appears to have been hitherto unascertained. When Sir Humphry Davy ventilated the House of Lords, in 1811, he used a pipe only one foot diameter to convey away the foul air. In 1813, this was increased to three feet diameter; an alteration which allowed *nine* times the quantity of air to escape; but even this was found quite insufficient for the purpose. And the various experiments of Watt, Rumford, Davy, Chabannes, and others, in ventilating various public buildings, prove that their methods were inadequate for the purpose, notwithstanding their plans might be considered as improvements upon preceding arrangements. The subject of ventilation has now however attracted more of public attention; and we may therefore hope that this important means of improving the public health, will henceforth be more fully considered; and that the time may come when architects will consider it as great a defect to neglect providing the means for the admission and discharge of the air required for ventilation, as they would to omit the doors and windows of the buildings they are called upon to design and erect. The vast importance of ventilation was most forcibly demonstrated by the evidence taken before the Committee of the House of Commons on the Health of Towns, in the year 1840. Scrofulous diseases are stated by the medical witnesses to be the result of bad ventilation; and that in the case of silk weavers, who pass their lives in a more close and confined air than almost any other class of persons, their children are peculiarly subject to scrofula and softening of the bones.[1] Most of the witnesses state that a deterioration of the race undoubtedly occurs among those classes most exposed to defective ventilation; and they consider that bad air deadens both the mental and bodily energies.[2] The statement of some of the diseases produced by bad air is absolutely sickening; and presents the consequences of violating the physical laws, in a point of view, which will scarcely find a parallel.[3] These are undoubtedly extreme cases; but although the ordinary effects of defective ventilation are less marked, it is certain that no violation of the physical and organic laws, however slight, can possibly be allowed, without the consequences becoming apparent in the deteriorated health of those who violate them; and it will be well when this fact is as universally acted upon, as it is generally assented to.

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[1] *Report on the Health of Towns*, pp. 18 and 201.

[2] *Ibid.*, pp. 54 and 201.

[3] *Ibid.*, *Mr. Walker's Evidence*, p. 211, et seq.

CHAPTER V.

ON THE THEORY OF GASEOUS EFFLUX.[1]

(326.) In the preceding chapter the theoretical determination of the flowing of air and other gases through apertures has been given, and its utility in calculating the proper size of ventilators pointed out: it will here be desirable to shew the grounds for believing that this theory truly represents the case, with the accuracy required for determining a physical law.

(327.) The theoretical determination of the velocity with which gaseous fluids are discharged through tubes and apertures under pressure, has often been submitted to mathematical investigation; and the subject being of importance in various branches of practical science, it is to be regretted that considerable differences exist in the results of the several formulæ which have been propounded for its elucidation. Dr. Papin,[2] in 1686, first shewed that the efflux of all fluids follows a general law; and that the velocities are inversely as the square roots of the specific gravities. Dr. Gregory has likewise given various formulæ for calculating the velocities of air in motion under different circumstances; and Mr. Davies Gilbert, Mr. Sylvester, Mr. Tredgold, and many other

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[1] This chapter contains the paper by the author which was read before the Institution of Civil Engineers, May, 1840, "*On the Efflux of Gaseous Fluids under Pressure.*"

[2] *Philosophical Transactions,* 1686.

writers of equal authority, have also investigated the subject.

(328.) The hydrodynamic law of spouting fluids has by all writers been applied in the calculations for the determination of this question. This law, it is well known, is the same as that of the accelerating velocity of falling bodies; and is proportional to the square root of the height of the superincumbent column of homogeneous fluid. But, although the various writers all agree in this fundamental principle, they differ materially in the mode of applying it, and in the several corrections introduced in their theorems; and the results they have arrived at are of a very contradictory character.

(329.) Dr. Gregory's formulæ for calculating the velocity with which air of the natural density will rush into a place containing rarer air, is based upon the velocity with which air flows into a vacuum. This is equal to the velocity a heavy body would acquire by falling freely from a height equal to that which a homogeneous atmosphere would have whose weight is equal to thirty inches of mercury. The height of this homogeneous atmosphere is 27,818 feet: and the velocity which a body would acquire by falling from this height (and consequently the velocity with which air will flow into a vacuum) is $\surd\,(27{,}818 \times 64{\cdot}36) = 1339$ feet per second. The density of the rarefied air divided by the density of the natural atmosphere, and this number subtracted from unity, represents the force which produces motion; and the square root of this number multiplied by 1339 feet (the velocity with which air rushes into a vacuum) is the velocity with which the atmosphere will rush into any place containing rarer air.[1]

(330.) The method employed by Mr. Davies Gilbert is also based upon the velocity with which air rushes

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[1] *Gregory's Mechanics*, vol. i. p. 515.

into a vacuum, when pressed by a homogeneous atmosphere, equal to the weight of the natural atmosphere at the earth's surface. This supposed homogeneous atmosphere is, according to Mr. Davies Gilbert's calculation, 26,058 feet: and the velocity with which air would rush into a vacuum when pressed by this weight, will be $\sqrt{(26058)} \times 8 = 1295$ feet per second. When this calculation is applied to two columns of air of unequal density—as for instance, the discharge of air through a chimney-shaft—the height of the heated column of air divided by the height of this homogeneous atmosphere, and the square root of this number multiplied by the velocity with which air flows into a vacuum, and this product again multiplied by the square root of the number representing the expansion of the heated air, will give the velocity in feet per second. The expansion of air when heated is found (by Mr. Gilbert's method) by raising the decimal 1·002083 (which represents a volume of air expanded by one degree of Fahrenheit) to the power whose index is the number of degrees which the temperature of the air is raised; or it is equal to the fraction $\overline{\left.\frac{481}{480}\right|}^{n}$ n being the number of degrees of Fahrenheit, which the temperature of the ascending column exceeds that of the external atmosphere.[1]

(331.) Mr. Sylvester's method of calculation proceeds upon the supposition, that the respective columns of light and heavy air represent two unequal weights suspended by a cord, hanging over a pulley; and this mode of calculation gives a result very much less than by any other method.

The unequal weight of two columns of air is found by Mr. Sylvester nearly in the same manner as by Mr. Gilbert. The volume of air expanded by one degree of heat, is equal to 1·00208; and this

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[1] *Quarterly Journal of Science*, vol. xiii. p. 113.

number, when raised to the power whose index is the excess of temperature of the heated column, gives the expanded volume of the air; and assuming the atmospheric density to be unity, we have $1 - \frac{1}{(1{\cdot}00208)^e} = d$; e being the excess of temperature of the heated column, and d the difference of density between the two columns. This difference of density multiplied by eight times the square root of the height of the tube or shaft containing the heated air, gives the velocity in feet per second.[1]

(332.) In Mr. Tredgold's theorem for calculating the efflux of air, the force which produces motion is assumed to be the difference in weight of a column of external and one of internal air, when the bases and heights are the same. The difference of temperature of the two columns by Fahrenheit's scale, divided by the constant number 450 plus the temperature of the heated column, and this quotient multiplied by the height of the tube or shaft, gives the difference in weight. Then by the common theorem for falling bodies, eight times the square root of this number will give the velocity in feet per second; or, accurately, $V = \sqrt{\frac{64\frac{1}{3}\, h\,(t-x)}{450+t}}$; h being the height of the tube, t the temperature of the internal, and x the temperature of the external air.[2]

(333.) The method of calculation proposed by Montgolfier appears however by recent experiments to be the most accurate, as it is also the most simple of all the modes of determining this question. The difference in height must be ascertained which two columns of air would assume when the one is heated to the given temperature, the other being the temperature of the external air; and the rate of efflux is equal to the velocity that a heavy body would acquire by falling freely through this difference of height.

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[1] *Annals of Philosophy*, vol. xix. p. 408.

[2] *Tredgold, on Warming Buildings*, p. 76.

The space which a gravitating body will pass through in one second, we know to be 16·09 feet; but, by the principle of accelerating forces, the velocity of a falling body at the end of any given time is equal to twice the space through which it has passed in that time; or the velocity is equal to the square root of the height of the fall, multiplied by the square root of 64·36 feet; or, again, to the square root of the number obtained by multiplying 64·36 feet by the height of the fall in feet.

When the *vis viva* is the difference in weight between two columns of air, caused by the expansion of one of these columns by heat, the decimal ·00208, which represents the expansion of air by 1° of Fahrenheit, must be multiplied by the number of degrees the temperature is raised, and this product again by the height of the heated column. Thus, if the height of the column is 50 feet, and the increase of temperature 20°, we shall have $20 \times {\cdot}00208 \times 50 = 2{\cdot}08$ feet; or 52·08 feet of hot air will balance 50 feet of the cold air, and the velocity of efflux of the heated column when pressed by the greater weight of the colder column, will be equal to $\sqrt{(2{\cdot}08 \times 64)} = 11{\cdot}55$ feet per second.[1]

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[1] This mode of calculation supposes an equal expansion of air by equal increments of temperature, which is generally assumed to be true at all moderate differences of temperature. There can however be but little doubt that air expands more, proportionally, at high temperatures than at low ones, for equal increments of heat; but, as all other bodies expand even more irregularly than air, we possess no means of measuring this deviation from regular expansion. Mr. Davies Gilbert's and Mr. Sylvester's mode of calculating the expansion of air already given, supposes a very considerable increase in the rate of expansion, and the following formula is used by Dr. Gregory:—The expansion of air for 180° is ·376; therefore, any other temperature will be $(1{\cdot}376)^{\frac{1}{180}} \times (1{\cdot}376)^x = (1{\cdot}0018) \times (1{\cdot}376)^x = V$; x being the temperature required, and V the volume of the air at this increased temperature (*Gregory's Mechanics*, vol. i. p. 486). This mode of calculation gives a less expansion than that of Mr. Gilbert.

The efflux of air under any given pressure can also be calculated by the same means. For the pressure being known, it is only necessary to calculate the height of a column of air which would be equal in weight to this pressure. Thus, if the pressure be equal to one inch of mercury, water is 827 times the weight of air, and mercury 13·5 times the weight of water; therefore, $827 \times 13{\cdot}5 = 11164$ inches, or 930·3 feet; and according to the preceding formula $\sqrt{(930{\cdot}3 \times 64)} = 244$ feet per second for the velocity of efflux under this pressure of one inch of mercury.

(334.) In all these cases the velocity thus ascertained is independent of any loss by friction; a certain deduction must be made for this loss, which will vary greatly, according to the nature and size of the tube or shaft through which the air passes, as well as with the velocity of the air. Like all other fluids, the retardation of the air by friction, in passing through straight tubes of any kind, will be *directly* as the length of the tube and the square of the velocity, and *inversely* as the diameter. This question, however, becomes very complicated under these circumstances, and particularly so when there are angular turns in the tube through which the air passes. The present state of our knowledge on this subject does not allow of any very accurate determination of the amount which ought to be deducted for friction from the initial velocity obtained by calculation; and it is only by empirical means we can arrive at an estimate of its amount.

(335.) We shall proceed now to ascertain how far these theoretical calculations agree with the results obtained by experiments.

In some new furnaces which Sir John Guest has lately added to his extensive iron works at Dowlais, some experiments have been made on the quantity of blast injected into the furnaces. In these experiments, the machinery employed being new and of the best construction, the loss occasioned by the escape of air through imperfections of the apparatus, was, perhaps, as small as possible. The engine for blowing the furnaces made, at the time of the experiments, 18 double strokes per minute. The diameter of the blowing cylinder was 100 inches, and the effective length of the stroke seven feet six inches. From these dimensions, therefore, it appears that 14,726 cubic feet of air was taken into the blowing cylinder per minute; and the tubes through which it was discharged from the receiver were six of four inches diameter, and six of one and a quarter inch diameter; the area of all these tubes was therefore ·5747 of a square foot, and the pressure of the blast, measured by a mercurial gauge, was equal to four and a half inches of mercury. Calculating by the formula already given, we shall have $\sqrt{(827 \times 13{\cdot}58 \times 4{\cdot}5 \div 12 \times 64)} = 519{\cdot}2$ feet; which is the velocity per second; and this number multiplied by 60, and then by the area of the tubes, will give $519{\cdot}2 \times 60 \times {\cdot}5747 = 17{,}903$ cubic feet of air discharged per minute. From this amount some deduction must be made for friction. The velocity of the discharged air is 354 miles per hour; and with this immense velocity, and through such small pipes, the friction is no doubt considerable. By deducting 18 per cent. from the calculated amount of 17,903 cubic feet, we shall have 14,681 cubic feet, which agrees within a fraction (namely, 45 feet) with the quantity obtained by measurement.

