A Practical Treatise

ON

THE BALANCE SPRING,

INCLUDING MAKING, FITTING,
ADJUSTING TO ISOCHRONISM AND POSITIONS,
AND RATING;

ALSO

THE ADJUSTMENT FOR HEAT AND COLD.

By "EXCELSIOR."

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INTRODUCTION.

The series of articles of which this is the introductory one will be pre-eminently practical. Not that we would disparage theory—far from it. A knowledge of the theoretical principles of any art is the proper preparation for the most successful practice in it. But if we should go into the philosophy of our trade, the whole of the *Jeweler's Circular* would not be sufficient for its proper treatment, and those who needed the instruction the most would not read it at all.

The majority of watchmakers would give more for an account of the actual practice among good workmen than for all the theoretical treatises ever published. This is not as it should be, but it is considered the part of wisdom to take things as they are. Hence, the editor, with a keen appreciation of the wants of his readers, and a liberal intention to do everything possible to fill them, instructs us to give articles "practical and exhaustive, going to the bottom of the subject, and useful to advanced workmen, as well as those with less experience." This we have undertaken to do, but with the proviso that we may smuggle in occasional doses of theoretical knowledge, well sugar-coated so as to have a practical flavor and go down easily.

The truth is that a very large share of our watchmakers are but imperfectly educated, either in theory or practice. The foreign system of long apprenticeships is not in vogue here, and even if it were, the most of our employers are not really competent to instruct apprentices. Many of them are not workmen at all—only dealers in the goods of our line. Such as are good workmen are becoming more and more averse to taking apprentices, because their time is too valuable to allow of giving thorough instruction, as they could better afford to do under the old apprentice-laws, which on the whole were certainly better for both masters and men. The result is that half-fledged workmen abound—most of them conscious of their shortcomings and anxious to learn, but they find themselves compelled to educate themselves, and to make their living while doing so.

Again, many workmen have fully learned their trade, according to the old style, but everything has changed greatly since then, even within the last ten years, and they find that they are getting out of date. There are new kinds of work to be done, new tools and machinery to be used, new materials, new ways of working, and above all, greater excellence in every respect is required than would have sufficed in the old verge and lepine days. This change is constantly going on, even now, and the good workman of to-day will soon be left among the old fogies unless he keeps himself informed of all the current improvements. There is scarcely any horological literature in the English language suitable for the wants of practical workmen, and even the works in German and French are generally so full of abstruse theories and mathematical formulas as to repel all who have not a superior education, fitting them to cope successfully with such problems.

Both of the classes named want to learn, but how shall they do it? Some pay their money to traveling quacks for the "secrets of the trade." Others pick up scraps of information from periodicals, from casual acquaintances, and from their own experience and study. A few go to the cities to take a course of "finishing" instructions from resident practitioners, at five dollars per lesson, more or less. This is very well for advanced workmen who can comprehend at once what is explained to them, but it is almost worthless to those less experienced. For they are told, very briefly, what to do, with a trifling amount of showing, and then left to study out the remainder of the oracles themselves—if they do not forget a good share of it before they succeed.

In these articles I shall give such directions that any workman of ordinary capacity may stay at home and learn all that he could by spending a year's savings to get the same in other ways—and I shall tell some things that even the quacks have never heard of,—all without costing the readers of the *Jeweler's Circular* a single farthing, and with the advantage that, being in print, they can refer back to my very words and details a hundred times if necessary, and study and practice on them *ad libitum*, till they are perfectly familiar with every point.

But I wish them to mark this:—They can never really know a thing till they have actually done it, and discovered by experience the peculiarities, dangers and difficulties of each operation. It matters not how carefully they read and understand, they must practice also. Instructions alone will not make one a workman, any more than a book of prescriptions makes a man a doctor. Therefore they should take the first opportunity, or make one, to put my directions in practice. They will then learn many minor points which space compels me to omit, will understand better what I do say, and they will remember it. Otherwise, as soon as they lose sight of the book they will know scarcely more about it than they did before. So when a small tool or fixture is described let them go to work and make one. Each one will take but little time, which they will never miss, but they will soon have a goodly collection of them, at the mere cost of material, which they could not buy for any money, for the good reason that most of them are not on sale; and, having made them, they will know how to use them.

Let no one feel discouraged because he has never had proper instruction in the trade. If he really desires to be a good workman, and has true grit in him, there can scarcely be any training more severe and improving than patient study and practice, working out of his own resources, and being held responsible for the performance of his work, either by an employer or by a customer of his own. If he persists in doing *the best he can*, and improves every opportunity to learn, he will gradually regain the ground he should have made during his apprenticeship, and may in time become the equal of any, and the superior of those with greater opportunities but less determination to excel. A large share of our very best workmen are thus largely self-taught—thorough, independent, versatile and progressive, but the lack of a long and rigid apprenticeship has cost many of them a fearful loss of time in the best years of their life—a loss which it is the object of these articles to lessen for their readers.

Habits are all-powerful with a workman, and I feel the importance of not leading any one into faulty or inferior ways of working. I shall try to tell all that is worth the telling, and worthy of being included in a first-class method of procedure—in fact, to give the latest and most advanced state of practical horology, so far as concerns watch repairers. This involves the examination and comparison (either experimentally or judging from general experience) of perhaps scores of different tools, methods, etc., each claimed to be the best, in order to sift out and arrange a complete, uniform and practically reliable system in each branch of repairing. While I shall not give all the new but visionary ideas floating about, I shall also exclude many old and generally accepted ones which I consider wrong in principle or superseded by better methods. I shall not only treat of things not generally known, but also of things very commonly done, but seldom done well, at least by learners, and which they need to know about, as they are at the root of all good work; of some things that are highly important, and also of "little things." But those little things are often just what constitute the difference between the good workman and the botch, which the former has learned by long and bitter experience, the fruit of years of labor, study and trials.

Much of what I shall say will, of course, be the standard practice among good workmen, and therefore not new to them. But I must take the risk of telling what is familiar to such, for the sake of that much larger class who have not had the opportunities of the former for learning. Another large share, however, will be the results of my own experience, investigations and observation, new and valuable even to experts and first-class workmen. I shall not claim perfection, either in judgment or experience, but if any specialist knows more about any particular subject than the writer, has a better way or tool than I name, and will prove it by writing out his views thereon, I have no doubt that the editor and all workmen, as well as myself, will be glad to have him do so.

What we need in our trade is more life, study, interest; more discussions and even quarrels, if necessary, to wake us up; more rivalry in letting such light as we have shine for the benefit of all. And if I should use rather sharp language in regard to some persons and things in the course of these articles, as I propose to do, my sole object in stirring them up will not be any personal feeling or prejudice, but a desire to tell the exact facts, according to my knowledge and belief. I shall adopt the plan of numbering the sections, in order to avoid repetition, so that any directions once given may afterwards be definitely referred to and easily found.

Before closing I wish to give a few words of advice which will have a very wide application, although addressed especially to young or inexperienced workmen. They should clearly understand that there is no royal road to success in our trade. No amount of experience or knowledge, no costly instructions, or "trade secrets"—*nothing whatever* will suffice except good, honest, thorough work. Whatever other advantages they may have, that is the one indispensable thing. A watch is a machine; when it is all right, throughout, it will perform properly, and not before. Experience *with* thoroughness will make a fast workman, but never without. He should never knowingly slight any part, however small, for even after he has done his best, there will always be enough to apologize for. This is what all old workmen will tell him, and he should settle down at once and forever upon that basis, and dismiss all ideas that there are any "secret ways," or ways that are not secret, known to any one, which will enable him to dispense with that requisite. Therefore it will be well for him to make up his mind never, under any circumstances, to shirk his work. He should do this for the sake of his reputation as a workman, of his self-respect as an honest man, and of avoiding the habit of shirking, which will surely grow upon him if indulged, till he will become actually incapacitated for doing a thorough job, by indifference and indisposition to exert himself.

On the other hand, don't do too much. This is a great fault with the inexperienced. They file, and bend, and hammer, and cut off, and make the most radical changes, on the slightest grounds or none at all. Now, a workman has no business to change any part of a watch unless he knows the precise purpose of that part, and of its peculiar construction; knows that it ought to be changed, and why; knows what object it is desirable to accomplish by changing it; that the proposed change will accomplish that object, and how to make that change in a workmanlike manner. If he does not know the difficulty and its cause, and the proper remedy, he has no right to butcher a watch on the "cut and try" principle. When he cannot improve it he should at least not injure it, but rely more on head-work and less on guess-work. That, after all, is the real secret of excellence. Of two men, alike in every other respect, the best thinker is invariably the best workman.

Note by the Author.—The following pages were originally written for the *Jeweler's Circular*, under the title of "Practical Hints on Watch Repairing." But in compliance with the demand for their publication in a more permanent form, they have been revised, occasional errors corrected, and numerous additions made. This will explain many allusions and expressions, which are left unaltered, to avoid the necessity of remodeling the entire series and changing the numbers of the sections. Even if any substantial advantage would be gained by this, which is doubtful, the author's time is too much taken up by business cares to admit of doing it. The sections of Part Third were originally included in the Isochronal Adjustment, and numbered (88) to (95) inclusive.

The introduction contains advice calculated for the whole range of watch-repairing, as well as work upon hair-springs. But that too has been left unchanged, as it is possible that succeeding essays on other subjects may also be republished in book form, in which case it would be as appropriate here as in its original place. Several items referred to in the text, or which add to its completeness, have been inserted, or added in an Appendix.

The Adjustment for heat and cold has also been added, so that the book may be a complete practical guide for the workman in all the fine adjustments known in the trade, for the very highest class of time-pieces.

There are many other points it would have been interesting and instructive to consider, as, the effects of heat on the elastic force of the hair-spring, the theory of isochronism, the mathematical analysis of the form and functions of terminal curves, the principles of the various secondary compensation devices, with the causes of their success or failure, etc., but they would have transcended the strictly practical character of the work, and were therefore omitted.

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Part First.

MAKING HAIR-SPRINGS.

(1.) Every watchmaker thinks he can "put in a hair-spring," and he does it,—after a sort. Probably there is no other one thing so generally done, in the whole range of the trade, about which there is such complete ignorance. Not one workman in a hundred can put in a hair-spring in all respects as it should be done; and when done, not one in fifty can tell whether it is properly fitted or not, if the general *appearance* is unobjectionable. Men will claim to be able to "fit a hair-spring the first time trying" who do not really know the object of a terminal curve, and who suppose the supplemental coil of the Breguet spring is designed to make the balance vibrate more freely!

(2.) Nor is this igorance confined to any particular class of workmen. It is found even among professional "springers," when they are induced to break their sapient silence and give some *reasons* for their routine manipulations. Theories are often put forth by persons undoubtedly well informed, which are not only absurd and without foundation in fact, but which it would seem that a single moment's reflection should have convinced their authors were untenable. But others, misled by the eminence of the authority, take them up, and defend and propagate them, until they almost become accepted as axioms, which no ordinary man dares dispute, lest he should be considered an ignoramus. I propose to take that risk, and show up the most prominent of these bug-bears, and sweep away some portion of the mist and humbug that hang around this subject—not by any assumption of superior knowledge, but by applying the plain test of mechanical laws, practical experience and common sense.

(3.) Before proceeding to the more usual operations, it will be useful to consider the mode of making springs. The material employed is the very best quality of cast steel, specially prepared and drawn into wire. Steel has the objection of liability to rust, and to be affected by magnetism, but thus far no substitute has been found which should preserve all of its valuable qualities and be free from these defects. The only rival worthy of being mentioned is wire made of 18 karat gold alloyed with pure copper, and worked into springs in accordance with the nature of the material. This is free from the two objections named, but long experience has shown that it is not as reliable as steel, besides that it is more difficult to work properly, and, its expansibility in heat being greater than that of steel, it requires heavier adjusting screws in the balance, thus introducing a train of evils which more than offset all its advantages over steel. It is to be hoped, however, that our inventors may yet succeed in discovering a material having all the advantages with none of the disadvantages of steel. Until then, owners must take proper care of their time-pieces or suffer the penalty of ruined springs.

(4.) Steel may be made elastic either by hardening and tempering, or by compression, and springs are made in both ways. Springs for marine chronometers are now almost always hardened and tempered, as are those for the finer classes of pocket watches—while cheap springs are wire-drawn and rolled to all degrees of hardness, then wound into shape, and blued by heat, which causes them to "set" in the proper form. The former are more expensive, but are in every way preferable when properly made. Their temper is more uniform, both in the body of the spring and throughout its length; their qualities, whatever they may be, are more permanent, and they are more certainly made of any desired temper. Where the elasticity is given by drawing through wire plates and by rolling, there is the danger of minute cracks being produced in the edges at the final rollings, when the wire is already hard, which, although imperceptible to the sight, will disturb the action of the spring. But if the spring is to be hardened by fire, it can be annealed and kept in safe workable condition till the moment of hardening.

(5.) In drawing (or rolling) the wire it is important, 1st: To draw always from the same direction, and, if it is rolled upon a spool after each drawing, it must be unwound and re-rolled before drawing again, so as to commence with the same end each time; 2d: To draw at a regular rate of speed—not fast at one time, then slow, etc., for such irregularity of speed will produce irregularity of texture in the wire; 3d: To have as few stops as possible, for there will be a difference of texture at that point of the wire that is in and behind the plate at the time of the stoppage, no matter how short the stop may be. The best way is to draw the whole length of the wire through at a regular speed without stopping at all; 4th: Wind the wire upon *large* spools or bobbins, if at all, and do not cramp or bend it any more than is unavoidable, until it is made up into springs; 5th: Instead of oil use bees-wax as a lubricant; that will adhere to the wire under any pressure, while oil will not; 6th: Before heating the wire, either to harden or "set" it, clean it thoroughly by rubbing it lengthways with a rag dipped in pure (or 98 *per cent.*) alcohol, and then do not handle it with the bare fingers, but with clean tools, or by interposing clean paper or cloth between the skin and the steel.

(6.) *Different forms of springs.* There are two principal forms for hair-springs: the flat spiral, either plain or with the Breguet curve, and the cylindrical or helical. The latter is adopted for chronometers, and the former for most pocket watches. There are many other forms, not often employed, as the spherical, which is largest in the middle and tapering down toward each end, making it globular in form. These are very troublesome to make and set true, and have no practical advantages over the helical form with proper terminal curves. Another method is to make half of the wire in the helical form and the rest is coiled up in the flat form at the end of the helix. The objections to this are that the flat portion of the wire is subjected to violent twistings, being first straightened out from the helix, then wound up again into the spiral form, which would be sufficiently objectionable if the wire was soft, but in this case it is done after the wire is hardened and ready for use. And, even if this objection could be avoided, there is another, that the coiling and uncoiling of the helix would inevitably throw the flat portion out of its plane at each vibration, and greatly disturb the isochronal properties of the spring, to improve which is the only object of the helico-spiral form. Then there is the reversed helix, being, in effect, a helix broken in two in the middle, and the two ends pinned into a stud in such a way that the upper half of the spring coils up while the lower half is uncoiling, and *vice versa*. This is difficult and unreliable. The same object is accomplished with flat springs, by using two of them, so attached that one coils up while the other uncoils, as above stated. But no form of spring has yet been tested which produces any better effects than can be obtained from the helix or the spiral, by proper manipulation.

(7.) There are good workmen who claim that a flat spring cannot be made isochronal—which, in view of innumerable instances to the contrary, is as ridiculous as the claim that the spring-detent or chronometer escapement is, *per se*, superior for keeping time to a detached lever escapement equally well made—a point which I shall touch upon hereafter. Theoretically, the helix, with its coils of equal diameters, is superior to the spiral; but practically, the average of the effects of the numerous coils of different diameters is equal to that of a spring with equal coils of an intermediate diameter. And a spiral spring with its outer end returned by a properly formed terminal curve is fully equal to a helical spring, for pocket watches; but for marine chronometers it is better to make the spring in the helical form, on account of the large size of the wire required for their heavy balances. As both forms are good, I will describe the mode of making each.

(8.) *Making helical springs.* For the helical spring a cylindrical brass block is made, and shallow grooves cut in its exterior surface, by a small screw-cutting lathe or otherwise, having the exact shape the spring is desired to take. The wire is then coiled tightly in these grooves, and each end is fastened by screws or pins. But as brass expands more than steel, when heat is applied the block will expand more than the wire wound upon it, and injure it more or less by straining it while heated and soft. We avoid this as follows: At each end the spring, if pinned, is drawn through holes drilled in the block, pulled tight and fastened with the pins. This produces a right-angled bend at the edge of the hole. The pins are then loosened, and the wire drawn out of the holes so that, when again pinned fast, these bends or elbows, instead of lying on the surface of the block, are about the breadth of the spring above it. These short upright portions will yield sufficiently to avoid straining the wire when heated, yet are stiff enough to hold it properly to its place. When the ends are fastened by screws instead of pins, the screws should be put on the ends of the block, not on its sides, and each end of the wire being drawn over the sharp edge, produces the elbow as before, which can be loosened up and refastened at the proper hight by the screws. The elbows may serve the same purpose of safety when bluing the spring. The object of using brass blocks is twofold: If of steel, they would be liable to warp more or less by hardening, and communicate an irregular form to the spring, which is, of all things, to be avoided; and a steel block will scale to some extent by the hardening process, and lose the perfect accuracy of its grooves—whereas a good brass block can with care be used many times. The block on which the cylindrical springs are hardened should be hollow, so that it will cool quickly. Its thickness should be no greater than will give sufficient rigidity and strength. The thickness is generally from one-eighth to one-sixth of the total diameter of the block.

(9.) If the spring is to be simply blued and "set," hold the block with the spring upon it in the flame of the alcohol lamp, turning it constantly, and heating slowly and evenly, till it acquires the proper color, then let it cool. One bluing is sufficient for a rolled spring, but coloring a hardened and tempered spring is a very different matter.

(10.) *Hardening springs.* If the spring is to be hardened by fire, it is sometimes wrapped in thin sheet copper or platina foil, fastened with binding wire or folded over the ends, having been previously well daubed over with common soap, softened by warmth, not moisture, which largely protects it from scaling and coloring by the heat, by keeping it from the air. When so wrapped up it must be hardened in water. But most workmen simply slip the block and its spring into a brass, copper, or iron tube, or even a common clay pipe bowl, and fill it around and over the block with fine wood-charcoal dust, well shaken down to fill all the interstices, and entirely exclude the air while the wire is being heated. A small piece of steel wire must be so placed that it can be occasionally taken out to judge of the heat, as charcoal packing is a very poor conductor of heat, and very deceptive to the inexperienced. Very fine silver filings have been proposed, being a good conductor, but I do not know that this has been tried. Animal charcoal is also used, but it makes the spring very hard and difficult to form the terminal curves. For a plain spiral spring, requiring no after manipulation, it would be excellent.

(11.) The whole must be carefully heated in a charcoal fire to a cherry red, but no higher, and, as soon as it reaches that, the block with its spring is emptied into oil or water—the preference being for oil, unless the block is wrapped up as stated above, when it should be quenched in soft water. The proper temperature for the quenching bath is about 60° Fahr., as that is found to give sufficient hardness without danger of causing the steel to crack. But if the wrapping is at all thick, a greater degree of cold will be safe, and in fact necessary—but that is to be avoided.

(12.) *Tempering springs.* If the spring has been hardened in oil, it is now drawn down to a straw color—if in water, to a purple—then removed from the block and polished inside and out, edges and all, with a stick and fine oil stone dust or "sharpe," again fastened tightly on the block as before, and the color brought down to a rich dark blue. This, however, is a matter which depends somewhat on the quality of the wire used, and can only be fixed by testing your sample. Some steel will be as hard and elastic at a dark blue as another sample will be at a straw color. The aim should be to stop just short of brittleness, so that a piece of the tempered wire may, *with care,* be bent cold to a right angle around your screw-driver, or a round broach, but would snap off if it was bent carelessly or over the square edge of your pliers. If the spring is to be used white, it should be brought to the proper temper before polishing. In forming the terminal curves the hardened spring must always be bent by heated tools, a subject I shall treat on hereafter under the head of isochronism.

(13.) In coloring a spring, it is not always necessary or even advisable to go by the color of the spring itself, as any piece of steel on the block or plates will do just as well. But there are certain precautions to be observed which are not necessary with larger articles of steel, because here even the slightest variation of the temper affects the action of the spring. Supposing the color should be a dark blue, if the mass (spring and block, or plates,) has been heated rapidly, the coloring must be stopped sooner, or at a lighter shade, say a purple or a reddish-brown; while if it has been heated very slowly, it may be carried to the exact shade desired.

(14.) The screw or piece by whose color we are guided should be hardened, as hard steel colors more rapidly, or with less heat, than a soft piece would do, and consequently there is less danger of reducing the temper too low. Some makers color or heat their springs once only; others clean the bluing off the color piece and blue again; some even heat their springs five or six times. My own opinion is that if the spring has been properly made, hardened and polished, one bluing is sufficient. But if it has scaled in hardening, or minute imperfections, roughness or cracks are feared, it will be safer to heat twice, but never more than three times. If the spring, after that, breaks under the test named in (12), it may be considered imperfect, unless it was packed in animal charcoal, when it will break even after the sixth bluing if bent cold. Such a spring, if smooth and perfect, may be blued three times, and will be sufficiently soft. It is understood, of course, that the color-piece requires a greater heat to bring it to a blue the second time than when it was hard, and still greater the third time, so that in reality it will be reduced to a lower temper or made a little softer at each bluing, although the color is exactly the same each time. This is also the case with the spring; but this need not be whitened after each heating, nor even loosened (if on a block) till done.

(15.) Another point is to avoid what are known as false colors. The color-piece, or some part of it near the middle of the whole mass, if practicable, is first ground off with the oil stone, or even Scotch gray. This bright spot must then be slightly dimmed again, by rubbing the finger over it once or twice before coloring, for the degree of temper cannot be closely judged from the color of a very bright piece, as will be found by trial. In coloring flat springs, as hereafter directed, the color-piece may be screwed in the center of the plates, holding them together, or in the center of the spring-cover of the bluing-pan, and the heating should be very slowly and evenly done, the center of the hair-spring resting just in the center of the pan, and the cover also being central.

(16.) Before leaving the subject of coloring springs, I may add that it furnishes us a ready means of discovering whether they are equally hardened or not. For instance, if the wrapping (10) touches the spring in some places and does not in others, the former will be harder when quenched. So if the wrapping is lapped on one side and thicker than on the other, the spring will not be so hard in the former places as in the latter. This we may test after cleaning the block, but before loosening the spring, by arranging the block to revolve freely between the centers of the "turns," then suspending a trough or half cylinder of sheet copper under it, reaching up on each side, protecting it from the blaze, but leaving the upper half exposed to view. Now apply the heat to this copper trough, which in turn will communicate it to the block, and the latter will be heated more evenly than could be done by applying the blaze directly to it. The block must be constantly turned by a piece of peg wood, and the lathe centers loosened up when it expands. When the spring reaches a purple in its darkest part, take away the lamp and trough, still turning the block till it has cooled somewhat, when an examination will reveal any inequality of temper. Any soft places will be indicated by a lighter color, in spots or streaks, according to its cause. Even the course of a carelessly applied binding wire may be traced. Should any such appearance be found, it must not be passed over as a slight matter, for it is proof positive that the spring is incapable of fine performance, and it must either be re-hardened, or, if it has been scaled in the first hardening, it must be rejected entirely and a new one made.

(17.) *Making flat spiral springs.* Spiral hair-springs are made on a tool which slightly resembles a winding-arbor, one end being held firmly in the sliding tongs. Instead of a ratchet wheel there is a round piece of flat brass or platinum, one-half inch in diameter, fast on the arbor, and another similar plate which can slide on the arbor as its center, with a nut outside to screw it up towards the first one. Between these two flat pieces a space is left equal to the breadth of the proposed springs to be made. The arbor has a shoulder between these pieces, and two or three slits are sawed down into this shoulder in the direction of its length, with a fine saw. Two, three or more springs are wound up at once, the number depending on the space to be left between the coils of the spring when finished. The fewer springs wound up at a time the closer the coils of each will be. In making Breguet springs, only two are wound at once, so that the coils shall be very close together.

(18.) The wire being cut into lengths of six or eight inches, or enough for a spring, the ends are fitted snugly in the slits in the shoulder, singly or together, the loose plate slipped on the arbor, which keeps the ends of the wire in their places, and the nut screwed up so as barely to leave the wire free between the plates. The pieces are then laid straight, and a pair of hand tongs or other weight clasped on the outside wire, which, hanging down from the winder, presses on the coils as the arbor is turned—the different wires being prevented from twisting, and occasionally pulled a little to insure close coiling. When the wire is all wound up, take hold of each piece in turn with the pliers, commencing with the one at the center, and pull gently on it to be sure that all is tightly coiled up, and fasten the end by twisting it sideways over a notch in the edge of the plate fast on the arbor, something as thread is fastened on a spool. If there is any doubt about the close coiling, pull the pieces again. Then screw the nut up tightly, to insure the coils being in a true plane, and heat the whole slowly and evenly, to blue the springs, and cause them to "set" in that form. When cool the springs are finished, if they are to be left soft.

(19.) But if they are to be hardened and tempered, they are placed either singly, or in a mass as made, between two flat pieces of brass, provided with steady-pins to prevent shifting or sliding, and tightly screwed together, then made red hot and treated as before described for helical springs, except that the polishing is done by passing a wire through the center of each to hold it while rolling it on a polishing block of bell metal with red-stuff or "sharpe." Some use a stick with a conical end to hold the spring upon, and scour it with a tooth brush. The stick is held in the left hand, its point in the center of the spring, which is stretched down over it into a shape similar to that of a hoop skirt, and kept in that position by the thumb resting upon it. The insides of the coils are polished by sharpening a piece of peg wood and forcing the spring into the same shape, while resting it on a flat piece of cork, rubbing it by moving the stick in both an oscillating and lateral direction, very carefully, to avoid bending the coils. The edges are polished by rubbing the spring around on a piece of smooth paper, by means of a cork pressed gently upon it. In all cases the polishing powder should be plentifully supplied. Springs should not be polished any more than necessary to obtain a clean smooth surface, lest some parts should be reduced more than others and cause irregular action. It is then blued in the bluing-pan, which is simply a flat brass disc on which the spring is laid and held down in close contact with it by a piece resembling a three-arm watch balance, on the end of a lever pivoted so that it is pressed down by a spring, but can be instantly raised by the finger on the other end of the lever. In Fig. 1, *a* is the cover, attached to the lever which is pivoted at *b* to the upright standard rising from the bottom piece, and held down by the spring *c*. When the desired color is reached the finished spring is thrown off to cool. See coloring, (12 to 16). In making the very finest quality of flat springs, a flat plate is sometimes taken and a spiral groove cut in its surface having the exact shape the spring is desired to take, in which it is placed and set by heat. But few watchmakers have the tools for cutting such a groove truly, or are capable of using them.

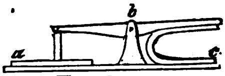


Fig. 1.

(20.) *Making the terminal curve.* Some workmen make the elbow of the Breguet spring before hardening and tempering, in which case a thin strip of brass must be placed between the main body of the spring and the supplemental coil above, and the whole then screwed together for hardening. But I do not advise to make any terminal curves till the last thing, but simply make the plain cylindrical or spiral spring, and ascertain its adaptability to the balance and the proper place for the elbow or the commencement of the curve, before expending any labor on that part of the spring, which will be treated of under the head of isochronism. When, however, the springs are heated in animal charcoal, (10), if the required size and number of coils, place for elbow, and shape of curves are known, it would be well enough to form the spring before hardening.

(21.) These directions are not designed as a complete guide for making springs—although I have told enough, I think, to enable any who wish to experiment successfully, and some things not before published—but to give a clear idea of the process of making them as a basis for better understanding of subsequent operations. Furthermore, the workman who proposes to fit a helical spring in a chronometer will generally find it necessary to make one to suit. Hence instructions upon that operation must include the making of the spring, as already described. But flat or spiral springs can be bought ready-made, of almost every strength and quality, so that a suitable one can be readily selected from a fair stock of them, and thus save time and labor.

(22.) *Diameter of springs.* The proper diameter for a hairspring is a matter of calculation in new chronometers and watches,—helical springs being generally one-third and spiral springs one-half the diameter of the balance. But a certain length in proportion to its thickness is indispensable to its free action, and if it is found that there is not room for that length of a helical spring, the coils being of the above-named diameter, then a spring with larger coils must be made, to secure the necessary length of wire. But the repairer should generally be guided by the old spring, if it yet remains, remembering that the new spring, when finished, will have expanded a little larger than the grooves in the block, or its first size when hardened. If your wire is not of the same stiffness as that of the old spring, more or less coils than the old one had must be used, to get the same strength of spring. But generally the old spring should be copied in all respects, unless there is good reason to believe that it was never satisfactory.

(23.) *Number of coils.* Helical springs have usually from nine to eleven coils, but it is well to make thirteen, to allow for testing the temper at the ends, etc., after which the superfluous length can be broken off. A rather long spring is better than a short one, especially if it is somewhat soft, as the angle of flexion, and the consequent danger of setting by use, are less. A spring should be thin and hard, rather than thicker and lower tempered, both being of the same strength. For the former will maintain the motion of the balance longer (without additional impulse from the hand or the movement), and consequently a watch with such a spring will be less affected by difference in the motive power, or friction, poor oil, jarrings, etc. The less the number of coils the harder the temper should be, and, conversely, the softer the spring the longer it must be. Hardened springs are less liable to be affected by magnetism than soft ones, and are to a great extent, but not entirely, free from the deterioration or loss of force to which all springs are more or less subject by constant action, even when the flexion does not approach the limits of their elasticity. The well-known phenomenon of hardened springs slightly accelerating on their rates, for a few months after being fitted, is an example of this change of condition. In this case the springs lose a portion of their excessive initial hardness, and gain in pliability and elasticity. After attaining their greatest degree of elasticity they remain nearly constant, while the deterioration of soft springs is comparatively rapid.

(24.) As for the proper number of coils for spiral springs, the custom is to use from nine to twelve in English lever watches, generally about ten; in the Swiss, eleven. For a duplex, eight or nine suffice. The Swiss, in their cheap watches, often use fifteen to eighteen coils—as the springs, being of soft wire, must necessarily be long to prevent bending by use. But this only preserves them for a time, and in a few years they frequently need re-springing in order to do even decent service. American watches have from thirteen to sixteen coils,—the higher number generally in the finer grades, and even with hardened and tempered springs. For the advantages of long springs, see (168).

(25.) *Breadth of springs.* The breadth of hairspring wire should be about twice its thickness, or rather more, for marine chronometer springs, but for pocket watches there is no regular rule. Round wire has been proposed for springs, as being more easily and perfectly made; but there can be no doubt that unnecessary thickness in the direction of flexion should be avoided, and greater stiffness secured by increasing the breadth rather than the thickness. Experience indicates that a breadth of from three to four times the thickness is a good proportion for flat spiral springs for watches.

Part Second.

FITTING HAIR SPRINGS.

(26.) *Fitting the flat spiral spring.* I will first give the ordinary method of fitting a plain spiral spring, followed by good workmen, and then describe my own method and tool for facilitating the work. It is not to be expected, of course, that pains will be taken to make the hair-spring perfectly isochronal, when the workman gets only $1, (which is the price in many places,) for fitting and regulating it. Nevertheless he should have some regard for his own reputation, inasmuch as it will be but little more trouble to approximate very closely to correctness, if he knows how, than to fit the spring in such a manner as to render its good performance impossible. He will therefore understand that the directions to be given in these articles are essential to success, although I omit any discussion or explanation of the reasons therefor till we reach that part of the subject relating to isochronism.

(27.) All tools used in working around hair-springs must be kept perfectly clean and dry, not allowed to become magnetized, nor touched with soldering-fluid or other corrosive substances, nor should any such things be allowed on the watch bench at all. Their place is upon the clock and jobbing bench. A pair of fine tweezers must be kept solely for this use. The points should be very slim and thin, flat and rough on the inside, hard tempered, the jaws broad and firmly connected so that they cannot yield sideways and let the points pass each other, and made to come easily together without giving any more spring or stiffness at the points than is just necessary to hold the spring, or a pin. *Too much strength* is the cause of pins snapping away and other "accidents" that bother the beginner, who imagines that the tweezers should not only carry the pin to its place, but hold it firmly enough to force it in. They must not be heated and softened, nor used as a pin punch, for picking teeth, cleaning finger nails, prying off watch dials, or corks out of oil bottles, or picking the saw dust out of keys, nor for anything whatever except working upon hair-springs. But if the points do accidentally get injured, it will be a saving of time to put them in perfect condition again before you undertake to work with them. The same remark applies equally to all other tools. There is no surer sign of a good workman than that his tools are always in perfect working order.

(28.) A spiral spring should be perfectly flat, evenly coiled, the coils becoming more distant from each other as they proceed from the center, being about twice as far apart at the outside as at the center; the wire should be of an equal temper, breadth and thickness, throughout its whole length, well polished and free from rust. It should also be long and closely coiled.