(336.) In other experiments made at the same place, the following were the results:—The quantity of air which entered the blowing cylinder was the same as before; namely, 14,726 cubic feet; the total area of the tubes which discharged the blast, was ·5502 of a square foot, and the pressure of the blast was equal to four inches of mercury. The calculation, therefore, will be $\sqrt{(827 \times 13{\cdot}58 \times 4 \div 12 \times 64)} = 489{\cdot}5$ feet per second; and therefore $489{\cdot}5 \times 60 \times {\cdot}5502 = 16{,}159$ cubic feet discharged per minute. The velocity of the blast in this case, was 333 miles per hour, and if we deduct for friction, nine per cent. from the calculated amount, the remainder is exactly the quantity of air which is ascertained by experiment to be discharged through the tubes.

(337.) In a work, published in 1834, by M. Dufrenoy, being a Report to the Director General of Mines in France, on the use of the Hot Blast in the Manufacture of Iron in England, the results are given of many similar experiments to the above; but with two exceptions, the details are not sufficiently ample to found any calculations upon. The two exceptions named, are the furnaces at the Clyde, and at the Butterly Iron Works, when they were blown with cold air. Both these blowing machines are described as having been in use for several years; and it is therefore natural to suppose the various parts were more worn, and fitted less accurately than in those experiments already described. The experiments were also made with less care. They shew a different result to those already detailed; as in these the calculated quantity of air appears to be less than the quantity which entered the blowing cylinders, in about the same proportion as it exceeded it in the former cases. This difference, no doubt, arises from the imperfect fitting of the piston of the blowing cylinder, which by allowing a portion of air to escape, would diminish the apparent pressure on the mercurial gauge, placed at the further extremity of the apparatus, and thence the calculated rate of efflux would of course be diminished.

(338.) In the experiments of the Clyde works, the quantity of air which was discharged into the furnaces, when estimated by the quantity that entered the blowing cylinder, was 2827 cubic feet per minute. The pressure of the blast was equal to six inches of mercury, and the area of the tubes ·0681 of a cubic foot. Calculating the discharge of air under this pressure, it amounts to 2450 cubic feet, being 13 per cent. less than the measured amount, supposing no loss to occur by imperfect fitting of the apparatus.

(339.) At the Butterly works, the quantity of air discharged into the furnace, estimated by the contents of the cylinder, was 2500 cubic feet per minute. The pressure of the blast was equal to five inches of mercury, and the area of the tubes ·0681 of a cubic foot. The quantity by calculation appears to be 2235 cubic feet, being less by 10½ per cent. than that shewn by experiment. In both these last cases, however, there is but little doubt that the loss of air from the cylinder caused the pressure on the mercurial gauge to be less than it would have been, had the apparatus been perfectly tight; and a very small diminution in the observed height of the mercury would account for a much greater difference in the velocity of efflux than is here shewn.

We are fully warranted in the conclusion from these experiments, that this method of calculation is as accurate as any theoretical determination of such a question can be; but, from the results so obtained, an allowance must always be made for friction, which will necessarily vary with the peculiar circumstances of each case.

The following Table will exhibit the results of the preceding experiments at one view:—

TABLE XXIX.

Place and Number of Experiment.	Pressure of Blast in Inches of Mercury.	Area of Tubes, Square Feet.	Velocity of Blast, Miles per Hour.	Quantity of Air by Experiment. Cubic Feet.	Quantity of Air by Calculation. Cubic Feet.	Difference in Quantity. Per Cent.
Dowlais, No. 1	4·5	·5747	354	14726	17903	+ 18
„ „ No. 2	4·0	·5502	333	14726	16159	+ 9
Clyde, No. 3	6·0	·0681	408	2827	2450	— 13
Butterly, No. 4	5·0	·0681	372	2500	2235	— 10·5

In order to shew the results of the several modes of calculation, which different mathematicians have adopted, the following Table has been calculated from the data given in experiment the second of the preceding table; and it shews how far the several modes differ from each other in their results:—

TABLE XXX.

Place of Experiment.	Pressure of Blast in Inches of Mercury.	Area of Tubes in Square Feet.	Quantity of Air by Experiment.	Quantity of Air discharged (by Calculation).				
				Mont-golfier.	Gregory.	Gilbert.	Sylvester.	Tredgold.
Dowlais.	4·	·5502	14726	16159	15152	14855	5017	15555

Considering the amount of friction which must result from the discharge of air at the immense velocity which was obtained in this experiment, namely, 333 miles per hour, and also that some of the tubes were only $1\frac{1}{4}$ inch diameter; it will probably be considered that the highest of these calculations is the nearest the truth, as it only allows of a deduction of nine per cent. being made for friction, to reduce the calculated amount to the quantity obtained by experiment. It may therefore be concluded that the method which gives this result, is the most accurate, as it is also the most simple for general use.

CHAPTER VI.

ON THE CHEMICAL CONSTITUTION OF COAL, AND THE COMBUSTION OF SMOKE.

Early Use of Coal in England—Chemical Composition of Coal—Analyses of Coal—Combustion of Coal—Loss by Imperfect Combustion — Loss from the Escape of Smoke — Loss by Carbonic Oxide—Causes of Imperfect Combustion—Theory of Combustion — Temperature required for Combustion — Effects of Rarefaction of the Air — Effects of Hot Air — Quantity of Air required for Combustion — Methods of admitting Air—Combustion of Anthracite Coal—Description of various Plans for consuming Smoke—Artificial Fuels.

(340.) The value and importance of coal, whether considered in its commercial or its physical character, or in the effects it has produced upon civilization, are sufficient to render all investigations concerning it singularly interesting. The changes which have been effected in the social condition of man by the instrumentality of this valuable substance, are as instructive as they are interesting; and great as are the other mineral riches of England, they would be comparatively valueless without the possession of that substance which, under the generic name of coal, is so entensively distributed throughout its various districts.

Important, however, as coal has now become, its value has been fully recognised for comparatively but a few years; and the apathy and indifference with which it was formerly regarded, contrasts most singularly with the present importance which it assumes.

(341.) The ancient Britons were acquainted with the use of coals before the arrival of the Romans. The Anglo-Saxons also knew and partly used them; but they are not mentioned by any of the writers in the times either of the Danes or Normans, till the reign of Henry III. who, in 1234, granted a charter to the inhabitants of Newcastle to work them. In 1306, they were prohibited at London as a nuisance; but in 1321 they were used at the Palace, and became soon afterwards an important article of commerce. They, however, gradually fell into disuse except among the poor; and even in the seventeenth century their use was confined to the lower orders, except for the working of metals.[1] Such a prejudice existed against them in the middle of the sixteenth century, that, in the reign of Elizabeth, an attempt was made again to prohibit their use in London, even for manufacturing purposes, during the sessions of Parliament; it being supposed that the air was rendered unwholesome by the smoke which they produced.

Previous to the commencement of the seventeenth century, the smelting of iron and other metallic ores was performed with charcoal; but at that period the large consumption of wood for making charcoal had so thinned the country of timber, that a probability appeared that many iron works would be stopped for the want of fuel. An important era now commenced. In 1619 a patent was obtained by Dudley, for smelting iron with the coke made from bituminous coal; which invention was applied on a limited scale for several years. Shortly previous to this, other persons had attempted the same process without success. Sturtevant in 1612, and Ravenson in 1613, both obtained patents for methods of using coal in blast furnaces for smelting iron; but both failed of success. Many years, however, elapsed before the

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[1] *Fosbroke's Archæology*, vol. i. p. 72.

use of coke, for this purpose, became general; but, from the period of the middle of the seventeenth century the use of coal became common, both for domestic and manufacturing purposes, in all cases where heat was required to be produced; and its consumption has steadily increased from that period.

These few historical remarks on the use of coal shew, in a striking point of view, the neglect with which this valuable substance was formerly treated; and it contrasts most singularly with the vast importance which is now attached to it. And when we consider the gigantic effects produced by its agency in our own times, and the still greater effects of which it yet gives promise, we can scarcely credit the apathy with which it was regarded at a period so little remote from our own age.

(342.) The several properties of coal are the result of two distinct substances, which are combined in different proportions in the specimens obtained from different localities. Carbon and bitumen are the two substances which give to coal its distinctive characters, though other substances exist in it in a greater or less degree; some being extraneous and the result of mere local situation, and others partaking of a more generic character. In discussing this subject we shall proceed to consider—first, the chemical character and composition of coal; secondly, its properties as a combustible; and lastly, the methods of consuming the smoke given off during its combustion, and of rendering it available in increasing the calorific effects of the fuel.

(343.) Some chemists have objected to the opinion that coal is a compound of carbon and bitumen. No process has yet been devised by which it has been possible, in the analyses of coal, to resolve it entirely into these two substances; but, together with them, there is always obtained a quantity of gaseous matter. Some portion of this gaseous matter readily distils from coal with comparatively a very slight increase of temperature; while other portions, evidently resulting from the decomposition of the bitumen, require for their elimination a much more intense heat. No specimens of coal yet discovered are entirely free from these gaseous products. The only kinds which may be supposed to be exempt from them, are the Anthracites; but these all contain a small portion of volatile matter, considered by some to be merely water, or its elements; but by others, on more accurate analysis, decided to be similar in composition, though far less in quantity, to the products obtained from bituminous coal.

Considerable discrepances exist in the analyses by different chemists of some varieties of coal. Enough however is known to afford very valuable information in the successful application of coal to the various useful purposes of the arts; though it must be confessed that hitherto the operations of the practitioner have availed far more than the theories of philosophy.

(344.) No accurate analyses of coal were made previous to those of Dr. Thomson in 1819. The method previously employed, by ascertaining the quantity of residuary carbon left after the volatile matter was driven off, was necessarily very inaccurate; because the gaseous products of the coal carried off a considerable portion of carbon in the form of carburetted hydrogen and carbonic oxide, by which the quantity of carbon in any given specimen appeared to be considerably less than really existed. Such a mode of analysis, however, is not without its use; because it shews, more accurately than any other, the quantity of coke which can practically be obtained from any given specimen of coal, and which by any other mode can only be found by calculation.

The earliest analyses of coal by this process which have been published, with the exception of those by

Kirwan, were made by Mr. Mushet: they are given in the following Table, together with several other more recent analyses by different experimentalists.

TABLE XXXI.