(29.) *Enlarging a spring.* The diameter, as already stated, (22) should be one-half that of the balance. If a spring cannot be found of just the right size, or larger, one of smaller diameter but having a suitable number of coils may be enlarged by the following process, which is also useful for spreading the coils apart when they are so close as to be liable to interfere with each other. Put the spring on a flat plate of either steel or brass, and over it another thin plate of bright steel, or, if of brass, with a hardened steel screw in the center. Heat the whole very slowly and evenly till the top plate or the color-piece becomes blue, then let it cool and it will be found equally expanded, unless the top plate has been too heavy to allow of free motion. If not sufficient it can be treated in the same way again—as the temper will not be reduced any lower, provided that the heat is not at any time greater than will blue the *hardened* bright plate or color-piece (14).

(30.) *Flattening a spring.* If a spring has been warped or bent out of flat, it may be flattened in a similar way, by fastening it *tightly* between two steel plates so as to *prevent* expansion, and blue the upper plate, which will cause the spring to "set" perfectly flat. But in all these cases great care must be taken not to exceed the bluing heat or, if the spring is of any other color, not to carry the color of the hardened color piece beyond the shade of the spring.

(31.) *Bulged springs.* If the center of the spring has been merely sprung up, the best way is to take the collet off the balance and slip it on your pin punch till it fits snugly, then take hold of the outer coil, or of the coil where the "bulge" commences, with a stiff pair of tweezers so that it can be firmly held horizontally, then push the center with the pin punch, in a direction exactly vertical to that in which you hold the outer coil, and the spring can generally be sprung back so truly as to be about as perfect as ever, and with very little trouble.

(32.) *Ruined springs.* If a spring has been very much distorted, it probably cannot be made perfectly true in the coils, although it may be true in the flat, and if it belongs in a fine watch, another spring should be fitted. Even if a distorted spring should be worked on with the tweezers till it was restored to exactly its former shape, it would not act the same as before. Every place where it has been bent and restored will be of a different stiffness from the original, and every such place exerts a disturbing influence, rendering a uniform action of the spring impossible. An inexperienced workman will often render a spring worthless for fine time-keeping simply by numerous changes and corrections of shape. A spring should not be bent or altered any more than it is absolutely necessary, and any changes of shape should be made by littles, rather than by bending too much and then having to bend part way back again. The injury caused by bending is greater in soft than in hardened springs. Hence Breguet springs should always be hardened, because they necessarily have to be bent more or less in perfecting the terminal curves.

(33.) *Number of vibrations.* In fitting a new spring, the first thing is to ascertain the number of vibrations the balance should make per minute, either by counting the vibrations of that watch, or of one like it, for exactly one minute. Or it may be done by calculation. As the center wheel revolves once per hour, we multiply the numbers of teeth in all the wheels from the center to the escape wheels, inclusive of both, into each other, and divide that result by the product of the numbers of the leaves in the pinions of all those wheels (except that of the center wheel), then double the quotient, as there are two vibrations to each tooth of the escape wheel. This gives the number of vibrations the watch makes in an hour, and dividing that by 60 gives the vibrations in one minute. Generally Swiss watches have 300 beats per minute, American watches 300 to 270, and English levers 240. Whenever there is a doubt, or the watch is of an unusual make, it is well to count up. If you have a movement which makes precisely the desired number of vibrations, you need only try your spring alongside of that, as described in (36), and any divergence between them will be seen at once, without counting.

(34.) *Selecting a spring.* You next lay the balance-bridge on the bench before you, bottom upwards, and with the regulator pretty well back towards the "slow," and selecting a hair-spring which you deem suitable, you place it on the bridge so that the center will come exactly at the pivot hole. Furthermore, the elbow or bend at the *point of attachment* of the spring to the collet must lie nearly in an imaginary straight line drawn from the pivot-hole to the hair-spring stud, for it is customary to avoid fractional parts of coils in flat spiral springs, as much as possible. In doing this, allowance must be made for any cutting out of the coils at the center, to make the spring fit the collet, and for any bending at the stud, as spoken of in (46), if either will be necessary, calculating as closely as convenient the point where the elbow of the inner coil will come after that shall have been done, and that point must be placed in line with the stud—the center of the spring remaining over the pivot-hole, as before described. Then note the particular coil which lies naturally between the regulator-pins when the spring is so placed.

(35.) Having now attached a small piece of beeswax to the balance-staff, just below the shoulder of the upper pivot, you stick the inner end of the spring to this wax, making a temporary but firm connection between the spring and the staff. Adjust the spring so that it will stand centrally and truly on the staff, then grasp it with the tweezers about one-eighth of an inch back of the point that lay in the regulator-pins, and, while the lower pivot rests on some hard, polished surface, you hold the balance upright by means of the spring, and cause it to vibrate. Care must be taken not to get so large a motion as to loosen the spring in the wax. By holding the coil in the tweezers pretty high, the spring can vibrate without coming in contact with the coils outside of the one held in the tweezers. The hand is rested on some convenient support. Instead of using wax as above, if the center of the spring is very small, and will have to be broken out, any way, the central coil may be bent so as to hug the staff tightly and dispense with the wax. But this should not be done when that coil will have to be bent back into shape again and used.

(36.) Everything being in readiness, you set the balance in motion, and count the vibrations it makes in exactly one minute. It will be much easier if they are counted only in one direction, as from left to right; then double the number. As already stated, if you have a movement making the proper number of vibrations, you can try your spring beside that, causing the two balances to vibrate together at first, and notice whether your spring lags behind or goes ahead. In either case, count the vibrations from the start till they come together again. If your spring loses a beat or gains one in fifteen seconds or less, it is certainly not suitable. It should not lose or gain *more* than a couple of beats in a minute. In the case of an American movement, you can rest the balance-pivot on the glass cover of the movement-box, directly over the balance going underneath, and readily compare the two.

(37.) *Pinning to the collet.* If the spring does not give very nearly the desired number of vibrations it is removed and another tried, and so on till one is found which meets the above requirements, when, in the case of a plain spiral spring, it may be pinned to the collet for a final trial. Aside from the convenience of using wax as described, for preliminary trials, there is a grave objection to pinning the spring to the collet at first. Collets differ much in size, and if a spring was cut out at the center to fit properly on a large collet, it would be greatly injured for any watch with a smaller one, if it did not happen to fit the one first tried. But with the temporary wax fastening no injury is done to the spring if it proves unsuitable. If it will be necessary, when pinning it to the collet, to cut out considerable of the inner end, additional length must be allowed at the outer coil to compensate for this shortening at the center—otherwise the watch will of course gain time. Springs are generally made small enough to fit the smallest collets, and often require considerable cutting to go on a large one. And if this additional length outside, when allowed for, would make the spring too large to lie freely in the regulator-pins, it must be rejected. This can be ascertained before cutting it.

(38.) The manner of pinning it to the collet is important. There should not be a large vacant space at the center of the spring, but the inner coil should be only far enough from the collet to avoid any danger of touching it, even in the longest vibrations—but it must not be too close. We often find springs with the inner coil actually hugging the collet—a certain proof that the watch has been in the hands of a botch. Either end of the pin sticking out so that the coil can hit it, is another evidence of botchwork. The inner end of the spring should be put into the hole in the collet entirely up to the elbow, where the straight joins on the curved portion. From the elbow the curve should diverge from the collet in such a manner that it will meet the regular spiral form in about one-eighth of a coil from the elbow. This is better than running the spiral itself up to the collet, except when the coils are very wide apart, in which case the spiral should reach and be pinned directly to the collet. If the spring diverges too boldly from the collet, its action will not be good. On the other hand, if it diverges too slowly, it will lie so near the collet as to be likely to touch it when closely coiled up, or a minute speck of dirt wedged in between them would produce the same effect. No portion of the spring, however small, should rest on the collet, or on any dirt upon the collet, or on any pin, nor should any coil touch another, even at the extreme end of the longest vibration the spring will make in use. The repairer should examine every doubtful hair-spring that passes through his hands, turning the balance with the finger in each direction, and holding it still while looking over the spring. Although a little out of its order here, I would also say that the spring must not touch anything above, below or around it, except the collet, stud and regulator; and them only at one point. All workmen know that this should be so, but they cannot know whether it *is* so, unless they move the balance to each extreme and hold it while they look, as above. It is very common for *two* coils to hit the regulator or the stud.

(39.) If, however, there is more space at the center than is supposed above, the curve should take more length to reach the regular spiral portion of the spring, but in no case more than 90° or one-fourth of a coil. If that is not enough to reach the spiral, with a moderate divergence, the space is too large. The object we have in view is to bring the entire length of the spring, from the regulator to the collet, into action as uniformly as possible. Any considerable variation from the spiral form at the center causes irregularity of action, *i. e.*, an action different from that of the rest of the spring, and the greater this variation the greater the resulting irregularity. In springs which diverge very boldly, or which have a large open space at the center, this sweep or curve becomes a veritable "terminal curve," modifying the action of the whole spring, always difficult to change or adjust, on account of its position, and frequently defying every effort to neutralize its injurious effects upon the isochronism. It is even necessary sometimes to make the collet larger, as hereafter noted.

(40.) In pinning the spring many workmen fasten the end "any way it happens," then *bend* the central coil up or down to make the spring stand truly, not knowing that as soon as it is flexed it will be thrown out of its true plane by reason of this central twist. The spring should always be leveled before the pin is tightened, so that when fast it will be true without any twisting. The pin should barely reach through the hole, not sticking out at either end, and particularly not at its large end next to the elbow. It should be made either of hard brass or steel, stiff and tapering but little. After filing it up, flatten one side so that it will go in nearly as far with the spring in the hole as out, and while both are in the hole mark where it projects from the collet on each side, cut it off at the end, file a notch around it at the other mark, then force it to its place and break it off while in the hole. The small end should not be pointed, but flat, so that it can readily be pushed back for altering, if necessary.

(41.) For this purpose you want a special pin-punch, made from a short needle, perfectly flat on the end, and firmly fixed in a stout handle. While pushing the pin in or out of the collet, you should hold the latter flatwise (the hole being outside of the end of the jaws), in a pair of pliers lined with soft iron or copper —by which you can hold it firmly without any need of marring it. The jaws also serve as guides in getting the spring flat. To try it, slip the collet on an arbor, and revolve it in the turns or calipers, either with a bow or with the fingers, noticing both the flat and also that the coils *rise evenly* from the center to the outside. But if, as your eye runs along the coil while it is turning, there seems to be any waving or "bobbing," the spring is not concentric with the collet, and must be made so by altering the central coil. Being true both in the flat and in the coil, you now put the collet on the balance-staff, and again try if the spring is flat and true, by whirling the balance in the turns, or even between the thumb and forefinger. The collet must be adjusted on the staff at such a hight that the spring, when pinned in the stud, will be perfectly level. If the collet end of the spring is higher or lower than the hole in the stud, the center will be bulged up or down, and satisfactory action will be impossible. It is important, for this reason, that the balance-staff itself should have no more end-shake than necessary.

(42.) *Pinning to the stud.* Before pinning the spring in the stud, you now verify its proper length more closely, by again counting the vibrations while holding it with the tweezers, remembering that the point which is to go in the stud should be about one-eighth to one-fourth of an inch beyond the place where it gives the correct number of vibrations in the tweezers. This is to allow for the effect of the regulator. The exact distance will be about one-third less than the actual distance from the regulator to the stud, along the coil. Having placed that point over the hole in the stud, while the pivot is in its jewel hole, the outer coil should lie freely in the regulator, and the elbow at the collet should be about in the line between the pivot and stud, as already described.

(43.) If the elbow varies much from this position, the isochronism of the spring will be more or less defective. Although the time shown by the watch at the end of each 24 hours may become correct, by dint of regulating, it will not be correct at any previous period,—nor afterwards, in case the watch is allowed to run over 24 hours before rewinding. It will either gain in the first 12 hours and lose in the last 12, or the reverse, making a correct *average* for the entire 24 hours. Such watches must be wound regularly, at precisely the same hour each day, to secure even fair time. And in regulating them they must be timed at the end of each 24 hours, and at no other time during the day, as that would damage the regulation instead of improving it. But no watchmaker who cares for his reputation should let a job go out in this condition. The correction of this error will be fully treated hereafter.

(44.) But if the spring has been fitted as I have directed, you may proceed to pin it to the stud, with full confidence that it will perform satisfactorily. It should not have been done before, because at that point in the stud there is always produced a bend or crimp, by the pin forcing it to conform in shape to the hole, and if it should afterwards be necessary to let it out and bring the crimp into the acting portion of the spring, that stiff point would interfere with perfect performance. Even filing the pin flat on one side does not entirely prevent this. Hence it is advisable not to pin a spring unless it is reasonably certain that it will answer the purpose, and then it should be so pinned that it will surely be *long enough*, and that any necessary alteration will be made by taking it up, or drawing it further through the stud, not by letting it out. In the next article I shall show how a spring may be selected, fitted and partly regulated in the watch before pinning it in the stud at all. But as springs occasionally need to be shifted, even after they are fitted, it might be a good idea in fine watches to pin them with a flatted pin on each side—unless some inventor can furnish us a stud with a slot instead of a round hole for the hair-spring.

[Mr. S. F. Gordon proposes to make a square steel punch, and hammer the stud upon it till the hole becomes square. If this plan is followed, however, it would be sufficient to have the punch square on one side only, leaving the other side of the hole round, as usual, for the pin.]

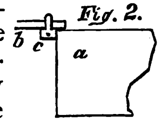
(45.) The spring must be pinned perfectly solid, both in the stud and the collet, so that not the slightest change or yielding can occur. The larger end of the pin should be towards the body of the spring and should not project at all outside of the stud, so that under no circumstances can it affect the action of the spring, as it would do if it extended alongside of it even for a short distance. But the point of the pin may project from the other side of the stud, next the end of the spring, for convenience of pushing out and also turning it with the pliers, to level the spring perfectly before making it fast. Enough spare spring must be left, when broken off, to have at least one-eighth to one-quarter of an inch beyond the stud, after the watch is regulated, to provide for future contingencies requiring it to be let out.

(46.) If the stud-hole in the bridge is further from or nearer to the balance jewel-hole than the regulator pins are, as sometimes happens, the spring must be bent near the stud to bring the outer coil within the circle of the pins as soon as possible, as, throughout the sweep of the regulator, the spring must lie *freely* between the pins, not pressing against either one of them, when the balance is at rest. If there is a considerable space between the pins, the spring should stand in the center of it. The position of the spring should be tested by screwing down the balance-bridge in its place and moving the regulator each way. Sometimes the regulator cap or center-piece gets screwed on the wrong way and causes the pins to stand further in than they should. If this is the cause of the trouble, reversing the cap will throw the regulator further out and obviate the need of bending the spring. But if it must be done, the bend should not be too abrupt at the point where the outer coil is made to become concentric with the regulator, but should be made far enough from the stud so that the change of direction it produces in the spring at that point will not be more than about 15°, —never over 25°.

(47.) When it is correct, take the balance-bridge off, and lay it bottom upwards; having taken the stud out of its hole, place the pivot of the balance in its jewel, and hold the staff nearly upright with the tweezers. Then the spring should lie naturally in the regulator-pins, while the stud must hang freely directly over its hole and must point straight down into it, which will show that the spring is properly pinned and correctly shaped. If it is not as described, it must be made so, for the spring must have exactly the same form when loose as when it is secured in the watch for running, so that it may stand perfectly free from any twist or constraint during its vibrations. This is indispensable to its good performance. When the stud is a heavy bar, the above test cannot be applied, and, instead of that, the collet should be removed from the staff, and the bar screwed into its place, when the collet should naturally come exactly concentric with the balance pivot-hole. If not, the spring should be bent to bring it so. We often see springs that are too large, with one side spread out, while the other is compressed within narrow limits. Also, springs twisted sideways at the stud, to go over or under a center wheel, and many similar makeshifts. Such jobs may be excusable when the owners will not pay a price for which the watchmaker can afford to do the work properly, but they should be given to understand that good service cannot be expected from them.

(48.) *Taking out the stud.* In taking out the stud we often see workmen use a knife to pry it up, and, if it should come up mo[re] easily than was expected, the knife-blade suddenly slips across the bridge, and off goes the pivot. Tweezers have been made for pushing out studs—also pliers for the same purpose. But as good a way as any is to rest the arm of the bridge upon any convenient square-edged block of metal, say an inch thick, to allow the balance to hang down from the stud, or rest partially on the bench, while you push the stud out from above with a pin-punch of suitable size. As the end of the arm is supported by the top of the block, close up to the stud, which is in contact with its side, it is very easy to hold the bridge level under any amount of force required for pushing out the stud, without the slightest risk to any part. In Fig. 2, *a* is the block; *b*, the arm of the balance-bridge, and *c*, the stud.

Fig. 2.



(49.) *Putting in beat.* Putting the watch in beat is an operation that frequently troubles beginners, and sometimes those who are very far from being beginners. I will therefore give directions for so much as relates to the hair-spring. Errors in the escapement, etc., will be treated in their proper places. When the power of the movement is cut off and the balance at rest, the position of the parts should be as follows:—In the chronometer, the unlocking jewel should stand just on the outside of the unlocking spring, *i. e.*, not on the same side as the escape-wheel, or the unlocking side, but on the opposite side. In the duplex, the slot in the roller-jewel on the staff should be in a line from the center of the staff to the center of the escape-wheel. In the detached lever, the ruby pin should be in a line between the centers of the balance-staff and lever-staff, or "pallet arbor." When the hair-spring stud is fixed to the balance-bridge, turn the regulator so that it will point to the lever-staff, while the bridge is screwed in its place. Then the ruby pin is easily put in line with the regulator while the balance-bridge is lying bottom upwards on the bench and the balance-pivot in its hole, and got very close before the spring is put into the watch at all. Then it can be tested by "sighting," or by placing a blunt screw-driver against the fourth wheel, or the one which carries the seconds-hand, and moving it very slowly so that the balance will vibrate as far in each direction as the lever carries it, but no further. Notice the position of the arm, or a screw in the rim, at each extreme, then turn the collet so as to cause it to stand at a point midway between them when at rest, and it will be in beat.

(50.) In the horizontal or cylinder escapement, the stud should be in line with the two impulse lips of the cylinder. But if the mechanism is not in its normal condition, and the watch does not prove to be in beat, upon trial, take your oiling-wire or a stiff bristle and with it move the balance very slowly each way till the escape-wheel tooth drops, but no further, noticing the position of the banking-pin on the rim, at each drop. Then place the pin halfway between these two drop-points, and hold the balance there while you "sight" a line through the center of the stud to the cylinder-pivot, and identify the point on the rim of the balance which is in that line, by means of some mark or stain, etc., or its distance from one of the arms, or in any other way. Then take off the bridge, remove from it the balance and stud, and turn the collet so that the stud will hang naturally in that line from the mark on the rim to the cylinder pivot, when the balance is held horizontally, and the watch will be in beat, provided the spring is not forced out of its normal shape when the stud is fastened in its place.

(51.) *Turning the collet.* Most workmen use a screw-driver or a knife-blade to shove the collet around with, and unless they move it very carefully it will slip off and "jab" into the spring; or it will pry open the cut and loosen the collet, rendering the watch liable to be thrown out of beat by jars, or even by running, making it unreliable for time and likely to stop. A tool can be made in a few minutes which will turn the collet without trouble or danger. Take a thin piece of steel, say a piece of the main-spring of an English lever watch, one-eighth of an inch broad, and hollow out the end into two claws or prongs—a long one on one side, and a short one on the other, as shown in Fig. 3. The latter should point towards the end of the former, and be so formed as to hook into the cut in the collet, while the former rests against the side of the collet. It is used by placing it flatwise on the spring, pressing it lightly against the collet, and *pulling*, not pushing, with the short claw in the cut. Mount it in a light handle, and keep the short claw in a good condition and a little under-cut.

Fig. 3.

(52.) *Oiling the escapement.* When everything is done, so that you are sure you will not have to take the balance out again, a little oil should be put to the jewel holes—they and the pivots being, of course, perfectly clean. Put in barely enough oil to fill the *holes*, but not stand at all in the oil-cup or concavity of the jewels. If it seems to be soon drawn away by capillary attraction between the hole-jewel and the end-stone, put in a little more. But put no oil on the pallets of a verge; a very little only on the long impulse-lip of a cylinder; a very little on the pallets of a lever watch, but none on the ruby pin nor in the notch of the lever; a little on the roller-jewel of a duplex staff, but none on the impulse pallet; none on either the unlocking or impulse-jewels of a chronometer, none on the detent-pallet, and but little on the balance-pivots. Use none but the very best watch-oil to be had at any price. Keep the bottle closed and in the dark; keep your oil-cup perfectly clean and covered; put but little oil in it at a time, and fill it often with fresh, wiping it perfectly dry and clean with paper every time you fill it. Make an oiling-wire by taking the temper out of a sewing-needle, file it tapering to a point as fine as a hair, then turn over the extreme end, and make the smallest possible loop or ring, so close that you can see no hole in the center, and mount it in a light handle. This loop will take up all the oil that any ordinary hole ought to have. Keep it away from soldering fluid, water or dirt, and keep it out of your mouth. Of course, if the balance, spring, etc., are at all greasy or dirty, they should have previously been hung on a wire hook and moved about in a bottle of benzine for a few seconds, then dried by exposure to the air.

(53.) *Timing the spring.* Having now put the movement together, with the hands on, set it to seconds and run it for exactly one minute, changing the regulator till it is correct. Then try it for fifteen minutes, and if it is about right it may be put into the case and hung up for the final regulation. Although I have dwelt upon a large number of details, the workmen should remember that it will take but little more time to do his work rightly, if he understands how it ought to be—and it has been the object of these explanations to clearly show the proper method, so that when his work is done it will be correctly done. The isochronal adjustment of the spring will be treated hereafter; also, testing and correcting the poise of the balance. I am aware that there are plenty of blunder-heads in the trade who will dispute this or that proposition, which may not agree with their theory or practice. I can assure the reader, however, that the directions given or to be given may be relied upon, and are approved by those best qualified to judge in these matters.

New Tool and Method for Fitting Hair-springs.

(54.) In my last article I gave the ordinary method of fitting hair-springs followed by good workmen, with such tools and appliances as every watchmaker has or ought to have in his shop. I shall now describe my own tool and method, by which we may test a spring in every way without injuring it in the least, and in a very short time, so that, if it should not be suitable for the watch on trial, it will still remain as perfect for the finest isochronal adjustment in another watch as when made,—a point of considerable importance when fitting fine and costly springs.

(55.) The tool I use is not designed for fitting hair-springs only, but is applicable for measuring heights and distances in fitting staffs, cylinders, pinions, wheels, etc., also for setting and re-setting jewels, upright drilling of pivot holes, etc., chamfering and countersinking, fitting screws, and many other uses, as will be seen hereafter. It is substantially an Upright Holder, carrying arbors for different uses, and so constructed that the upright portion can be moved in any direction to bring the arbor over any hole in the watch, and there fastened. It consists of a clamp, to be fastened to the movement in any convenient place, carrying a round upright rod, movable up, down and on its own center, and having a head through which moves a horizontal slide carrying the vertical arbors.

(56.) The clamp is made from a thick piece of metal, (steel, cast iron or hard brass,) flat on its under surface, nearly rectangular in shape, 1½ inches long, by 1 inch wide, half an inch thick in the center and one-eighth inch at the edges, with one edge hollowed out to form two projections or claws, one at each corner, and about 1¼ inches apart. Under each of these claws there is a jaw, made something like the jaws on a universal lathe chuck, capable of being fastened parallel with the surface of the clamp, and at any desired distance from it—so as to be screwed to the potance plate alone, or, if necessary, they can take in the whole thickness of the watch movement. The claws are slipped in between the bridges, or upon the plates, wherever a good bearing can be got, and the jaws screwed up to hold the clamp firmly in place—its flat under surface being, of course, in the same plane with the plate of the watch. The jaws can be faced with thin leather or rubber, if thought best, to give them a good hold without much pressure. In that case, they could be clamped directly on the dial without danger. My own tool is made double, having two claws 1¼ inches apart as above, and, on the opposite side of the clamp, two other claws or projections only ¾ inch apart, so that one side or the other will fit readily upon all sizes of movements. The jaws are also reversible, being turned at their center to point towards either pair of claws which are in use.

(57.) Through the center of this piece or clamp is drilled a vertical hole to take an upright steel rod $\frac{3}{16}$ inch in diameter, and about 1½ inches long, having a head at its top, and fastened at any desired height by a screw, like the centers in a bow-lathe. In the head is a rectangular slot through which slides, horizontally, a steel strip 1½ inches long, ¼ inch wide, and $\frac{1}{16}$ thick, (a piece of an old pair of tweezers will do,) edge up, and fastened wherever desired by a screw. This strip also has an enlargement or head at its inner end, with a vertical hole to take in the different arbors to be used. These arbors may be the centers of your bow-lathe, or depthing tool, or any others you have already on hand, if you do not wish to make them specially for this tool.

But I advise to use tolerably large ones, at least $\frac{1}{8}$ inch in diameter, so that the head will take in arbors for setting jewels, etc., to be described hereafter. But the arbor we use for hair-spring fitting should be reduced to a diameter of about $\frac{1}{16}$ inch for half an inch from each end, so as to penetrate into the smallest places, and also to enable us to bring our false regulator pins near to the center when wanted. One end should be brought to a fine central point, the other tapered down a little, and the end truly and centrally countersunk. Or two sets of arbors can be made, one fine, the other larger, each having its own horizontal slide and head.

(58.) The use of this tool is obvious. Having first fastened the clamp firmly to some part of the movement, the upright rod is inserted with its head at any desired height, and the horizontal slide placed so that the point of its arbor will rest in the balance jewel-hole, when the slides are screwed fast. We reverse the arbor, and bring the other end, which has the female center, down upon the upper pivot of the balance (or any other piece you are fitting,) and hold it upright the same as would be done by the bridge itself. The angle of this female center should be rather acute, *i. e.*, it should be deeper than it is wide at its mouth, so that it can be raised sufficiently to give the pivot freedom and yet not allow it any play sideways. The surface should be well polished and hard, kept clean and free from rust, and it will form a very tolerable substitute for the balance bridge.

(59.) This arbor has two hubs, which slide freely upon it, and are each fastened by a set screw. In each of them is fixed a steel wire, $\frac{1}{16}$ inch in diameter, pointing horizontally outward from the center of its hub. Each of these wires has a smaller hub, which slides to and from the arbor, and is fastened by a screw. One of them has two pins, to represent the regulator; the other has a clamp to grasp the hair-spring instead of the tweezers, and therefore represents a stud. This clamp can be either self-acting and spring-tight, or be opened and closed by a screw. The points are made thin, so as not to touch the adjacent coils of the spring, and both they and the regulator pins point vertically downwards. The two hubs, carrying the clamp and the pins, are adjustable independently of each other, as to distance from the arbor, height, and distance from each other, to correspond with the relative positions of the stud and regulator in the watch. The wires which carry the two small hubs are filed flat on one side, so that the set screws can be loosened enough to allow the hubs to slide along, while they cannot turn over. If the spring on trial requires to be altered, we simply open the clamp to release it, and raise the arbor, when the balance can be taken out, and after altering can be as readily replaced and refastened, everything being in the same position as before.

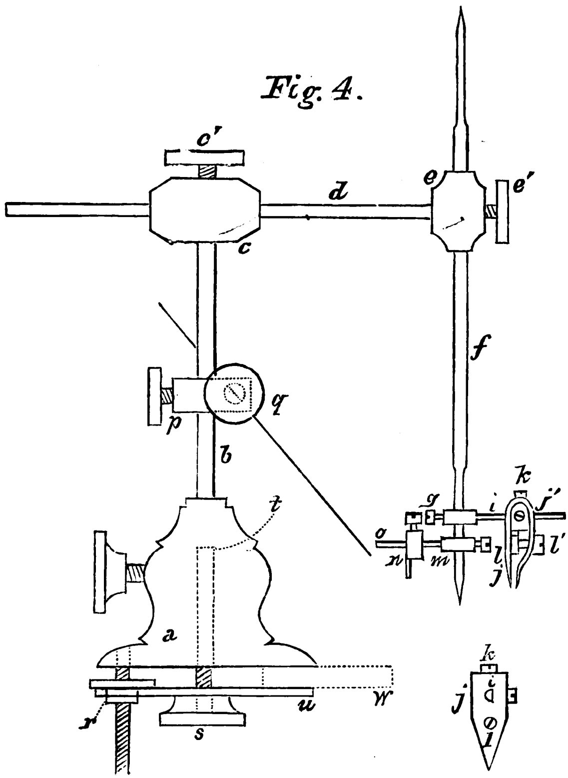
(60.) In my own tool I also have holes in different places, in any one of which a small plug with a milled head will fit—the plug being sawed through the center so that the two halves spring outward and hold the plug in any position in which it is placed. This plug carries a stiff bristle, and I place it in any hole suitable to the watch, so that by turning the milled head with the fingers I can lower the end of the bristle upon the balance rim, or raise it, in an instant, for the purpose of holding the balance still or liberating it. I also provide holes for causing a bristle to rest against the balance staff while it is running, should it be desired to make the vibrations small while isochronizing the spring, as hereafter specified.

(61.) Now, there may seem to be a good deal of this tool, but it is all perfectly simple and easy to construct, and any man fit to touch a watch ought to make one all complete in a day, at the utmost. If he has much work to do it will save him days and weeks of time, to say nothing of the satisfaction in its use, and the superiority of the work. Perfection is not required in any part for hair-spring fitting—the only point at all essential is that the arbor shall stand vertically or nearly so. There is nothing obligatory about any of the sizes or details given. The rectangular slot can be easily made by riveting together flat pieces, and leaving a space for the horizontal slide. But, whatever time may be required to make it, it is a tool for which every workman will find frequent and profitable use.

Figure 4 is a sketch of a lighter and cheaper tool that I have, adapted only for hair-spring fitting. The clamp, *a*, was made from a round piece of harness mounting, and the heads, *c* and *e*, from a piece of brass lightning-rod point,—showing how refuse scraps may be worked up into valuable tools and save cost. In this Holder, the horizontal slide is a round rod, and the vertical arbor, *f*, is simply got into line with the upright rod, *b*, by the eye, as exactness is not required in fitting hair-springs. But in the tool as previously described, the slide, *d*, should be flat, to maintain the vertical position of the arbor, *f*.

In this tool, *a* is a round clamp, with a set screw in the center on the back side, while the front edge is filed out to make the two claws; *b* is the vertical rod, with its head *c*, and set screw, *c'*. This rod slides down between the two jaws, *u*, which are made from a broad flat piece of steel. The nut, *r*, runs on a screw fixed in the clamp, *a*, and its center passes through the jaws, to give more substance for the screw to hold in. The tightening screws, *s*, are near enough to the center of the clamp to be bedded in the metal up to *t*, before coming out. The dotted lines, *w*, represent a plate to which the Holder is supposed to be fastened; *d*, is the horizontal rod, with its head, *e*, and set screw, *e'*; *f* is the vertical arbor, point upward. The holes are drilled entirely through the heads, *c* and *e*, at right angles, one side of the center taking in the rods, which should be screwed in very tight and fast,—the other side taking in the set screws. *g* is the hair-spring hub with set

Fig. 4.



screw and smaller hub, *h*, sliding on the wire, *i*, which is filed flat on one side, and is fastened thereon by the set screw seen in front; *j*, is a steel strip bent around the hub, *h*, to which it is fastened by the screw, *k*, and terminating in fine points at the lower ends, which grasp the hair-spring; *l* is a brass piece riveted in the back half, to give substance for holding the screw, *l'*, which draws the points together upon the spring. The small figure below is a transverse view of the same. *m* is the regulator slide, with hub, *n*, sliding on the wire, *o*, which is flatted on the top; *p* is a brass strip which slides along the rod, *b*, and turns in any direction, with plug, *q*, carrying a bristle. The set screw of this strip is long enough to fasten it upon the rod, *b*, *d*, or *f*,—wherever it will be best to have it. All the parts are drawn in the best position for showing their construction, not for use.

(62.) Our Upright Holder being fastened to the movement so that the point of the arbor rests in the lower balance jewel hole, we select a spring for trial and stick it to the staff according to previous directions, then put the balance into its place in the watch. Reversing the arbor, we bring the end with the female center down upon the upper pivot, holding it in position, but leaving it free to vibrate. The hubs having been previously slipped on the arbor and fastened by their set-screws, we place the hair-spring clamp at the proper distance from the center to grasp the spring at the point which, before, we held in the tweezers, and fasten the whole properly. We then place the false regulator pins about as the real ones stand in the watch, and fasten them also. Then we loosen the arbor and turn the whole—the arbor, with its hair-spring clamp, and the pins,—all together, and bring the balance in beat, or near enough for the watch to go freely, and fasten it again.