Name of Coal.	Carbon.	Ashes.	Volatile Matter.	Specific Gravity of the Coal.	Specific Gravity of the Coke.	Authority.
Welsh Furnace Coal .	88·068	3·432	8·500	1·337	1·0	Mushet.[1]
Alfreton Furnace Coal	52·456	2·044	45·50	1·235		
Butterly Furnace Coal	52·882	4·288	42·830	1·264	1·100	
Welsh Stone Coal .	89·700	2·300	8·000	1·368	1·393	
Welsh Slaty Coal .	84·175	6·725	9·100	1·409		
Derbyshire Cannel Coal	48·362	4·638	47·000	1·278		
Kilkenny Coal . .	92·877	2·873	4·250	1·602	1.656	
Do. Slaty Coal .	80·475	6·525	13·000	1·445		
Scotch Cannel Coal .	39·430	4·000	56 570			
Boolavooneen Coal .	82·960	3·240	13·800	1·436	1·596	
Corgee Coal . .	87·491	3·409	9·100	1·403	1·656	
Queen's County Coal .	86 560	3·140	10 300	1 403	1·621	
Stone Wood, Giant's Causeway .	54·697	11·933	33·370	1·150		
Caking Coal . .	75·900	1·500	22·600	1·269		Dr. Thomson.[2]
Splint Coal . .	55·230	9 500	35·270	1·290		
Cherry Coal . .	42·246	10·000	47·754	1·265		
Cannel Coal . .	29·000	11·000	60·000	1·272		
Kilkenny Coal . .	89·3	4·0	6·7	1·435		
Anthracite, Lehigh .	90·1	3·3	6·6			Vanuxem.[3]
Do. Rhode Island American	90·03	5·07	4·9			
Do. Do. .	77·7	15·6	6·7			
Anthracite, Llanelly .	41·62	39·98	18·4	1·571		Daniells.
Do. Milford Lower Vein	88·74	2·46	8·8	1.374		
Do. American . .	85·98	4·62	9·4	1·518		

These analyses shew the very great difference which exists in the composition of the various descriptions of coal. This difference not only exists between the several species of coal, but likewise in the different specimens of the same species, obtained from different localities. This is particularly the

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[1] *Philosophical Magazine*, vol. xxxii. p. 140. The same author has recently increased this list by some hundreds of analyses of different coals, and published the results in his "*Papers on Iron and Steel.*"

[2] *Annals of Philosophy*, vol. xiv. p. 81, and vol. xv. p. 394.

[3] *Annals of Philosophy*, vol. xxvii. p. 104. In this analysis the volatile matter is considered to be entirely composed of water.

case with the Anthracite coal, which passes through every stage of difference, from nearly a pure carbon down to the state of ordinary bituminous coal.

(345.) A more intimate knowledge of the nature of coal was obtained by Dr. Thomson's analyses, before alluded to, by which the exact constituents of the volatile matter were ascertained. The following Table gives these analyses, together with the results obtained by other chemists in determining the nature of the gaseous products obtained from coal.

TABLE XXXII.

Name of Coal.	Carbon.	Hydrogen.	Azote.	Oxygen.	Specific Gravity.	Authority.
Caking Coal . .	75·28	4·18	15·96	4·58	1·269	Dr. Thomson.[1]
Splint Coal . . .	75·00	6·25	6·25	12·50	1·290	
Cherry Coal . .	74·45	12·40	10·22	2·93	1·265	
Cannel Coal . .	64·72	21·56	13·72	0·0	1·272	
Splint Coal . . .	70·90	4·30	0·0	24·80	1·266	Dr. Ure.[2]
Cannel Coal . .	72·22	3·93	2·8	21·05	1·228	
			Oxygen & Azote.		Ashes.	
Splint Coal, Wylam	74·823	6·180	5·085		13·912	Richardson.[3]
Ditto, Glasgow .	82·924	5·491	10·457		1·128	
Cannel Coal, Lancas.	83·753	5·660	8·039		2·548	
Ditto, Edinburgh .	67·597	5·405	12·432		14·566	
Cherry Coal, Newcas.	84·846	5·048	8·430		1·676	
Ditto, Glasgow .	81·204	5·452	11·923		1·421	
Caking Coal, Newcas.	87·952	5·239	5·416		1·393	
Ditto, Durham .	83·274	5·171	9·036		2·519	
Anthracite, Wales .	92·56	3·33	2·53		1·58	Reynault.[4]
Ditto, Pennsylvania	90·45	2·43	2·45		4·67	
Ditto, Meyenn . .	91·98	3·92	3·16		0·94	
Ditto, Roldue . .	91·45	4·18	2·12		2·25	
Ditto, Wales . .	89·43	3·56	3·95		1·70	Jacquelain.[5]
Ditto, Pembrokeshire	92·43	3·37	2·49		1·73	Schafhaeutl.[6]

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[1] *Annals of Philosophy*, vol. xiv. p. 95.

[2] *Chemical Dictionary*, Art. *Coal.*

[3] *London and Edinburgh Philosophical Magazine*, vol. xiii. p. 131.

[4] *Annales de Chimie*, vol. lxvi. p. 337.

[5] *London and Edinburgh Philosophical Magazine*, vol. xvii. p. 213. In this analysis the coal contained 1·36 per cent. of water.

[6] *Ibid.* p. 215. In the ashes of this analysis ·12 per cent. is sulphur.

By comparing together the results of Dr. Thomson's analyses given in the preceding Tables, we shall see how greatly the nature of the volatile matter contained in any specimen of coal affects the resulting quantity of coke. By Table XXXII. it appears that the aggregate quantity of the gaseous products of caking, splint, and cherry coal, are very nearly similar; while by Table XXXI. we perceive that the quantity of coke obtainable from these several species, varies more than 45 per cent. This, however, can readily be accounted for, when we ascertain the nature of the gas which predominates in each species: for, where hydrogen and oxygen abound, a large quantity of carburetted hydrogen and carbonic oxide is formed, at the expense of a certain proportion of the carbon; while in such specimens as contain azote in the largest proportion, a far smaller loss of the carbonaceous portion of the coal is sustained.

(346.) Of all the volatile constituents of coal, the azote is that which quits it with the greatest difficulty. Professor Proust[1] considers that coal always contains azote, even when reduced to coke; for when coke is treated with potass, a prussic lixivium is always obtained; and the same he even found to be the case with anthracite coal. The prussic radical is a compound of azote and carbon; and it may be a question, whether any part of the difference which is known to exist in the heating power of "oven coke" and "retort coke," is owing, in the former case, to the presence of a larger portion of nitrogen. Some of the prussic compounds are very inflammable, and may therefore be supposed to produce some calorific effect by their presence.

Sulphur, which is another substance retained with the greatest pertinacity by coal, exists in nearly all the species in a greater or less degree. It is, perhaps,

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[1] *Nicholson's Journal*, vol. xviii. pp. 166 and 173.

the only one of their constituents which, according to our present knowledge, is wholly valueless. Its injurious tendency is not more remarkable than the tenacity with which the coal retains it. Generally it exists in combination with iron, in the form of pyrites. In the process of coking, a portion of the sulphur escapes in the state of sulphuretted hydrogen gas; but no degree of heat is sufficient to drive off the whole of the sulphur; and many beds of coal are rendered almost useless, in consequence of the large quantity of sulphur which the coal contains, preventing its use in metallurgy, and many other processes in the arts. The presence of sulphur, indeed, is generally more perceptible in coke than in coal: the mass of volatile matter which escapes from the latter, disguises the presence of the sulphur in a great degree; while, with coke, the fumes of sulphurous acid are generally very perceptible. No mode, practically applicable, has yet been discovered for freeing coal from the sulphur it contains. By treating it with nitric acid the pyrites are dissolved, and the sulphur and the iron may be washed out; but the coal is converted by the operation into a bulky coke, and is entirely changed in its character, and ceases to afford the same gaseous products as before.[1] It is probable that some kinds of anthracite coal are nearly free from the presence of sulphur; and, indeed, several kinds afford no evidence of its existence.

(347.) The application of coal to the purposes of fuel depends, like that of all other combustible bodies, on the chemical change which it undergoes in uniting by the agency of heat with some body for which it possesses a powerful affinity. In all ordinary cases this effect is produced by its union with oxygen; and we shall therefore inquire into the modes of effecting this in the best manner.

When coal is entirely consumed, the carbon is

[1] *Nicholson's Journal*, vol. xviii. p. 170.

wholly converted into carbonic acid gas, and the hydrogen into water,—the latter being in the state of vapour. The air supplies the necessary oxygen for this purpose; and in this state the products of the combustion are nearly or quite invisible, both the products being colourless fluids. *Smoke, therefore, is always the result of imperfect combustion.*

(348.) It has generally been considered that when coal is carefully coked, the residuary coke will produce as much heat when applied as a fuel as the original quantity of coal would have done from which it was produced. This of course can only be taken in a general sense; because much must depend upon the method of coking, and the prevention of waste, as well as the extent to which the process of coking has been carried. Many experiments confirmatory of this general view of the relative values of coal and coke have been made; the most recent are those of Mr. Apsley Pellat, Mr. Parkes, and the Count de Pambour. But it should be observed that in the residuary coke from the process of gas-making, the peculiar mode of carbonization lessens its heating power to a considerable extent; and it is principally to what is known as "oven-made coke," that this remark will therefore apply.

We have the clearest evidence from this fact of the great difference in the heating powers of *equal weights* of coal and of coke, that the waste must be very great in the usual modes of burning coal. We know that a large proportion of the gaseous products of coal—which we have already seen constitute on a rough average about one-fourth of its total weight—consists of matter which is capable of producing the most intense heat; and yet we find, practically, that its effect in furnaces is absolutely negative. This can arise only from some imperfection in our methods of combustion; and we may obtain a tolerably accurate notion of the extent of the loss thus sustained, by a reference to the analyses of coal already given. Let us take as an example the caking coal, according to Dr. Thomson's analysis in Table XXXII.—which is the Newcastle coal so generally used. We find that in every 100 lbs. of coal there are contained 4·18 lbs. of hydrogen, and 4·58 lbs. of oxygen. When these gaseous products are driven off by heat, they will both combine with a portion of carbon. The quantity of carbon which combines with the hydrogen is very variable; differing with the degree of heat to which it is exposed. When the temperature is very high the hydrogen will combine with three times its weight of carbon, forming the true carburetted hydrogen; but, from a coke oven, a large portion of the hydrogen escapes nearly in an uncombined state, and therefore the quantity of carbon thus abstracted will be only about one-half the quantity which would constitute true carburetted hydrogen; or about 6 lbs. of carbon may be assumed as the quantity carried off in the latter case. Dr. Dalton ascertained that the combustion of 1 lb. of hydrogen would melt 320 lbs. of ice; therefore, 4·18 lbs. would melt 1337 lbs. of ice; and the heat produced by 6 lbs. of carbon will be sufficient to melt 376 lbs. of ice, according to the average of the experiments of Watt, Rumford, and Black.[1] The 4·58 lbs. of oxygen contained in the coal will combine with 3·5 lbs. of carbon, and form 8·08 lbs. of carbonic oxide. According to Dr. Dalton, 1 lb. of this gas will melt 25 lbs. of ice; therefore 8·08 lbs. will melt 202 lbs. of ice. These results amount together to 1915 lbs. of ice melted by the heat obtainable from these several substances; which

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[1] The average of the experiments of Watt, Rumford, and Black, gives 39 lbs. of water raised 180 degrees, by the combustion of 1 lb. of coal; or 7020 lbs. of water raised 1 degree. The latent heat of ice being 140 degrees, this will be equal to melting 50·14 lbs. of ice with 1 lb. of coal; and the heating power of coke, compared with coal, being as 10 to 8, 1 lb. of coke will melt 62·7 lbs. of ice.

number multiplied by 140 degrees, the latent heat of ice, and this product divided by 7020, the number of pounds weight of water which can be raised I degree by the combustion of 1 lb. of coal, we shall find the total heat of these several gaseous products are equal to the calorific effects of 38 lbs. of coal. It is not known whether the azote which the coal contains produces any heating effect; nor will the heat necessary for its expulsion from the coal cause any loss which is appreciable, even if the whole of it be driven off by heat, which, however, we have already seen, is not the case. By the experiments of Berard and Delaroche, on the specific heat of gases, we find that to raise the temperature of the 15·96 lbs. of azote to the temperature of 500 degrees Fahrenheit, will only require 4·9 ounces of coal—a quantity too small to be taken into account. The loss, therefore, by the escape of these gaseous products of the coal, amounts by these calculations, to 38 per cent.; and the coke which remains will be of the description known by the name of "oven coke," and will produce the same calorific effect as the original quantity of coal would have done, *provided the latter were burned in the usual manner.*