(63.) *Testing the spring.* Lastly, we turn the balance a little, so that it will start off promptly on being liberated, and lower our bristle upon the rim to hold it so till we are ready to begin, then count the vibrations and proceed as before described (36,) except that we now shift the spring in the clamp instead of in the tweezers. If the number of vibrations is about right, we pin the spring to the collet (37, 38,) and try again, shifting the spring if necessary till the correct number is obtained, then pin it in the stud at the point grasped by the clamp, put the watch together, and a very little regulation will finish the job, (53, 78.) In this way you will never have to change a spring once pinned in the watch, for it is obvious that it will perform almost exactly the same there as in our Holder, provided the regulator and stud occupied the same relative positions in each. In timing springs before breaking off the superfluous outer coils, the claws grasping the proper coil should be raised sufficiently for them to clear the other coils vibrating below. And, of course, the first trials should be made with a small vibration to avoid danger of loosening the spring in the wax.

(64.) *Rule for selecting a spring.* But if we should get say 250 vibrations with our first spring, when we required 300, instead of sticking other springs on and trying each one in the same way till we find one to suit, as is usually done, we test the strength of our first spring in a hair-spring gauge—Bottum's is too well known to need description—and examine the rest of our stock of springs in the gauge, without attaching them to the balance, and find what we want by means of the following Rule: *The forces of two different springs, attached to the same balance, will be in the same proportion to each other as the squares of the numbers of vibrations which each makes.* Supposing that the spring tried gave 250 vibrations, when we want 300, and in the gauge the strength is, say, 20. Then our problem may be stated thus: If a spring which gives 250 vibrations per minute gauges 20, what must a spring gauge that will give 300 vibrations?

(65.) According to our rule, the square of 250 will be in the same proportion to the square of 300, (the desired number of vibrations,) as 20, the force of our present spring, is to the force of spring which will give 300 vibrations—which is what we want to find out. We will therefore represent that unknown force by the letter X, during this calculation, and having squared 250 and 300 (*i. e.*, multiplied each into itself), we write the proportion down as follows: 62,500 : 90,000 :: 20 : X. Now multiply the two end terms of the proportion together, and the two middle terms together, and the two products will be equal, according to the law of proportions. Multiplying, we get 62,500 X = 1,800,000, and by dividing we find that one X is equal to about 29, which is the gauge of a spring that will make 300 vibrations per minute; or, to express our process more methodically, $X = \frac{90000 \times 20}{62500} = 29$, nearly. As it takes but a moment to lay each spring on the balance-bridge, and seize it with the tweezers where it lies in the regulator, then test its strength in the gauge, we save all the trouble of attaching it to the balance, counting, etc. In fact, we can gauge a number of springs while we would be testing one in the usual way. Of course, any other figures obtained by the workman in each particular case may be substituted for those given above.

(66.) Having found among our springs one which gauges 29, we have but little more to do, and that has been already described. With a fair stock of springs, it is quite practicable to fit one in and have the watch passably regulated in one hour. Even the Breguet spring can be fitted in half the usual time with this tool, and done better, with no risk of injuring it by numerous trial pinnings in the collet and stud, which is almost unavoidable while following the usual methods, as I shall show in my next article, which will be on the isochronism of the hair-spring.

(67.) Cases are occasionally found where the tool cannot be used exactly as described, and when it will be required to attach the holder clamp to the balance-bridge, place the upper pivot in its hole, and vibrate the balance by hand, counting, etc., as before. But these instances are exceedingly rare, for in most English lever and other under-sprung watches the spring can just as well be stuck to the *upper* pivot for trial, while the balance is placed in the watch for running as usual. And even after the spring is pinned in the collet, that can be stuck on the upper side of the balance with wax, concentric with the pivot, and tested as before described, the balance receiving its motion from the movement, the same as if the watch was finished and going.

(68.) *The regulator.* A few words about the regulator are necessary, since even its purpose does not seem to be always comprehended. If we could make the ideal perfect regulator, it would be in effect a movable stud, which would allow of being shifted in either direction as the exigencies of the timing should require, but would then become the *end* of the working portion of the spring, holding it as firmly as the real stud does, and cutting off the part behind it from any influence upon the time of the watch. But since this cannot be practically realized—at least, it has not been done, so far as I know—we should come as near to this ideal as we can, by placing the regulator pins as closely together as possible, without binding on the spring when the regulator is shifted. The most perfect results in time are obtained when the regulator stands pretty well back towards the "slow," *i. e.*, near the stud—and, in fitting in a spring, if it does not give the correct number of vibrations with the regulator standing between the middle of its scale and the stud, the spring should be drawn further through the stud to shorten it, rather than move the regulator further towards the "fast."

(69.) *Poising the balance.* After the watch is put in beat and is fitted for running, we must know if the balance is perfectly in poise, for if it is heavier on one side it can never give reliable time. The poise cannot be finally tested until now, with most watches, because they generally have an open cut in one side of the collet, making it lighter on that side; and it would be useles to finish the poise till the position of that cut had been fixed, as any turning of the collet for the purpose of putting the watch in beat would bring the cut into a different position and throw the balance out of poise again. If the balance has movable screws in its rim, the perfecting of the poise may be done by drawing out one of these screws a little. If much correction is needed, two or more screws should be drawn, so that their position would be altered but little, and nearly alike. But this mode of correcting the poise is not allowable with a cut balance, which is adjusted for heat and cold, but only for uncut or unadjusted balances, in cheap watches. A collet with a very wide cut should not be permitted with an adjusted compensation balance, but rejected and a new one made with the cut entirely closed. In such a balance there are generally four screws called "quarter-screws," which may be moved to perfect the poise,—one at each end of the center-bar, and another pair midway between them on the rim. But the latter pair should only be moved very slightly, as it is likely to disturb the compensation for heat and cold; while the former pair will affect only the rate, and even this may be avoided by moving both screws to poise the balance,—one of them in, and the opposite one out, which of course maintains the *mean* distance of the two from the center of the balance the same as it was before. See also (215.)

(70.) The rule is to take off the hair-spring and collet to poise the balance, which shows the astonishing stupidity of those who "make the rules" and of those workmen who blindly follow rules so palpably wrong. Notwithstanding that it is so taught in "the best shops in Europe," I advise the reader to use his own reason and common sense on this and all other matters, regardless of what "the best workmen" may have practiced from their boyhood. There is no lack of old fogies in our trade, as in all others, but we should not choose them for our teachers.

(71.) It is, of course, desirable that the balance should be in poise before the spring is put on, as that facilitates the final poising. Besides that, the parts then on the staff are considered fixed and permanent, but the collet and spring are movable; therefore the fixed parts, as a whole, should be poised, and then the movable parts prevented from destroying that poise. Inasmuch as our object is to have the balance in poise while running, it must be plain that the balance should be in poise with everything on it *exactly as it will be when running*. That is, the roller table, the hair-spring and the collet, and all other parts should be on the staff; and if the collet or any other piece is not perfectly poised *in itself*, its final position must be determined before the poising is finished. In chronometers it is common to drill a hole in the roller-table, opposite the impulse jewel and notch, to make up for the metal there cut out and balance its weight; and a similar course would be desirable in fine lever watches. Chronometer collets and springs can be poised separately if desired. As already stated, the best remedy for an open circular collet is to make a closed one.

(72.) *Poising tools.* There are two kinds of poising tools, the notch and the straight-edge. It is best to do the main portion of the poising upon the notch tool, using the straight-edge for the final tests only, as much time will be saved thereby. The poising tool consists simply of two jaws or pieces of hard metal, whose distance apart can be changed to suit the length of the piece being poised. By making suitable notches in a straight-edge tool, you have both kinds in one. The jaws may be of either brass or steel, with the edges perfectly straight, smooth, polished and thin, like two knife blades, parallel to each other and with the edges upwards. At each end of the jaws may be made a pair of notches—one pair fine, the other larger. The notch should be about the depth and a little *wider* than any pivot that is to go in it, the bottom semi-circular in form, and the edges filed very thin so as to present almost a knife edge to the pivot, and must be kept clean and polished.

(73.) The staff should be so placed in the notches that they will not rub on the shoulders of the pivots. If the balance seems to be correct and does not turn of itself, whirl it with a bristle, and if it stops with all sides up, indifferently, it may be placed on the straight edges, which should be horizontal so that there will be no tendency for it to roll. It is not necessary to whirl the balance here, but simply place it with different sides up, and if it shows no disposition to change its position it is in poise, for there is no friction on the pivots to prevent it rolling over if there was the slightest tendency to do so. Whirling the balance will inevitably cause one or the other of the shoulders to bring up against the jaws, and necessitate another test. But a well fitted notch leaves little to be desired, or accomplished by the straight edges.

(74.) *Rules for poising.* In these tests the hair-spring should be unpinned from the stud, and there should be a preponderance of weight on the side where the outer end of the spring is, corresponding to the weight of so much of the spring as exceeds the number of coils—that is, to the weight of any fractional part of a coil there may be at the outer end, *whether it belongs before or behind the stud when pinned.* This may seem unreasonable at first thought, but experience shows that, if the spring is evenly coiled, an allowance for the weight of this fractional end will secure a correct poise when the spring is properly pinned in the stud, and this allowance is easily made either by the judgment of the experienced workman, or by hanging an equal length of the spring-wire on the opposite arm of the balance and at an equal distance from the center. This balancing weight should be very slightly too heavy rather than too light, if exactness is not attainable.

(75.) This rule applies only to the plain flat spiral springs, not to the Breguet or the helical springs. Nor does it apply even to the plain spiral when it is unevenly coiled, or its outer end is so irregularly shaped that the workman cannot judge of the balancing weight or its proper position as there described. In all of the above cases, and also when the workman has no spring-wire suitable for the balancing weight, or has not experience enough to judge without balancing, the poise should be first tested without the spring and its collet, then with the collet on and the pin in its place in the collet—but without the spring. If any error is found, the correction should be made in the collet itself, not in the balance, till the collet can be turned in any position without disturbing the poise. This can be done before the spring is fitted, whenever it is seen that the rule given in section (74) is not applicable. The subsequent addition of the spring will not seriously disturb the poise. Of course, the flat spring can be poised as in (74) *before* its end is formed into its irregular shape. A helical spring can be poised according to that rule, after the lower terminal curve is formed and pinned in the collet, but *before* the upper curve is formed, *i. e.*, while the upper end retains its cylindrical shape. But after both terminal curves are formed, the balance cannot be correctly poised with the spring on. It is generally supposed that, if the terminal curves are properly formed, the center of gravity of the entire spring will be on the balance center when running. But this is a mistake which I shall show up hereafter; nor can a Breguet spring be poised after the terminal curve, or even the elbow, are formed, except so far as the experience and *judgment* of the workman may enable him to approximate to *probable* correctness.

(76.) *Testing the poise.* The poise may be tested after the watch is running, by timing it for 3 or 6 hours each in the four vertical positions, *viz.*, with figures XII and VI, III and IX alternately upwards, and if the times are the same in the different positions, the balance is supposed to be in poise. See also (85, 93). But in order that this test should be trustworthy it is necessary that the balance jewel-holes be well fitted to the pivots, the escapement in perfect order, and the lever poised, so that there may be equal friction in each position; and the watch must be wound up an equal distance for each test, so that the motive force may be the same in each position. Otherwise, errors due to unequal friction or action, imperfect fitting, or lack of isochronism in the spring, may be erroneously ascribed to want of poise in the balance.

(77.) *Timing the spring.* I will conclude with a description of my method of timing to seconds. As an error of one second in a minute will amount to 24 minutes in a day, it is important to be as exact as possible in our trials. In the usual method of fitting springs, where the balance is caused to vibrate only by the strength of the spring, counteracted by the staggering of the balance as it is supported by the stiffness of the spring itself as held in the tweezers, there is no possibility of any accuracy till the spring is actually pinned and tried in the watch. But with my tool we may observe correctly from the start.

(78.) Passing over those cases already mentioned (33, 36,) where no counting or timing is required, but only a comparison of the speeds of two contiguous balances, we will suppose that a spring has been selected, etc., (22 to 36,) the balance placed ready for the start, (63,) the movement secured in a movement-holder, dial downwards, and we wish to count the vibrations for one minute. For this we need either a regulator or watch whose seconds-hand makes one revolution in exactly 60 seconds. If we have such a regulator, we take a small hand-mirror or piece of looking glass, place it beside the movement and at an angle that will reflect the regulator dial with its seconds-hand, so that we can keep the balance in our eye plainly enough to count its vibrations while we are watching the seconds-hand in the mirror. As the seconds-hand crosses the figure 60 on its dial we raise the bristle and commence counting the vibrations, (36), giving an occasional glance in the mirror, and by watching the seconds-hand as it approaches the end of the minute, we can very easily tell exactly when the time is up. If we have a watch that can be depended on as correct, we may place its seconds-dial as near our balance as possible and observe that, as before.

(79.) When we wish to test for a longer time than a minute, we dispense with the counting and go by the seconds-hand, comparing it either with the regulator or a watch, and at the exact instant the time of the trial closes, we give the plug (60) a twist and bring the bristle down upon the balance, after which we can examine the hands at our leisure. The method of comparing time closely, described by Mr. Fritz in the *Jeweler's Circular* for January, is an excellent one if the movement is already cased or boxed up, and I have followed it with great satisfaction. (See Appendix.)

Part Third.

THE ADJUSTMENT TO POSITIONS.

(80.) The *adjustment to positions* is another point which must now receive attention. We know that in nearly all watches the balance has a larger motion, or longer vibration, in a horizontal position than when it is in a vertical position, or with its edge up. This is caused by a greater friction on the balance pivots in the latter case. The adjustment to positions is effected by equalizing the frictions, so that the hair-spring will be able to move the balance through the same arc in any position in which it may be held. Generally, watches are adjusted for the two horizontal positions, dial upward and balance-bridge upwards, and two vertical positions, with the figure XII upwards, and III upwards. But a fine watch should be adjusted for all four vertical positions, XII, VI, III and IX upwards. In all cases the equalizing of the frictions is to be done by *lessening the greater* ones—never increasing frictions unless that is unavoidable.

(81.) The two horizontal frictions are equalized by making the ends of the balance pivots equally flat and well polished. The extent of the vibrations can be readily observed when the dial is upwards, by setting the movement holder upon a piece of looking-glass on the bench. The balance and works can even be examined with the eye-glass while in that position, by looking from one side at such an angle that its image will be reflected into the glass. This is much better than holding the movement above one's head in order to see its under side, insures a true and equal horizontal position each time, and obviates the trembling of the hand while holding it, which interferes with the motion of the balance—and is, besides, easier and safer.

(82.) If the vertical vibrations are smaller than the horizontal ones, the other conditions being as described in sections (93, 94,) the only way is to flatten the ends of the pivots, till the balance will keep up about the same motion in all positions. Some workmen not only flatten the ends, but go further and use round grinders or laps to hollow out the pivot end a little, and cause the entire weight to be sustained upon the ring of metal left around the outer edge of the pivot end. This brings the rubbing surface nearly as far from the center of the pivot in the horizontal as in the vertical position, but the practice is objectionable for several reasons, besides being difficult of execution. It is sufficient for all practical purposes to make the end of the pivots perfectly flat, or as nearly so as may be found necessary on trial.

(83.) On the other hand, if the vibrations are greater in the vertical than in the horizontal position, then we slightly round off the end of the pivots to increase the arc in the horizontal position to an equal extent. These changes of the shape of the pivots should be done in a lathe, and very slowly and cautiously, lest we do too much. The best tool is a pivot burnisher, as that both polishes and hardens the surface. If a stone or lap is used, the burnisher should finish the job. In rounding off the end, the departure from a perfect flatness on the end of the pivot should be only sufficient to prevent actual contact with the end-stone, so that the rounding off shall be barely perceptible to the eye. First remove a narrow ring around the outer edge and try. If not enough, take off a little nearer to the center of the pivot. If too much is taken off, we shall have to flatten the end again, which will shorten the pivot. Therefore we take off but little at a time, and as equally as possible off each pivot. Always remove any "feather-edge" that may appear at the corners of the pivots, with an oil-stone slip.

(84.) Having substantially equalized the vibrations, any remaining error can be easily compensated for by the isochronizing of the spring, which should *follow*, not precede, the adjustment to positions. Most workmen test that adjustment by *timing* the watch in different positions, and make the alterations of the pivots according to the errors found in the time, instead of by the differences in the vibrations as above directed. But it is clear that if the spring were isochronal, there would be no change of time in the different positions, even if the frictions and arcs of vibration were different. Hence that test is of no use, except before the spring is isochronized, and even then it is a mere waste of time and labor, because the same information can be gained instantly by simply observing the extent of the arcs of vibration in the different positions. For, if the arcs are the same, the times will be the same. And when we have equalized the arcs, we may be certain that they will be performed in equal times, without taking the trouble to try them.

(85.) *Faulty methods.* Other methods of adjusting to positions are often followed by "the best workmen." Some throw the balance out of poise in such way as to equalize the vibrations in different positions. For instance, if the watch goes faster in the hanging position, or XII up, than when horizontal, they make it go slower by increasing the arc of vibration, thus:—Allowing the balance to come to rest, they make that side which is at the top when the figure XII is up heavier, by drawing out one or two screws in the rim or otherwise. Or, if it loses in that position, they make the bottom heavier, so that the motion will be lessened. Now in an adjusted compensation balance this would probably destroy the adjustment for heat and cold. Even with an unadjusted balance this plan may be unsuccessful, for a greater vibration may be either quicker or slower, according to the spring—and the change of vibration may produce the opposite effect to that designed. Or, if the spring be isochronal, it will have no effect upon the time except the injurious one caused by the want of poise.

(86.) Others bend the hair-spring to one side, instead of leaving it free and concentric with the balance axis, as it should be. For instance, if the watch loses with XII up, but goes correctly with III up, the spring is bent towards the figure XII, so that when that side is upwards, the spring will partly support the balance and lessen the friction in that position. Workmen who follow this method adjust only for the two horizontal positions and two vertical positions, viz.:—XII up and III up. And they calculate that, by thus adding a side pressure of the pivot to the friction upon its end, they will increase the friction while in the horizontal positions, and so make it equal in the horizontal and vertical positions. Now it is sufficient to say that either of the two preceding methods is entirely wrong in principle, being directly destructive of the isochronism of the spring, and injures the watch in *all* positions for the sake of a little apparent improvement in one or two. No good workman will practice either of them, nor will he need to do so if he properly understands his business.

(87.) The arc of vibration should be the same in each of the four vertical positions. If it is not, there may be different causes. The balance may be out of poise; the balance jewel holes may not be round, not evenly polished inside, or too large for the pivot—allowing the balance to fall towards the lever, escape wheel, etc., or away from them, and interfere or change the action of the parts. The change of the arcs when held in the different positions will guide us to the cause. Inasmuch as the greater the friction is, the smaller the arc will be, we know in which position to remedy the inequality of the friction, and we may also ascertain the effect of our alterations by simply noting the change in the arcs. It is desirable to equalize the frictions in the different positions as nearly as possible, as it leaves less to be accomplished by isochronizing the spring, and there is a limit to the amount of irregularity which this adjustment can compensate for. Besides, the more perfect all the parts of the watch are, the finer the performance which we may hope to obtain from the spring.

PART FOURTH.

THE ISOCHRONAL ADJUSTMENT.

(88.) We have now reached that portion of our subject which relates to the final adjustments of the hair-spring for the purpose of insuring that the vibrations of the balance, whether they be great or small, shall always be accomplished in equal times, when the spring is said to be isochronized or adjusted to isochronism. In my previous articles I have given general directions for fitting springs, which, if followed, will prevent any very great errors of time from varying arcs of vibration, and which, moreover, must be attended to before the last finishing touches, presently to be described, can be proceeded with. The isochronal adjustment of the hair-spring is, without doubt, the most delicate and least understood operation the watchmaker is called upon to perform. Many who talk and write most glibly about it do not appear to know even the meaning of the term. And upon considering their ideas we are forced to the conclusion that unless their practice is better than their theories, it is not worth much; or else, if they do really understand the subject, they are purposely trying to lead others off upon a wrong tack, in order to keep their knowledge to themselves. But to this there are, of course, honorable exceptions.

(89.) I do not propose to advance any new theories, but to regard it in a very practical light, as a merely mechanical problem, requiring no profound knowledge, either scientific or mathematical, but which may be satisfactorily solved by any watchmaker of ordinary skill and patience. And I shall endeavor to give all necessary instructions for doing so. Even if the workman does not intend to undertake the isochronal adjustment, it is important that he should know how to discover whether the watches he buys and pays an extra price for as isochronized, are so or not, for there is as much swindling of ignorant dealers on " isochronal hair-springs" as on "compensation balances, adjusted for heat and cold," of which not one out of a hundred so called are adjusted at all.

(90.) *Action of non-isochronal springs.* If the hair-spring is not isochronal, the watch will vary from correct time whenever the extent of the motion of the balance, or the "arc of vibration," as it is termed, is changed. In a watch having a going-barrel the vibrations are largest or longest when first wound up, and become smaller as the motive power becomes weaker, so that during every hour of the 24 the watch may keep a perceptibly different time. Some springs perform the short vibrations in less time than they do the long ones, while others do the reverse. A well made and well fitted spring will not vary much from uniform time, while a spring that is misshapen, crooked, out of center, unevenly coiled or tempered; that has been scraped, ground, much bent, or is very soft, will vary sometimes several minutes during the day, although it may be somewhere near right at the *end* of the day. Every change of the arc of vibration caused by jarring, carrying, keeping it in different positions or different temperatures, irregular winding, poor oil, dirt, etc., causes it to vary, so that for accurate timekeeping it is valueless.

(91.) In duplex and cylinder escapements the resistance to the momentum of the balance caused by the pressure of the escape wheel during the free arc of motion of the balance, is greater or less in proportion to the greater or less motive force, and therefore these escapements are in some degree self-compensating for irregular motive forces. Yet they do vibrate further when first wound up. In English levers and chronometers the fusee and chain are employed to equalize the motive power. But, to do this accurately, the fusee must be cut in conformity to the varying strength of the particular main-spring used, which is seldom done, as is shown by the varying arcs. But were it so, the friction upon the balance pivots *in different positions* is another disturbing influence in all watches. And even if the watch is adjusted for positions, the thickening of the oil, accumulation of dirt, etc., by running, cause the vibrations to gradually diminish.

(92.) As it is practically impossible to prevent the arc of vibration from varying more or less, it is necessary in fine watches, after reducing that variation to the smallest possible amount, to adjust the hair-spring within those limits, so that no error of time shall result from such unavoidable changes of the arcs of the balance. This adjustment or isochronizing of the hair-spring can be done in different ways, which we shall consider at some length. But before undertaking this, and even before we can safely test our spring to see what and how much adjustment it requires, there are certain other points to be attended to.

(93.) *Requirements of isochronism.* Besides observing the instructions already given for the correct forming and fitting of the spring itself, the balance and the lever must be perfectly poised; the balance, spring, lever, and all other parts in the watch, even the springs in the case, must be free from magnetism; the movement must be in good condition to transmit the motive force uniformly to the balance; the escapement particularly must be as perfect as it can be made; the end-shake of the balance, lever and escape-wheel no greater than is necessary to give freedom of motion, so that there can be no material change in their relative positions; the pivots of the lever and balance staffs well fitted to their jewel holes; the lever pivots well polished and free from any "binding" in any position of the movement; the balance pivots straight, hard and round, well polished, as small as is consistent with strength, their shoulders well clear of the jewels, and the balance not running too near the plate, bridge or any other part; the hole jewels thin and the holes round and finely polished; the holes not perfectly cylindrical, but a little rounded out or enlarged towards each end, to diminish the extent of surface in contact with the pivots, and prevent any possible binding by either the jewel or pivot not being set exactly true, as well as to lessen the adhesion of the oil to the pivot; and in lever watches the ruby pin must be perfectly firm in its place and vertical, or parallel to the balance axis, and the slot in the end of the lever polished and well fitted to the ruby pin.

(94.) If all this is not the case, it should be made so as nearly as possible, after which there is a certain order to be observed in our further proceedings. It is an established rule among workmen that the adjustment of the hair-spring for isochronism should be made before the balance is cut, because after that is done the sections of the rim will fly outward by centrifugal force while vibrating, and disturb the perfection of the result. Which reminds one of the old lady who gave her darling daughter permission to go in to swim, but cautioned her not to go near the water. That is precisely the reason why the balance *should* be cut, so that our adjustment may cover that irregularity. If all balances when vibrating would fly out alike, or the same amount in long vibrations as in short ones, then it might be *possible*, although difficult, to make a certain allowance for that effect, when isochronizing the spring, so that it should perform as correctly after cutting the balance as before. But it is not so.

(95.) Most workmen have an idea that isochronism is some mysterious property of the spring which will enable it to overcome irregularities and difficulties and make the balance "come to time" in spite of them. Now that is just as incorrect as to say that it is one of the properties of a pivot to fit its jewel hole. It will fit the hole after it is made to fit, and not until then. So, a hair-spring is isochronal after we have isochronized it, and not before. That is to say, after we have adjusted the shape of the spring, so that, under the effects of all disturbing influences acting upon it while the watch is going, it will make unequal vibrations in equal times, it is isochronized, or isochronal. Just as we say, after we have fitted the pivot, "it fits." But the fit is not a "property" of the pivot, nor is isochronism a property of the hair-spring. It is simply a term representing a certain *condition* of being adjusted to act in a certain way under certain circumstances. But if those circumstances are changed one atom, there is no property or power in the spring to vary its action to suit that change, or correct its effects. Whatever peculiarity of action it may have as the result of our manipulations, that action is unvarying. If we want it to overcome certain difficulties, we must alter it till it does overcome them. Hence the spring should be isochronized with the balance cut and with all other influences, good or bad, which it is desired to neutralize, acting precisely as they will when the watch is finished and passed over to the customer.

(96.) *Common errors.* But "the best workmen" and writers very profoundly inform us that, in practice, it is better that the isochronism should *not* be quite perfect, because after running awhile the oil will thicken and dirt will clog the works and weaken the effective motive force, while the motion of the balance will be impeded by the same cause acting upon its pivots, so that the vibrations will constantly become smaller; and that, therefore, the short vibrations should gain upon the long ones, because otherwise the increased friction in the diminished vibrations would cause them to lose time, but by quickening them a little they will perform correctly. Just so! How remarkable!

(97.) With all due respect to eminent authorities, life-long experience and profound wisdom, I beg to say that such a practice or such an opinion is a sorry comment upon the skill of its author. It is commonly supposed that Marine Chronometers, at least, have isochronized hair-springs. But if their makers really possessed the ability to isochronize springs, why should they recommend to make the short vibrations gain on the long ones, as they do, (different makers varying all the way from 4 to 15 seconds in 24 hours,) when the arcs are reduced from a turn and a quarter to three-quarters of a turn? It is to meet precisely such conditions that springs are isochronized. Either they do not believe that springs really can be so adjusted as to perform great and small arcs in equal times, or they have not the skill to do it, and adopt this clever method of excusing their incompetence.

(98.) Their idea appears to be that, because of the friction, the watch will lose time. Now we know that the smaller vibrations may be performed either quicker or slower than the long ones, according to the nature of the spring attached to the balance. Therefore if these men honestly believe what they say, and if their idea amounts to anything at all, it is that the friction affects the time of the vibration independently of its extent. Or, to put it in its most naked form, they believe that a vibration made small by friction will be slower than a vibration of the same extent free from that friction—and that the small vibrations of a dirty chronometer will lose, therefore we must provide for this beforehand by making them gain while the chronometer is clean! It seems scarcely credible that any workman of average intelligence should harbor such a belief, for it is almost self-evident that the only effect of increased friction is to lessen the extent of the vibration, and that the time required to accomplish a vibration is dependent upon its *extent*, and not at all upon the friction—except indirectly, through its effect upon the extent of the arc.

(99.) But, to satisfy those who are susceptible to only one method of proof, that of actual trial, let them try it in a lever watch with a going barrel, first timing it with a small motion free from friction, the main-spring only wound up half a turn, and re-wound at intervals, for 12 hours; then try it another 12 hours with the spring wound entirely up to its greatest strength, and kept so by frequent winding as before—but reduce the motion of the balance to the same arc it had previously, by some sort of friction. This may be done by fixing a bristle or hair to rest against the balance staff, or by lubricating the lower pivot with castor oil, molasses or other thick liquid, or even by unscrewing the end-stone and allowing the pivot shoulder to rub on the jewel. Be careful that this friction shall be equal throughout the test, and not so great as to prevent the watch from *keeping time*. The use of the bristle is best, because most under control. This is a crude experiment, but is adapted to convince people with such crude ideas that the time in which a certain arc of vibration will be performed depends on the amount of friction which has been overcome. Leaving them to ponder over the above at their leisure, we will proceed, with the understanding that, practically, we have nothing to do with the frictions upon the balance pivots, in adjusting the spring for isochronism, but need look no further back than the *extent* of the vibrations.

(100.) *Testing the isochronism.* Premising that all previous requirements have been properly attended to, we are ready to test our hair-spring to see whether it is isochronal, and if not, in which direction it errs and how much. This is done by causing the arcs of vibration to vary considerably, in the manner that is most convenient, and accurately observing the rate of the watch for an equal period with the long and with the short vibrations. In Marine Chronometers it is done by keying up or letting down the main-spring by the ratchet—making the motive force stronger or weaker and thereby changing the arcs. The same thing can be done with fusee watches, but not to so great an extent, as their main-springs are generally so short that there is little extra length for keying up or letting down.

(101.) In such cases we may change the arcs as follows: Wind the chain entirely up on the fusee, hook it to the barrel and key up the spring one turn. This gives the weakest force of the main-spring, with the chain upon the smallest part of the fusee, where the power of the spring is transmitted to the train at the greatest disadvantage, so that the vibrations will be very small. We then take the time for four hours; or, if that is not enough, wind it up and repeat till the desired length of time for the trial is passed. Next try it with the chain wound only one turn on the fusee, while the main-spring is keyed entirely up. This gives the other extreme, or the greatest strength of the spring acting on the fusee at the greatest advantage, and giving the largest vibrations the movement is capable of. Take the time as before, either for four hours, or any desired period, winding it up at intervals as needed to prevent running down. All this is easily done if the barrel arbor has a good square on its projecting end.

(102.) The above is an extremely severe test, and any hair-spring that will bear it may be considered practically perfect. The more common method is to wind the chain entirely up on the fusee, then hook it to the barrel, and key up the spring enough to run the watch say six hours; then, without disturbing the fusee, key up the spring enough for another six hours, and so on, till the chain has all left the fusee, when the main-spring will generally be properly keyed up for the ordinary running of the watch. The times must be carefully taken for each period of six hours, and if the different times are alike the spring is isochronal. In watches with going barrels, the time may be taken first with the spring wound entirely up, rewinding at regular intervals to keep up the motive power; then with the main-spring wound up only one turn, rewinding as before to prevent running down.

(103.) Perhaps as good a way as any, because so completely under the workman's control, is to set a bristle in the Upright Holder so as to rest against the balance staff, (60, 99,) and diminish the vibrations in that way, if the construction of the movement will allow it. This method can also be followed after the balance bridge is in its place and the Holder dispensed with, by fastening the bristle in a tiny clamp which can be attached by a set screw to one of the plates of the movement, or even to one of the pillars or bridges,—turning it to give the bristle the desired pressure against the balance axis, but which should never be so great as to interfere with the free movement of the balance.

(104.) When no other convenient way is available, the watch may be tried first in the horizontal, then in the vertical position, and the motion of the balance will generally vary enough for our purposes in the different positions, unless it has been adjusted to positions. When the arcs are changed in this way, *the same* vertical position should be adopted in each trial, unless there is a difference of rate in the four vertical positions, arising from defective pivot fittings, want of poise in the balance, etc. If so, it will be necessary to divide the time of the trial between two opposite vertical positions and take the mean of the two, in order to neutralize the irregularity. For instance, if the trial in the horizontal position is for 12 hours, then the watch should be tried 6 hours with XII up, and 6 with VI up, by which means the accelerating or retarding influences in the two positions would neutralize each other, and the result of this 12 hours could safely be compared with the other. A still better way is to run it 3 hours each in the four vertical positions.* But this method is at best a makeshift, and should never be followed if the variations between the several vertical positions arise from poor condition of the escapement, nor at all unless the variations are very slight. The proper course is to remove their cause before isochronizing.

(105.) *Cause of errors.* To detect the cause of the variations between the different vertical positions, we have the following indications, supposing the balance to be properly poised. As a general rule any increase of friction in the *escapement* tends to retard the short arcs more than the long ones. If the trouble is in the escapement it will be shown by moving the roller or rollers of the lever or chronometer around on the balance staff, putting in beat and trying, when the errors will take place in the same positions with reference to the roller as before, irrespective of the position of the balance. But if they occur in the same positions with reference to *the balance* as before, then, if the balance is in poise, the pivots are not round, and their revolution causes them to alternately raise the balance and let it down, according as the greatest width of the pivot is vertically or horizontally across the jewel hole. If the pivot is so placed that, in moving from the

* This course is not really necessary, for *testing* the isochronism, but only for its correct adjustment. For merely testing it, that vertical position may be chosen which gives the smallest vibrations.

point of rest to either side, it raises the balance, it will act as if the balance was top-heavy. But if such motion results in lowering the balance, it will appear to be bottom-heavy. A three-sided or other irregularly shaped pivot will have a similar effect. For these defects changing the poise will be of no avail. There is no remedy but a new staff with properly formed pivots, or making the pivots round and fitting new jewels to them. It should be noted that if the pivots are bent, or not made in the center of the staff, or if the balance is not riveted concentrically upon the staff, the results will be the same as above stated, although in these cases it may often be possible to correct the error by poising, if the pivots are correctly shaped. It should be understood that the deductions above given are to be taken only after the more ordinary corrections of mechanical errors, already described, have been made, and fail to account for the variations noted.