Another method may be employed for ascertaining the loss sustained by the escape of the volatile matter of coal, by calculating the heating power of the various products obtained from coal in the process of gas-making. The quantity of carburetted hydrogen gas obtainable from 100 lbs. of caking coal, of good average quality, may be stated at about 450 cubic feet; of which the specific gravity is about ·50 to ·55. Twenty-four cubic feet of this gas will weigh 1 lb.; and as 1 lb. weight of this gas will melt 85 lbs. of ice, according to Dr. Dalton's experiments, we shall have $\frac{450}{24} \times 85 = 1593$ lbs. of ice melted by the combustion of the gas obtainable from 100 lbs. of coal. Reducing this, as in the former case, to the mean of the results obtained by Watt, Rumford, and Black, we shall find that it is equal to the total effect of 31·76 lbs. of coal. In addition to this there will be about 8 lbs. of tar obtained from 100 lbs. of coal. This, when decomposed by heat, yields about 100 cubic feet of an impure hydro-carburet, mixed with about one-third by weight of carbonic oxide. Reckoning the heat of this by the data already given, it will be equal to the effect of 10·4 lbs. of coal. The other product of the distillation is ammoniacal liquor. Of this about 7½ lbs. will be obtained from 100 lbs. of coal; consisting of 5¾ lbs. of water, and 1¾ lbs. of ammonia; the former containing in its composition ·64 lb. of hydrogen, and the latter ·29 lb., making together ·93 lb. of hydrogen; and the heat obtainable from this quantity of hydrogen will be equal to 5·93 lbs. of coal. These several results amount together to a loss equivalent to 43·09 lbs. of coal; but as the residuary product of the distillation will be only "retort coke," which is inferior to oven coke in its heating power to the extent of 12½ per cent., according to the experiments of M. de Pambour, we must deduct from the above amount the difference between the heating power of this coke and that which was supposed to be obtained by the former mode of calculation,—the quantity being considered the same in both cases. We shall therefore find the statement will stand as follows:—

		lbs. of Coal.
Heat obtainable from 450 cubic feet of carburetted hydrogen	=	31·76
Do. . . . . 8 lbs. of Tar	=	10·40
Do. . . . ·93 lb. of hydrogen, contained in the ammoniacal liquor	=	5·93
		48·09
Deduct difference in heating power of residuary coke, viz. 75 lbs. at 12½ per cent.	=	9·37
Total loss		38·72

By this method of calculation, the loss occasioned by the non-combustion of the volatile products of the coal amounts to 38½ per cent., which is an extremely near approximation to the result obtained by the former method. We cannot, however, consider that the whole of this amount is always lost by the escape of smoke in the combustion of coal. With open fires, no doubt, this is the case, as well as other sources of loss peculiar to this method of combustion. But in furnaces, however imperfectly they are constructed, some portion of the smoke is always consumed; and by that amount, whatever it may be, the loss is diminished. The smaller the quantity of volatile matter which the coal contains, the less will be the loss in this way; but the kind of coal selected for these calculations is a quality which may be considered to afford a fair average.

(349.) But, in addition to the loss of calorific effect which is here shewn by the escape of unconsumed smoke, there is another source of loss which always exists in a greater or less degree, arising from the formation of carbonic oxide. It is of importance to understand correctly the theory of the formation of this carbonic oxide, as it materially affects the question of economy, in the combustion of fuel.

(350.) When atmospheric air comes in contact with coal or coke, at a very high temperature, the combination of the oxygen of the air with the carbon of the fuel, always forms carbonic acid gas, and produces the phenomenon of combustion.[1] Such is the effect of atmospheric air entering through the grate-bars of a furnace, on the lower stratum of fuel, lying immediately on the bars. But while this carbonic acid gas passes upwards through the upper strata of the heated fuel, a further portion of carbon combines with it, and it becomes converted into carbonic

[1] The lowest temperature at which this combination of oxygen and carbon takes place, is a little above the boiling point of mercury. At this temperature carbonic acid gas is formed, without any luminous appearance; at higher temperatures true combustion occurs, and carbonic acid is produced with great rapidity, (*Davy's Experiments on Flame, Philosophical Magazine,* vol. l. p. 10).

oxide;—carbonic *acid* consisting of two volumes of oxygen and one volume of carbon; while carbonic *oxide* is composed of equal volumes of oxygen and carbon.

The result of this conversion of carbonic acid gas into carbonic oxide, by passing the former through highly-heated carbon, is a considerable loss of heat, when the carbonic oxide escapes from the furnace in this state: for a given weight of carbon, converted into carbonic oxide, only produces half the heat which it would do, were it converted into carbonic acid gas. The combustion of fuel, therefore, cannot be perfect, where any considerable quantity of carbonic oxide escapes undecomposed; although it may often happen that no smoke is visible even when there is a large escape of carbonic oxide. This is particularly the case when coke is used as fuel. There is in this case no smoke; but if there is a deficiency of atmospheric air to supply the necessary amount of oxygen to convert the product of the combustion wholly into carbonic acid gas, a large quantity of carbonic oxide is formed, which not only causes a very great loss of fuel, but it is probably even more unwholesome than the most dense smoke.

(351.) In the case of bituminous coal, the economy of fuel must necessarily consist both in consuming the smoke and in preventing the escape of undecomposed carbonic oxide. Smoke always arises from one of two causes, deficiency of air, or an insufficient degree of heat to cause the chemical union between the constituents of the fuel and the oxygen derived from the air; and sometimes it arises from both these causes combined. The loss arising from the carbonic oxide is almost entirely owing to deficiency of oxygen. In open fireplaces the smoke is caused by deficiency of heat; in close furnaces it is generally caused by deficiency of air; and all the different methods which have been proposed for *consuming smoke* in close furnaces, however variously these plans may be applied, are all based on the principle of supplying additional air to the burning fuel. Two or three plans, indeed, for *destroying smoke* have been proposed which will presently be mentioned; but we shall first inquire into the methods of beneficially applying the combustion of the gaseous products of coal, to the ordinary purposes of fuel.

(352.) A vast deal of misconception upon a very simple subject has occurred from parties interested in particular inventions, discussing the general question of the combustion of smoke in the way best calculated to recommend their own inventions and to depreciate those of others. The inquiries as to whether hot air or cold air is most advantageous for consuming smoke, or whether smoke is really capable of being *consumed* after it is once formed, or whether the only remedy for it is to prevent its formation, are entirely of this kind. But that which will be found to be the fact, is, that smoke is as capable of being consumed as any other combustible, and that there are many methods of accomplishing this both by hot and by cold air.

The combustion of smoke, and indeed of any other substance, is not to be supposed to involve its total annihilation; for matter of all kinds, so far as our knowledge extends, is indestructible. But the combustion of smoke is that change of state produced by chemical union with other substances, which entirely alters its character and appearance.

(353.) The constituents of smoke can be accurately judged of from a knowledge of the chemical composition of the coal which produces it. Nitrogen, oxygen, hydrogen, and carbon, with the various combinations of these bodies, namely, carbonic acid, carbonic oxide, carburetted hydrogen, ammonia, and vapour of water, together with minute portions of various resins, salts, and earthy matters, must necessarily constitute the substance known under the general name of smoke. All these substances, except the carbonic acid, are capable of further combinations with atmospheric air, by means of a high temperature; and practically they do all undergo a change, except that the nitrogen exists in too large a proportion to enable any considerable quantity of it to combine chemically with the other substances. Thus, then there is nothing to prevent a true 'combustion of smoke' from taking place; by which means chemical combinations are produced, the principal one being that the uncombined carbon which gives the black colour to smoke, unites with oxygen derived from the air, and becomes converted into the colourless carbonic acid gas.

As regards the actual destruction of the black colour of smoke, it matters but little whether hot or cold air be admitted into the furnace; for so long as the furnace is sufficiently hot, and the quantity of air is sufficiently abundant, the combustion will take place. But before the air can enter into combustion, it is necessary that it be raised to a high temperature; in most cases, about 800° or 900° of Fahrenheit being required for this purpose. When the air is not heated previous to its entrance into the furnace, this heat which is necessary for its combination, is obtained from the bodies with which it combines; their temperature is therefore necessarily lowered, by parting with the requisite heat to raise the temperature of the air to that degree at which it will enter into chemical union with the gaseous and solid matter of the fuel.

(354.) The experiments of Sir Humphry Davy on combustion,[1] clearly shew the necessity of a high temperature before active combustion can take place, and the advantages that must therefore result from

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[1] *Researches on Flame*, by Sir Humphry Davy. *Philosophical Transactions*, Part i. for 1817, and *Philosophical Magazine*, vol. l. p. 1, et seq.

extrinsically heating the air which supports combustion. They also entirely refute the assertions that the rarefaction of the air by heat is injurious to complete combustion, his experiments having in fact been undertaken with the view of testing the accuracy of a theory to this effect, propounded by M. de Grotthus and others, and which he found to be erroneous.

When Sir Humphry Davy caused a jet of hydrogen gas, one-sixth of an inch in height, to burn in the receiver of an air pump, the flame enlarged as the receiver was exhausted by the pump, and was at its maximum when the pressure of the air was between four and five times less than that of the atmosphere; and when a larger jet was used, the same phenomenon occurred even when the air was rarefied ten times. This effect, from a larger jet, was found to arise from the increased heat produced; and the conclusion drawn from all the experiments was, " that among combustible bodies, those which require least heat for their combustion, burn in more rarefied air than those that require more heat; and those that produce much heat in their combustion, burn, other circumstances being the same, in more rarefied air than those that produce little heat." The experiments also proved that " by preserving heat in rarefied air, or giving heat to a mixture, inflammation may be continued when, under common circumstances, it would be extinguished." When these mixtures were heated before combustion, Sir Humphry Davy found " that expansion by heat, instead of diminishing the combustibility of gases, on the contrary, enables them to explode apparently at a lower temperature; which seems perfectly reasonable, as a part of the heat communicated by any ignited body must be lost in gradually raising the temperature." It was also found that " the cooling power of mixtures of elastic fluids in preventing combustion increases with their condensation, and diminishes with their rarefaction;

at the same time, the quantity of matter entering into combustion in given spaces, is relatively increased and diminished. The experiments on flame in rarefied atmospherical air, shew that the quantity of heat in combustion is very slowly diminished by rarefaction, the diminution of the cooling power of the azote being apparently in a higher ratio than the diminution of the heating powers of the burning bodies." When the rarefaction of the air, however, is produced by heat, not only is there no loss whatever in the available heat produced by combustion, but the extensive application of heated air by means of the "hot blast" to the smelting of iron, proves that there is an enormous increase in the effect, both on the solid matter of the fuel as well as on its gaseous products. And the same result will necessarily occur with respect to all kinds of furnaces for the combustion of fuel. The heated air, when carefully kept from imbibing moisture, will always enter into combustion more readily than cold air; will cause a much greater heat in the furnace; and will produce more perfect combustion of the fuel. And Sir Humphry Davy not only proved "that the combustion of all gaseous mixtures is increased by rarefaction by heat," but he ascertained by his experiments, that a general law obtained "that at high temperatures gases not concerned in combustion will have less power of preventing that operation, and likewise, that steam and vapours, which require a considerable heat for their formation, will have less effect in preventing combustion (particularly of those bodies requiring low temperatures) than gases at the common heat of the atmosphere." The well known effect of cold frosty air, in causing fires to burn clear and bright, in no way militates against these conclusions. The effect produced by cold air, arises from the decreased quantity of moisture which it then contains, and not from the greater density of the air: for Sir Humphry Davy found that even with atmospheric air condensed to *five times* its natural density, scarcely any appreciable difference could be perceived in its effects on combustion. Neither can these effects be different, whether the combustible be a solid or a gaseous body; except that the latter would be more easily lowered in its temperature, and reduced below the temperature requisite for its accension.