(106.) But in whatever way the extents of the arcs of vibration may be changed, if we find that the watch keeps the same time while running 4, 6 or 12 hours with the long vibrations, as during the same period with the short ones, the spring is already isochronal. But generally the watch will run slower with the long vibrations than with the short ones. In some cases the difference may be only a second or two—barely perceptible; in others, it may be several minutes. If the variation is considerable, it is better to repeat the test before making any change in the hairspring, to ascertain whether it is not due to some irregularity in the action of the movement. For it is useless to attempt to isochronize the spring unless the movement is in good condition.

(107.) Nor is it possible to do it without a regulator whose rate can be depended upon as absolutely correct. Those with well-made mercurial pendulums are best. But in the absence of this a good chronometer may be used, but is not so convenient as a regulator with either a center seconds or a separate seconds-dial, and a visible pendulum beating seconds. During these trials the watch should not be subjected to any great change of temperature, as the effect of heat and cold would be confounded with the normal action of the spring and mislead the workman. The compensation for heat and cold is no part of the duty of the hair-spring, but, on the contrary, the adjustment of that compensation must cover the effects of heat and cold upon the spring. It must therefore be kept at a uniform temperature while being isochronized.

(108.) "*Quick test.*" Just here I would notice a "quick and easy method of testing the isochronism of a spring;" widely taught and highly indorsed;—"Insert four pins in the rim of a balance, about a quarter of an inch long and equidistant from each other. Then fix a temporary detent by the side of one of the pins when the spring is free. Then turn the balance one quarter around, and let the next pin rest against the detent, and find the weight that will just balance the force of the spring when placed on the pin. Turn the balance another quarter around, and if the weight that pin will sustain is just double the former, the spring is isochronal. Turn the balance to the third pin and the weight should then be three times the first. If the spring will not sustain that weight, it will be too slow in the long vibrations. If it sustains more than that, it will be too fast in the long vibrations," and so on.

(109.) Notwithstanding the eminent indorsement of the above "test," it is simply another piece of eminent ignorance and nonsense, only approximately true in theory, and worthless in practice. There is no practical method of testing the isochronism of a spring except by testing it in the watch, in the precise circumstances for which it is required to be isochronal, by timing it as already described. Were the strength of the spring the only factor to be considered, this test would be theoretically correct for a perfect spring. But since all escapements do in some degree disturb the oscillations of the balance, and different escapements do this very differently, it must be impossible to isochronize a spring independently of the escapement, *i. e.*, otherwise than in the watch to which it belongs. And this conclusion is the more evident when we consider the many other disturbing influences, of which we cannot foresee the nature, degree or manner of their occurrence, but which must necessarily be provided for.

(110.) Even were it possible to secure certain and definite conditions, and to know the exact form and strength of the spring adapted to them, the above test would be practically worthless from its clumsiness. A watch makes, we will say, 400,000 vibrations in 24 hours. Now does any one suppose that, by the above or any other weighing process, it would be possible to detect a variation from the proper *progression* in the strength of the spring, so slight that, after multiplying the effect it produces on a single vibration 400,000 times, it only causes an error of a few seconds more or less? The idea is absurd. It does seem as if there was more idiotic balderdash written, talked, and believed about this subject of isochronism than any other. Perhaps it is because every man thinks no one knows any more about it than he does, and therefore he may air his pretended knowledge with perfect safety. The above "test" might possibly detect errors amounting to several minutes in a day, but such errors cannot occur if previous directions for selecting springs have been followed, and any good workman would know that such a spring was unsuitable or defective, without any test at all.

(111.) *Comparing the results.* We will suppose that, on running our watch 12 hours with the long vibrations, its hands show 11 hours, 59 minutes, 45 seconds—and, for the 12 hours with the short vibrations, 12 hours, 15 seconds. Then there is a difference of 30 seconds—the long vibrations being slower than the short ones, or taking longer time to accomplish them. This point must be clearly understood, to prevent blunders and improper alterations. Whenever *the watch gains*, it is because more than the proper number of vibrations have been made in the given time, therefore they are shorter than they should be. When the watch loses, less than the proper number are made, because each one takes longer than it should. But it does not matter whether the times kept by the watch are faster or slower than the correct time, nor if our alterations make both of them faster or both slower than they should be. All that is necessary for these tests is to compare the two times *with each other*, to see whether the short vibrations are quicker or slower than the long ones. And the only use of correct time, at present, is to enable us to compare the two results and know the exact difference.

(112.) *What is isochronism?* The question naturally arises why the long vibrations are slower or quicker than the short ones, when the length of the hair-spring is exactly the same in each case. The prevailing theory is that the isochronism of the spring depends on its being of a certain length in proportion to its strength, and if it is longer than that it will lose in the long vibrations, but if shorter, it will gain in the long vibrations. This theory is credited to Pierre le Roy, and has the indorsement of Jurgensen, and a host of other eminent authorities from le Roy's day to this. Yet it is not true, for a spring will have *several* different isochronal points, while it is not isochronal at any intervening points. In fact, there appears to be an isochronal point somewhere in every coil, provided that its length is not so great or small as to interfere with its free and proper action. This theory has the appearance of truth, because, when the isochronal point is found for the particular spring, if it is lengthened it will lose, and if shortened will gain, in the long arcs. But that isochronal point depends upon many other conditions besides the proportionate length and strength of the spring. The number of coils and manner of coiling, the mode of attachment to the stud and collet, the shape of the terminal curves at the ends, are among the conditions in the spring itself which may either improve or destroy its isochronism. And outside of the spring are many others. The truth is that a spring which has been perfectly isochronized, is so only for the precise conditions for which it is adjusted.

(113.) An esteemed friend, after reading the preceding article, No. 6, sends me his definition of isochronism as follows: "Isochronism is a certain correspondence or relation between the proportions of a hair-spring and of a balance, and such that under proper conditions the spring will move the balance through greater or smaller arcs in equal times." This is very good so far as it goes, but, as already shown, there are many other points which theoretically and really are concerned in bringing about the complete result we call isochronism. And, to satisfy all, however learned, that I have carefully examined all the various elements that enter into this intricate subject, before reaching the conclusions which I have or shall hereafter put forth, I will depart slightly from the original plan of these articles, to consider some of the principal elements.

(114.) *Modifying influences.* It would be interesting to go fully into the theoretical consideration of the conditions of isochronism, the effects of all the modifying influences upon the extent and the time of the vibrations. But to do so would require several articles, and I will content myself with a brief classification of a few of the more prominent influences and their practical effects. And to make my idea of them perfectly clear to the reader, we will take a pyramidal figure to illustrate them. The base line of this pyramid represents the length or extent of the vibration, while the momentum of the balance is represented by its sides, which rise to a greater distance from the base as the momentum increases, and after passing the centre fall again as the momentum decreases, till it meets the other end of the base line or end of the vibration. The apex of the pyramid, or highest point from the base, represents the greatest momentum, at the middle of the vibration; and the greater or less inclination of the sides corresponds to the progressive increase and decrease of the momentum.

(115.) Now the effeet of any friction or retarding influence which is equal and continuous throughout the whole of the vibration, as the friction of the pivots, thickening of the oil, pressure of the duplex or cylinder escape wheel against the balance axis, (during the free arc of motion,) etc., may be represented by taking a uniform slice off the bottom of the pyramid, *i. e.*, a uniform loss through the whole vibration. This leaves the base narrower, (or the vibration shorter,) but the angles of the sides (or the ratio of the momentum of the balance,) unchanged.

(116.) There is another class of influences, the principal and type of which is the resistance of the air to the motion of the balance. This depends on the construction, weight, specific gravity and exposed surface of its parts, and it increases with the increase of the arc of vibration in the proportion of the squares of the velocities. That is, if one balance vibrates twice as far as another, and in the same time, the resistance of the air to the motion of the former would be four times as great as of the latter. But as the momentum of the balance also increases as the squares of the arcs, they therefore increase and decrease uniformly. Of course a smooth, heavy balance will meet with less resistance than a large and light one, with numerous screws, etc. But whether that resistance be great or small, whatever the amount may be, it will increase and decrease as the squares of the velocities. Therefore, if the inclinations of the sides of our pyramid correctly represent the increase and decrease of the momentum of the balance, the resistance of the air may be represented by taking off a thin uniform slice up one side and down the other, leaving the shape precisely the same but making the base a little narrower, as before—that is, shortening the length of the vibration, and lessening the momentum, but without changing its ratio. The greater the resistance, the thicker this slice to be taken off.

(117.) Thirdly, different escapements affect the time of the vibrations, because they interfere with the normal time which the spring alone would give, by breaking in at a certain point and giving the balance a push, thereby hurrying up its motion while in contact. So that the length of the time of contact, or angle of impulse, becomes a factor in the problem, as well as the frequency of these contacts—whether occurring at each vibration, or only alternate ones, as in the chronometer and duplex; and whether there is any recoil in the escapement, as in the duplex and cylinder escapements under certain circumstances. The power required to unlock the escapement, giving more or less of a check to the motion of the balance, is another factor; the fall or "drop" of the escape wheel teeth against a cylinder or balance staff, urged on by the entire motive force, must at the instant of impact exert a checking influence. In the cylinder escapement the side pressure upon the balance axis is removed during the arc of escape, at the middle of the vibration,—another point to be considered.

(118.) But practically, these influences of the third class become null in a well-made escapement, as, after the balance has acquired its full motion, the accelerating influence (or its excess over the checking influences) is only sufficient to keep up the vibration of the balance and make up for power absorbed by the various resistances to its motion. That this maintaining power is its only effect upon the balance may be seen by suddenly disconnecting or cutting off the motive force of the movement, when the balance will at first vibrate precisely as before—and then gradually fall off. All of the three preceding classes of influences have their effects in the *extent* of the vibrations, which only we need consider, in practice. I may say here, however, that a cylinder watch cannot be isochronized unless there is the correct proportion between the weight and diameter of the balance, the size of the cylinder, and the motive power. And further, the opening of the cylinder and the impulse angle of the escape wheel teeth must be such as to give, if not the best, at least fully satisfactory, performance.

(119.) Lastly, there are the irregular influences, among which may be mentioned unavoidable imperfections in the metal or form of the spring, unequal hardening or temper, imperfections in the balance, pivots, escapement, and others already mentioned. A soft spring cannot be isochronized, and if it could it would not stay so. Even the mere bending of a spring, although it may have been restored to its former shape, produces an unevenness of texture at that point, and the lower the temper of the spring the greater is the effect of such treatment. If these spots are stiffer than the remainder of the spring they do not bend with the other parts, or not equally, and throw the spring out of shape; if they are not so stiff, they bend too soon and the same result follows. If a spring is let out at the stud, the crimp made where it was pinned will produce a stiff spot and interfere with uniform inflexion of the spring. A beginner will frequently render a spring worthless for isochronal adjustment by numerous changes and corrections. It should be bent as little as possible, and when necessary it should be done a little at a time and repeated, rather than bent too much and then have to take back a part.

(120.) This class of influences no foresight can entirely prevent, nor can we know in what part of the vibration they will occur, or how great they will be, until we ascertain by actual test. No theory can avail against their occurrence nor do away with their effects. This can only be done, if done at all, by proceeding at once to *adjust* it in the direction indicated by the test, until success is attained or found to be unattainable. And, from what has already been said of the first three classes, it must be plain that, for all practical purposes, the workman will find that nothing further is necessary in the isochronal adjustment than to secure the mechanical correctness of the different parts, (71, 93, 95,) and then to govern his proceedings entirely by the *extent* of the vibrations, and the *times* given during his trials.

(121.) It is doubtless desirable that he should understand the theory as well as the practice of his art, but it is no small task to sift out the truth from the multitude of discordant theories and opinions put forth on every hand by those who claim to know it,

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and unless he has both leisure and ability to give the subject a thorough study he will waste his time in investigating the theory of it at all, as hundreds of enthusiastic but unqualified workmen have found to their cost. The subject of isochronism is exceedingly difficult and abstruse, requiring for its elucidation the most complicated reasonings and investigations. Not only am I precluded from giving these by want of space and the exclusively practical *role* imposed upon me in these articles, but, if given, they would only be understood by those familiar with the very highest branches of mathematics, and the mechanical laws, both static and dynamic, applicable to the case. I shall therefore not try to pilot him through the maze of theory, but will now give him the results and lessons derived from much study and practice, in as few words as possible, and try to avoid going into the whys and wherefores any further than is necessary to make clear the practical directions given, and which may be followed by any intelligent workman.

Methods of Isochronizing the Hair-spring.

(122.) *By a certain length.* A number of different methods have been proposed for isochronizing a hair-spring, of which some are good, some not so good, and some good for nothing. We will consider the most important ones. The first method is based upon the theory mentioned in section (112), that isochronism depends on the spring being of a certain length in proportion to its strength, and the practical application of it consists in trying the spring pinned in different places, till the isochronal point is found, after which the watch is brought to time in some way without changing the length of the spring. This method, which is substantially a mere feeling around after the isochronal point, is further considered in section (134), which tells us where to commence feeling, so as to find the right spot as quickly as possible.

(123.) *By tapering the spring.* Another method was practiced by Ferdinand Berthoud and others, and consisted in tapering the spring at the end, either by a file or oil stone, and is equally well backed up by good authority. But it is evident that the operation must be a bungling one at best, not workmanlike, nor is it possible to lessen the thickness of the spring in true proportion by such means. Moreover, the thinning is done before the spring is wound into shape, so that the whole is a mere matter of guesswork, as to the correct taper, and the correct length of the tapered portion from the end. Lastly, a spring tapered at the end, in any manner, according to my observations and ideas, is ruined for all fine time-keeping. As the process is mechanically impracticable and worthless, I shall not dwell upon the philosophy of the manner in which the tapering is claimed to secure isochronism, or the details of its execution.

(124.) *The isochronous stud.* A third method, by what is called the isochronous stud, applicable to the flat spiral spring, is that, instead of the stud to which the outer end of the spring is pinned being fixed to the balance-bridge or plate as usual, it is carried at the end of a short, straight, supplemental spring, attached at a tangent to the coils, *i. e.*, the longitudinal direction of this spring is at right angles to a line drawn from the stud to the center of the hair-spring. This short spring is fixed to a bar screwed on the plate or balance-bridge. This method is not adopted in practice, being objectionable from the difficulty of proper execution, want of stability, and other reasons. It secures the very important advantage of allowing the outer end of the spiral spring, which is fixed in the stud, to move towards and from the center of the hair-spring as its coils enlarge or diminish, and obviates the side pressure resulting from the usual rigid attachment of the stud; but equally good results can be obtained in another, simpler and easier way. I will therefore omit details of mode of testing and adjusting the proper length and stiffness of the supplemental spring, position of the stud, etc.

(125.) *By the regulator pins.* A fourth method is by opening or closing together the pins of the regulator, and is an attempt to secure the same results of changing the stiffness of the hair-spring as are secured by terminal curves. It is mainly applicable to the ordinary flat spiral springs. In this method the stiffening of the spring is effected by its contact with its pins; the action of the spring, before stiffening, takes place while it remains free between the pins and is virtually without any control entirely up to the stud. The idea is that the longer it remains free the slower the vibrations will be, while the earlier in the vibration the pins come into contact with the spring and stiffen it, the quicker the vibration will be. Of course, this effect is produced in both the long and short vibrations, but it is greater in the latter, because the difference produced by opening or closing the pins is in a greater proportion to a short arc than to a long one. Hence, if the watch loses in the short vibrations, it shows that the stiffening of the spring does not commence early enough, consequently the regulator pins are too wide and must be brought closer together. If it gains in the short vibrations, it begins to stiffen too soon and completes the vibrations too quickly. The pins must therefore be opened a little, which increases the length of the slow part of the vibration before the spring comes against the pins, and shortens that part of it in which it is stiffened and hurried up by the contact with the pins.

(126.) At first thought, this appears to be all that could be desired, being easy, quickly done, and apparently meets all the conditions of isochronism. But the objection is that the regulator has its own office to perform in the mechanism of the watch, and for its perfect performance it must be made in a certain manner. Among other things, the pins should be as closely together as possible, while avoiding any binding upon the spring when its position is shifted (68). Therefore we should not permit any material departure from the form which will best preserve its true functional character, for the sake of accomplishing some other end. But this method is well adapted for all classes of fine clocks, both American and imported, and whether having lever or cylinder escapements. For watches it is not well adapted, except those in which there are but few coils of the hair-spring and they are wide apart, to which more room is usually given in the regulator, as will be noticed in a large share of English lever and duplex watches.

(127.) The cylinder escapement watches may also be advantageously isochronized in this way, as their low price generally precludes the employment of the more expensive methods. And it must be admitted that a well-made cylinder or duplex watch, particularly when provided with the fusee and chain, may be adjusted very closely by this method. For this purpose the regulator pins are placed further apart than stated in (126), when fitting the spring, so as to allow of either opening or closing them a little, as might be required by the adjustment.

(128.) But in fine watches, its use, if allowed at all, should be restricted to the finishing touches, which would require only the very slightest alterations of the pins, which, in this case, I should advise to be placed at the proper distance apart at the start, (68,) and only change them by opening them very slightly. Should a still wider opening be required, or if it proved necessary to bring the pins a little closer together, (which, of course, could not be done,) the hair-spring should be moved in the stud, according to section (136). In all cases, when the adjustment is completed the two pins should be left parallel, not inclining toward each other, so that, if the spring should play between them at a higher or lower level, it would still find the same width of opening. Some workmen make the short arcs faster by causing the hair-spring to press more or less against the regulator. But this practice is entirely wrong.

(129.) *By altering the coils.* Fifthly, we may change the action of a spring by making its coils closer and more numerous, or more open and fewer in number, still retaining the same length of wire in each. The former can only be done, generally, in making a spring—as by rewinding it after being made the coils are apt to be unevenly compressed. But the opening of the coils can be safely done as shown in section (29). The philosophy of the operation may be stated thus: We know that if a spring, in its inflexion from the point of rest to the extent of the largest vibration, increases its strength or relative force in too rapid a ratio, it will gain in the long arcs and lose in the short ones, and *vice versa.* Now it is evident that, if a spring has five coils, giving the balance one turn will produce a greater displacement and compression of the coils than would occur if it had ten coils, and *vice versa.* Hence if it acquires greater force in moving from the point of rest in the former case than in the latter, that force must have augmented in a more rapid ratio.

(130.) From this we deduce the practical lesson that when the spring gains in the long vibrations, or its force augments in too rapid a ratio, the coils should be made smaller and more numerous. When it loses in the long arcs and its force augments too slowly, we should open the coils a little. But, although the principle is correct, it is practically available only within very narrow limits, and when no other method can be adopted, or another spring cannot be obtained. But it is incomparably preferable to the practice of grinding or dipping into acid throughout its entire length to weaken it, the worse practice of dipping it for only a portion of its length, or the outrageous butchery of "scraping" the outer coil.

(131.) *By altering the collet and stud.* Sixthly, in exceptional cases we may improve the isochronism by changing the diameter of the hair-spring collet, when it is not suitable for the spring, or when the spring itself is defective in shape. Rather than have too large an open space in the center of the spiral, (38,) and the spring diverging too boldly from the collet to meet the spiral, (39,) it is better to make a larger collet, which will enable the spiral to come nearer to the collet. But a moderate size should be adhered to —neither much larger or smaller than the proper proportion for the size and weight of the balance to which it belongs. A too large collet will be indicated (if all other conditions are correct) by the watch gaining in the long arcs and losing in the short ones. If the collet is too small, the spring will have too little leverage or power over the balance, which will lose in the long vibrations and gain in the short ones. It must be remembered that, by these words "gain" and "lose," in this connection, it is not meant that the watch both gains in the long arcs and loses in the short ones, or the reverse, but simply that, on comparing times, we find that the long vibrations are the quicker and the short ones the slower of the two, or the reverse, as the case may be. It will seldom be necessary or advisable to change the size of the collet, except for the purpose of filling up the open space at the center and improving the shape of the inner end of the spring without fitting a new one, or where a terminal curve is not fastened to the collet at the proper distance from the center, *i. e.*, at half the radius of the spring. In such case the bar of the collet must be changed, or a new and correct one made. The stud, also, should be changed if it does not receive the spring in conformity to the above rule for the distance from the center.

(132.) *By altering the balance.* Seventhly, it is possible to vary the isochronism by changing the weight and specific gravity of the screws in the rim of the balance,—for instance, by substituting screws of brass, gold or platinum for those of either of the other of these metals; or by changing the weight or diameter of the balance; or in any way changing the relative force of the spring as connected with that balance. But as no rule can be given for these alterations, which must be made by mere blind guess-work, it is not worth while to discuss here the theory or practice of this method.

(133.) *By altering the frictions.* In the duplex and cylinder escapements we may vary the isochronism by varying the relative amounts of the escapement-friction and the arcs of vibration. For instance, if the escapement be changed so as to transmit the motive force more advantageously, and increase the impulse-power, without changing the friction upon the roller or cylinder, the arc of vibration will be increased and the long arcs will be slower than the short ones. (So in general, any alteration which increases the arcs without changing the escapement-friction, will make the long arcs slower than the short ones.) But increasing the friction without increasing the impulse-power, will make the long arcs quicker. So, in general, any change which lessens the effective impulse-power, without lessening the escapement-friction, will make the long arcs quicker than the short ones. In the chronometer, the short arcs may be made slower by making the locking spring stiffer, or by giving the escape wheel more drop upon the impulse pallet, both of which operations are highly objectionable. But these methods are of no great practical importance, because it is, of course, not advisable to make the escapement worse off in order to improve the isochronism; and on the other hand, the escapement should be in as good order as we can get it, before we undertake to isochronize the spring. So there is very little margin left for our alterations, except by increasing or diminishing the strength of the mainspring,—which, also, should be done with great caution, for there is a correct proportion between the motive force of the mainspring and the weight and diameter of the balance, which should not be greatly departed from. When the vibrations are very large, in the chronometer, it is allowable to lessen the force of the mainspring, or put in a weaker one, to make the short arcs slower; and the reverse of this may be done to make the short arcs faster, if the vibrations are rather short, and can be safely enlarged. But the above remarks will show how incorrect is the idea that isochronism can depend upon the hair-spring alone.

(134.) *By even coils.* Ninthly, we have for isochronizing the flat spiral springs, a method which consists in bringing the two ends of the spring, or "*points d'attache*," as they are termed, in the same diametrical line. This method is in accordance with the custom among good watchmakers to avoid fractional parts of coils as much as possible in the flat spiral. I shall not dwell upon the philosophy of this method, because any method which proposes to make a spring isochronal by means of any fixed manner of treatment whatever, except by actual adjustment of it to suit the watch to which it belongs, cannot be correct. If the spring alone was concerned it might be possible to isochronize it by a certain invariable mode of pinning the ends. But this is not the case.

(135.) With any given hair-spring, the isochronal point would require to be at different places in it, depending upon the construction of the balance, the escapement, etc.,—even changing the size of the coils will cause the isochronal point to vary its position. The most that any method can do is to enable us to approximate to the isochronal point, leaving the corrections to be done by means of testing and adjusting. And, although I have examined a great many fine-running watches for that purpose, I have not yet found one where the spring was pinned *exactly* according to this theory,—the nearest always being a little to one side or the other. Nor have I succeeded in closely isochronizing a spring according to this theory, without resorting to the regulator pins (125) to enable me to complete the adjustment without changing the *points d'attache* of the springs. But as this mode of pinning enables the workman to fit his spring with tolerable accuracy attended with scarcely any extra labor, it should be generally followed, even when the spring is not intended to be isochronized, as I have already recommended (34, 43). Even a low-priced job should always be done as well as can be afforded. This method will at least guide us to an eligible starting point, at or near which we may reasonably expect the spring to be isochronal. It should be observed that if the regulator is not very near to the stud; that is to say, within 20° to 25° from it, the whole coils are reckoned from the point touching the collet to the *regulator pins*, instead of to the stud. Further remarks on this subject will be found in Part Fifth, on Rating.

(136.) *My method.* The process of fitting and isochronizing a flat spiral spring is as follows: First proceed as already directed in sections (34 to 46, 62, 63,) till we find the point where it gives about correct time. Then test it for isochronism as in sections (100 to 106, 111.) If it loses in the long vibrations, (*i. e.*, they are slower than the short ones,) the spring should be shortened by drawing it through the clamps of the upright holder (36, 63,) first noting the point at which the spring was held when giving correct time, or marking it there by a speck of whiting mixed with oil. If the long arcs are quicker than the short ones, the spring should be let out. After the isochronal point is thus found, if the rate of the watch is still nearly correct, it may be brought to time by moving the regulator or by the balance. But if the error of time is considerable, the spring must be manipulated as follows.

(137.) Mark down on a piece of paper the relative positions of the two *points d'attache*, (or the point pinned to the collet, and the point held in the clamps, while the spring gives the isochronal vibrations,) with reference to the center of the spring. Now the problem is to alter the length of the spring till it will give correct time, and yet leave these *points d'attache* in the same relative position, or nearly so. For example, if these two points are in the same radial line, *i. e.*, a straight line drawn from the center of the spring to the outside passes through both points, but the marked correct-time point (136) is a quarter of a coil nearer the outer end, we let out the spring (in the clamps) a quarter of a coil at the outside and break off enough at the center to bring the two new *points d'attache* in line again as before, when the spring will both be isochronal and give correct time. In Fig. 5, *a* is a radial line, passing through both the point pinned to the collet, and the isochronal point in the outer coil; *b* is the correct-time point. We draw the spring through the clamp, from *a* to *b*, and break out the central coil so as to bring the point touching the collet into line with *b*. In practice it will be necessary to let out the spring a little more than the quarter of a coil, in order to compensate for amount broken off at the center. This will carry us on to *c*, and the dotted line then passes through both the end at the collet and the correct-time point, as before, and the spring is isochronal. In short, we are to alter the spring at the center so that, *when finished*, the point pinned to the collet shall be in line with the point in the outer coil which gives correct time in the clamps.

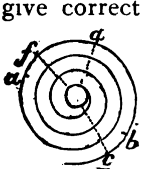

Fig. 5.

(138.) But when the correct-time point is *inside* of the isochronal point instead of outside, as above supposed, we do not reverse the process, but we must proceed a little differently at the start. For if we should take up the spring to the former point, we could not then bring the new *points d'attache* in line by letting it out at the center to correspond. We cannot let it out at all,—or, at any rate, but very little. We simply take up the spring to the correct-time point and break out the inner coil enough to enable us to bring the *points d'attache* into line as in the last paragraph of section (137), after allowing at the outside as much additional length of spring as we have had to take off at the center in our alterations—so as to avoid changing the rate by a difference in the total length of the spring. A quarter or half coil at the center will have but little effect on the rate, but a great effect on the isochronism. In this case, the correct-time point is at *d*. We take up the spring to *d*, and break out the central coil to bring the collet end in line with *d*. But, as what we have broken out would shorten the spring, we now let it out to *e*; then we have to break out the center a little more to bring the collet end in line. Allowing for that, at the outside, carries us on to *f*, and the dotted line passes through both *points d'attache* and the spring is isochronal. In these tests, we should bear in mind that, inasmuch as every coil may be isochronized, we may find an isochronal point *in either direction* from the correct-time point, in different coils, and we should choose the one which is nearest to the correct time-point and requires the least alteration of the spring. Therefore, if breaking out the center, as just spoken of, would be objectionable in any case, (38, 39,) and we could find another isochronal point on the other side of the correct-time point and not so distant from it as the former, we may choose the latter and so avoid a portion of the objectionable alteration. For instance, in Fig. 5, it is supposed that the spring will have an isochronal point in each different coil, nearly in the line from *a* to the center, although, of course, the rate given by the spring would be different in each case, if the same balance was used. Having by our manipulations caused the isochronal and correct-time points to coincide, or nearly so, we finally test for the isochronal point, pin the spring properly to the stud at that point, and correct the rate of the watch by the regulator, or the balance.

(139.) When the two *points d'attache* are not in a radial line, as has been thus far supposed to be the case, their real position, as found by trial, should be accurately marked down, and the spring then altered as already directed till it gives correct time and the *points d'attache* are also brought into *that position*, again. It is advisable to first make all changes *on paper*, to see how they will come out, before actually breaking or altering the spring. In the present case we draw an outline of the spring as in Fig. 6, make a dot at the center, then draw one line, *a*, from the center through the point pinned at the collet, and another to the point held in the clamps or stud when giving isochronal vibrations, say at *b*. Suppose that the two lines are 45 ° or one-eighth of a circle or coil apart. Now our task is to bring the point pinned in the collet into the same relative position to the correct-time point as it now has to the isochronal point, *viz.*, 45 ° from it; when, if the amount of spring broken off has been properly allowed for, it will both keep correct time and be isochronal. Let *c* be the correct-time point. If we let out the spring in the clamps to *c*, to cause the correct time and isochronal points to coincide, we must break out the central coil so that the end at the collet will be in line, *not* with *c*, but with *d*, which is 45 ° outside of the isochronal point, as before. After making allowance for the amount broken out, by shifting the spring further through the clamps, as in (137), we will have the spring pinned in the stud or held in the clamps say at *e*, and the collet end broken out in line with *f*, when the spring will be correct both as to rate and isochronism.—The alteration supposed in section (138) will be made by shifting the spring in the opposite direction as there described. By proper care in the first pinning of the spring to the collet, and using pencil and paper freely, as just described, we shall never have to break out the center much, if any; for, if we find a certain spring is likely to be suitable to our balance, we should cut out the center no more than barely enough to fit the collet properly (38), and then, if we have to take out a little more, it will not leave open space enough at the center to do any harm. It is not necessary to actually draw the coils, as in the cuts,—a mere circle will do, to indicate the outer coil.

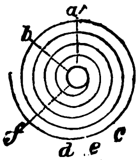

Fig. 6.

(140.) It is well to state, however, that we are not obliged to invariably bring the isochronal and correct-time points of the spring *together* as previously directed. For it is optional with us to do that, or to at once pin the spring to the stud at its isochronal point, when found, and omit the causing of the points to coincide, but bring the watch to time by the regulator or balance. (See article on regulating, hereafter.) This will often be the quickest and easiest way to do, and is unobjectionable when the rate at the isochronal point is very nearly correct, *i. e.*, the isochronal and correct-time points are not very far apart. When this course is followed, the process is to select the spring as directed in articles Nos. 3, 4 and 6, fasten it at the collet in accordance with section (38), find the isochronal point, pin to the stud at that point, then bring to time as just stated, without disturbing the central coil after the first pinning. The foregoing directions for isochronizing the flat spiral are entirely different from any before published, and, it is believed, cover all cases. We have now described all the methods of isochronizing hair-springs worthy of consideration, except that by terminal curves, which may justly be regarded as the acme of horological triumphs and worthy of being treated at considerable length, so that we may make plain to all that which is as yet comprehended by very few. I may say here, that from the statement in the first part of the succeeding section (141), it would seem, theoretically, that a perfect isochronism cannot be secured in the plain flat spiral spring, and it is so held by very many good workmen. But practically, if these errors are not too great, they can be compensated for in the isochronal adjustment so as to perform as well as the Breguet or the helical spring.

Securing Isochronism by Means of Terminal Curves.

(141.) *Conditions of isochronism.* Lastly, isochronism is obtained by bending one or both ends of the hair-spring into certain shapes, and forming what are termed "terminal curves" or "eyes." In the helical spring both ends are similarly curved; in the Breguet spring, only the outer end,—the inner end being fastened to a circular collet as in other flat spiral springs. As we have already seen, it is necessary, in order to secure isochronism, that during all the successive changes in the size or form of the spring, while vibrating, its center should continue to coincide with the center of the axis of the balance. It is therefore desirable, firstly, that it should be so formed that, as it expands, it may do so equally on all sides of the balance, and should contract equally also. If, during any part of its vibration, it springs off to one side, *i. e.*, becomes eccentric, its isochronism will be injured or destroyed, according to the nature or extent of the faulty action. For the eccentricity will prevent a uniform action of the spring, or a uniform effect upon the balance, will cause a pressure of the pivots against the sides of the jewel holes, and the center of gravity of the spring will not be upon the center of the balance axis. Secondly, the stiffness of the spring must increase, during the vibrations, in such a ratio as will cause the balance to perform its vibrations, whether large or small, in equal times, notwithstanding the injurious influences in the way.

(142.) All these points are secured by curving the ends of the spring in the following manner. The curved portion being considered by itself, its beginning is where it joins the body of the spring, and its end is the place of attachment to the collet or stud. The beginning of the terminal curve must meet the circle of the first coil of the spring at a tangent, *i. e.*, at right angles to a line drawn from the point of meeting to the center; or, practically speaking, the terminal curve must not leave the body of the spring by an abrupt bend, but bending very slightly at first, curving in gradually more and more towards the center, till it reaches its end, which must be fixed to the stud or collet at a point half-way from the outside to the center of the spring, or, as it is termed, at half the radius.