(355.) The expansion of air by heat, previous to its entrance into the furnace, cannot at all reduce the quantity of oxygen which combines with the fuel. For as air will not support combustion, until it be raised to a very high temperature (about 800° or 900°), its expansion must necessarily be the same, whether this heat be communicated to it, within or without the furnace.

(356.) The quantity of atmospheric air required for the combustion of coal is very great. Taking Richardson's analysis of Newcastle coal (Table XXXII. Art. 345), it appears that 355,376 cubic feet of air, of ordinary density, would be required for the combustion of one ton of this coal. If heated air be used, the number of cubic feet must be increased according as the density of the air is diminished; so that sometimes, when the air is very highly heated, twice, or even three times this number of cubic feet of air may be necessary for the perfect combustion of the coal.

The actual quantity of air which enters into a furnace, where complete combustion takes place, must be sufficient to convert the carbon into carbonic acid, and the hydrogen into water. The former requires 2·66 times, and the latter eight times their weight of oxygen to make these combinations; and the oxygen of the air being one-fifth of its total weight, we can thus calculate the quantity of atmospheric air required for the combustion of any particular kind of coal.

But this quantity of atmospheric air, large as appears its amount, will not be sufficient for perfect combustion; for this calculation supposes that the whole of the oxygen is abstracted from the air in the process of combustion, a result which experience proves is never practically produced. Some interesting experiments on this subject have been made by Mr. Hunt,[1] on the furnaces of the principal engines in Cornwall; and the average of the analyses of the air, taken from the chimneys of the furnaces, after it has performed its office in the combustion of the fuel, shews that the mixed gases passing off through the chimney, contain one-tenth of their volume of free oxygen. The amount of carbonic acid was also found to be, on an average, one-ninth of the total volume of the gaseous matter passing through the chimney. It appears, therefore, that but little more than one-half the oxygen of the air is abstracted in the process of combustion; and these experiments prove that practically it requires double the quantity of air to produce complete combustion in furnaces, that theoretical calculations would give, when based on the assumption of the entire abstraction of the oxygen from the air.

(357.) Whenever the gases eliminated from the combustion of coal are made to unite with the proper quantity of oxygen, and the temperature of the mixture be sufficiently high, the smoke will be consumed, in whatever part of the furnace or flues the admixture takes place. This fact has been disputed, but without any grounds for so doing. It has also been asserted that more atmospheric air is required to produce combustion of the smoke after it is mixed with the carbonic acid formed in the furnace, than would be required previous to this intermixture. This is true, theoretically, as the experiments of Sir

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[1] *Transactions of the Cornwall Polytechnic Society*, 1843; and *Glasgow Engineer's Magazine*, vol. iii. p. 93.

Humphry Davy proved; and he ascertained, that carbonic acid gas has rather a greater power of preventing the firing of explosive mixtures than azote would have.[1] Perhaps, therefore, the most advantageous place to introduce atmospheric air would be at the front of the furnace; but, in all probability, the difference in this respect is very small, as we have already seen that, in ordinary cases of combustion, only about one-half the oxygen of the air combines in the process of combustion, arising, no doubt, from the difficulty of sufficiently mixing the gases together during their passage through the furnace. But the longer these gases are in contact, and the more they are agitated and mixed together by passing through the different obstructions of a furnace, the more likely is the oxygen of the air to be abstracted, and chemical combination to take place. And, contrary to the opinion that smoke, after it is once formed, cannot be burned, a recent patent has been obtained for burning the smoke of furnaces by passing it over a second fire, at a considerable distance from the principal fire, with a fresh supply of atmospheric air; and however distant this second fire may be from the primary one, the combustion of the smoke is complete, and an immense heat is derived from these gaseous products, which, under ordinary circumstances, would only produce the black smoke of common furnaces.[2]

(358.) The actual quantity of heat produced by different qualities of coal, does not exactly depend upon the quantity of oxygen with which they combine. Dr. Ure made experiments[3] on the actual amount of heat given out by several qualities of coal, when consumed in a calorimeter of very perfect con-

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[1] *Philosophical Transactions*, Part ii., 1815; and *Philosophical Magazine*, vol. xlvi. p. 449.

[2] See *Collier's Patent*, Art. 413.

[3] *Reports of the British Scientific Association*, vol. viii. (1839) p. 20.

struction; by which, as nearly as possible, the entire heat from the coals was obtained; and taking the number of pounds of water raised 1° by the combustion of one pound of coal as the standard of comparison, the proportions were—

Lambton's Wall's End	7,500
Llangennech Coal	9,000
Anthracite Coal	12,000

The cause of the less degree of heat by the combustion of coals containing large quantities of hydrogen, Dr. Ure considers to arise from the great amount of heat rendered latent by the formation of steam and carburetted hydrogen gas; though the experiments of Dalton, Davy, Lavoisier, and Crawford, all proved that the heat produced by the combustion of hydrogen is greater than from any other substance.[1] All experiments, however, agree in proving the great heat which is derivable from the combustion of Anthracite coal. Considerable difficulty attends its combustion, on account of this kind of coal always breaking up in the furnace into small pieces, except it be very gradually heated; and unless this precaution be adopted, the draught of the fire is wholly stopped. The breakage of the coal arises from its slow conducting power, which causes the outside surfaces to expand more than the inner parts, when exposed to a high temperature; and this expansion causes the exterior parts continually to separate from the interior, until the whole substance is broken up. The elasticity which bitumen gives to coal, prevents this result with the ordinary qualities of bituminous coal. To remedy this inconvenience with Anthracite coal, various plans have been proposed for supplying it with vapour of water, in order to render it less brittle. The advantages of this operation, however, are very questionable. For, in America, where large

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[1] *Ure's Dictionary of Chemistry*, art. *Combustion.*

quantities of Anthracite are burned, experiments have been made in order to ascertain the cause of the corrosion which sometimes occurs to boilers, iron chimneys, and stove pipes, by the combustion of Anthracite coal: and from a report of the Franklin Institute of Pennsylvania,[1] it appears that in these cases the ashy deposit has been found to contain muriate and sulphate of ammonia; sometimes as much as three-fourths of the deposit consisting of these salts. Where moisture is present, the action of these salts must be much increased in activity; and it therefore deserves serious inquiry whether by the addition of vapour of water, all descriptions of Anthracite become in some degree corrosive, or whether the effect is peculiar to the coal of certain districts.[2] It is probable, that the destructive effect which is sometimes produced on thin copper boilers by particular kinds of fuel, may arise from something of this kind. Where the boiler is of such a form that the fire acts particularly on the sharp edges which form the connexion between the bottom and sides of the boiler, instances have repeatedly occurred of the corrosion being so active, that the bottom has separated from the sides as though it had been cut with a chisel; and in other cases, the surface of the boiler, when very thin, has been so corroded as to become full of holes in the course of a few months' wear (Art. 87).

(359.) The inventions which have been brought forward for consuming and for preventing smoke are very numerous. The following list will give a tolerable idea of the plans which have been proposed,

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[1] *Mechanic's Magazine*, vol. xxxvi. p. 439.

[2] Experiments have led the author to conclude that this effect is not peculiar to Anthracite coal, but that coke when burned with moisture produces the same results. The circumstance is interesting in a chemical point of view; and if more careful and extensive experiments shew this opinion to be correct, they may give rise to important inquiries concerning the compound nature of certain (so called) simple substances.

and of the general methods by which the object is sought to be obtained. Those of which a description is known to have been published, have a reference to such description; but the list is not given as a perfectly accurate account of all the inventions for this purpose, as no doubt there are others which have escaped the author's notice.[1]

(360.) The first attempt at consuming smoke appears to have been made by M. Delesme, sometime prior to 1669, by means of a stove with a downward draught; but it was not at all suitable for furnaces (*Philosophical Transactions*, 1686).

(361.) Dr. Papin (1695), proposed a plan for forcing air down a shaft upon the fuel, in order to burn the smoke of furnaces (*Philosophical Transactions*, 1697).

(362.) James Watt (1785), patent for consuming smoke, by admitting air through openings in the front of the furnace door, and also by gradually coking the coals (*Repertory of Arts*, vol. iv. (1796), p. 226).

(363.) C. W. Ward (1792), patent for condensing smoke by drawing it, by means of an air pump or bellows, through cold water (*Repertory of Arts*, vol. i. (1794), p. 373).

(364.) W. Thompson (1796), proposed a furnace to burn smoke, by letting air in *behind* the bridge (*Repertory of Arts*, vol. iv. (1796), p. 316).

(365.) Roberton, of Glasgow (1800), patent for admission of heated air in thin streams over the fire door; for coking the coals in front of the furnace; and also a hopper to supply the fuel (*Repertory of Arts*, vol. xvi. (1802), p. 364).

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[1] In the following descriptions of the various inventions, there are several which profess to accomplish results utterly unattainable by the means proposed. The statements are chiefly taken from the published accounts of the various plans, and several of them are totally contrary to the principles of science. The descriptions given must not be taken as the author's explanation of the operations or the effects.

(366.) M. de Prony (1809 or 1810), Report on apparatus erected at the Royal Mint, Paris, for consuming smoke, by two pipes passing from the front of the furnace door and delivering hot air at the bridge. He also states that this plan had previously been used by MM. Clement and Desormes, and others. (*Annales de Chimie; and Retrospect of Science*, vol. v. p. 439.)

(367.) Wm. Sheffield (1812), patent for hollow or split bridge, which delivered the air in a *horizontal* stream towards the front of the furnace. (*Gill's Technical Repository*, vol. i. pp. 16 and 42.)

(368.) J. Wakefield (Manchester), a similar patent to the above, and of subsequent date. (*Ibid.*)

(369.) Wm. Johnson (Salford), a similar and subsequent patent. (*Ibid.*)

(370.) Losh (1815), patent for dividing the furnace into two parts, lengthways; the two compartments being supplied with fuel alternately, by which the smoke from the fresh fuel passed over the more perfectly ignited fuel, and was thus consumed.

(371.) Brunton (1816), patent for revolving grate and feeding hopper; by which the fuel was equally distributed over the furnace, and in small quantities at a time, and thereby preventing all dense smoke. (*Mechanic's Magazine*, vol. i. p. 121.)

(372.) John Gregson (1816), patent for bringing air down a shaft, near the bridge, to promote combustion. Mechanical means were used to supply the fuel by a snail wheel, moved by springs. (*Quarterly Journal of Science*, vol. iii. p. 348.)

(373.) Josiah Parkes (1820), patent for split bridge, precisely similar to Sheffield's patent of 1812. (*Mechanic's Magazine*, vol. ii. p. 250.)

(374.) Mr. Marsh (1824) consumed the smoke of furnaces by leaving two openings in the flue at the back of the furnace. (*Gill's Technical Repository*, vol. vi. p. 213.)

(375.) Chapman (1824) described a plan for hollow furnace bars, that conveyed heated air into the furnace through a split bridge which projected the heated air horizontally. Also a hopper to supply the fuel. (*Transactions of the Society of Arts*, vol. xlii. p. 32; and *Quarterly Journal of Science*, vol. xix. p. 138.)

(376.) James Nevill, patent for a fan fixed in the flue, which produced a rapid draught up the chimney.

(377.) Stanley's patent for a feeder for furnaces, which consisted of a hopper, and grooved rollers to crush the coal. Two revolving pans scattered the coal over the fire in small quantities at a time, and thus prevented the dense smoke.

(378.) Jeffries (1824), patent for *destroying* smoke by a shower of water. Two chimneys were used, and the smoke passes up one and down the other, in which latter a shower of water falls from a colander, and carries the smoke in the form of soot into a drain. (*Mechanic's Magazine*, vol. xxxiv. p. 198.)

(379.) Mr. Oldam, of the Bank of England, employed a plan of rocking bars, moved by a small eccentric on a shaft worked by the engine.

(380.) Wm. Taylor (1830), patent for consuming smoke, by forcing it through the fire, mixed with atmospheric air by means of an air pump. Also for a mode of passing the smoke through red-hot pipes placed in the furnace among the fuel, which pipes form the only outlet to the chimney. (*Repertory of Arts*, vol. i. (1834), p. 282.)

(381.) J. C. Douglass (1833), patent for two or more sets of bars. The smoke from the first set passes downwards below a bridge, and then upwards through a second set of bars, on which burning fuel is placed. (*Repertory of Arts*, vol. v. (1836), p. 346.)

(382.) J. G. Bodmer (1834), patent for traversing bars, moved by machinery, which receive the fuel from a feeder, and discharge the ashes at the further end of the furnace.

(383.) Richard Coad (1835), patent for heating the air by passing it through pipes placed in the flues, and delivering the air at the bridge of the furnace. (*Mechanic's Magazine*, vol. xxvii. p. 375.)

(384.) T. Hedley's patent for *purifying* smoke by four or six flues, of which one-half ascend and the other half descend. A shower of water falls through the descending flues and washes the smoke, depositing the carbon in the form of lamp-black.

(385.) William Richard, of Leeds, patent for gazometer applied to furnaces, so that on opening the furnace-door to feed the fire, a passage is opened from the gazometer containing condensed air, to a number of holes at the back of the bridge, and the supply of air gradually diminishes as the fire burns clear.

(386.) Samuel Hall (1836), patent for cast-iron pipes placed upright in the flue at the back of the furnace, and then passing towards the front. The air is thus heated to about 300°, and the gases inflame in front of the furnace. (*Mechanic's Magazine*, vol. xxviii. p. 226.)

(387.) John Hopkins (1836), patent for a curved bridge, by which the smoke and gases are thrown back again upon the burning fuel. (*Repertory of Arts*, vol. vii. (1837) p. 252.)

(388.) Jacob Perkins (1836), patent for two sets of bars and two ash-pits. The second ash-pit is closed, and supplied with air by a fan, so as to give more air to that part of the furnace, and thus burn the smoke from the fuel on both sets of bars. (*Repertory of Arts*, vol. viii. (1837) p. 268.)

(389.) Joseph Chanter (1837, etc.), several patents for smoke burning, principally by inclined bars—double sets of bars—air supplied through tubes placed under the first set of bars—and hot air supplied at the bridge.

(390.) James Drew, Manchester, patent for two sets of bars. The coal is coked on the first set, and passed on to the second set, which is then raised by rack-work as near the boiler as possible.

(391.) Paul Chappe, patent for injecting small jets of boiling water over the fire, in front of the bridge.

(392.) Ivison and Bell (1838), patent for injecting small jets of steam into the furnace, and also for heating the air by passing it through tubes. (*Mechanic's Magazine*, vol. xxviii. p. 221, and vol. xxx. pp. 69 and 107.)

(393.) Rodda's patent for a furnace divided across into two parts. The fuel is first put into the compartment nearest the door, and afterwards thrown backwards to the further compartment. The smoke is burned by passing over the clear fire of the second compartment. (*Mechanic's Magazine*, vol. xxxi. p. 386)

(394.) Cheetham and Bayley, patent for a fan which catches the smoke and forces it, mixed with fresh air, through the ash-pit and furnace-bars, the ash-pit being made air tight.

(395.) Thomas Hall (Leeds), patent for dividing the furnace in two compartments lengthways, which are supplied with fuel alternately, and the smoke thereby passes over red-hot fuel.

(396.) James Nevill (1837), patent for two sets of hollow bars containing water. A downward draught is produced by the chimney drawing only from the lower set of bars, and the smoke burned by passing through the hot fuel in contact with the bars. (*Repertory of Arts*, vol. xii. (1839), p. 220.)

(397.) John Juckes (1838), patent for heating the fuel by passing it through highly-heated pipes or other surfaces by which it is coked before it passes into the fire, which is effected by mechanical means. (*Repertory of Arts*, vol. xiii. (1840), p. 122.)

(398.) J. A. Caldwell (1839), patent for a rotary fan, by which air is forced into a closed ash-pit: the furnace-bars are placed very close together, and a moveable damper is applied in the chimney, by which the velocity of the smoke escaping is retarded, and the heated gases retained longer in the furnace. (*Repertory of Arts*, vol. xiii. (1840), p. 83.)

(399.) William Miller (1839), patent for rocking bars, by which each alternate bar is made to move lengthways in opposite directions, backwards and forwards; and thus preventing clinkers, and consuming the smoke by allowing a free passage for the air through the bars. (*Repertory of Arts*, vol. xvii. (1842), p. 143.)

(400.) C. W. Williams (1839), patent for supplying air in jets to the furnace, principally behind the bridge, by a diffusion box. The air is supplied cold.

(401.) André Kurtz (1840), patent for three sets of bars; those at each end inclined, and the middle set lower than the others. Hollow bearing bars which convey heated air into the furnace. (*Mechanic's Magazine*, vol. xxxiv. p. 397.)

(402.) Junius Smith (1840), patent for a double fan or blower, which passes heated air with the smoke through the furnace-bars a second time. The heavy gases are allowed to fall by their gravity below the fan, which then forces them down, and filters them through gravel or sand. (*Repertory of Arts*, vol. xvi. (1841), p. 81.)

(403.) Baron Von Rathen (1840), patent for hollow fire-bars, resting upon bearers with steps, forming two sides of a triangle, which allows more air to pass into the furnace. Also a coal-feeder placed over the dead plate, which supplies fuel without opening the door. (*Mechanic's Magazine*, vol. xxxv. p. 27.)

(404.) Godson and Foard (Jan. 1841), patent for a box placed below the furnace-bars with a moveable bottom. The box being filled with fuel, the bottom is gradually raised by a lever, and supplies fuel from below, the smoke from which is consumed by passing through the red-hot fuel. (*Repertory of Arts*, vol. xviii. (1842), p. 129.)

(405.) M. Coupland (Sept. 1841), a patent for moveable centre bars which pass downwards into a box, nearly similar to Godson's. (*Repertory of Arts*, vol. xviii. p. 207).

(406.) F. Heindruckx (1841), patent for a furnace without bars. The sides of the furnace are inclined, and a narrow opening is left at the bottom, the whole length of the furnace, through which the air enters, and is regulated by a longitudinal valve. (*Mechanic's Magazine*, vol. xxxv. p. 366).

(407.) J. C. March (1841), patent for causing air to be blown in streams on the upper surface of the fuel without passing through the fire. No furnace-bars are used by this plan. (*Mechanic's Magazine*, vol. xxxv. p. 492). See also a somewhat similar plan, Art. 361.

(408.) John Juckes (1841), patent for a furnace grating passing over rollers at each end of the furnace like an endless chain. The bars revolve by machinery, receiving fuel from a feeder placed near the door, and deliver the ashes at the further end of the furnace. (*Repertory of Arts*, vol. xvii. (1842), p. 210).

(409.) J. Prosser (1842), patent for a furnace-bridge, with square holes for the admission of air. The bridge is fixed close against the bottom of the boiler.

(410). Kymer and Leighton (1843), patent for diagonal bars resting in small longitudinal troughs of water. A closed ash-pit is used, and a fan forces air through the bars and also over the fuel. The plan used principally for anthracite coal.

(411.) Schofield, of Leeds (1842), proposed the use of very narrow furnace-bars, quarter of an inch wide at top, and as thin as possible at bottom, and two inches deep. These bars admit a larger quantity of air than usual, and thus consume the smoke.

(412). E. Billingsley, of Bradford (1842), proposed a focal bridge beyond the furnace-bars, and a sliding rack or grating in front of the furnace to admit air. (*Mining Journal*, Jan. 7, 1843).

(413). E. H. Collier (1843), patent for the use of a second fire at a distance from the usual fire. The smoke, after passing through the ordinary flues, is carried over this second fire, and there mixed with an additional quantity of air, when it inflames, and is carried through a second set of flues before passing into the chimney.

(414.) These appear to be the principal plans that have been proposed for effecting the combustion of smoke. Many of them, it will be perceived, are identical with each other, and in some cases the same plans have been patented several times over. In all those which are at all capable of producing any useful effect, the principle is the same,—to bring an additional quantity of air to the burning fuel. In most of these inventions this is very clearly brought into view, but in others this principle is not so plainly developed. Among the latter may be noticed the inventions in which a jet of steam is thrown into the furnace, and two other inventions in which a shower of water falls down the flue with considerable velocity. In all these cases the great velocity of the steam and the water, give an additional impetus to the motion of the gaseous bodies within their immediate sphere; and these again communicate their velocity to those which are more distant, and thus draw into the furnace an additional quantity of air.[1] There are

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[1] This peculiar property of fluids, both liquid and aeriform, to communicate motion to other fluid bodies, not in actual contact with them, is comparatively but little known, and yet is most extensively an operative cause in many phenomena produced by

practical difficulties, however, attending the use of a shower of water used in this way, which must effectually prevent these inventions coming into very general use.

(415.) A second class of inventions are those in which the fuel is gradually coked, before it enters

nature and by art. In very few works on natural or experimental science is this principle at all alluded to. The peculiar property in question may be illustrated by supposing a pipe of several feet in length and of considerable diameter—say, for example, 12 or 14 inches—and open at both ends; let there be also a small pipe of about one inch diameter, inserted into one end of the large pipe for a short distance, and let there be a current of air or steam forced through the small pipe with considerable velocity. The action of this current of air or steam will be such, that it will continue its course after leaving the small pipe, for a very considerable distance along the large pipe, at its original velocity and with scarcely any *lateral* expansion; and it will communicate its own velocity to a very great body of air in the large pipe, which will thus have a current produced in it of considerable intensity. The distance to which the current passing along the small pipe will proceed, without losing its velocity and mixing with the aeriform fluid contained in the large pipe, will depend upon the initial velocity which is given to it; but this distance is very considerable, and the quantity of air is very great, which may be put in motion in the large pipe, by an extremely small jet of air in the small pipe. The currents and eddies of many rivers and lakes have their origin in this cause. The draught caused in the chimneys of locomotive engines by a jet of steam, the action of all chimney cowls, and other of the phenomena which occasionally present themselves in practical science, are due to this fact. In the case of chimney cowls the effect is very remarkable. Whatever efficacy any chimney cowl really possesses, arises entirely from this cause; though very few of the contrivers of these instruments are aware of the fact. The only inventions for chimney cowls which appear to have been specially contrived with the knowledge of this principle, are those patented by Mr. Carson in 1840, and a more recent invention called the Himalaya chimney funnel. The former, however, though constructed strictly on this principle, has the disadvantage common to all cowls which turn around with the wind, of sometimes meeting the current of air instead of being always turned in the same direction as the wind; while the latter cowl or funnel, being a fixture, can never be in a wrong direction with respect to the wind. This latter invention consists of a double pipe or funnel; the smoke passes into combustion. When coal is suddenly exposed to a high temperature, a very large quantity of gaseous matter is given off, which quantity gradually diminishes as the coal becomes more nearly converted into coke. By slowly heating the coal, a more equable evolution of gas is produced. This result is very effectually accomplished by using a large dead, or dumb plate, in front of the furnace. The coals being placed on this plate are gradually warmed, and at last arrive at a state of incandescence, when all the gas has been driven off; by which gradual distillation of the volatile gases, the necessary quantity of air to produce combustion is more easily obtained, as the demand for it thus continues nearly uniform throughout the whole of the process of combustion, instead of the very large additional quantity required when a fresh charge of coal is thrown on the fire in the ordinary method of supplying fuel. The use of a large dead plate in this way, is quite sufficient of itself, without any additional contrivance, to consume all the smoke of a furnace, provided the fire on the bars be kept thin, so as to allow a more ready entrance for the air through the fuel. Considerable attention is however required on the part of the fireman, that the fuel on the dead plate be gradually pushed forward into the furnace as it becomes heated. When the fuel is supplied through a hopper, placed in front of the furnace, the necessity for opening the furnace door becomes much less frequent, and the unnecessary cooling of the furnace is thus prevented. Where no air is