(143.) The points of attachment should be firmly fixed, so that the ends of the spring cannot vary the angle at which they meet the stud or collet. It is of no consequence whether the ends of the two curves in the helical spring are pinned over each other or not;—they may be in any position which results from the total length of the spring as required by the timing of the watch, although the spring is thought to "look better" when the two ends commence on opposite sides of the center. But the ends should be pinned at an equal distance from the center, and the form of the two curves should not be very unlike each other. But in the Breguet spring, the end of the terminal curve should be in the same radial line as the collet end, to avoid fractional parts of coils, the same as in the ordinary flat spiral.

(144.) This method of isochronizing hair-springs is the best of all. The theory of the formation of the terminal curve has been fully developed by Prof. Phillips, of the Polytechnical School of Paris, and his treatise is almost universally accepted as the highest authority on the subject. One cannot but admire the learning and powers of reasoning by which he has arrived at his results, yet, as I shall show, the practical workman may attain the same or even better results by a simple process of measurement within the capacity of any watchmaker, and the only requisites are a pair of sharp pointed dividers with a pencil for striking circles. These he may get, with a set of drafting tools, as low as $1.50, although those selling for about $2.50 are much better. But not one workman in a thousand can follow Prof. Phillips' rules, or even understand them. In fact, if we may judge from their work, the majority of even practical springers follow no rules, and have no regular system for forming the curves, but simply make them of such a shape as "looks as if it would do." If on trial it does not perform correctly, they lengthen or shorten the curve, and improve it more or less, but seldom get it very close, because they seldom give it such a *shape* as renders a close isochronism possible. It is not sufficient to have a terminal curve of the proper length, but its shape must also be correct, and *proportionate to its length.* All these points may be easily secured.

(145.) *Delineating the curve.* Having made or selected a spring of proper diameter and strength for the balance, you first measure its diameter exactly. In a helical spring, measure entirely across from outside to outside, through the center, lay off this distance on paper with the dividers, then set the points to just half this distance, which of course is the semi-diameter or radius. If it is a flat spiral spring, take the measure from the elbow to the centre as the semi-diameter. With the points of the dividers set to the semi-diameter obtained in either of these ways, you mark a circle the exact size of the spring upon a thin flat piece of copper or brass. Divide this circle into quarters by lines through the center, then into eighths, by drawing other lines half way between the quarter lines, as shown in Figs. 8 and 9.

(146.) To make the process quite clear, I have given a diagram on an enlarged scale, Fig. 7 showing a half circle only. A, is the center, B C D, the circumference or size of outer coil before bending, which in this case is divided off into ten equal parts, and a radial line drawn from the center to each of the dividing points. Next we bisect or halve the line A D, which is called the radius of the circle. The point E, thus found, is to be the end of our terminal curve, or where the acting end of the hair-spring is to come, half way between the center and the circumference. From this point E, our terminal curve is to sweep outwards till it reaches the circumference, which represents the outer coil of the hair-spring, at the point B.

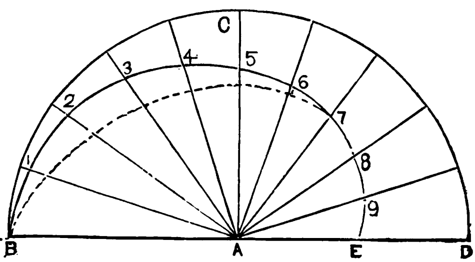

Fig. 7.

(147.) *Length of a curve.* The proper length for a terminal curve cannot be certainly known beforehand, but it is to be at least half a turn around the center, or 180°, and not over three-quarters of a circle, or 270°. If the spring is quite long, it will be nearer to 180°, but if quite short, or the coils are large and wide apart, it will be nearly or quite 270°. Having decided upon the length according to your best judgment, you mark the distance from D, along the circumference, or in other words, you mark the place upon the outer coil, at B, as we have supposed it to form an arc of just 180°, in Fig. 7. From this point B, to the end of the spring at E, our curve must sweep around the center, drawing gradually nearer to it, and end at the latter point.

(148.) *Marking the curve.* In order to mark this gradual approach to the center, we find the point where the curve should cross each radial line. As it will cross ten such lines in passing from B to E, we divide the distance E D, into ten equal parts, which is easily done by "pricking off" on paper, and set the dividers at that distance. Then mark one such space from the circumference on the first line, at 1, two spaces on the next line, at 2, three at 3, and so on to the tenth line, where the tenth space will of course come at E. Now draw a curved line from B through these different points as shown, B, 1, 2, 3, etc., to E, and you have your terminal curve. To mark this curve with the dividers, set the points to reach from 1 to A, then move the back leg from A to some point from which as a center the other leg will strike a curve from B to 1. Then set the dividers from 2 to A, and strike the curve 1 to 2, and so through all.

(149.) In Fig. 7, we have divided the curve into ten equal parts, but the number is of no consequence, except that the more parts the arc is divided into, the more evenly will the different portions of the curve change their shape and merge into each other. But on a small scale, as that of the real size of the spring, it will not be convenient to divide the circle into more than eight parts, as shown by the small cut.

Fig. 8.

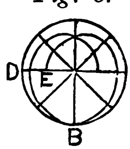

FIG. 9.

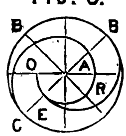

Fig. 8 shows a curve extending through three-quarters of a circle, or 270°, and crossing six radial lines, therefore E D is here divided into six parts and marked off as before. Fig. 9 shows two curves; one, B to E, of 180°, divided into four parts; the other, C to A, 225°, in five parts. The same rule applies to the other end of the spring, by simply running the curve in the opposite direction. Fig. 8, shows two curves thus formed. Having clearly marked the curve upon the plate with the point of the dividers, as above described, it may be used so, as a guide in forming the spring to that shape. Some merely mark the curve with the drafting pen upon a piece of stiff paper, and use as a guide, but it is generally better to use a thin metal plate, as stated, and file off all outside of the curve, from B to E, Fig. 7, marking both points plainly, to indicate the end of the curve and its junction with the normal coil, and use it in that form as a gauge. During this filing, any unevenness in the sections can be removed, so as to make a gradual and uniform curve from B to E. File it straight from E to D, and the line B D is the full diameter of the spring. The fitting of the curve is considerably facilitated by having the other half of the circle, from D around to B, clearly marked on the plate, as then both the curve and the normal coil, as they should be, can be simultaneously compared with the spring as it is. When completed and tried in the watch, if a longer or shorter curve is required, it is but a short job to make a new gauge.

(150.) This curve, as will be noticed, is not in perfect accordance with Prof. Phillips' theory, which would require it to approach nearer to the shape shown inside of the other, in dotted lines. But, with all due respect to Prof. Phillips and others who have indorsed his theory as an entirety, I submit to the candid and thinking minds of the trade, that a curve formed according to my plan will meet the proper purpose of a terminal curve, as explained below, more closely than one formed by his theory. I shall not weary the reader with a mathematical analysis of its action and demonstration of the correctness of this claim, but simply challenge the test of a fair practical trial.

(151.) *Requirements of the curve.* Prof. Phillips places great stress upon getting the center of gravity of the entire spring to coincide with the center of the axis of the balance. He supposes that if it does so, and remains there throughout the vibration, the center of the coils will remain there also, and the spring, if otherwise correct, will be isochronal (141). This is true so far as concerns the normal coils, but it is not correct as regards the terminal curves. For, even supposing that the two curves have been made according to his rules, so that the center of gravity of the entire spring is then on the center of the axis, it will not be so when pinned in the watch and running, because one curve will then be supported by the stud, leaving the other curve unbalanced, and *its* center of gravity is certainly not on the center of the balance-axis. In the case of a box chronometer, whose spring is made from heavy wire, the want of poise would be very perceptible. And if not, it is theoretically faulty, according to his own theory. In this respect, therefore, the Breguet spring has the advantage over the helical, for when the terminal curve of the former is supported by the stud the remainder of the spring is still in poise. But I think he attributes too much importance to the center of gravity of the terminal curves. For, in case it was *not* upon the center of the axis, we could readily rectify the want of poise by the screws in the rim or otherwise (69, 75), but that would not correct the isochronism of the spring a particle. Again, the isochronism may vary from correctness as greatly, in either direction, even when the spring wire is so slight that the difference of its weight could not be perceived.

(152.) Now according to my view of the matter, the shape of a terminal curve should not be treated with respect to its center of gravity at all, but with an entirely different purpose in view, viz., to cause the entire length of the spring to come gradually into action, without any abrupt change of strength, but by a regularly progressive increase of it throughout the whole of even the largest vibrations, while at the same time allowing it to be flexed in either direction without forcing the body of the spring out of center, and, incidentally, causing side pressure against the balance-axis. Hence any special trouble about the center of gravity of the curves, except so far as it is accomplished by the above means, is useless if not injurious.

(153.) The curve being shaped in obedience to the above requirements, and the foregoing obstacles to isochronal action being thereby prevented from appearing, isochronism is then secured by a proper *length* of the curve, within certain limits. Coarser adjustments must be made by altering the length of the main body of the spring included *between* the curves. Or, if such change would cause too great an error in the rate, a new spring must be substituted. If the views stated in the preceding section are correct, then I submit to any person capable of working out such a problem correctly, if the shape of curve as drawn by my plan, in Fig. 7, will not secure those ends more closely than the one shown in dotted lines? Will not a spring with the former curves be nearer to the ideal free hair-spring, perfectly balanced in all directions, exerting no side pressure against the balance axis, and remaining concentric therewith whatever the extent of the vibrations may be? The deductions from reasoning are in its favor, and experience, the only certain proof, will, I think, convince any candid experimenter that it is so.

(154.) There is another point in which this curve differs slightly from that of Prof. Phillips. He holds that the end of the terminal curve must strike the circle of the collet at a tangent, *i. e.*, where it is pinned to the collet it must be at a right angle with a line drawn from that *point d'attache* to the center of the spring. And of course the other end must be pinned in the same way to the stud. I dissent from this assumed necessity, and propose, as more favorable to isochronal action, the angle by which the curve will end when formed according to my plan. Figs. 7 and 9 show at E the greatest possible variation between my curve and that of Prof. Phillips, because a curve of 180° is the shortest length allowed. The engraver has made the variation at E, Fig. 7, greater than it should be. As the length of the curve increases, the angle of the end becomes nearer toa right angle, as in Fig. 8.

(155.) The difference, even in a curve of 180°, is very slight, and in practically forming the curve upon a spring can scarcely be perceived. Nevertheless there is a difference, and we ought always to know precisely what our model is, which we are to copy. Those who adhere to Prof. Phillips' theory, can adopt my method of delineating the curve by *ending it* according to the tangential theory. It would certainly appear, however, that the difference between the two curves, both in the manner of ending and the form of the body, is in favor of my plan, as being nearer in accord with the known action of springs in coiling and uncoiling. I may add that I propose, as soon as other engagements will permit, to prepare an elaborate mathematical paper on the action and merits of this curve, for submission to the British Horological Institute, the leading association of eminent horologists in the world, in which I shall challenge criticism of the theories, methods and demonstrations given.

(156.) *Proper form for the curve.* We will now consider the form of the terminal curve required to suit any particular case. Remembering that the function of these terminal curves is to cause the hair-spring to stiffen up more rapidly than it would do if all the coils were left in their normal size, it is obvious that the longer the curve is, the more slowly and gradually will its stiffness increase, and, on the contrary, the shorter and more compressed its form, the stiffer it will be and the more rapidly it will cause the whole spring to stiffen. (I trust professional readers will pardon my unscientific expressions, as I wish to make the matter plain even to the most inexperienced.) Therefore, if the watch loses in the long vibrations, as compared with the short ones, the strength of the spring does not increase fast enough and the terminal curve is too long and weak. We therefore shorten it by bending a portion of it out into the normal coil, and commence the inward sweep at a point nearer the stud—or nearer to the collet, if we are working at the collet end. For instance, if the curve was like C A, Fig. 9, (see section 149,) we shorten it up like to B E, drawing a new gauge by which to form it. If but slight change is needed, the old gauge will serve well enough to show the alterations. This will cause the strength of the spring to increase faster, and quicken the long vibrations.

(157.) But if the watch gains in the long vibrations, the spring stiffens up too rapidly and accomplishes the long vibrations too soon. We therefore make the curve longer and weaker like B E, Fig. 8, or at any length between C A, Fig. 9, and B E, Fig. 8, that we may think necessary to reduce the ratio of increase of strength sufficiently to accomplish the long vibrations as slowly as the short ones. This is done by taking more of the normal coil into the curve.

(158.) This is the whole secret. The isochronism is obtained by changing the *length* of the terminal curve, until the spring stiffens up in the proper ratio to make the long and short vibrations in the same times. The *shape* of the curve must correspond to its length, (142,) in order to render isochronism possible, (152, 153.) Therefore, when we lengthen the curve by taking a portion of the normal coil into it, or shorten it by returning a portion of the curve to the normal coil, as the case may be, the shape of the whole curve should be slightly changed to conform to its new length, (as prescribed in sections 156 and 157.) This, however, is very easily done, as we shall see.

(159.) *Altering the spring.* But if the difference of times between the long and short vibrations exceeds a few seconds for 24 hours, the total length of the hair-spring should be changed in order to correct it,—unpinning and taking it up to make the long vibrations quicker, or letting it out to make them slower. In such cases, bend the curve so that the new place of attachment to the stud (or collet) will come *naturally* in the hole. This change of length, of course, changes the *rate* of the watch in both long and short vibrations, but *a comparison of the two* will show the effect upon the *isochronism.* That being found correct, the rate of the watch is a matter to be corrected by regulating it. This distinction between changing the rate and changing the isochronism should be clearly understood. Of course, if we find that in securing isochronism we have changed the rate so much that we cannot regulate it, we shall have to substitute another spring of more suitable strength. But after a spring is isochronized closely it must never be taken up or let out to get correct time, for that would destroy the isochronal adjustment at once. The proper method of correcting the rate, by making the balance lighter or heavier, changing the screws, etc., will be treated in the article on regulation.

(160.) *Caution.* A word of caution is necessary here. Whenever we find a considerable error in the isochronism, and especially when there is a gain in the long arcs, we should, before altering the spring, ascertain whether there is not some abrupt change of direction in the curve, or irregularity in the form, so that it does not all come into action uniformly. If so, this must be corrected and another trial made, as, where a part of the curve acts imperfectly, or during only a portion of the vibration, error will result. As for those terminal curves we often find in cheap work, and which are not *curves* at all, but consist of a number of "kinks," or bends, serving to bring the end of the spring to the semi-radial place of attachment, we can only say that, while they may be better than no curve at all, it is impossible for them to give fine results, and the workman who should seek to secure such from them would only waste his time. Another point is, that all springs, after a change of shape, have a tendency to return more or less to their previous form, and this settling back must be first gone through with before permanently trustworthy tests of the effect of the change can be made. In the preliminary and coarser alterations, the test may be had at once, but as we approach closer to correctness it will be necessary to wait at least three or four hours, or over night, before testing. The watch should be kept running during the settling-back process, as the vibration hastens the completion of the change in the spring. After arriving at correct isochronism, the watch should be brought to exact time, then finally make another test of the isochronism, to discover if any further slight reversion has taken place during the interval.

(161.) *Making curves on the helical spring.* Having shown the proper forms of the terminal curve, and their characteristics, we will now consider the means of making them as we want them. We will take up the helical spring first, as the curves are more easily applied to it, closing with the Breguet spring, which also requires an elbow, in order to permit the application of the curve. In fitting a helical spring, the order of proceeding is, first, to try our spring with the Upright Holder, as in sections (62, 63), before bending either end, to find whether the number of coils which gives about correct time is neither too great for the space at our disposal between the plate and the balance-bridge, nor too few for a good action, (22, 23, 33.) Then make the lower terminal curve, (147,) and pin it to the collet-bar, (142.) Next, try it again in the Holder to find the place at the upper end which gives correct time, hold it there, and test for isochronism.

(162.) If it is nearly correct, the point at which the coil is held in the clamps of the holder is to be the end of your upper terminal curve, and the place of its attachment to the stud, leaving exactly the same amount of spring outside of the stud as was outside of the clamps, irrespective of the width of either. By "outside," I mean here *not held in the clamps*—although it is on the side next the body of the spring. But if a three or four hours' test shows several seconds difference between the long and short arcs, the spring must be shifted in the clamps till the isochronism is nearly perfect, when the point then in the clamps will be the place for the end of the curve, whose length and shape, like those of the lower curve, you will decide upon according to your judgment, guided by section (147). But if the rate given at that point is too far from right to be conveniently corrected by the balance, (186,) the spring is unsuitable. Having found this point of approximate correctness, it should be marked, then break off the superfluous length of spring, (leaving at least a quarter of an inch for safety,) in such a manner as to bring its end in the same radial line as the point of attachment to the collet-bar, *i. e.*, avoid fractional parts of coils, and poise the balance, (74, 75,) making the adjustment of the poise by filing the collet-bar as required. This should be very carefully done, as you cannot poise the spring and collet after you have once changed the upper coil from its circular form, (151,) but must remove the spring and collet from the balance in any subsequent test of the poise of the latter. You may now again break off any unnecessary spring, leaving a little for safety, then form the upper terminal curve like the lower one, pin it to the stud at the proper point, put the movement together, and finish the isochronal adjustment as directed in sections (156, 157, 159).

(163.) *Forming tools.* For making the curves, some workmen use simply the ordinary double hair-spring tweezers, having broad flat points at one end and curved points at the other, and in the usual manner. This would do very well for soft springs, but such never are, or at least never ought to be, fitted with terminal curves, (32.) For hardened and tempered springs such tweezers could not well be used successfully, from want of strength in the fingers. To give more power, pliers with convex and concave jaws are often used. But the better way is to heat the tools, whether pliers or anything else, as the spring yields more readily to manipulation, and the heat gives the additional advantage of causing the spring to "set" in its new form, instead of springing back as it does when bent cold, which obliges the workmen to bend it a great ways to produce any effect, and at imminent risk of breakage. Some use merely heated round wires or broaches, either straight or turned over at right angles at the end, and bend the springs over them. Every workman has his own way, which is most convenient for him, and which he thinks is the best way.

(164.) The very best way, without doubt, is to make two gauges, (145, 149,) of the required shape, filing off one to fit the outside and the other the inside of the curve, then clamp the spring tightly between them at the proper place, while heated, and let the whole cool, or quench in alcohol. But this is more trouble than would be justified for any but the finest jobs. The labor can be lessened considerably by making a tool to hold the convex or inside gauge firmly, while opposite and pointing towards its edge are a series of screws, which, being turned, force the spring in close contact with the convex gauge, whatever it shape might be. Between their ends and the hair-spring should be interposed a piece of a clock hair-spring, to make perfect contact on both sides of the spring through the length of the curve, and prevent the heat being unequally conducted, *at* the screw points and not *between* them. This tool would be valuable to professional springers, but watch repairers would probably choose one of the other methods.

(165.) When heated pliers, etc., are used, the parts likely to touch the fingers should be covered with paper or pasteboard, pasted or fastened with binding wire, so as to be permanent and substantial. The heating can be done in the alcohol lamp or otherwise, observing that the heating of the tool in the lamp, and the working of the spring upon it, must not be ventured at the same time. Some workmen use an iron block a couple of inches square, having holes drilled into it for inserting wires of different sizes, changeable as needed. They heat the block on a stove or in a lamp till it turns a dark blue, then put it into a wooden block cut out to receive it, with a cover having holes bored for the forming wires to pass through into the block. This wood casing not only protects the hands from injury, but keeps the block from cooling off too rapidly. Instead of plain forming wires, either straight or with their ends bent down horizontally, as above spoken of, clamps of different shapes can be held and heated by the block. These can be simply two wires brought together by a screw through both, or a more elaborate arrangement like the common pin vise, closed either by a thumbscrew or a sliding ring—the former being preferable, as obviating any danger of the fingers slipping and injuring the spring.

(166.) *Use of the forming tools.* Whatever tool is used, it must not be too highly heated, as it will reduce the temper of the spring too low, and even ruin it entirely by causing it to curl up out of all shape. It is not absolutely necessary that the heat should be sufficient to even color the spring, although it facilitates both the bending and the setting. Yet the heat may be considerable without affecting the color, as steel may be raised to about 425° Fahr. before a change of color takes place; at 450° the article will take a straw color; at 500°, a brown; at 530°, a purple; at 575° to 600°, the different blues. The forming wire or tool should be of steel, or, if of brass or other metal, a hardened steel screw should be planted in it as a color-piece, (13, 15,) to indicate the temperature. The heat should never be greater than will give the color-piece a dark-blue shade. If the hair-spring is of a lighter shade, the color-piece should not go beyond *that* shade, else the terminal curve will be reduced lower than the rest of the spring.

(167.) If repeated heatings are necessary, the color-piece should not reach the shade of the spring, (13, 14.) If the spring is a dark-blue, the color-piece should then not go below a purple, either removing the spring at that stage of the process, or taking the forming wire from the block and quenching the whole in alcohol. If the spring is fine, or the heating is done very rapidly, from the block being large, too hot, or any other reason, great care must be used to avoid reducing the temper of the spring too much. The color-piece, or that part of the wire which you brighten up to show the color, (13,) should be very near where the hair-spring is held by it, and before the spring is put into it at all, the heat should be ascertained. If the color goes beyond the blue, the block or tool must be cooled a little till it does not exceed the proper shade, when it may safely be used. As every different tool requires different management, I will not give more specific directions, but recommend the workman to make the best he can afford, and experiment a little on an old spring, and he will learn more about it in a few minutes than I could explain in a couple of columns. Be sure to compare your spring often with the gauge, see that it fits *without pressure*, using the eye-glass to insure accuracy.

(168.) *The Breguet hair-spring.* What is called the Breguet hair-spring is a flat spiral provided with a terminal curve at its outer end, which is raised up by means of an elbow or bend, so that it can be returned toward the center *over* the other coils. As we have seen, all flat spiral springs which are desired to possess isochronism should be as long as possible and closely coiled, as the angle of inflexion of each coil will be thereby reduced, its action will be more uniform and easy, and it will have less tendency to be forced out of center and exert a side pressure against the axis of the balance. This is particularly important with the Breguet spring, which should be broad and flat, the coils very close together and more numerous than for a plain spiral of the same diameter. It is usual to give the Breguet from one-third to one-half more coils than the plain spiral would have in a similar situation. Being sc close, the least injury or irregularity in the coils renders the spring worthless for fine adjustments.

(169.) *Trial curve.* In fitting a Breguet spring, we proceed as directed in sections (34 to 46, 62, 63), except that we pay no attention to the position of the two *points d'attache*, for the present, till we find the correct-time point approximately; then break it off into even coils, leaving at least half an inch of spring outside of that point (74, 162,) and poise the balance first alone, then with the spring and collet on, (75.) Then form the elbow, three-quarters of a coil back from the correct-time point, which should have been previously marked, (136, 180.) Having restored the general shape of the outer coil, if disturbed by the preceding process, we again try in the upright holder till we get the correct-time point, and make that point the end of a *trial curve*, being careful to notice, while doing so, how much will have to be broken out at the center to bring that *point d'attache* in a line with the correct-time point, and to make the proper allowance at the outside, etc., so that the total length from the collet to the end of the curve shall remain the same as before. This can be readily done by finding how much further the correct-time point will reach around the center when sprung (not bent) into the general shape of a curve, than when in the full normal coil. Then sketch the proposed changes on paper, and find the proper point for the end of the curve (before forming it) by taking off in one place and adding on in another, allowing for the greater reach of the curve around the center, etc., and the point where the correct-time point will come, after these changes are allowed for and measured off on the spring, is to be the end of the trial curve, one-half turn or 180° in length, (146, 149,) which need not be perfect in shape, but should be approximately correct, and the end should also be at half the radius, as shown in Fig. 7, (146.) Now test for the isochronal point, shifting the spring a little in the clamps, if necessary, (136, 159,) and bring the correct-time and the isochronal points together, as directed for the plain spiral, (137, 140,) and that point where both the rate and the isochronism are approximately correct (*i. e.*, the variation between the long and short vibrations being *not more* than two or three seconds for a six hours' trial, and the rate being within half a minute per day of correct), is to be the end of your *terminal curve.*

(170.) *The terminal curve.* Having formed the terminal curve in all respects as directed in section (143), determining its length according to the isochronal action of the trial curve, the isochronism is once more tested in the holder. If correct, mark the exact point which comes just outside the clamps, and this mark must come just outside of the stud (162) when pinned in it, which you will now do, (44, 45, 46,) put the movement together and test with the utmost accuracy for final alterations of the curve, (156, 157.) If the difference between the long and the short arcs is but a few seconds for twenty-four hours, correct it by changing the terminal curve as directed in (156, 157, 158). If the error is greater than that, the spring should be moved a little in the stud, (159.) When the isochronism is correct, the watch is then rated or brought to exact time by the regulator or by the balance, (214 to 226.) But the balance should not be disturbed during the isochronal adjustment.

(171.) If perfection is not sought for, this process can, of course, be greatly abridged. Probably the majority of workmen do not take even as much pains as prescribed in the preceding section (169), and would accept what I have called a trial curve as their terminal curve, for we seldom find what we may call a perfectly isochronal spring. But my object is to give the method of obtaining the very best results, and I do not hold myself responsible for those who choose to stop short of that end. In my directions I have supposed that the workman will make an upright holder (54 to 61) for the saving of time and superior work to be accomplished by it. Those who do not wish to do that, will modify their proceedings according to the necessities of the case (35), especially as regards pinning the spring to the stud at an early stage in the fitting process. And whenever I have said "clamps" in my directions, they will substitute the "stud" of the watch.

(172.) I have said that the terminal curve of the Breguet spring should be made precisely the same as that of the helical spring. This is the rule when a regulator is dispensed with. The theory of the terminal curve requires its ends to be rigidly fixed, so that the angle at which it meets the stud may be as invariable as possible. But when a regulator is used in conjunction with a Breguet spring, a new element is added to the problem. Whether the regulator pins are open or close, they are injurious to the proper action of the spring. If they are open, they interfere with the normal effect of the curve, by preventing it from flexing and vibrating naturally and properly. On the other hand, even if the pins are so close as to constitute the ideal regulator and virtually become the stud, they would derange the action of the curve by changing its operative length and its place of attachment to the (supposed) new stud. For if the pins were made to conform to the position of the curve, as they were moved along it, the further they were from the stud the further they would be from the center of the spring, and therefore the curve would not be attached to the supposed new stud at half the radius, as required. But if the pins retained their proper distance from the center, as they moved along the curve they would draw it to their own circle, and obviously force both it and the entire spring out of place and entirely destroy the isochronism. This is the usual result, when the ordinary Breguet spring is "regulated" by an inexperienced workman.

(173.) *The concentric arc of the Breguet spring.* It is common, therefore, to form a portion of the last coil, next to the stud, concentric, *i. e.*, bend it so that it will form a part of a true circle, having the center of the spring for its center and half the radius of the spring for its radius; as if, for instance, the terminal curve C A, Fig. 9, (149,) joined on to a concentric, semicircular arc reaching from A to O, and the spring was pinned in the stud at O instead of A, where the terminal curve ends. This concentric portion is sometimes made as much as half a coil in length, as just described, and is acted upon by the pins of the regulator the same as the outer coil of the ordinary flat spring.

(174.) But this arrangement has also its disadvantages. At the junction of the concentric portion and the terminal curve, at A, Fig. 9, the spring is not rigidly fastened, as the theory of the curve requires, unless the regulator pins clasp it firmly, precisely at that point, and act as a stud. But if the pins are in the least open, the yielding of the spring at and behind the pins would allow the entire terminal curve to move more or less without changing its form at all, and during the remainder of the vibration the amount and direction of its flexion would be modified by the amount of yielding in the concentric portion of the spring behind the pins. This yielding, in turn, would depend on the position of the regulator between the point A and the stud. The nearer it was to the stud, the greater this yielding would be, and it would also involve the further difficulty that the point A, or real end of the terminal curve, would not even be fixed at half the radius, but would be at all sorts of distances from the center, sometimes further than it should be, sometimes less—and every movement of the regulator, nearer to or further from the point A, giving it greater or less liberty and scope of motion, would change the entire position, condition, and action of the terminal curve.

(175.) Theoretically, such a spring cannot possibly be isochronal. But, practically, we find that if, by making this concentric arc very short, we reduce these irregularities below a certain amount, we may overcome them. There are unavoidable irregularities of all kinds. No part or operation can be perfect, but after doing our best we shall have faults left, and these faults, of whatever kind, we must endeavor to remedy, neutralize or harmonize, by the adjustment of the spring to meet the necessities of each case. The nearer we succeed in doing this, the nearer to perfect isochronism we shall come. The reader will doubtless have noticed such expressions as "closely isochronized," "improving the isochronism," "lack of isochronism," etc., and may have thought them rather strange. The truth is that, in practice, the term isochronism is rather indefinite. Perfect isochronism is the condition of a spring when there is absolutely no difference in time between the longest and shortest vibrations. But such a spring we seldom find. Workmen have certain standards of excellence, and when they attain their standard of performance, they call that isochronism. Others find difficulties they cannot overcome, and get the spring as closely as they can conveniently, when they pronounce it isochronized. Some make very little effort, or do not know how, and *their* idea of an isochnal spring is very low indeed. Theoretically, isochronism is a fixed term, but practically it is only a relative one, being high or low as compared with others which are better or worse. Hence, I use the term "peıfectly isochronized" as the ideal which we are to strive after, but, for convenience, I speak of "improving the isochronism," and similar expressions, to indicate the change produced in the adjustment by our manipulations. So, in the present case, we are to take the imperfections belonging to this form of spring, and make the best of them.

(176.) *Length of the concentric arc.* It is an undoubted advantage to have the use of a regulator for rating a watch, and another advantage of having a concentric portion at the end of the spring is that, if necessary, it may be moved through the stud without thereby changing the distance of the end of the terminal curve from the center and so necessitating a remodeling of the shape of the curve, (158.) But the length of this concentric arc should not exceed one-eighth of a coil, or from the point A to the next radial line at R, Fig. 9, (149,) which must be the place of attachment to the stud, and the regulator must only act upon the spring between these two points. Another instance is the curve B E joining on the concentric arc E O, of 45°. By confining the concentric portion within these limits we may enjoy the above advantages and yet be able to secure very fine isochronal action. But the regulator pins should be very close together. Further remarks on this form of spring will be made in connection with Regulation, in section (222).

(177.) *Forming the curve with concentric arc.* The workmen can scarcely need any instructions for forming gauges, or the curve itself, for this style of spring, in addition to those already given, except that he should commence his curves (both trial and terminal,) *not* at the place where the correct-time and isochronal points coincide approximately, (169,) but the length of the concentric arc inside of that place, not over 45° or one-eighth of a coil from it, and half that distance would be better if the spring is likely to require any letting out (162,) so that after all is done the point A, or end of the curve, shall not *exceed* 45° from the stud. Then with the point R in the stud or the clamps of the upright holder, and the point A in its false regulator, the correct-time and the isochronal points must be brought to coincide by moving the spring in the clamps for any large change required, or changing the form of the curve for slight changes, as already described. But during these changes, the regulator pins must be kept at or near the point A, or junction of the curve and the concentric arc, while the point R, or acting end of the spring, must be kept in or near the same radial line with the point pinned to the collet (137 to 140,) or as may be required in order to secure isochronism, (139, 135.)

(178.) *The elbow of the Breguet spring.* We have now to consider the elbow. It is popularly supposed that the placing of the elbow correctly is a point requiring great experience and judgment, and renders the making of a Breguet spring a very difficult and complicated job. Now, I contend that the exact position of the elbow is not an essential matter, its object being merely to raise the final or supplementary coil so that we can curve it towards the center as we find needful, without interfering with the other coils. The terminal curve need not begin at the elbow, unless we find it necessary, upon trial, to make it so long as to reach to that point. The curve may begin at any distance from the end of the spring which will secure isochronal vibrations. The position of the elbow has nothing to do with that adjustment, provided it is far enough from the end of the spring to be out of our way. It simply, on the flat spiral, enables us to enjoy the same freedom in forming the terminal curve that we have in the helical spring.