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through the inner pipe, and the air passing between the inner and outer pipe, gives velocity to the smoke passing through the inner pipe. Mr. Carson's invention is described in the *Repertory of Arts,* vol. xv. (1841) p. 71; and in his apparatus, the air passes through the inner pipe and the smoke through the outer pipe. Some interesting experiments have lately been made by Mr. Ewbank on this subject, which are given in the *Franklin Journal of Pennsylvania,* and also in the *Mechanic's Magazine,* vol. xxxvii. p. 372.

admitted except through the furnace-bars, there will however always be a considerable quantity of carbonic oxide formed during the combustion; and although, under these circumstances, there is no smoke, the greatest effect of the fuel is not, by this means, produced. A moderate quantity of air ought to be introduced into the furnace, to mix with the gases distilled from the coal, and also to convert the carbonic oxide formed by the upper strata of coal, into carbonic acid. This air ought to be heated before it enters the furnace, as it thus more readily inflames, mixes more easily with the heated gases of the furnace, and prevents injury by the unequal action of cold currents impinging against the bottom of the boiler. It perhaps matters but little in what part of the furnace this air be introduced; but the more it is diffused the better, as the heat is then less likely to become too intense on one particular part. Various simple methods of introducing heated air may be used; and the plan of using two pipes in the manner originally employed at the Royal Mint at Paris (Art. 366), as long ago as the year 1809, answers the purpose extremely well. The apertures to the pipes should be furnished with covers which can be partially closed; and by the experiments of Mr. Houldsworth,[1] it appears that an aperture for the air, varying from 1½ to three square inches, for each square foot of the area of the furnace-bars, will be sufficient for this purpose, the size of the pipes varying with the nature and quality of the coals.

(416.) The gradual coking of the fuel is likewise effected by such plans as those of Drew, Godson, and Coupland. Godson's plan effectually cokes the coal, and is perfectly compatible with any method of introducing additional air above the fuel to consume the carbonic oxide. The plans of Losh, Rodda, Thomas

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[1] *Report of the Select Committee of the House of Commons on the Prevention of Smoke*, p. 105.

Hall, Collier, and some others, in which the flame from one fire passes over a second fire of clear bright burning fuel, is another mode of accomplishing the same object, but apparently less simple in its operation; and the mechanical means of continually feeding the fire, used by Stanley, and by Brunton, produce nearly the same effect as the method of coking the coals would do; as by these means the evolution of the gases from the coal is equalised throughout the combustion, and the extraordinary demand for air, when fresh charges of coal are supplied in the common mode of firing, is thereby avoided.

(417.) The method of supplying heated air through a split bridge has been repeatedly patented. Mr. Sheffield, in 1812, was undoubtedly the first to propose this plan, and his method of making the aperture deliver the heated air horizontally into the furnace, is perfectly correct in principle. The defect of these plans has frequently been that too large a quantity of air has thus been brought into the furnace, and the effect has been to lower its temperature. Mr. C. W. Williams' plan of diffusion would be very good, if it were used with hot air, instead of cold air, which latter is specially directed by the patent to be used; but by the former method, it would approach very near to the prior plan of Mr. Samuel Hall, differing only in being more simple and inexpensive. It should not however be overlooked, that it is not so easy to heat large quantities of atmospheric air to a high temperature as some persons imagine. When hot air is applied to blast furnaces, it is found that to heat the air to about 600° Fahrenheit, it is necessary for it to traverse a surface of cast-iron pipes at nearly a red heat, for a period of 1·66 minutes, or about one minute and 40 seconds. The mere instantaneous passing of air through a heated metallic perforated plate, would therefore add but little to its temperature, unless it were also made to travel through heated pipes for some considerable distance.

(418.) Probably one of the most effectual methods of burning smoke is the plan of Mr. March (Art. 407), by blowing air downwards upon the fuel by a fan, and dispensing with the use of furnace-bars. There can be no question that a most perfect combustion of the fuel may be thus produced; but it is very doubtful whether the additional trouble which this method would cause, and the necessity for a mechanical power to produce the requisite blast of air, will not prevent its adoption to any considerable extent. A similar plan to this is stated to have been tried experimentally in some of the furnaces used in the manufacture of iron; and as the whole of the carbonic oxide must, by this plan, be consumed, there will necessarily be a considerable saving of fuel.[1]

(419.) It has been objected to the various plans for the admission of air to the gases above the fuel of the furnace, that the air, when thus admitted, prevents to a certain extent the admission of the air through the furnace-bars, and thus reduces the rate of the combustion of the fuel on the furnace-bars. This to a certain extent is true, but it can be no argument against the plan; for it can only be when the air is improperly admitted, and escapes through the flues in an uncombined state, that the total combustion of the furnace can be reduced by the admission of air above the fuel. And in general it will follow, that the heat of the furnace being increased by the perfect combustion of the gases on the top of the fuel, the draft of the furnace will be increased, and therefore there will be a greater tendency to the influx of air through the furnace-bars

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[1] Some interesting researches by M. Ebelmen on the application of the carbonic oxide from blast furnaces, to useful purposes, have shewn that the loss of effect by the escape of the carbonic oxide, amounts to 62 per cent. of the total quantity of fuel consumed in blast furnaces. (*Repertory of Arts*, vol. xviii. (1842), pp. 116—313.)

as well as through the other apertures. The use of heated air, however, in preference to cold air, is far more likely to prevent any loss by the passing of air in an uncombined state through the flues. When cold air is used, this result is not unlikely to occur; for gases, at temperatures differing considerably from each other, mix together very slowly; and therefore it may often happen that by introducing cold air into a furnace, the mixture of the air with the gases will not take place until they have passed into the flues, and the temperature become too much reduced to cause their accension.

(420.) The practical result of these remarks is, that there are many effectual contrivances for the cumbustion of smoke, combining the advantage of great economy of fuel. For this purpose, the more simple the apparatus the better; and with a very slight degree of attention on the part of the firemen, several of the plans which have been described would be certain to succeed in abating the nuisance of smoke entirely, and with considerable economy in the consumption of fuel.

(421.) Before concluding these remarks, a few words on artificial fuels may not be amiss. A great number of patents have been obtained for forming artificial fuel, the principle of them all being, to combine the small and refuse coal into a solid body. As early as 1799, a patent was obtained by M. Chabannes for this purpose, and it is difficult to discover in what this patent differs from the various subsequent and recent ones for the same object. The principal ingredients used in all these compositions are coal-dust, coke, peat, bark, saw-dust, tan, clay, sand, pitch, coal-tar, alum, nitre, vegetable matter, and animal excrement. Different persons combine these substances in different proportions, and some omit altogether certain of these ingredients. A very powerful and efficient fuel can be composed by mixtures of these substances; and it appears by some experiments reported by Dr. Buckland to the British Scientific Association,[1] that when tried against Welsh coal, Pontop coal, and Wylam main coal, the artificial compound was found to be very considerably more powerful in heating effect than either of these coals. These compound fuels, however, are subject to one inconvenience when used by themselves in furnaces; that the coal-tar is very liable to distil from the fuel without being consumed, in which case it clogs up the furnace-bars and partially stops the due admission of air. When it is used with a certain proportion of ordinary coal, this inconvenience is less likely to occur, and probably with moderate care it may be avoided. And these methods of combining refuse coal, which must otherwise be nearly valueless, may in many places be most efficiently applied to obtaining a powerful and useful fuel at a moderate expense.

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[1] *Report of the British Scientific Association*, vol. vii. (1838), p. 85.

APPENDIX.

TABLE I.

Table of the Expansive Force of Steam, in Atmospheres, and in lbs. per square inch; for Temperatures above 212° of Fahrenheit.

N.B.—The steam is supposed to be in contact with the water from which it is formed, and the water and steam to be alike in temperature.

Heat in Degrees of Fahrenheit.	Pressure.		Heat in Degrees of Fahrenheit.	Pressure.		Heat in Degrees of Fahrenheit.	Pressure.		Heat in Degrees of Fahrenheit.	Pressure.	
	Atmospheres.	lbs.		Atmospheres.	lbs.		Atmospheres.	lbs.		Atmospheres.	lbs.
212	1	15	351	9	135	487	40	600	663	170	2550
216	—	16·5	359	10	150	499	45	675	671	180	2700
220	—	17·7	367	11	165	511	50	750	679	190	2850
225	—	19·5	374	12	180	521	55	825	686	200	3000
230	—	21·5	381	13	195	531	60	900	694	210	3150
235	—	23·6	387	14	210	540	65	975	700	220	3300
240	—	25·8	393	15	225	549	70	1050	707	230	3450
245	—	28·1	399	16	240	557	75	1125	713	240	3600
250	2	30·9	404	17	255	565	80	1200	719	250	3750
255	—	33·6	409	18	270	572	85	1275	726	260	3900
260	—	36·1	414	19	285	579	90	1350	731	270	4050
265	—	39·0	418	20	300	586	95	1425	737	280	4200
270	—	43·1	423	21	315	592	100	1500	742	290	4350
275	3	45·	427	22	330	605	110	1650	748	300	4500
294	4	60	431	23	345	616	120	1800	753	310	4650
308	5	75	436	24	360	627	130	1950	758	320	4800
320	6	90	439	25	375	636	140	2100	763	330	4950
332	7	105	457	30	450	646	150	2250	768	340	5100
342	8	120	473	35	525	655	160	2400	772	350	5250

⁂ The pressures above three atmospheres in the above Table, are deduced from the experiments of MM. Dulong and Arago. Their calculations extend only as far as 50 atmospheres; from thence the pressures are now calculated to 350 atmospheres by their formula, viz.:—

$$t = \frac{\sqrt[5]{e} - 1}{\cdot 7153}$$

where e represents the pressure in atmospheres, and t the temperature above 100° of Centigrade. In this equation each 100° of Centigrade is represented by unity.

In reducing these temperatures from Centigrade to Fahrenheit's scale, where the fractions amount to ·5, they have been taken as the next degree above, and all fractions below ·5 have been rejected.

TABLE II.

Table of the Quantity of Vapour contained in Atmospheric Air, at different Temperatures, when saturated.

Temperature of Air.	Quantity of Vapour per Cubic Foot; in Grains Weight.	Temperature of the Air.	Quantity of Vapour per Cubic Foot; in Grains Weight.	Temperature of the Air.	Quantity of Vapour per Cubic Foot; in Grains Weight.
20°	1·52	48°	3·94	76°	9·38
22	1·64	50	4·19	78	9·99
24	1·76	52	4·46	80	10·59
26	1·89	54	4·77	82	11·29
28	2·03	56	5·06	84	11·98
30	2·16	58	5·40	86	12·68
32	2·31	60	5·76	88	13·36
34	2·43	62	6·12	90	14·15
36	2·62	64	6·50	92	14·93
38	2·80	66	6·91	94	15·81
40	2·99	68	7·31	96	16·76
42	3·21	70	7·77	98	17·83
44	3·45	72	8·27	100	19·00
46	3·69	74	8·80	—	—

⁂ The above Table is computed from Dr. Dalton's experiments on the Elastic Force of Vapour.