(179.) My meaning will be more evident by supposing that, with the exception of the outer coil being *raised up* by the elbow, no change has been made in its shape, the outer coil having the same size and distance from the center as before. The spring will therefore perform nearly the same as before, except so far as this elbow has made it shorter and stiffer. Accordingly, whether the elbow is a half, three-quarters, or whole turn from the end makes very little difference practically, although it is considered well to make it as near the end of the spring as will give room for the terminal curve. *That* is the real means of securing isochronism, not the elbow. The stiffness of the elbow is, of course, a disturbing influence or cause of irregular action in the spring, to a certain extent, but it is unavoidable, and we must correct or neutralize its effect in our adjustment of the terminal curve, along with all other unavoidable irregularities, such as resistance of the air to the balance, unequal springing out of the sections of the rim, effects of friction in the balance jewel holes and the escapement, the oil, mechanical imperfections of all kinds, in the spring itself, as well as elsewhere —so that in spite of all of them the vibrations shall be isochronal, or as nearly so as we can make them. Many workmen insist that the supplemental coil must be just one turn in length, from the elbow to the stud. It will be noticed that following my directions will generally make it so. But that length is not imperative, for it may be either more or less, without harm. Instead of a single supplemental coil, some workmen have two, three, or even more. These supplemental coils wind *inward* from the elbow, becoming smaller towards the end, which is finally formed into a terminal curve. In this form of spring, the regulator is either dispensed with, or its pins brought nearer to the center than in the ordinary Breguet spring, and the end of the terminal curve is pinned as near to the center as possible. It is claimed that this spring renders unnecessary a strict attention to the precise form of the terminal curve, or to the relative positions of the *points d'attache*, as a good isochronal action is generally obtained. Admitting that to be the case, the difficulty of forming such a spring properly is greater than to form a terminal curve as already prescribed, which will insure us the best results possible. Hence this may be classed among the fancy forms of spring, and will need no further discussion in a practical treatise like the present.

(180.) *Making the elbow.* Nor is the *making* of the elbow difficult. Some workmen drill a hole through a piece of *hard* brass, large enough to admit a slotting file, with which they cut in one side of the hole a narrow notch, just the width and depth of the spring, then plug up the hole so that the spring shall be firmly supported both on its sides and edges. Another way is to make a slot with straight sides and edges, just the width of the spring, and wedge the latter tightly in at one end of the slot. A good way is to take one of the double forming wires (165), one slightly convex the other similarly concave on their inner surfaces, cut a very shallow groove in one of them to fit the spring, then screw them tightly together upon the spring. Another similar tool is fitted in a handle, or a pair of hand tongs opening with a spring are bushed with iron, and a shallow slot cut in one side as above described. This last tool or the tongs are for taking hold of the spring near the forming wire or piece in which the spring is fastened, and slightly bending it, first on one side, then on the other. The forming wire is to be held in position, in the block or otherwise, all the tools used must be carefully heated, and by bending the spring gently after it has become thoroughly warmed up, even the hardest may be sufficiently bent with proper care. The novice should first practice a little on an old spring, or on the superfluous end of the one he is at work upon.

(181.) The thickness of the piece in which the hole or slot is cut (180), or of the forming wire in which the spring is held, should be the length of the straight portion of the elbow, between the two bends, and will depend on how much the spring can be bent without danger of injuring or weakening it at those points. No attempt should be made to bend the spring upright at the elbow, even if it could be done. As a general rule the angle at which the elbow rises from the plane of the spring should be about 25°, or a very little more if the spring will bear it—less if it will not. This can be ascertained by experimenting upon the surplus spring not wanted at the outside. For the benefit of those who do not understand "angles," I may explain that a right angle or a quarter circle is 90°, one-sixth of that is 15°. The radial lines in Fig. 7, (146) are 18° apart; the lines in Figs. 8 and 9 are 45°, and by dividing one of those spaces into two equal parts each one will be

$22\frac{1}{2}°$, or if divided into three parts each will be 15°. In the same way any other divisions may be made, as in Fig. 10. If the spring, instead of running from *a* to 5, was at *b* bent up to *c* and there again bent horizontally so as to run to 1, the two bends would be 90° or right angles. If bent as shown to run to 2 the bends would be 45°; to 4 would be 15°, and to 3 would be 30°. I have seen elbows rising at an angle of 45° but they should not exceed 30° or 32° in any case.

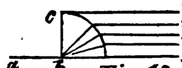

Fig 10.

(182.) *Height and position of the supplemental coil.* The supplemental coil, or the coil outside of the elbow, is to be raised so that there will be, between it and the other coils, a space about twice the breadth of the spring. Some give even more, but that necessitates a longer elbow and increases the amount of torsion or side twist which it produces upon the spring when vibrating. The space named gives ample clearance, which is all that is necessary. Some good makers give only one and a half times the width of the spring, but that is bringing the two parts rather close. The less the spring will bear to be bent without producing the slightest injury, or the greater the clearance to be given, the longer the straight portion of the elbow, between the bends, must be, and *vice versa.* After the elbow is formed, if the clearance is found too great, the bends can be made a little less abrupt by simply squeezing them between the heated tongs (180), or double forming wires, or even the jaws of a pair of very narrow flat pliers, or the ordinary round-nosed pliers, smooth inside, which by the help of the heat flatten the bends and so partly straighten them. The clearance must be sufficient to prevent the under coils touching either the supplemental coil or the stud.

(183.) The supplemental coil must be perfectly parallel to the other coils. If not, it can be made so by flattening one of the two bends. If the supplemental points upwards from the body of the spring, flattening the first bend will bring it down. Or, if it lies too low, flattening the last bend, or the one nearest the end, will cause it to point higher and be parallel. This flattening is done by squeezing the spring flatwise, not by applying force to its edges. The supplemental may also be leveled by twisting the elbow sideways to throw the end upwards or downwards. But this should only be done for very slight errors, as the edges of the elbow as well as other parts should be truly vertical, *i. e.*, the breadth of the spring-wire should invariably be at right angles to the horizontal plane of the spring, and parallel to the balance axis.

(184.) Some may think all this is a good deal of trouble to isochronize a hair-spring. Well, it *is* some trouble to adjust a spring perfectly. Nothing good is to be had without trouble.

But it is not so hard as it might seem at first, from the number of details given. I have endeavored to touch every point important to know, have even occasionally repeated directions in different ways, have used ungrammatical and unscientific expressions, have been diffuse and redundant in style, from a desire to make sure that my meanings should be *noticed* and clearly understood by all. But when once comprehended and become familiar, when the principles or models which are to be copied are fixed in the mind, the numerous details I have found it necessary to explain and dwell upon will become matter-of-course, and the practical work simple and easy, so that we may hope for an improvement in the manner of treating springs which seems to prevail at present with many makers. Judging from their work, a good share of workmen now merely try the spring by some "quick test," (108,) and let it go at that. But from what has been said, it will be seen that it is little better than a barefaced swindle to pass off such a spring as isochronal, for a spring may stand that test or even a severer one, and yet not be adjusted for isochronism at all. One has no more moral right to call such a spring isochronal than he has to represent a chain as gold because it has a few grains of that metal in it or on it.

(185.) I have now given all directions necessary for selecting and fitting hair-springs in the very best manner, and making all adjustments required even in the finest watches or chronometers. It is not to be expected that the workmen will observe all the niceties explained, in common watches or on low-priced jobs. But if he understands fully what has been said in these articles, and uses a reasonable amount of thought and judgment in applying it in practice, he can, with little or no loss of time, do even his common jobs in a manner approximating correctness, and which will not only please his customers, but satisfy other workmen, into whose hands they may come, that he understood his business. Above all will be the satisfaction to himself of working from knowledge, instead of blind groping and guess-work—and the ability to judge whether work is properly done or not. In order to get the most benefit from his knowledge—to both learn and *improve*—he should put it into practice at every opportunity, even if it involves extra trouble or doing a little more than he gets paid for. He will be amply rewarded by his improvement in information and dexterity. But without practice his knowledge will be both useless and fleeting. In my next I shall give directions for rating or regulating watches, with or without regulators, without injuring their adjustments, and even so as to improve them—together with several other matters of importance.

Part Fifth.

REGULATING, OR RATING.

(186.) Regulating a fine watch is an operation which but few workmen are capable of doing properly, or, indeed, without injuring it. And even with the cheaper grades of time-pieces, there is more in it than many suppose. When a watch is merely cleaned, or the repairing of it does not require any alteration of the hair-spring, the greatest care should be taken, especially with fine work, that it be put together precisely as it was before. The regulator should be at the same place, and the hair-spring should occupy the same position between the regulator pins, as before it was taken down. To insure this, a careful examination should have been made, with the balance at rest, free from the motive force of the main-spring, and the position of both the regulator and hair-spring noted down—for in a fine watch both of them have probably been carefully adjusted, and changing either of them or opening or closing the regulator pins might seriously damage the adjustment. Even in cheap watches, following this rule will frequently save several days in bringing them to time.

(187.) *Pre-requisites of the rating.* But if a watch does not perform satisfactorily on trial, or if the workman is sure from inspection that it will not do so, the defective conditions must of course be changed and corrected. I have already stated how the hair-spring should be pinned in the collet, (34, 38, 41,) and stud, (45, 46;) that it should be perfectly free from constraint when fastened in the movement, (47;) that the outer coil should stand perfectly free between the regulator pins as they are moved through the whole of their sweep from "slow" to "fast," not moving nearer to or against either pin at any point in the sweep;

and that the regulator should stand pretty well back towards the "slow" when the watch is regulated. The pins should both be tight in their places, so that they cannot yield any when the spring presses against them. If one of them has a foot, to close the bottom of the opening between them, the spring should be entirely free from it, nor should any dirt be allowed to accumulate there and touch the spring.

(188.) *The Regulator.* As a general rule, the regulator-pins should be as close together as possible and yet leave the spring free between them, (68.) But if they are found otherwise, they should not be closed without good reason, for they may have been so opened for a purpose, by some one who fully understood the effects of so doing. But wide pins may justly be regarded with suspicion. The effect of having the pins very open is not only to render the spring less susceptible to control by the regulator, but also to cause sudden and violent checks to its motion, making uniform progression of force (141, 152) difficult, if not impossible. Moreover, the spring vibrates upon the pin against which it rests, as a fulcrum or pivot, moving in one direction on one side of the pin, while back of it it yields in the opposite direction. Sometimes the spring will even slide along the pin with every vibration. In either case, an irregularity of motion results which is injurious to its proper action, and should be avoided whenever the position of the regulator-pins comes within the scope of the repairer's duty.

(189.) *The end-stones.* I have also described mechanical conditions for other parts of the movement, essential to fine time-keeping, and which should be looked to, (93, 105.) I now call the attention of the workman to a very general fault, viz., leaving the end-stones loose in their caps or settings. If they are not set and held in the metal they must be cemented fast, for no watch can keep time with the cap or foot jewel shucking around, constantly changing its position, falling down upon the end of the pivot, or falling away when the pivot rests on it, perhaps turning up more or less edgewise and pinching the pivot against one side of the jewel-hole. It is by no means rare to see a cap jewel wobbling about with every motion of the balance, upon whose pivot it is resting. It is an invariable rule that the jewel must be fast in its cap, and the cap fast in its place.

(190.) To cement the jewel in its cap or setting, take a small fragment of shellac, and melt it in the socket of the jewel, over the lamp. Then lay the jewel on, right side up, melt the wax till the jewel sinks into it, and quickly turning the cap over lay it upon the paper on your bench, and press it down with the tweezers, to bring the cap in contact with the paper. This forces the jewel into the soft wax up to its proper place where it has the support of the metal, and insures that its surface will be level with the cap. If not so, it must be heated again till it becomes so. Generally, a cap or foot jewel should be just even with the surface of its setting or cap, not lower, nor sticking out any above it. But cases occasionally occur requiring a variation from this rule. Before altering or cementing a cap jewel, feel of it with a sharp-pointed piece to see if it is tight in its place. Also notice if it is pushed as far towards the hole jewel as it can be. If necessary, fit in a larger jewel, so as to bring its flat surface, when cemented, as it was before, if that was correct.

(191.) A cap or foot jewel must invariably be fixed parallel with the under surface of the cap, or the upper surface of the slip, so as to present a perfectly horizontal support for the end of the pivot. Otherwise, it will slide down the inclined surface of the jewel and be wedged in against one side of the jewel-hole. This point must be carefully attended to. In the case of the foot jewel, which is out of sight, a little wax left outside of the jewel does no harm, and considerably strengthens the jewel. But for cap jewels, where no wax must appear to the eye, after prying the cap off the paper, and scraping the superfluous shellac from the under surface, see that the jewel is flat and true, lay it down on the bench, the jewel underneath, and carefully scrape the wax from the outside of the socket, without loosening the jewel. It will do no harm to leave a very little around the edge, as by again melting carefully, (and pressing down on the bench as before,) it will take a smooth, shining surface, and not be noticed. There are many workman who denounce "sticking jewels in" with shellac as botchwork. So far as hole jewels are concerned I agree with them, but with cap and foot jewels it is often a necessity, and it is certainly far better than to plug the holes around the jewels with paper, slivers of wood, etc., as we see every day. Doubtless our carping friends would sooner leave them loose than "stick them in" with wax. But then, *some* people are so *very* nice!

(192.) *Getting correct time.* The manner of taking observations of the sun or stars for correct time, by transits, quadrants, sextants, dipleidoscopes, and many cheaper contrivances, does not properly come in here, but I may consider it in the future. Supposing that you have a good regulator, the watch is to be set by it exactly. I will only say here that the seconds-hand should never be moved after it is properly fastened on its pivot, but when it is just at the 60 the balance should be checked by a bristle and held so as to start off when it is raised, which should be done just as the seconds-hand of the regulator strikes its 60. Or the watch may be stopped with its seconds-hand on the 60, and held ready to give it a twirl as the seconds-hand of the regulator comes to its 60. Then set the minute and hour hands. These must not interfere, nor touch the dial or glass, nor have too much movement up and down.

(193.) *The hands and their operating mechanism.* If the minute hand, cannon pinion, or center post is suspected to touch the glass, place the thumb nail on the glass and run it along just over the hand, and by getting the light right, and looking through the edge of the glass, you can see the exact distance between its under surface and the hand. Or, turn the hands and listen for any grating or squeak. Also, look for any mark on the glass over the cannon pinion. If there be the slightest evidence of touching, a higher glass should be substituted. If that cannot be done, confine the end play of the center pinion or post, or, if that is correct, the top must be taken off a little. Be sure to turn the minute hand once around, examining it frequently to see that it nowhere touches either glass or dial, and does not "cant up" on one side and down on the other. If it does, the center-pinion wants uprighting. Also try if the hour hand is perfectly free at every point during this revolution of the minute hand. If not, it must be made so, for any binding will affect the time if it does not stop the watch. A black mark in the hole in the dial shows that either the hour wheel or the socket of the hand rubs there. If the hour hand trembles or bobs or jumps as it is turned, it shows something wrong about the fitting of the dial wheels. If the seconds-hand points higher on one side than on the other, bring the hour hand over it at its highest position to see if there is any possibility of their interfering. Also try if the point of the minute hand can touch it anywhere.

(194.) In putting together a movement, the dial should first be fastened so that it cannot move about or become loose, then the seconds-hand should be put on and trained as closely as possible to the dial without touching at any point of its revolution. The hour-hand is next put on firmly, turned to point exactly to the I, and the minute-hand put on pointing to the dot of the XII. This position will cause the hour-hand to point correctly to all the other figures, if the dial is correctly marked. In fitting it upon the hour wheel, the hour-hand when at its lowest end-shake must clear the seconds-hand at its highest, and the minute-hand, in turn, must clear the hour-hand at *its* highest and, finally, the glass must clear the minute-hand at *its* highest point.

(195.) Hence the play of the different hands should be no greater than will give perfect freedom of motion. If the hour-hand has too much play, a spring foil washer should be placed on the hour wheel to prevent end-shake, but it must still remain perfectly free to revolve. The washer is not designed to exert any pressure upon the wheel when in its correct position, but only to prevent it getting out of its proper place and having unnecessary play. These washers are sold by all material dealers, and are so cheap that there is no excuse for the use of unyielding paper plugs between the hour wheel and dial.

(196.) Finally, bring the minute over the hour-hand at the most dangerous place, hold the movement dial downwards, and with the key turn the minute-hand back and forth past the other while in that position, watching closely when they pass each other. Too much care cannot be given to the perfect fitting of the hands and the mechanism propelling them, for any trouble here may prevent the most perfect movement from doing even decent service, and it is useless to undertake the regulation until it is corrected. If the glass is thin and it is suspected that it may be sprung down upon the center post and interfere with running, put a little oil on the tip of the post, shut down the glass and press it cautiously with the fingers, after pushing the post to its highest end-shake. If any contact occurs, the oil will be found on the glass. Or the oil can be left on the post while the watch is worn in the pocket for a few days, and the glass then examined. When satisfied that there is no contact, absorb the oil off the post with tissue paper.

(197.) If the cannon pinion or center post is loose, it may be tightened by twisting the arbor or post around between the jaws of a pair of dull cutting pliers. The sharp edges raise a couple of ridges or rings around the arbor, making it practically so much larger. If too large, twist the arbor in the flat pliers, which will flatten the ridges a little, till they just fit the cannon or center pinion snugly enough to surely carry the hands, but no tighter than that. By holding the arbor or post *straight* across the jaws of the cutting pliers and using reasonable care, there is not the least danger of either cutting or breaking the post off, or even bending it in the slightest degree. If this operation will not enlarge it enough, it is better to fit a new one than to tighten it with bristles or to flatten it with a hammer as many workmen do, for the former lasts but a little while, and both are sure to make the post and hand one-sided and probably cause "canting," besides lengthening it and disarranging the dial wheel mechanism. When the post is soft and but little enlarging is needed, it is often done by rolling it between two sharp files with a heavy pressure, thus producing a multitude of fine burrs on its surface. In a cheap watch, the cannon pinion is sometimes filed in at one side, nearly to the bore, then a punch causes the thin metal to project into the bore enough to secure a tight fit.

(198.) A cannon pinion on a center post must be proof against any possible accidental turning. But if on a center-pinion arbor, it must only be tight enough to certainly carry the hands.

If it has a tendency to work up and become loose by setting the hands, making a ridge near the top end of the arbor will generally cure this. But if the arbor is very much tapering, the part of it which forms the bearing in the cannon should be made more nearly cylindrical, or smaller at the base, then properly tightened. If the cannon pinion is tight enough in some places, but on turning it a little further around becomes loose, this fault should be corrected by taking the "humps" off the arbor, then ridging it at some place where it is round.

(199.) In *setting the hands*, if they do not turn hard and the movement is in good condition, they may be moved either forward or backward,—the way which will require the least turning. But if they move at all hard, and the lever is short, they should be turned forward only, or the balance pivots may be bent or broken, or the watch stopped. Repeaters, alarm watches, and all complicated movements had better always be turned forward, at least by the customer, and by the workman also, unless he is perfectly familiar with the requirements of the movement in hand. If the hands move very hard, they should not be turned at all, as damage is almost sure to be done, but the difficulty should be ascertained and remedied immediately. All of the foregoing and any other defective points in the movement should have been examined while taking it apart, and all repairs made either at once or at least before cleaning. But I have mentioned them here, because they are among the pre-requisites of the timing.

(200.) *Variations in running*. In regulating a watch, the workman should remember the distinction between an error in the rate and one arising from its not being in good condition. Having set it accurately, we examine it at intervals and compare its time with the standard. If it gains or loses an equal amount in each six hours after being wound and set, and four times as much at the end of the twenty-four hours as at the end of the first six, or even if it gains or loses the same amount in the last twelve hours as in the first twelve, the error is one of rate, and can be corrected by the regulator. In such case, we say it "gains," or it "loses," so much per day. But if it gains in the first twelve hours and loses in the last twelve, or the reverse, then we say it "varies," and the fault is not in the rate but in the condition of the mechanism—generally a non-isochronal hair-spring, (43, 90,) and a variation in the motive force. The only remedy for this is to remove its cause, as directed in previous sections.

(201.) *Regulating a varying watch*. Such a watch can only be regulated to produce a correct *average* at the *end* of each day, (43,) and the customer must be impressed with the importance of winding it at precisely the same hour every day. It does not matter much what hour that may be, only he should choose one in accordance with his habits and which he will be sure to remember. Furthermore, he must compare its time with the standard regulator at the same hour of the day, for if he compares it in the forenoon at one time, and in the afternoon or evening the next time, regulating and setting on each occasion, his watch will soon keep no time at all. He may even set it in the forenoon, and in the afternoon of the same day find it a minute or two out of the way, while it may be right again the next forenoon, twenty-four hours after setting, if it is not disturbed. A workman who fully appreciates this point may make quite inferior watches give tolerable satisfaction, while if he alters the regulator for the customer whenever he happens to come in the shop, or allows him to do it himself, his reputation as a workman will soon "peter out."

(202.) *Proper order in regulating.* In regulating, there is a certain order to be followed. Workmen often find watches stopped, and after cautious examination and perhaps much loss of time, discover that they had forgotten to wind them, or they find a watch more out of the way after regulating than before, and cannot tell whether they had set it or not, after turning the regulator; or they will wind and set, but forget to regulate it. The proper way is first to change the regulator, the hands remaining as they were, so that no mistake can be made about the correct change required. Next wind the watch, lastly set it. After winding always give the watch a little shake, or be sure that it is going, as cheap watches often stop from winding or turning the hands backwards, etc. After winding all your watches glance over them, and if every one is properly set to time, you may be sure that they are also regulated and wound. By following the above rules invariably, you will never have any doubts or mistakes. In regulating fine watches, either keep a memorandum book, or attach a tag to each, and note down the error and the date, thus: "Aug. 10, 45 s. fast," "Aug. 12, 52 s. fast, Reg. and Set." Or the foregoing can be abbreviated into "12, 52 s. f., R. S." In this way you will know how long a time the watch has been in making the error, and what effect your previous alterations had; also whether the rate was regular or varied. Always turn the regulator too little rather than too much, and in fine alterations use the eye-glass to observe the amount of movement it has received, especially if it has a tendency to spring back.

When not to regulate. When the watch is running closely, do not regulate it too often. If it gains ½ minute in a day, leave it so and see if it has gained one minute, the next day. If so, it will then be safe to turn the regulator. If not, the watch may have been exposed to the sun, or to unusual cold or heat, or kept in a different position, or had different usage. In the same way, when the watch is running closely in the customer's pocket, do not alter it for a slight error, but tell him to remember how it is and try it a little longer. Common watches will vary more or less from the sort of usage they receive, and it is better not to correct each small error, but get them so they will *average* closely, whatever the variation may be from day to day, *i. e.*, they may now be a little fast, and then a little slow, but the mean rate will be about correct. Another cause of apparent error in the rate, which in a cheap watch may amount to as much as one or two minutes, is a want of truth in the marking of the dial. The only remedy for this is to always compare the time when the minute hand is at the same part of the dial, say at the figure XII. If the dial is not on concentrically with the main plate, *i. e.*, the cannon pinion is not in the center of the circle of the dial figures and spaces, there will be an apparent error of rate, even when the watch runs correctly, and the dial is perfectly spaced off. For instance, if the figure XII is too near the center post, the watch would be correct at XII and VI, but will appear to be fast at IX and slow at III. The error may be as much as a minute, and will diminish gradually in amount in each direction from those points, till the minute hand reaches XII or VI, when it will disappear, to reappear as the hand goes beyond those points. This defect may be detected by training the point of the hand to run close to the dial, and turning it through one revolution; the points which are nearest and furtherest from the center post, are the places where the watch should be compared and regulated. All watches with any such defects should be put in a corner of the board by themselves, to insure their receiving the special treatment they require.

(203.) *Time of winding*. Many watchmakers do their winding at night. This is all right for watches known to be in perfect order, and therefore needing nothing but regulation. But for custom watches, the preference is to do it the first thing in the morning, so that if any alterations or examinations are needed they can be made at once. If a watch is found still, or acting strangely, at night, it may start on before morning, and every workman knows that the best time to examine into any trouble is while that trouble is yet in operation and can be seen, but it may escape notice or require a long search if allowed to pass on. Besides, this work is a good preparation for the more serious labors of the day. No one feels like sitting down to the bench in the morning and plunging right into some delicate job the first thing, but after winding he is ready to take hold of anything that is waiting for him. Use always solid-pipe, well-fitting bench keys for winding. Careless workmen ruin more winding-posts and bend more teeth by not following this rule than their heads are worth. When winding, turn the key, but hold the watch still. Many persons twist the watch as much as they do the key, at the risk of overbanking, breaking off the ruby pin, stoppage, etc.

(204.) *Proper care of watches.* When watches are hung up they should not rest against a hard backing, as a plastered wall, etc., nor be allowed to swing upon their hooks. Nor should they be subjected to any jarring or trembling of the supports to which they are attached. Especially to be avoided is a regular or periodical jarring or thumping, whose intervals may be in unison with the vibrations of the balance, whether exactly so, or coinciding alternately, or in any similar way. They should also be protected from both cold and heat, moisture and dust, and the customers must be instructed not to lay them on marble, metal or other substance that will rapidly abstract their warmth. Watches should not be opened where the air is much warmer than they are, as the moisture of the air is condensed by contact with the cold movement, causing rust of the steel parts on which it settles. The workman must keep the watch as nearly as possible at a uniform temperature while *regulating* it. If it is to be compensated for heat and cold, that is a separate adjustment, which has nothing to do with the rating.

(205.) If watches are hung up during the day, while regulating, they should retain the same position at night; and if laid down days, they should also be laid down nights. A common watch will vary in different positions, but you are not to attempt to correct that error by regulating. After it has been closely regulated for hanging, in the shop, the finishing touches should be given while it is in actual use, and subjected to the regular treatment customary with its owner, who should be instructed to follow precisely the same routine every day. If he carries it during the day, and hangs it up at night, he should hang it up *every* night. If he lays it down at night, it should invariably be laid down, horizontally, the pendant ring turned underneath, and with the same side up, and protected as directed in the preceding section. Fine watches vary less from such causes, but they are also expected to run more closely than others, so that these rules are beneficial in all cases. It is by attending to such little matters that satisfaction is given, and it cannot be done without.

(206.) If the watch cases are thin, they should be carried where no undue pressure can come upon them, to force them down upon the end of the center post, and stop the hands or the watch itself. Always examine the inside of the case to see if there are any marks of touching. If so, the post must be shortened or otherwise protected. Ladies' watches often run very irregularly, or stop, from being squeezed too tightly in their belts. But it is not much better to carry them in their bosoms, as they are kept too warm and moist. The best place is a pocket in the dress-skirt just below the belt, made of a size to fit the watch. The pocket should not be too low. As for chatelaine watches, the workman should never promise that they will keep good time, for it is impossible for them to do so—swung and flopped and jerked and knocked about in the way they are. The best place, for a man, is a pocket in the pants, where the watch will rest upon the abdomen, and be less affected by pressure and blows, than if resting against the unyielding ribs.

(207.) If we find that the error in the rate of our watch is so great that the regulator will not correct it, or if the regulator is already at the limit of its sweep, our course must be guided altogether by the circumstances of the case. Certain remedies may be justifiable in cheap watches, which would not only be utterly inexcusable in fine work, but would render the workman liable to prosecution for malpractice and payment of damages for the injury done. We will first consider the treatment of common watches, reserving the questions connected with the regulation of the finest movements, without injuring any of their adjustments, for subsequent treatment, as there is considerable to be said on that subject.

(208.) *Altering the hair-spring.* If the watch loses time, we can take up the hair-spring enough to approximately correct the error, and finish by the regulator. Before taking off the balance-bridge, see if the watch is in beat. If not, notice in which direction the error is, and how much. An over-sprung watch, and some others, can often be put in beat without taking out the balance or stud, (removing only the balance-bridge,) by the use of the tool named in (51). But it is safer, generally, to take the balance out. First note the distance of the stud from the nearest arm of the balance, or from some screw in the rim, or other mark, and also the distance required to place it in beat, which will show what position the stud should have when in beat. Now draw the spring through the stud the proper distance, and pin again. Next loosen the stud and take out the balance, bend the spring, if necessary, to bring it into proper shape, (46, 47,) and move the collet around till the stud takes the correct position as noted above. See also (49). If the watch gains, we let out the spring in the same way.

(209.) *Grinding the hair-spring.* But if it gains and we have no spare spring to let out, we have three remedies, besides fitting a new spring. First, we can grind the spring on its under edge, till we reduce its breadth and weaken it sufficiently. To do this, take a flat piece of soft cork, considerably larger than the spring and half an inch thick. Make one side very flat and smooth with a knife and sharp file, then cut a hole in the center to allow the collet to be forced in with one or two central coils while the grinding is going on. Spread the spring evenly on the cork, which should first be oiled a little to secure its adhesion, then lay the cork carefully down on a clean, sharp oil stone. Before moving the cork at all, press it down hard, to slightly imbed the coils in its surface, and cause them to retain their position while grinding, then rub it over the stone in circles in all directions, so as to grind the spring as evenly as possible. Keep the stone well oiled, don't grind too fast, press the cork down flatly by the finger on its center, do not move the cork without pressing it down, nor lift it up till you have finished. Then take it from the cork, absorb the oil by paper, and finish by soaking in alcohol, dry, replace the collet on the balance-axis, pin in the stud, put in beat and try. Should the spring be soft, or from any other reason there should unfortunately be a "feather-edge" of metal on the coils, it must be removed by dipping the spring in acid, (210.) I have sometimes found springs on which the workmen had left long fibres like hairs, caused by this feather-edge splitting off, and preventing any proper motion of the spring.

(210.) *Weakening with acid.* To weaken a spring with acid, it should first be cleaned from grease, etc., so that the action of the acid will be all over alike. This may be done by soaking it in absolute alcohol, or in a warm solution of caustic soda in water—such as is used to clean articles for electroplating. If the latter method is adopted, it should afterwards be soaked in clean water, then in alcohol. It is best to remove the spring from the collet during this process, but if it is not, after drying it off, put a very little oil at each end of the hole in the collet, to fill the hole, and keep the acid out. The acid is made by mixing in a watch-glass ten drops of water and one drop of the strongest sulphuric or nitric acid, or more in the same proportion. Mix well with a bit of glass, and immerse the spring for a few seconds, or until it becomes black. No time can be specified, as it depends on the strength of the acid, size of spring, and amount of action wanted, but great care must be taken not to eat the spring too much.

(211.) Rinse the spring in water, and soak it in the soda to completely neutralize the acid, then in alcohol, and finally dry it off between folds of tissue paper. If you have no caustic soda solution, lime water, or a solution of potash, common soda, or salts of tartar will do to neutralize the acid. If the effect is found to be not sufficient, the operation can be repeated. This process, if carefully performed, is safer than grinding, and more equal in its effects, but it blackens the spring, while grinding does not produce any change of appearance that is visible while running. And probably the acid will least injure the isochronism of the spring,—a result which must in *some* degree follow every effort to alter the strength of a hair-spring, no matter how it is done. For this reason the following process may be preferable, as the hair-spring is not disturbed at all. But whenever any change is made, it should be as nearly equal as possible throughout the whole length of the spring.

(212.) *Making a plain balance heavier.* The third method is to make a plain steel, gold, or brass balance heavier, by tinning it. The spring and all parts that would be injured by heat must be removed, the lower surface of the rim scraped to get a perfectly clean surface, but the edges must not be scraped, lest the tin should run up on them. Then rub over the scraped surface a little soft-soldering-fluid. Now take a strip of thick sheet tin, $1\frac{1}{2}$ inches broad and 3 inches long, bent into the form of a letter Z, only the middle part is nearly vertical. The heat of the lamp is to be applied to the upper part, the middle being between the flame and the balance, and conducting the heat to the lower part, upon which some block tin is melted and spread all over its upper surface. Take the balance in the pliers, at the junction of an arm with the rim, and, when the tin flows freely, rub it on this lower portion of the Z till one-third of the rim is well tinned, then treat the other sections in the same way. No more heat must be used than is necessary to make the tin flow easily, as too much would color the balance. Wash off in clean, soft water, *without soap*, then soak in alcohol and dry, being sure to remove every trace of the soldering fluid, which would rust the balance and other parts of the watch if it remained. To neutralize it, the balance, after washing, could be dipped into the soda-bath, (210,) or in water in which a little common carbonate of soda is dissolved. Then wash again, etc., as above.

(213.) Take off any lumps with the scraper, level the surface of the tin, and poise properly without the spring, etc. Then fit on the spring, and proceed as in section (209). Many workmen do not allow that this operation is workmanlike, but if properly performed, and the change makes the weight of the balance more suitable than before, it would be difficult to raise any valid objection to it. Most certainly no injury, but an improvement has resulted. It must be distinctly understood that I do not justify the two first methods in any but cheap watches, and even then it is hard to see why the workman might not about as well fit a new spring, which he could afford to do for a very little more, and no one could find fault. If he has no suitable new spring, the foregoing methods may be excusable. But the practice of scraping springs is not excusable under any circumstances whatever. It is botch-work and butchery, out-and-out, while the methods just named, if carefully carried out, may give very fair results, and the last one, results that are entirely unobjectionable.

(214.) *Regulating fine watches.* We will now consider the regulation of fine watches, in which it is not expected, of course, that any great change will be necessary, as in that case a new spring would be fitted. Supposing that we have an isochronized hair-spring, it must not be let out nor taken up to change the rate, but we must alter the balance. Even if the watch has a regulator, it should be moved but very little, as by so doing we virtually change the length of the spring, and injure or destroy the isochronism. After moving a regulator to change the rate to the extent of half a minute per day, or more, the isochronism should be tested, and if it has been injured by the change, the regulator should be replaced where it was, or where the isochronism will be restored, and the rate be corrected by the balance. This is important in all cases, but particularly so in springs with terminal curves. Of course, in watches without regulators, the rate is to be corrected by the balance only, according to the directions given. But as most watches have them, the greater portion of this article is devoted to them.

(215.) *Timing screws.* In genuine chronometer or compensation balances adjusted for temperatures, there are generally four mean-time screws,—two at the ends of the center-bar, and two others midway between them on the rim, being thus a quarter of a circle apart, and hence also termed "quarter-screws." The office of these timing screws is to adjust the rate of the watch, by screwing them further in, and thus by carrying their weight nearer to the center of the balance, to make it virtually smaller or lighter, and cause the watch to gain; or turning them out further from the center, to make the balance virtually heavier, and lose. Any alterations should of course be made equally on the two opposite screws, to preserve the poise of the balance. This can be done by noticing the slits in their heads and giving each one exactly the same angle of turn. If there is any doubt, the poise should be tested. Should it be found incorrect, the two screws must be made to restore it. But inasmuch as all watch manufacturers do not use four mean-time screws as above, it will be safer to alter only the *two* at the end of the center bar. In any case, the other pair must never be changed more than a mere trifle, because any change of a screw upon the cut section of the rim, by moving it either in or out, must infallibly disturb the compensation for heat and cold. Even if a cut balance is not adjusted, it is not advisable to alter the screws near the ends of the sections, but only those near the center bar, where their effects upon the compensation, or the errors caused in different temperatures, will be less in amount, although the effect upon the regulation will be just as great.

(216.) *Chronometer balance.* Not all cut balances, even when they are genuine chronometer balances, are compensated; and whether any particular balance is adjusted or not can only be certainly known by trying it in different temperatures. There are very few makers whose stamp, "adjusted," may be fully trusted without trial. A cut balance that is not adjusted may be either better or worse than an uncut balance; as it may happen to be very near correct, or, on the other hand, the position of the screws and the action of the sections of the rim may be so unsuitable to each other as to cause the balance to "act like the devil," when exposed to changes of temperatures. But as the adjustment of the compensation balance for heat and cold is a special subject by itself, I shall not consider it here, but merely observe that it is important to keep our watches at a temperature as nearly uniform as possible while regulating them, in order to eliminate from our task all the irregularities which would otherwise be mixed up with the action of the hair-spring. We can regulate a watch, in one temperature, but we cannot, if we try, make the regulation cover the compensation for temperatures, and by trying we shall not only fail in that, but injure our regulation besides. This rule is specially important with cheap watches. And the best are always *regulated* in one temperature and *compensated* in different temperatures.

(217.) *Screw balance.* If we have an isochronal spring with a screw-balance which is not cut, we can alter any or all of the screws in the rim indifferently, so long as we do not destroy the poise. If the watch loses, we must make the balance either actually or virtually lighter. If the screws cannot be turned in, we may either file off the heads a little, taking care to do this squarely and in a workmanlike manner, or we can drill out in the center of the heads, leaving the exterior appearance unchanged. Some workmen file out the slots wider and deeper, in the heads, when only a slight alteration is needed. Or we can take out gold screws and substitute lighter ones of brass, or smaller gold screws. Or, if change enough is required, we can remove an opposite pair of screws entirely. On the other hand, if the watch loses, we can turn out one or two opposite pairs a little. If that is not sufficient, turn out others equally far, being careful not to draw out either of them more than the rest, and drawing out more screws rather than move a few too much. We can also substitute gold or platinum screws for those of lighter metal, or substitute larger screws, or put in an additional pair to increase the weight of the balance. These changes of weight will slightly disturb the isochronism of the spring, which must be readjusted as already directed. If the watch has a regulator, the isochronism can generally be restored by opening or closing the pins, (125.) If not, it can be done as per section (136,) or, in the case of a terminal curve, by slightly altering that, (156,) after the watch is closely regulated for time. But the isochronism should never be corrected by the regulator pins with any but the plain flat spiral springs.

(218.) *Making a plain balance lighter.* If, instead of a screw balance, we have a plain one, whether of gold, brass, or steel, the best way to make it lighter is to hold it by the exterior of its rim in one of the step chucks of the American lathe, or any similar way, and turn out a very little with the graver, on the under side, being careful not to cut away too much. In this way, with due caution, the poise will not be disturbed. Others simply file a little from the inner edge of the under side of the rim, equally in three different places, to preserve the poise. The only way to make a plain balance heavier is to tin it, (212.)

(219.) *The effect produced upon the isochronism of a hair-spring by moving its regulator* is, in general, greater in the short vibrations than in the long ones. Turning the regulator towards the "slow" makes all the vibrations slower, but the short ones proportionately more so than the long ones. And, *vice versa*, turning the regulator towards the "fast," not only makes the watch gain, but also causes the short arcs to gain on the long ones. If the spring is isochronal, and the watch gains or loses but little, the error of rate should be corrected, not by the regulator, but by altering the balance. But if the balance has no screws, such alteration would be troublesome, and we may prefer to move the regulator to correct the rate, and then restore the isochronism by opening or closing the regulator pins a little. This course is more often allowable when the required motion of the regulator is towards the stud than when away from it. But when the error of rate is considerable, we must move the spring through the stud, bearing in mind the requirements of isochronism, in the flat spiral spring, (the Breguet spring will be specially noticed in section 222,) as to maintaining the relative positions of the *points d'attache*, etc. That is to say, after taking up or letting it out, we must restore their previous relative position, (if correct,) by altering the central coil, etc., as in sections (137 to 140.) If that alteration of the spring, etc., is not allowable or practicable, on account of destroying the correct proportions of the central coil, (38, 39,) or for any other reason, then we must change the weight of the balance to the required amount, as already described, or, if too much change is needed, a new spring should be fitted; for we must perform the regulation in such a way as not to destroy either the harmonious proportions of the movement or the isochronism of the spring, and to improve both if possible.

(220.) But it is always a grave question for the workman to answer to his own sense of right, how far he is justified in permanently altering a watch by changing the weight of the balance, to save himself the trouble of fitting a new spring. Even in cheap watches he would require a strong excuse for removing or adding a pair of screws, or very much changing the weight of a balance by tinning or filing it; and in good watches it could only be allowed on the supposition that the weight of the balance did not bear a correct proportion to the motive force of the mainspring. If this proportion was correct, then his duty would be to conform the strength of the hair-spring to the weight of the balance, so that the balance and hair-spring, as an entirety, would be suitable to the movement. The altering of the balance to conform to the strength of the hair-spring, in such a case, would destroy the correct proportions of the entire movement, and such a practice should only be followed within very narrow limits.

(221.) In watches with regulators, the adjustment of the isochronism becomes more difficult as the distance of the pins from the stud increases. So much so, that many high authorities have claimed that a spring cannot be isochronized at all with a regulator,—probably because, in bringing the watch to time, they had got the regulator too far from the stud. There is no denying that, theoretically, the action of the pins renders a perfect progression in the increase of elastic force impossible,—since the spring cannot vibrate as it would if it ended at the regulator, nor as if its action extended to the stud uninfluenced by the regulator, but there will be a mixture of the two, varied by the effect of the pins, and further complicated by the reverse action of the portion of the spring between the pins and the stud. But, practically, if the spring has been fitted in accordance with the instructions heretofore given, and the pins are near the stud, we can so add to or take from the composite action resulting from all these different influences, as to secure a correct progression of strength, and consequently isochronal vibrations. The workman should endeavor, in regulating his watches with flat spiral springs, to keep the regulator as near the stud as possible, not only for the sake of the isochronal perfection of the spring's action, but because even the regulation to time is more easily and closely effected by so doing. It should also be remarked that the effect of opening or closing the pins increases as they are nearer to the stud, so that the isochronal adjustment is more easily made, or restored, when disturbed by moving the regulator. If the regulator cannot be got within 20° or 25° from the stud when the rate is correct, it is well to move it to different positions, and test the isochronism in each, to find the best place—paying no attention to the rate till the point is found where the isochronism is nearest correct, then bring to time by the balance screws. But if this will take the regulator more than 45° distant from the stud, it is better to take up the hair-spring, to bring the regulator back, then adjust the isochronism. Many workmen claim that when the regulator is more than 20° or 25° from the stud, the even coils should invariably be reckoned from the point touching the collet to the regulator pins instead of to the stud, (134, 135.) And if the watch does not give correct time with the regulator in that position, the balance screws should be altered. It should also necessarily follow that if the hair-spring has to be taken up or let out, the regulator should be moved correspondingly, in order to retain the whole coils; and when the isochronism is correct, if the rate is not, then it should be corrected by the balance, not by moving the regulator, as that would again destroy the isochronal adjustment. If these views were correct, then any change in the length of the spring which might be required to secure isochronal vibrations, could be made by simply moving the regulator in the proper direction and distance, afterwards restoring the rate by the balance screws. But they are not correct, as a rule, although they are, to some extent, in many cases; as, for instance, when the regulator is altogether too far from the stud, say from one-quarter to one-half coil distant. In such a case the isochronal action would probably be better if the even coils were taken from the collet to the regulator pins than if to the stud. But in neither case would the action be as good as if the parts were all in the positions we have before recommended. It has already been stated that the theory of even coils is merely approximative in any case, (135,) and the actual position of the isochronal point in the spring must be found by trial. So that, even when the r views are in the main correct, they must be followed with this qualification.

(222.) *Regulating the Breguet spring.* It has already been stated that, before taking down a watch with an isochronized hair-spring, the workman should examine and make a minute of the position of the regulator, the position of the spring between the pins, and the width of opening, in order to restore everything to precisely the same condition when done. This is especially important with a Breguet spring, for reasons before given. But when an error of rate requires the *status* to be changed, there are certain points to be observed in the regulation of the

Breguet spring different from that of others. We first ascertain whether the terminal curve extends to the stud, or only to a concentric arc, or portion of a coil, which is pinned to the stud. This can be told by moving the regulator. So far as the spring retains the same position between the regulator pins, the coil may be considered concentric. But if the spring, from being free between the pins, soon presses against the outer pin, as the regulator is moved away from the stud, the point where this outward divergence begins may be considered the end of the terminal curve, from which point it sweeps gradually outward till it reaches the normal spiral form at the exterior coil of the spring.

(223.) *With terminal curve to the end.* If the former is the case, or the terminal curve extends to the stud, the workman should conduct the regulation to time with the aim to get the regulator as near to the stud as possible. And to this end, he should make the watch go slower by moving the regulator towards the stud; but he should not move it from the stud in case the watch must be made to go faster, but, if practicable, produce that alteration by means of the balance, (215.) If he was able, without much change in the weight of the balance, or alteration of its screws, to cause the watch to gain sufficiently to allow of bringing the regulator entirely to the stud, it would certainly be wise to do so, for he would obtain the very best conditions for the perfect action of the terminal curve—simulating a spring without a regulator. The more closely to the stud he can bring it, the more nearly will the curve be free from restraint, and able to produce the legitimate effect sought for by its form. When springs whose curves reach to the stud are provided with regulators, every shifting of the regulator must be accompanied by a bending of its pins to conform properly to the spring in its new position; but the spring must never be bent to give it freedom between the pins of the regulator, as that would at once destroy the correctness of the terminal curve.

(224.) *With concentric arc at the end.* On the other hand, if there is, between the end of the terminal curve and the stud, a concentric arc, (173,) then his aim should be to bring the regulator to the point where the spring changes from a concentric to a divergent form. When the watch loses, he should move the regulator from the stud towards that point, and when it gains, he should not move the regulator back, but draw out the screws of the balance. When the watch keeps time with the regulator at that point, and with the pins well closed together, the position of all the parts is the one most favorable for securing isochronism that the spring, in its then shape, is capable of giving. If the isochronal action is not satisfactory, the curve should be altered as already directed, (156, 157.)

(225.) *With too long concentric arc.* But the preceding section is correct only when the concentric portion is within the limits prescribed in section (176). If its length exceeds 45°, it is evident that the supplemental coil has not been formed with proper regard to the requirements of isochronism, as there stated, and we shall obtain better results by modifying the course taken in section (224). If the watch loses, the correction should not be made either by the regulator or by the balance, but by drawing the spring through the stud; while, if it gains, the balance screws should be drawn out. If, by taking up the spring and drawing out the balance screws to a reasonable extent, we can bring the end of the terminal curve (and the regulator pins) within 45° from the stud, or less, we may hope for fine action of the spring. But if that point is more than that distance from the stud, even though we have the regulator pins at the end of the terminal curve, we cannot expect perfect isochronism. The regulator should never be moved beyond that point, and on the terminal curve, to make the watch go faster, but either take up the spring or turn in the balance screws to cause the gain in time. Nor should the spring ever be let out to produce a slower rate, if that alteration would carry the end of the curve more than 45° from the stud, but we should draw out the balance screws for that purpose.

(226.) *Recapitulation.* Lest this subject should seem complicated, I will recapitulate briefly. 1st. If the terminal curve of a Breguet spring reaches to the stud, the object should be to conduct the regulation or alterations so as to bring the regulator as near the stud as possible; and rather than move it *from* the stud, the balance should be altered. 2d. If there is a concentric arc at the end of the spring, the aim is to bring the regulator to the junction of the concentric and divergent portions of the spring, and all alterations should be made to favor that purpose. 3d. But if this junction is over 45° distant from the stud, the chief object is to reduce that distance to 45°, or less, and the next is to bring the regulator to the junction; and all changes must be made so as to favor the first object, *if at all possible*, and if not, then to favor the second. Whenever any of these changes disturb the isochronal adjustment, it should of course be restored, in the most convenient way.

(227.) These directions are based on the supposition that the workman is willing to take a little extra trouble for the sake of improving the isochronal action when it is not perfect. But if he cares for nothing but to bring the watch to time in the easiest way that will do no harm, or as little as possible, he should make his corrections of the rate principally by the balance. But whether he does or does not observe these rules, he will at least know how he may secure the most perfect results, if he so desires, or how to avoid injuring the timepieces in his care, when he has the choice of modes in which to make necessary alterations. If he only travels a little way in the paths recommended, or even only avoids taking wrong ones, that will be much better than working in the dark, not knowing whether he is improving or ruining his jobs.

(228.) There are different degrees of excellence in Breguet springs, represented by the three preceding classes, in their order. Yet even the third and lowest degree, with a concentric arc greater than 45°, and the regulator far from the junction, is without doubt much better than a plain flat spiral not isochronized at all, because the outer coil of the former can contract and expand more evenly on all sides of the balance axis. But we should not be contented without doing in every case the very best we are capable of doing. If we are fitting a spring, let us fit it in the manner that will give the best action; if we are only regulating a spring already fitted, let us strive to obtain the best results which the form of the spring can yield. Only thus can we improve in our art, impress upon our memory the maxims which lead to perfection, familiarize ourselves practically with the finer manipulations, and gain the delicacy and dexterity which we should need if we were called upon to do a perfect job, but which we could not possess unless we had obtained experience by following the above course in our work, even upon cheap jobs or those in which we get no pay for our extra care.

(229.) *Acceleration of rate.* I have already alluded to a phenomenon (23) noticed in fitting new springs which have been hardened and tempered, viz., that they accelerate on their rate for the first few weeks or months, and then, having attained their highest degree of pliability and elastic force, become constant. For this reason, the watch or chronometer cannot be regulated immediately after fitting such a spring, to maintain a perfectly uniform rate for a long period. But after bringing it closely to time, the mean-time screws may be drawn out to cause a loss of a few seconds per day, (two to five, generally,) by which means it will take nearly a correct rate after the accelerating process is ended. The amount is, of course, a matter of guess work, but a moderate alteration will make the final rate nearer correct than if there had been no change. Where the precise permanent rate must be known, as in marine chronometers, whose error of rate is a vital element in the calculation of longitudes, etc., it is necessary to await the completion of this acceleration before a trustworthy rate can be got. Cases occasionally occur where the spring continues to change for several years, but generally they do so only for a few months.

(230.) *Effects of magnetism.* Besides the condition of the watch itself, we have to guard against an external disturbing influence which often produces vagaries in the regulation so incomprehensible as to cause the workman to give up in despair of overcoming them. This influence is magnetism or electricity, and is more commonly felt than is supposed by the majority of workmen. It has already been said that the balance should not be magnetized. Chronometer makers fully appreciate the importance of this point, and guard against it by causing their balances to vibrate a turn and a quarter. By this means a balance is secured from any injurious effect even if it is magnetic. A magnetized balance has a constant tendency to turn to some particular position, but with the above arc of vibration this tendency is neutralized, by the retarding and accelerating influences counterbalancing each other during the course of the vibration, so that no effect is produced upon the rate. Another advantage of vibrating 1¼ turns is that the effect of a want of poise is less than if the arcs are either greater or smaller. It is scarcely necessary to say that the advantages thus secured are not confined to marine chronometers, but may be obtained in the same way for all watches, by giving that vibration, when their balances are wholly or partly of steel, iron or nickel. Balances of gold or brass are not affected by magnetism, but steel screws used in their rims, or elsewhere in their construction, may have a disturbing influence. In going-barrel watches, whose balances have varying arcs from the varying motive force, if we make the average between the largest and smallest vibrations to be 1¼ turns, we practically secure the advantages named as well as can be done in such cases.

(231.) But the above precautions will not prevent evil effects from the application of a magnet near to a watch, and the effect is the same whether the case be open or shut. Powerful electro-magnetic batteries or machines will magnetize a watch at a distance of several feet, and persons who work around batteries, etc., should lay their watches aside during working hours. Even if the balance is of gold or brass, the magnet may attract the lever so strongly as seriously to disturb the rate. Never allow any magnet or magnetized piece, loadstone, electric machine, galvanic battery, conducting wires, etc., near a fine watch, or carried in the pocket with it. Thousands of watches have been ruined by fooling around them with magnets, etc., either knowingly or ignorantly, and when the watches are not injured by such a practice, their running is disturbed. It is often thought that a solid or uncut steel balance cannot be affected by magnetism, because it is a circle. But the arms have ends, and may be magnetized or attracted the same as plain bars, notwithstanding that they are attached to a rim. A watchmaker should take no chances in such matters, but avoid even the possibility of his adjustments being interfered with by this or any other influences known to be injurious. If the owner insists on exposing his watch to injury, it is his privilege to do so,—and to pay for it.

(232.) *Testing for magnetism.* Whenever it is suspected that a watch is magnetized, it can easily be tested by dipping the steel parts into clean, fine iron filings, having first made the pieces free from moisture, oil, etc. If magnetic, the filings will adhere to them, and most plentifully at the points where the magnetism is the strongest, or "poles." Another way is to hold the suspended pieces very near to a small and well balanced compass. This is specially adapted for testing balances, springs, etc. If no part of them shows any tendency to attract one pole of the compass more than another, they may be considered free from magnetism. But if one part cause the North pole to move, and another the South pole, they are of dubious value, for in whatever position the watch is placed, they will be affected by the earth's magnetism. As far as my experience goes, there is no remedy but either to bring the pieces to a red heat, or replace them with others.*

(233.) *Effect of running down.* In conclusion, I may mention a fact not generally known:—that if a watch which has been closely regulated is allowed to run down, its rate will almost invariably be different when again wound and set going. Whether the change of rate is due to the relaxation of the mainspring when relieved from tension, or whatever the philosophy of it may be, we may derive from the fact a useful practical lesson,—not only to guard against such a mishap while regulating our watches, but, when it does occur, to avoid moving the regulator to correct the error. Many watchmakers allow their watches to run down every Sunday, to save the trouble of winding on that day. This is a great mistake, for it generally takes them several days to fully recover their former or permanent rate, and if the regulator is changed before this takes place, it is evident that an injury is done which will have to be undone again when it has returned to

* I find in *Scribner's Monthly* a method of demagnetizing watches, discovered by Prof. Mayer, of the Stevens Institute. If any watchmaker succeeds in really and permanently restoring a magnetized watch to perfect condition by this or any similar method, I would be pleased to learn of it, either directly, or through the columns of the *Jeweler's Circular.* Only a practical workman can judge as to the reality of the remedy, which will be found in the Appendix.

its normal condition. It is well to keep customers' watches running till they are called for, unless they are left for an unreasonable length of time. So, also, sale watches which have been closely regulated, and from which purchasers will expect fine performance, should be kept running. But if they have been allowed to lie still for a while, no account must be made of their rate for the first week after rewinding—simply giving that time for them to settle down again. At the end of the week, set them, without changing the regulator, and they will generally run the same as before. If they do not, it will then be safe to move the regulator, and bring them to time in the usual way.

PART SIXTH.

THE ADJUSTMENT FOR HEAT AND COLD.

(234.) *Adjustment to temperatures.* The compensation for heat and cold completes the list of adjustments which are found in the modern fine portable time-piece. It may be accurately adjusted to positions and isochronism, and yet be utterly untrustworthy for time. Every change in the weather, or other circumstances, however trivial or unavoidable, which warms or cools the movement, will produce an error in the rate, which may vary from a few seconds to as many minutes in a single day. Change of temperature affects the time given by a watch or chronometer in three ways:—1st. Heat expands the balance, making it, for the time being, of larger diameter, and causing it to vibrate more slowly. 2d. It expands the hair-spring, making it longer, and causing a loss of time. 3d. It diminishes the elastic force of the hair-spring, causing a still greater loss,—the effect produced upon the hair-spring being much more than that upon the balance itself. The opposite of the effects above noted takes place in cold.

(235.) The first attempts to remedy these errors were by contrivances acting upon the hairspring—an example of which is the "parachute regulator," often seen in old escapement or anker watches, which opens or closes the pins of the regulator by means of a compensating quadrant, as the temperature changes. It would be very interesting to examine the various methods of compensating for the effects of heat and cold which have been proposed at different times, and trace the progress of invention from the first crude ideas through successive discoveries and improvements, but the practical character of these articles forbids. At the present day the means almost universally employed for that purpose are embodied in what is generally known as the chronometer balance, more correctly termed the compensation balance of ordinary construction. Of the other forms proposed, only three seem to have any great practical value, viz.:—Dent's, Hartnup's, and Kullberg's. Fritz's balance, with adjustable radial compensating segments, lately described in the horological journals, is certainly very promising, and based upon the correct principle, but as yet has not the standing given by long practical trial, like the others named. Should it prove stable and permanent in its action, as claimed by its inventor, and which there seems to be no reason to doubt, it will give its competitors a hard pull in the race for precedence.

(236.) *The compensation balance of ordinary construction* consists of a steel center-bar, carrying a circular compound rim, which is cut into two or four sections, each having one free end and the other end attached to the center-bar. This rim is composed of two metals, which are unequally affected by heat and cold, usually steel and brass. The brass expands and contracts much more than the steel, and it is by means of this difference that the rim "compensates." When the balance is exposed to heat it expands and the watch would consequently run slower. But this is counteracted by the action of the rim, which, from the brass being outside and expanding more than the steel, curves the free end of the rim inward, and carries the weight or screws upon it towards the center of the balance. In cold the whole balance contracts, and, from being smaller, would vibrate more rapidly, but the brass exterior contracting more than the steel, tends to straighten the rim and carry its screws outward, thus neutralizing the effects of the cold. The first balances of this kind were made by fastening the steel and brass strips together by rivets at frequent intervals, and afterwards they were soft-soldered together. At present they are united either by hard-solder or melting the brass upon the steel.

(237.) *Making a balance.* In making this balance, a piece of the best cast steel is selected, a hole of proper size drilled through the center, it is then mounted on an arbor and turned perfectly flat on both sides and on the edges, which should be parallel to the sides of the center-hole and at right angles to the flat sides. We then have a round piece of steel, of the thickness of the rim of the proposed balance, and of the exact diameter to be given to the steel part of the rim. The brass is then either melted on the outside, or a piece of brass is stamped out, of the right size, and soldered on. Some prefer one method, some the other. But there is probably but little difference between the products of each, when equally well made.

(238.) *Uniting the metals by fusion.* When the brass is to be melted on, the hole in the center of the circular steel plate is first filled up with plumbago, pipe clay, or even fine chalk pressed in wet and allowed to dry. Some turn out a plug of slate pencil to fit the hole perfectly, and many other means are employed to prevent the melted brass from entering the hole during the process. It is indispensable that this hole remain unaltered, as upon it depends the truth of all the parts and the equal action of the segments when finished. The outer edge of the plate must be perfectly clean, to secure a perfect union and adhesion of the metals throughout the whole rim, and thereby insure equal and uniform action in all its parts. Some makers even gild the steel to prevent any danger of oxidation of the metal. The surface is then coated with powdered borax and water in the usual way, which is allowed to dry, the steel plate is then placed in a crucible, or in a heated mold of fire clay or soapstone. In the former case, enough of the best brass is put into the crucible to surround and cover the steel plate when melted, and the whole is exposed to the fire in a suitable stove or furnace, till the brass melts and flows freely, then the whole is immediately removed and allowed to cool gradually. In the latter case, the brass is melted separately. As soon as it becomes thoroughly liquid, and the characteristic greenish flame appears, it should be poured into the red hot mold. Old English watch movements are found to furnish brass which is generally very satisfactory. The melting should be done by a charcoal or coke fire. The fumes from coal are very objectionable, especially from soft or bituminous coal, and ordinary wood is not much better, unless thoroughly seasoned and dry. When the brass is to be soldered on, a thin film of silver solder is interposed between the steel plate and brass ring when the latter is driven on, plenty of borax applied, and the whole is carefully exposed to heat till the solder flows satisfactorily.

(239.) *Finishing the balance.* When cold, the center-hole is cleaned out, the superfluous brass filed off the sides, and also on the edges till it is about three times the thickness it is to be when done, then the rim is carefully hammered to harden the brass without denting it or breaking the grain. This hammering should bring the rim to about the diameter it is to remain, so that as little as possible of the metal will have to be turned off, as that would remove more or less of the hardened surface and impair its value. The edges and outside of the rim are turned perfectly flat and true, and the inside of the steel plate is turned out in such a way as to leave the metal at the bottom of the cavity, of the thickness the center-bar is desired to be, and the steel part of the rim about one-half the thickness of the brass portion outside.

(240.) The bottom is next pierced and filed out, leaving the center-bar of exactly the same size and shape on each side of the center, and the rim of the same thickness from edge to edge, without filing or scratching the portion of it which was cut out in the lathe. It is then drilled and tapped for the screws, the number of which varies. American watches generally have thirteen holes on each half of the rim. Some makers locate the holes at a progressively decreasing distance apart as they approach the free ends of the segments,—others make them an equal distance apart throughout. This is not material, but it is absolutely indispensable that each opposite pair of screws be exactly in a diametrical line passing through the precise center of the balance. Instead of screws, chronometer makers often use sliding weights, which may be moved along the rims and fastened at any desired point by a set-screw. But the use of screws for compensating is becoming the rule. The balance is then set up in the lathe again, and the rim polished. It is now cut, generally near the center-bar, so as to form two long sections or segments, but sometimes midway between the ends of the center-bar, thus forming four shorter segments. The drilling and cutting are best done by the help of a dividing engine, to insure exactness, and so that the two segments should be of precisely the same length, and shape of cut. It is necessary that all the opposite parts of the balance be of exactly the same thickness, shape and weight, as otherwise, even if the balance was in poise at the mean or middle temperature, it would not be so when the segments had changed their positions under the influence of heat or cold, for their unequal motions would carry the compensating screws to different distances from the center, and render the rate utterly unreliable in different positions, or in carrying. It must also be staked or riveted concentrically upon the balance staff, as any fault here would vitiate all previous painstaking.

(241.) *Cutting the rim.* Where the rim shall be cut is determined largely by the construction of the balance itself. Every maker tries to have a definite system, which he rigidly adheres to, and by this means he produces balances comparatively uniform, or at least having a certain character. The balances of some makers are more sensitive than those of others. The former do not need so long segments to produce the same effect. And each maker will by careful observation and experience find the length of segment which is suitable to his balances. Very long segments are apt to be irregular in extreme temperatures, while short ones may not have action enough to effect a compensation. If the rim is sufficiently sensitive, it may with advantage be cut into four equal segments. But, in any case, when there are but two compensating segments, the cut should be far enough from the center-bar to afford a good hold upon the balance while handling it, without the fingers pressing on the free ends of the segments.

(242.) *Trueing up a balance.* When the rim is cut apart, the segments fly "out of round," and require to be trued up. This is always done by hand, by very gradual and gentle curves, and is a somewhat tedious operation. In trueing a balance, whether new or one that has been bent, use no pliers or other tools to bend it into shape, but spring it very carefully with the fingers. If a rather sharp bend is wanted at any particular point, place the thumb or finger nails at that point as a support, and spring the segment on each side, against the nail. The novice must use the utmost care, or he will bend it too much, or in some screw hole, and will be very likely to crack it, when it will be ruined, beyond the power of the cleverest workman to remedy. At first he had better practice only on abandoned balances, till he has acquired a little skill and experience. To find the change required, place the ballance in the calipers, or even in the "turns," with sufficient pressure on the pivots of the staff, (or the arbor, if it has not been staked upon the staff,) to hold it in any position it may be placed in. Then set the rest of the lathe, or slip-piece of the calipers, to barely touch the upper edge of the rim with its sharp corner.

(243.) *Eccentric balance.* First test if the balance is staked upon the staff concentrically. If so, the outside of the rim, at the end of the center-bar, will be equally distant from the center, or will touch the rest alike. If not, perfect action cannot be expected, for it is evident that the two segments have different centers of motion from which to act in either direction under change of temperature. But if this error is not too great the balance may do for ordinary watches. The quickest and best way to remedy this, (without bending the staff or pivots,) is, probably, to drive the balance off the staff, turn or stone it down a little smaller, so that the balance will go on somewhat loosely, then, by riveting it a little harder on one side than the other, throw the balance a little further out on that side, and make the rim concentric. If the balance hole was already too large for the staff, and that was the cause of the eccentricity, re-staking properly will bring it concentric with the pivots. Or if the arbor of the staff was not concentric with the pivots, it should be made so in the lathe, and the balance then riveted concentrically upon it. Never attempt to bend the arms of the center-bar, except to straighten or level them after some botch has bent them out of shape; such a balance is of little value for accurate performance.

(244.) *Rounding the balance.* The rim being concentric at the ends of the center-bar, turn the balance slowly with a piece of pegwood, and note where the rim begins to go in or out from the true circle indicated by the sharp corner of the slip-piece or rest. Have ready a little whiting and oil, mixed, and mark the rim with a speck of this, on the outside where it begins to go out, on the inside where it begins to go inward. So go around the whole rim, marking every such place, and you will have a clear idea of the condition of the balance. In trueing, take one segment at a time, begin at the center-bar and work from there to the end of the segment, testing it after every alteration before making another, till it is true to the end. Then true the other segment in the same way. All this should be done at the middle temperature for which the balance is to be adjusted. If the extremes are to be 30° and 120°, the mean will be 75°, at which temperature the balance should be caused to be round or concentric. If the extremes are 55° and 95°, the mean will be 65°. The temperature of the adjustment-room should be kept at that degree, and if the heat of the sun, stove, lamp, fingers or breath, should warm the balance above that, it should be cooled in a dish of alcohol before testing the roundness in the calipers, as the balance will not be round when it is either warmer or colder than that temperature. Should there be jewels on the staff which are fastened in with shellac, the alcohol would loosen them, and water should be used instead. After rounding the balance, it is then heated on a metal plate to from 140° to 155° Fahr., and, when cooled to the above temperature, if not round, it is rounded again as before. This heating and rounding is repeated if necessary. The object is to temper the balance, and free it from the tension or strain which the hammering process produces in the metals. Otherwise, it would be very likely to change its form gradually, while running, and derange the rate. If the balance is hammered too much in making, or not heated enough afterwards, the rim will probably curve inwards and "set" in that shape, causing a gain in time. Or, if not hammered enough, or heated too much, it will spring outward and lose time. In warm weather, merely handling the balance with the bare fingers is liable to cause the segments to "set" differently. They should therefore be handled as little as possible. See that the rim is true in "the flat," as well as in "the round," which should always be tried with the balance in the vertical position, or edge upwards, so that the segments may assume their natural position as regards flatness.

(245.) *Poising the balance.* Then poise it accurately, (71,) with the screws (except the timing or quarter-screws,) turned clear in, but not tight. If they were screwed in tightly, the pressure of their heads against the rim would affect its curvature while the brass part of it was expanded under the influence of heat, and might even cause a change of shape in the rim, which, from the method of its production, is comparatively soft. The above directions apply only to new balances. We often find balances in use having their screws all considerably turned out to make the rate slower. In that case we must let them remain so, if the rate is correct and the opposite screws are at equal distances from the center, as turning them in would necessitate the fitting of a new hair-spring. But if we have orders to make everything right, as it should be, we ought to turn the screws home, as directed above, then fit a hair-spring which will give correct time,—provided the balance is of the right size and weight for the movement. If not, it should be entirely discarded, and a new one put in. Also now test the balance for magnetism, (232,) if it has not been done before.