The weight of a cubic foot of steam, at the pressure of 30 inches of mercury, is 257·119 grains; therefore at any other pressure p, the weight will be $\frac{p \times 257\cdot119}{30} = x$. But as vapours expand $\frac{1}{480}$ for each degree of Fahrenheit, this equation must be corrected for the difference in the expansion of the vapour at the temperature of 212°, and the temperature p, in the preceding equation. Therefore, the volume of the vapour at the temperature p, will be $1+\frac{p}{480}$; the volume at 212°, being $1+\frac{212}{480}=1{\cdot}441$, when the volume is assumed to be unity at zero. The weight of a cubic foot of vapour will therefore be $\frac{1{\cdot}441 \times x}{1+\frac{p}{480}}=w$.

TABLE III.

Table of the Expansion of Air and other Gases by Heat, when perfectly free from Vapour.

Temperature, Fahrenheit's Scale.	Expansion.	Temperature, Fahrenheit's Scale.	Expansion.
32°	1000	100°	1152
35	1007	110	1178
40	1021	120	1194
45	1032	130	1215
50	1043	140	1235
55	1055	150	1255
60	1066	160	1275
65	1077	170	1295
70	1089	180	1315
75	1099	190	1334
80	1110	200	1354
85	1121	210	1372
90	1132	212	1376
95	1142		

⁂ The above numbers are obtained from Dr. Dalton's experiments, which give an average of $\frac{1}{483}$ part, or ·00207 for the expansion by each degree of Fahrenheit. Gay Lussac found it to be equal to $\frac{1}{480}$ part, or ·002083 for each degree of Fahrenheit; and that the same law extends to condensible vapours when excluded from contact of the liquids which produce them.

TABLE IV.

Table of the Specific Gravity and Expansion of Water at different Temperatures.

Temperature, Fahrenheit's Scale.	Expansion.	Specific Gravity.	Weight of 1 Cubic Inch, in Grains.	Temperature, Fahrenheit's Scale.	Expansion.	Specific Gravity.	Weight of 1 Cubic Inch, in Grains.
30°	·00017	·9998	252·714	121°	·01236	·9878	249·677
32	·00010	·9999	252·734	124	·01319	·9870	349·473
34	·00005	·9999	252·745	127	·01403	·9861	249·265
36	·00004	·9999	252·753	130	·01490	·9853	249·053
38	·000002	·9999	252·758	133	·01578	·9844	248·836
39	·00000	1·0000	252·759	136	·01668	·9836	248·615
43	·00003	·9999	252·750	139	·01760	·9827	248·391
46	·00010	·9999	252·734	142	·01853	·9818	248·163
49	·00021	·9997	252·704	145	·01947	·9809	247·931
52	·00036	·9996	252·667	148	·02043	·9799	247·697
55	·00054	·9994	252·621	151	·02141	·9790	247·459
58	·00076	·9992	252·566	154	·02240	·9780	247·219
61	·00101	·9989	252·502	157	·02340	·9771	246·976
64	·00130	·9986	252·429	160	·02441	·9760	246·707
67	·00163	·9983	252·349	163	·02543	·9751	246·483
70	·00198	·9981	252·285	166	·02647	·9741	246·233
73	·00237	·9976	252·162	169	·02751	·9731	245·982
76	·00278	·9972	252·058	172	·02856	·9721	245·729
79	·00323	·9967	251·945	175	·02962	·9711	245·474
82	·00371	·9963	251·825	178	·03068	·9701	245·218
85	·00422	·9958	251·698	181	·03176	·9691	244·962
88	·00476	·9952	251·564	184	·03284	·9681	244·704
91	·00533	·9947	251·422	187	·03392	·9671	244·446
94	·00592	·9941	251·275	190	·03501	·9660	244·187
97	·00654	·9935	251·121	193	·03610	·9650	243·928
100	·00718	·9928	250·960	196	·03720	·9640	243·669
103	·00785	·9922	250·794	199	·03829	·9630	243·410
106	·00855	·9915	250·621	202	·03939	·9619	243·151
109	·00927	·9908	250·443	205	·04049	·9609	242·893
112	·01001	·9901	250·259	208	·04159	·9599	242·635
115	·01077	·9893	250·070	212	·04306	·9585	242·293
118	·01156	·9885	249·876				

⁂ In the above Table the expansions are calculated by Dr. Young's formula, 22 f^2 (1—·002 f) in 10 millionths. The diminution of specific gravity is calculated by this equation:—·0000022 f^2 — ·00000000472 f^3. In both equations, f represents the number of degrees above or below 39° of Fahrenheit. The absolute weight of a cubic inch of water, at any temperature, may be found by multiplying the weight of a cubic inch at 39°, by the specific gravity at the required temperature.

TABLE V.

Table of the Specific Heat, Specific Gravity, and Expansion by Heat of different Bodies.

Barometer 30 Inches.—Thermometer 60°.

——	Specific Heat.		Specific Gravity.	Weight of 100 Cubic Inches.	Linear Expansion by 180° of Heat, from 32° to 212°.
	Of equal Weights, by Berard, Delaroche,	and Petit and Dulong.		Barometer 30 Inches. Thermometer 60°.	
				Grains.	
Air (atmospheric)	·2669	...	1·000	30·519	
—— (dry) *Apjohn*	·2767	...	...	...	
Aqueous vapour	·8470	...	·633	19·058*	
Azote	·2754	...	·9722	29·65	
—— oxide of	·2369	...	1·5277	46·596	
Carbonic acid	·2210	...	1·5277	46·596	
———— oxide	·2884	...	·9722	29·65	
Hydrogen	3·2936	...	·0694	2·118	
Olefiant Gas	·4207	...	·9722	29·65	
Oxygen	·2361	...	1·1111	33·888	
				Ounces.	
Water	...	1·000	1·000	57·87	
Bismuth	...	·0288	9·880	571·7	
Brass	...	...	7·824	452·77	·00186671 $=\frac{1}{535}$
—— wire	...	...	8·396	485·87	·00193000 $=\frac{1}{518}$
Cobalt	...	·1498	8·600	497·6	......
Copper	...	·0949	8·900	515·0	·00172244 $=\frac{1}{581}$
Gold	...	·0298	19·250	1114·0	·00146606 $=\frac{1}{682}$
Glass (flint)	...	...	2·760	159·72	·00081166 $=\frac{1}{1248}$
—— (tube)	...	...	2·520	145·83	·00087572 $=\frac{1}{1142}$
Iron (cast)	...	...	7·248	418·9	·00111111 $=\frac{1}{900}$
—— (bar)	...	·1100	7·788	450·2	·00122045 $=\frac{1}{819}$
Lead	...	·0293	11·350	656·8	·00284836 $=\frac{1}{351}$
Nickel	...	·1035	8·279	478·5	
Pewter (fine)	...	...	...	...	·00228300 $=\frac{1}{438}$
Platinum	...	·0314	21·470	1242·4	·00099180 $=\frac{1}{1008}$
Silver	...	·0557	10·470	605·8	·00208260 $=\frac{1}{480}$
Solder (lead 2 + tin 1)	...	...	...	...	·00250800 $=\frac{1}{398}$
Spelter (brass 2 + zinc 1)	...	...	...	...	·00205800 $=\frac{1}{486}$
Steel (untempered)	...	...	7.840	453·7	·00107875 $=\frac{1}{927}$
—— (yellow tempered)	...	...	7·816	452·31	·00136900 $=\frac{1}{730}$
Sulphur	...	·1880	1·990	115·1	
Tellurium	...	·0912	6·115	353·5	
Tin	...	·0514	7·291	421·9	·00217298 $=\frac{1}{462}$
Zinc	...	·0927	7·191	416·0	·00294200 $=\frac{1}{339}$

*** Air is taken as the standard for the specific gravity of the gases, and water as the standard for the solids.

The specific heat of gases has been recently investigated by Dr. Apjohn, and a somewhat different result obtained. (See *London and Edinburgh Philosophical Magazine*, vol. xii. 102; xiii. 261, 339.

* Specific gravity of steam at 212° = ·481. Weight of 100 cubic inches, 14·879 grains.

TABLE VI.

TABLE OF THE EFFECTS OF HEAT.

	Fahrenheit's Scale.
Soft iron melts (Clement and Desormes)	3945°
Maximum temperature by Daniell's Pyrometer	3280
Cast iron melts	2786
Gold melts	2016
Copper melts	1996
Silver melts	1873
Bronze melts (copper 15 parts, tin 1 part)	1750
Brass melts (copper 3 parts, zinc 1 part)	1690
,, (copper 2 parts, zinc 2 parts)	1672
Diamond burns	1552
Bronze melts (copper 7 parts, tin 1 part)	1534
,, (copper 3 parts, tin 1 part)	1446
Enamel colours burnt	1392
Iron red-hot in daylight	1272
,, in the twilight	884
,, in the dark	800
Charcoal burns	802
Heat of a common fire	790
Zinc melts (Davy 680°) (Daniell)	773
Mercury boils (Black 600°) (Crichton 655°) (Dalton 660°) (Petit and Dulong 656°) (Irvine 672°) (Secondat 644°)	660
Linseed oil boils	640
Lowest ignition of iron in the dark	635
Lead melts (Guyton and Irvine 594°) (Crichton)	612
Steel becomes dark blue, verging on black	600
,, a full blue	560
Sulphur burns	560
Steel becomes blue	550
,, purple	530
,, brown, with purple spots	510
,, brown	490
Bismuth melts	476
Steel becomes a full yellow	470
,, a pale straw colour	450
Tin melts	442
Steel becomes a very faint yellow	430
Tin 3 + lead 2 + bismuth 1, melts	334
Tin and bismuth, equal parts, melt	283
Sulphur melts	218

Table of the Effects of Heat (*continued*).

	Fahrenheit's Scale.
Bismuth 5 + tin 3 + lead 2, melts	212°
Water boils (barometer 30 inches)	212
Wax melts	149
Spermaceti melts	112
Tallow melts (Nicholson 127°)	92
Acetic acid congeals	50
Olive oil congeals	36
Water freezes	32
Milk freezes	30
Vinegar freezes	28
Sea-water freezes	28
Strong wine freezes	20
Oil of turpentine freezes	14
Mercury congeals	—39
Sulphuric æther congeals	—47
Natural temperature of Hudson's Bay	—51
Greatest artificial cold	—91

Table VII.

Table of the Quantity of Water contained in 100 Feet of Pipe, of different Diameters.

Diameter of Pipe.	Contents of 100 Feet in length.
Inches.	Gallons.
½	·84
1	3·39
1½	7·64
2	13·58
2½	21·22
3	30·56
4	54·33
5	84·90
6	122·26

TABLE VIII.

Table of the Strength, or Cohesive Force, of different Substances: By Mr. GEORGE RENNIE.

Bars of six inches long and a quarter of an inch square will break with the following weight suspended lengthways:—

	lbs.
Cast Iron (horizontal)	1166
Ditto (vertical)	1218
Cast Steel (tilted)	8391
Blistered Steel (hammered)	8322
Shear Steel (ditto)	7977
Swedish Iron	4504
English Iron	3492
Hard Gun-metal	2273
Wrought Copper (hammered)	2112
Cast Copper	1192
Fine Yellow Brass	1123
Cast Tin	296
Cast Lead	114

⁂ A round bar of best English Iron, one-inch diameter, when subjected to a longitudinal strain, will break with a weight of 43,520 lbs., or rather less than 19½ tons. This agrees very nearly with the amount above stated.

Table of the Relative Cohesive Strength of Metals: By SICKENGER.

Gold	150,955
Silver	190,771
Platinum	262,361
Copper	304,696
Soft Iron	362,927
Hard Iron	559,880

By MUSCHENBROEK.

Copper 6 + Tin 1	41,000
Swedish Copper 6 + Malacca Tin 1	64,000
Brass	51,000
Block Tin 3 + Lead 1	10,200
Ditto 8 + Zinc 1	10,000
Tin 4 + Regulus of Antimony 1	12,000
Lead 8 + Zinc 1	4,500
Tin 4 + Lead 1 + Zinc 1	13,000

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