(246.) *Irregular action.* Whenever a balance shows any irregularity in time, it should be tested as to its *poise in extreme temperatures*, say 35° and 120° Fahrenheit. And it is well to test the balances of all fine movements before beginning the compensation. Sometimes the brass and steel are not firmly united, and will separate more or less under change of temperature. This defect may not be so great as to be discoverable by prying the metals apart, and yet cause the two segments to operate very irregularly and differently. Sometimes the rim is "out of round," or not truly circular, when the segments will spring in or out differently, from their different shape or curvature. Sometimes one segment has been bent accidentally and trued up again, or for some other reason one segment has been bent back and forth more than the other, and as this bending impairs the elasticity and changes the condition of the metals, its action will be different from than of the other segment. It is of the highest importance to handle a compensation balance with the utmost care, to avoid the slightest springing or straining of the segments. Flaws or defects in the metal or workmanship of the balance will also cause a difference of action in the segments. If one side has been bruised or dented in the hammering process, that side will show the effects ever after. Care should also be taken not to expose a balance to a heat exceeding 130° to 140° in waxing it on the lathe, or for any other purpose, and not for any length of time to that temperature, as it is liable to cause the segments to "set" more or less differently from their former shape.

(247.) *Poising in extremes* may be done by placing the balance properly in the notches of the poising tool, (73,) and then exposing it to heat and cold in the manner hereafter described. If its position is found changed when the oven or cold-box is opened, the segment found down in cold, or up in heat, has acted more strongly than the other, and both should be closely examined. If its position has remained unchanged it may be inferred that the error is very small, if any exists, provided the poising tool is in good condition. But if the balance is very small and light, a considerable error might fail to be detected, owing to the mass or weight moved being too slight to overcome its inertia and the friction of the pivots. In such cases, a wire can be passed through the wall of the adjusting oven or cold-box at any convenient place, bent into a ring on the outside for convenience of turning, and split inside to hold a bristle. The balance should be placed where the bristle can touch its rim, and after the desired temperature is reached give the wire a twist, which will cause the bristle to strike the balance inside and whirl it around. In the oven the balance can be observed from the outside, and several trials made before opening it. But in the cold-box it will be necessary to open it and see the position of the balance at each trial. If it stops in all positions indifferently, it may be considered to remain in poise at all temperatures. But if one side is repeatedly found down, in heat or in cold, the error must be traced out and corrected before proceeding further.

(248.) *What is compensation?* Having our balance in the watch and running, let us consider what it should do. We have already seen that in heat the greater expansion of the brass exterior of the rim will curl the segments inwards, and carry the screws or weights towards the center. In cold the greater contraction of the brass carries the weight outwards, and thus compensates for the contraction of the entire balance, which would otherwise cause a gain in time. Obviously, the weight should be carried inward in heat, and outward in cold, just enough to make up for the expansion or contraction of the balance, the effects of heat or cold on the hair-spring, and all other changes resulting from the change of temperature. Whether it does so or not can only be told by actually trying it in heat and cold. Even when marked "adjusted," they seldom can be safely guaranteed to be closely compensated, till they have been tested and their actual performance ascertained. As a general rule, any movement costing less than $50 may be considered doubtful. The custom with movements of that class is to test them, and those which perform with tolerable accuracy are marked "adjusted," while the rest are sold as unadjusted. It will be seen that even the former are really not *adjusted* at all, but only found to be close. Watchmakers who have many customers for fine watches can frequently make it profitable to buy these unadjusted movements, and adjust them themselves, thereby raising them to the value of the adjusted movements of the same class. The process is somewhat tedious and troublesome, but this is largely compensated for by the number which may be under way at the same time, with but little more trouble and expense than one would be.

(249.) *Over-compensation.* Instead of the weights or screws on the rim being moved inward and outward just enough to compensate for heat and cold, they may be moved too far, or not far enough. In the former case, the watch is said to be "over-compensated." It will gain in heat, because the weights are carried too near the center, thus making the balance virtually smaller; in cold the weights will be carried too far outwards, and cause a loss of time. The segments act too strongly, but as we cannot change their action, we must find some means to lessen its effects. It would not do to lessen the weights, as that would cause a gain in time by making the balance lighter. But we can move the weight or screws back from the cut ends of the segments towards the center-bar. The motion of the segments inward and outward being greatest at their free ends, the further back we place the screws, the less they will be moved. So that we can regulate the effect produced to almost any degree. For it is evident that if the weights were placed just at the ends of the center-bar, there would be no compensation at all, except that produced by the weight of the segments themselves. And we have the entire length of the segments as a range for the weights, according to the effect we desire. Sometimes the action of the segments is so strong that they compensate too much, even when the screws are all moved back as far as they can be. In such case, we must substitute lighter screws in place of those nearest to the ends of the segments, and correspondingly increase the weight of those next to the center-bar.

(250.) *Under-compensation.* On the other hand, if the watch loses in heat and gains in cold, the weights are not carried far enough to produce the required effect, and it is said to be "under-compensated." The remedy for this is the opposite of that for over-compensation, viz.: to move the weights or screws nearer to the ends of the segments, and increase the effect produced by their motion. In making these changes, the screws must, of course, be moved in pairs, to prevent destroying the poise of the balance. Take out one of the screws, and change to another hole, nearer the end, if we wish to strengthen the compensation, or further from the end, if we desire to weaken it. Then move the screw which was exactly opposite to it, in the same way. We frequently need to move several pairs, and not merely one hole, but perhaps change their position by several holes, according to the indications of the trials. If the compensating action is so weak that even massing the screws at the ends of the segments does not produce sufficient effect, we can substitute heavier screws for those nearest the ends, and lighter ones for those furtherest back,—as, for instance, screws of gold or platinum for those of brass or aluminum; and the reverse may be done for over-compensation. But in making these changes, the total weight of the balance must be kept the same, otherwise the rate will be altered.

(251.) *Range of the adjustment.* The range of temperature for which the balance is adjusted varies with the ideas of the manufacturers, or the climate in which the chronometer is expected to be used. For temperate climates, a range from 50° to 90° is thought to be sufficient. Many makers adjust only for 50° to 70°. For hot climates, 60° to 90° is considered ample to include all ordinary vicissitudes of temperature. 50° to 85° will generally cover the temperatures to which ship chronometers are exposed on board. And instruments have been carried with expeditions to the polar regions without experiencing any greater range than that, owing to the care taken of them. But pocket watches should be adjusted for a range from 35° to 95°, in order to cover the temperatures to which they will be frequently exposed. During the day they are kept warm by contact with the person, while at night they are often exposed to the temperature of freezing, zero, or even lower. Some American watch companies adjust from about zero to about 130°. This, however, is rather more than is beneficial, as the residuary error spoken of in a subsequent section becomes very considerable in so extended a range. And besides, the errors at such extreme temperatures do not always indicate or correspond to those found at the more ordinary temperatures in which it is commonly used. For a balance may perform quite satisfactorily in the latter, and then afterwards show a considerable error when exposed to the former, so that such tests are not necessarily trustworthy guides as to the real value of a balance. We should adjust for a range that will include the reasonable exposures to be expected, and then divide up the error between the mean and the two extremes, so that it shall nowhere be very large.

(252.) *Length of trials.* The length of time the trials should last also varies according to the circumstances of the case. In the first trials, six hours will generally be sufficient to show the error clearly. But as each correction diminishes the error, the length of the trial must be increased to twelve, and finally to twenty-four hours. Where great accuracy is required, chronometers are often kept for a week in heat and cold alternately. In all cases, the same period must be taken for heat, cold and mean temperature, so that the results can be safely compared. If the trial in one temperature is for six hours, the others must also be for six hours. The longer trials not only give time for the errors of compensation to accumulate to an appreciable quantity, but they have the further advantage of averaging errors due to other causes, as lack of isochronism, mechanical defects, etc.

(253.) *Requisites of compensation.* It is always desirable, and is supposed to be the case, that before the trials for compensation commence, the movement shall be in perfect order,—the escapement particularly being as closely adapted as possible, adjusted to positions, the hairspring closely isochronized, regulated to mean-time, and observations made by a regulator whose rate may implicitly be depended upon as correct and uniform. If there is any doubt on any of these points, the trials should be repeated, to ascertain if the results coincide. If not, it is evident that the errors arise from some other source than the compensation,—unless the balance is defective as noted in sections (243, 246). If the adjustment to positions has not been made, the movement must be placed in exactly the same position during each trial. And at the final trials, in order that the adjustment may be relied upon as perfect, the chronometer is kept a week in cold, then a week in heat, and lastly a week in cold again. This gives time to develop the actual performance of the instrument. Then finally test for a week at the mean temperature, and get the rate as correct as possible if it has been disturbed by any of the changes made during the adjustment, or by the tests, for when a chronometer has been going for some time at a very high or low temperature, the rims frequently "set" a little, causing a change of rate at mean temperature.

(254.) When a balance is properly compensated, the adjustment is not altered by changing the hair-spring, or changing its length in bringing it to time, although it may be considerably longer or shorter than before, or than the old one was. The explanation of this lies in the fact that the heat or cold affects the spring in the the same proportion, or percentage, whatever its length may be. For instance, if we suppose that the heat is sufficient to expand a spring one-fiftieth in length, it does not matter what the real length may be. One spring may be twice as long as another; then the increase of length in the former will be twice the amount of that in the latter,—but both will be *increased by one-fiftieth.* So if the cold increases the effective strength of a spring ten per cent., the precise strength of the spring is immaterial. We are now only concerned with the proportion or ratio by which its strength is changed, and having compensated our balance to cover that progressive increase or decrease of strength found at the temperatures for which it is adjusted, the compensation will be correct for any other hair-spring having that progression, *i. e.*, having about the same form, nature and temper. But if a soft spring be substituted for one hardened and tempered, or the reverse, or its temper considerably changed, then the progression will be altered, and the compensation would require a readjustment to suit the changed conditions. For it must be remembered that the rate depends upon the absolute quantity of effective force in the spring, but the compensation is affected only by the ratio of its increase or decrease under the influence of different temperatures.

(255.) *Distinguishing "Adjusted" Balances.* No one can tell by mere inspection when a balance is adjusted, for there is absolutely no difference in appearance between one adjusted and one not adjusted. One may be as near perfect as the highest skill and many efforts can get it, while the other may be "wild," but no one can distinguish them by their looks. So of the balances sold by material dealers,—they may be from an excellent maker, made with every care, and all apparently equally good in every respect. Yet a trial will show that no two will act just alike. While some will be good, others may be worthless for accurate performance. The only way to ascertain is to test their running in heat and cold. It may be said, however, that the thinner and higher the rim the stronger the compensating action will be. These remarks of course refer only to balances completed and cut as already described. Very many watches are provided with balances having rims of steel and brass, with screws inserted, the same as before stated, except that the rims are not cut, or are cut only partly through, which amounts to the same thing. These are in fact chronometer balances, but the *laminæ* or compensating segments cannot compensate, because they are not allowed to act. Any balance the rim of which is not cut entirely through, is certainly not "adjusted," although it may be called a compensation balance. It is no better than the common balances of one metal, with screws in their rims, which are only imitations of chronometer balances. Such balances, however, are better than plain ones, in that they may be timed by these screws, either turning them in or out, or putting in lighter or heavier screws, to suit the strength of the hair-spring, as in section (217). They are also safer from injury while being handled by bungling workmen, and add something to the appearance of the movement, which is all that many people judge by. They are good enough for customers who do not comprehend the value of a real compensation balance, and are unwilling to pay the additional price,—and consequently they cannot expect anything better than an imitation balance.

(256.) *Performance when adjusted.* If a watch keeps the same time in heat, cold, and mean temperature, it is accurately compensated. But this is very seldom the case with the ordinary compensation balance, except by accident, when the limits within which it is tried are very circumscribed. And it may be valuable to the novice to know what performance may be considered good, average, or poor. Marine chronometers come nearest to perfection, and the very best made and most accurately adjusted instruments will gain daily, on an average, from five to six-tenths of a second more at the mean temperature than at the extremes,—supposing the former to be, say 70°, and the latter 55° and 85°. What may be called superior instruments, but not *the best*, will lose from one-tenth to one-fifth of a second for each degree of change of temperature either way from the mean, in twenty-four hours. When exposed to temperatures 10° to 20° beyond these extremes, they will lose from one-quarter to three-quarters of a second, daily, more than at the extremes. So regular are these variations, that when the connection between certain temperatures and the daily rate of a chronometer has been ascertained, the error of rate may be computed from observations of the thermometer. It will be sufficient for all practical purposes to determine the rate in the three temperatures for which it is adjusted, or the mean and the two extremes, and also say 15° outside of each extreme. In good instruments this connection will remain constant for a long time. The rate at the middle temperature is generally the standard or starting point, from which variations are noted. But cases sometimes occur when it is desirable to regulate to mean-time at one of the extremes. As, if a chronometer is exposed habitually to a temperature of 95°, it can be regulated to mean-time at that temperature, and the rate at the mean, or say 60°, will then be said to be so much slower or faster than the mean rate. Sometimes instruments are even adjusted with three rates,—as if, for instance, the rate was made correct with mean-time at 95°, but there was an error at the other extreme, or 35°, and still another rate at the mean, or 60°. The owner being furnished with a schedule of the rates corresponding to certain temperatures, could very easily compute the approximate error of his instrument by noticing the degrees on the thermometer, as already stated.

(257.) *Ordinary rates.* But the above-named results are shown only by the finest instruments. Ordinary chronometers will vary from one or two, up to five or six seconds daily when the temperature changes from the extremes for which they are adjusted, to the extent of 10° to 20° beyond. Pocket-watches may be made to come nearly as close as marine chronometers, but they seldom do so. Watches marked "adjusted" will frequently vary from three to ten seconds in twenty-four hours, at the temperatures of 55° or 95°. A closely adjusted movement of the first quality ought not, however, to vary more than one to three seconds in twenty-four hours, when the temperature is changed from the mean of 75°, to 55° or 95°. At the first trials, an unadjusted balance may vary from thirty seconds to two minutes in twenty-four hours heat or cold. And a variation of only fifteen or twenty seconds per day may be considered good for the first trials. All the foregoing rates apply only to the true compensation balance. Uncut balances, and the ordinary ones of one metal, will vary from three to six minutes when the temperature is changed from 35° to 95°.

(258.) *Marine chronometers.* It must not be supposed that all ship-chronometers are good timepieces, and reliably compensated for heat and cold, for they are not. The majority of those in use are hired by the month, and in order to save a few shillings per month in the rent, shipmasters will deliberately choose instruments which are inferior in performance to a decent watch. So well is this understood by chronometer-makers, that they are in great measure deterred from experimenting for the sake of improving the compensation, or from availing themselves of the discoveries of others, well knowing that they can scarcely hope to make good their outlay. A large share of their customers will pass by a really good instrument at a fair price, and take a "thing" offered by some competitor at a dollar less per month. It is only for some special uses that the most accurate performance is insisted upon, such as instruments for observatories, expeditions, watchmakers' time, and a few first-class vessels. As a matter of ordinary business, a perfect compensation is not profitable, and consequently not sought for. Of course, instruments designed for competition are made and adjusted regardless of time, trouble, and expense, if only they may take the first or at least a leading place in the list of competitors. And for this purpose almost innumerable devices have been employed to reduce or remove the error which always remains after adjusting the ordinary compensation balance, and which will be further considered in a subsequent section.

(259.) *Apparatus for adjusting.* In adjusting the compensation for heat and cold, we need an apparatus for obtaining an elevated temperature which may be of any degree required and may be maintained nearly constant for a considerable time; and another for producing cold in the same way. The former is called the adjusting-oven, the latter the cold-box. Many different constructions are in use, and the reader may perhaps know or discover some improvements on those described in these articles, although they have been found very serviceable. When only an occasional watch is to be tested or adjusted, any simple and inexpensive means available may be adopted for producing heat or cold; care only being taken that the heat never exceeds 120°, which is as high as can be employed without danger of injuring the oil, or perhaps the movement. The watch must also be so inclosed as to be protected from dust or moisture. And when great accuracy is required, it should be set to time, or the variation from the regulator noted down, *after* the movement has become thoroughly heated or cooled to the proper temperature in every part, which may take from half an hour to an hour. By this means, the times of exposure to the proper degrees of heat and cold will be alike. But if it is set and then put into the oven or cold-box, unless they were so constructed as to occupy the same length of time in attaining the required temperature in each case, the times during which it would actually be affected by the proper degree of heat or cold would be different, and cause an apparent error even when the compensation was correct.

(260.) *For testing in heat*, some watchmakers put the movement in a tight tin box, which they bury in a vessel of sand. The whole is then heated on a stove, in the oven, or in any other convenient way, and its temperature kept as uniform as possible by frequent examination of a thermometer also immersed in the sand. Others use a cubical box of tin, zinc, or copper, which is divided into four or five air-tight compartments by means of horizontal metal partitions inside. The upper compartment should be large enough to take in a thermometer with the watches to be tested, and then tightly closed. It is well to have a double glass window in the door in the top, so that the thermometer can be watched without opening the chamber. Heat slowly by means of a small alcohol lamp underneath, till the thermometer shows the proper temperature, where it should be kept, either by reducing the size of the flame or moving it further from the bottom of the box, or else by alternately removing and replacing the lamp as needed. It is well to have a wood or pasteboard casing to set over the box, to prevent loss of heat by radiation, and preserve a more uniform temperature.

(261.) *Adjusting-oven.* A very complete apparatus, and one not expensive, is shown in Fig. 11. This consists of a reservoir containing water, made of tin or copper, the bottom portion about eight inches front, by six back, and two deep, with two side branches four or five inches high and about one inch deep. The bottom and branches extend from front to back inside the casing. These branches are closed over at the top, and have each a short pipe extending to the outside of the casing, for use both in putting in water, and allowing the safe escape of the vapor arising from the heated liquid. Every joint of this reservoir must be securely soldered up, so that no moisture or vapor can enter the chamber containing the movements. The water should not fill it quite to the bottom of the pipes. One or two glass shelves, for receiving the watches, are supported by wires or cleats soldered on the sides of the branches, and at such a hight as to bring them about midway up the sides of the branches, and leave unobscured the scale of the thermometer fastened at the back of the chamber. It will be observed that the front, back and top of this chamber are formed by the wood casing, leaving the heated water only below and at the sides of the movements. Experience has shown that the temperature is more even when arranged in this way than when the source of heat *surrounds* the watches.

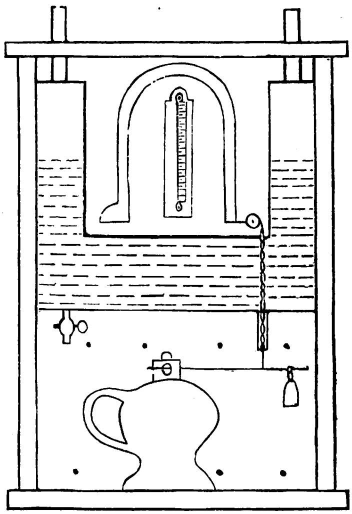

Fig. 11.

(262.) The casing should be either of thick wood, or made double, with an air chamber between the walls, which is preferable but not indispensable. Pine, whitewood, or any soft wood will answer. Not only should the door fit the front of the case tightly, (or be packed with tailors' listing,) but the bottom of the reservoir should fit snugly both to the box and the door, to prevent the fumes from the lamp beneath entering the chamber. In the door and the top of the casing, double glass windows are inserted to allow of observing the movements and the thermometer without opening the door. One glass should be fastened to the outside of the wall, the other to the inside, making a tight, non-conducting air chamber between them.

(263.) *Automatic heat regulator.* A compound bar of steel and brass, fastened by one end to the back of the chamber, regulates the heat by the motion of its free end, which curves and straightens similarly to the compensating segments of the balance. The brass is double the thickness of the steel, which may be a piece of clock spring, while the former is any hard or springy brass, the two being soft-soldered together in the form of a common magnet, with the brass outside. To one end is riveted or soldered a flat piece for screwing it in position. When finished, this bar should be well washed and cleaned from the soldering fluid, (212.) To the free end is attached a cord which passes over a grooved pulley and through a small hole to the outside of the casing, thence to the valve which regulates the supply of gas to the burner. When oil or alcohol is used, the cord passes down inside the casing, through a tube which passes through the bottom portion of the reservoir, to the wheel which turns the wick of the burner. This tube is soldered in both the upper and lower sheet of the reservoir perfectly water-tight, and should extend down a little lower than the row of holes provided for the exit of the heated air from the lamp chamber, so that the fumes will not rise through it into the movement chamber. For this reason the tube should be of small diameter.

(264.) The gas valve, or wick turner of the lamp, is turned by means of a lever attached to it, having a weight near the end heavy enough to pull it down. This lever is supported by the cord, which is tied to it, and it is only when the motion of the compound-bar allows the cord to yield that the lever can drop and shut off the gas, or reduce the flame of the lamp, more or less, according to the motion of the bar. When the temperature falls, the bar contracts, draws up the cord and lever, turns on the gas, or enlarges the flame, and an increased temperature in the reservoir results. The cord is attached to the lever at such a distance from its pivot or center of motion that the movement of the bar will give sufficient motion to the lever. For instance, if the free end of the bar moves half an inch for the increase of temperature from the mean to 95°, or any other degree chosen for the heat-extreme, then the cord should be attached to the lever at a point where that half-inch of motion will turn the valve or wick down enough to just maintain the desired temperature, and no more. This can be told by a little trial, moving the lamp to suit the changes of the cord. If preferred, the temperature can first be raised to the right degree in the chamber, then turn down the wick or valve to about the proper amount, as above mentioned, attach the lever to the valve in a horizontal position and connect the cord. Then any increase or decrease of temperature from that degree will cause the lever to be moved in the proper direction to correct it. The gas valve, or wick turner, should be made to operate very easily, and the lever made with a sort of spring clamp to slip on the thumb piece of the valve, or the wheel of the burner, and hold itself tightly in place. In the case of a gas cock, the lever might be permanently fitted to it, if desired; but with a lamp it could not, because there is no certainty in the position of the thumb wheel. Every trimming or alteration of the wick will change the position of the wheel, and the lever must be capable of being slipped on after the right position is found.

(265.) Air holes are made in the lamp chamber, through the casing, in two rows. The upper row should be an inch or so below the bottom of the reservoir, in order to retain the most highly heated portion of the air in the chamber, in contact with the reservoir,—only allowing it to escape after it has yielded up some portion of its heat and fallen to the level of the holes. Another row of holes for entrance of air is made near the bottom of the casing. Three or four half-inch holes are generally enough for each row, and all should be made on the same side, or on adjacent sides, to prevent wind blowing *through* the chamber, and disturbing the flame or putting it out. The hight of this lamp chamber should be made to conform to the requirements of the lamp or flame which it is proposed to use for heating.

(266.) *The Cold-box.* For testing watches in cold, they may simply be kept in a cold room, if the season is suitable, or placed in a tight metal box and kept in an ordinary refrigerator. It is much better, however, to have an apparatus constructed with special reference to that use, an example of which is shown in Fig. 12. It consists of a tight wooden box, with double walls, packed between with sawdust, and lined with zinc so as to be water-tight. It comes to an edge at the bottom, both for convenience of drawing off the water by a cock inserted at the lowest point, and to insure contact of the ice with the metal chamber which holds the movements during the trials. This chamber may be about six inches square, and there should be at least 1½ inches space between it and the sides of the casing, to prevent the ice packing and clogging, instead of passing on to the bottom. This whole space, above, at the sides of, and below, the metal chamber, is to be filled with broken ice, well packed down with a flat-ending stick. The movement chamber is to be perfectly water-tight, open only in front, where a snugly fitting wooden door is provided. It is tightly fastened and packed to the casing where it goes through, to prevent leakage, and supported by wooden strips below and at the back end, to prevent it changing position and working loose at the front. One or two glass shelves

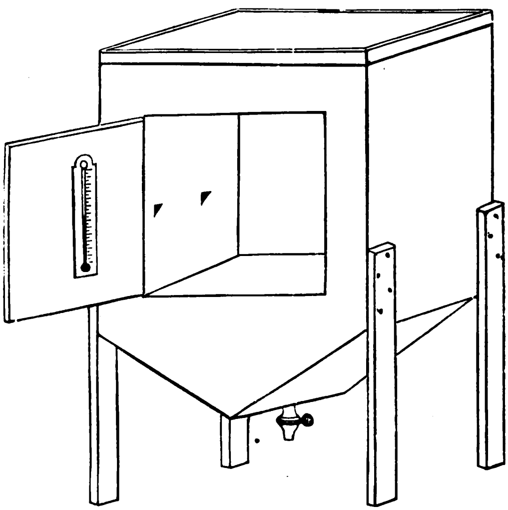

Fig. 12.

are used, as in the oven. The thermometer is here attached to the door, and windows for observation are omitted, as the condensation of moisture upon them by the cold air within would prevent seeing inside. Legs are attached to support the box; and when the cover is removed, the whole top should be open for convenience of filling and packing the ice.

(267.) *Degrees of cold.* If ice alone is used, a pretty constant temperature of about 35° will be maintained. When a greater cold is desired, common coarse packing salt should be mixed with the powdered ice, throwing in two or three handfuls of ice, then a handful or two of salt, mixing and packing down with a stick; then another layer, and so on. This will give a temperature of about zero. As the ice melts by contact with the salt, and the water passes off, it should be poked down occasionally with a stick and a fresh supply added at the top. When the cold-extreme chosen is only 50° or 55°, less ice must be used, and no salt. Sometimes it will be sufficient to keep a supply of ice on the top of the chamber, not being necessary to pack the whole space around it. For so moderate a degree of cold as that, the ordinary household refrigerator will answer every purpose. For regulating the temperature of the chamber in the cold-box, a compensating bar would be useless, but is sometimes used to *indicate* the temperature within the chamber. In that case it is attached to the door, and the cord passes over a pulley, with its axis penetrating the door, and on the outside carrying a pointer, which is set to point to an index corresponding to the degrees of the thermometer inside. But it is much better, as well as less troublesome, to choose for the cold-extreme a temperature which can be easily produced, and kept at the same point without watching and regulating it,—as, that of 35°.

(268.) For breaking up the ice, the best way is to make a stout wooden box, about a foot square and six inches deep inside. Put in ice enough at a time to fill it about an inch deep when broken up. Pound it with a hard-wood pestle, with perfectly flat bottom, say three or four inches square. A stick of stove-wood, with one end cut down small enough for a handle, makes a good pounder,—its weight helping along the powdering process. Break the ice pretty fine, leaving no pieces over an inch square, and empty each boxful into a tub, till enough has been broken up to fill the cold-box, before you begin to pack it. When packed, protect it from the sun, and throw an old rug or piece of carpet over it to keep it as cool as possible and save ice.

(269.) *Proper order of trials.* Everything being ready, as in section (253), the watch being closely regulated to mean-time, and set exactly, or its variation from the regulator noted down, we subject it first to cold for six hours, (252,) and put down the precise error of time in the adjustment-book; then expose to heat, and again note down the error. Many workmen expose first to heat, then to cold, but I prefer the order recommended, for the reason that when the movement is taken from the cold-box it condenses upon itself the moisture always present in the atmosphere, owing to its being colder, causing a liability to rust. But by then exposing the movement to heat, it is dried off and all danger obviated.

(270.) *Disturbing the rate.* After altering the screws to change the compensation, the trials should include not only cold and heat, but also mean temperature, to see if the alterations have disturbed the rate. If so, the two (or four) mean-time screws should be changed to correct that, (215,) at the same time that the other screws are moved to change the compensation. If the error of rate is very small, as a second or so per day, it will generally be sufficient to turn *one* of the timing screws as little as it can be seen to move. But the screw thus changed should be noted, so that any similar change afterwards required may be made upon its opposite, otherwise the balance might be thrown out of poise. It must also be remembered that the timing or "quarter-screws" (215) should not be moved from their holes for the purpose of correcting the compensation, but the screws on either side of them may be moved *past* them, to the other side, if necessary. The timing screws are not designed for acting upon the compensation, but only for correcting the rate or the poise.

(271.) *Rating and compensating at the same time.* After both the timing and compensating screws have been changed as above, the next series of trials should commence with a test at the mean, to ascertain the rate, then in cold and heat, comparing the three results to find the error of compensation. For instance, if the rate was discovered to be two seconds slow in six hours; the loss in cold, four seconds; the gain in heat, six seconds, then, if the rate had been correct, the real loss in cold would have been only two seconds, and the real gain in heat, eight seconds. This was the actual effect of the compensation, but the error of rate increased the apparent loss and decreased the apparent gain. It is in the highest degree important, however, that the rate be as nearly correct as it can be got before testing the compensation, for it is often hard enough to make out the real cause of the error even then, and any further complication would make "confusion worse confounded," with the beginner. Some workmen follow a different system. Having first determined the rate at mean temperature, they test in cold, alter the screws for the error, test again in cold, and so on till the error in cold is removed; then test in heat, and proceed in the same way; then test in cold again, removing the error in each extreme before they leave it. This is quicker than the method above mentioned, but is not so good, unless a saving of time is the paramount object.

(272.) *Irregular compensation.* As already stated, if the watch loses in cold and gains in heat, the compensation is too strong, termed over-compensated, and the remedy is to move the weights back on the segments. If it gains in cold and loses in heat, it is under-compensated, and the screws should be moved towards the free ends of the segments. But there are frequent cases of irregular compensation. If the watch gains in both heat and cold, the compensation is too strong in heat and too weak in cold. If the screws were moved back to lessen the error in heat, we should thereby increase the error in cold to a nearly equal extent; or, if we lessen the error in cold by moving the screws forward, we shall increase the error for heat. For this there is no remedy. All we can do is to get the error equal in both heat and cold, which will of course reduce the error in each extreme to the smallest amount possible. In exceptional cases, where a chronometer or watch will seldom be exposed to one of the extremes, we can locate nearly all the error in that extreme, and thus free the other extreme, in which it will be generally used, almost entirely from variation. For instance, if the balance is adjusted for 35° and 95°, as the two extremes, the middle temperature will be 65°. Now if the instrument will only be exposed to temperatures between 65° and 95°, we can correct the error for heat by moving the screws in the proper manner to make the mean temperature rate and heat rate alike, and so place all the error in the extreme of cold, where it will rarely or never trouble us. Nearly as good results may be obtained with such balances by adjusting them from 65° to 95°, with the mean at 80°, but it is more trouble to adjust for a limited range, both from the difficulty of keeping the temperature just at the exact point,—which is more necessary in this case because the entire range of temperature is so small that any variation would reduce it to little or nothing,—and from the greater difficulty of noting the error of rate produced by so slight a change of temperature, requiring a longer time for it to accumulate into an observable amount.

(273.) If the watch loses in both heat and cold, (as compared with the mean temperature rate,) which is a common error, the compensation is too weak in heat and too strong in cold, *i. e.*, the weights or screws are not carried fast enough, or far enough, towards the center of the balance, in heat, to compensate for the effects of heat on the balance and the hair-spring; and they are carried outwards in cold too rapidly, or too far, causing a loss of time in both cases. For this error, like the one just mentioned, there is no remedy. We can only hide it, or get it out of the way, as above noted, (272.) All the foregoing errors are due to the construction of the balance not being such as will admit of the weights being moved in accordance with the law which governs the number of vibrations, viz.:—*The weight of a balance and strength of its hair-spring remaining the same, the number of vibrations it makes will be inversely proportionate to the square of the diameter.* That is, a 1-inch balance will make four times as many vibrations as a 2-inch, and nine times as many as a 3-inch balance. And conversely, a balance 2 inches in diameter will make $\frac{1}{4}$ as many vibrations in a certain length of time as one 1 inch in diameter, and a 3-inch balance will make $\frac{1}{9}$ as many, etc. Hence, in order to compensate for the contraction and expansion of the balance, the weights or screws must be moved towards the center, in heat, in a geometrically increasing ratio. When to this is added the effect of heat and cold upon the hairspring, to be compensated for by the same means, it will be seen that the weights must move towards the center in heat in a rapidly increasing ratio, while they must move from the center in cold in a less and less rapidly decreasing ratio.

(274.) *Middle temperature error.* This is very seldom done in a perfectly correct ratio. The smallest error is found when the difficulty in the balance is over or under-compensation. In these cases, by moving the screws judiciously on the segments, the variation between the rate at the two extremes and that at the mean can be reduced to a very slight error. This residuary error, which remains in spite of all we can do, is technically termed the middle temperature error. Even the best made and most carefully adjusted chronometer balances, when adjusted to give *the same* rate at 35° and 95°, or the two temperatures chosen for the heat and cold extremes, will have a different rate at those temperatures from that at the mean. Of course, the more limited the range of temperature between the extremes, the less this error will be; but it is never entirely eliminated in balances of the ordinary construction, varying from a part of a second to several seconds per day, according to the range, the skill and patience of the adjuster, and the peculiarities of the balance, its hair-spring, etc. Sometimes the rate at the extremes will be a trifle faster than the mean temperature rate, but, almost invariably, when the rate has been made alike at the two extremes, it will be slower than the mean temperature rate; that is to say, the chronometer being regulated at the mean temperature, it will lose time as the temperature becomes higher or lower. Or, if the rate be made the same at the mean and either extreme, the loss will be all located in the other extreme, as already stated.

(275.) *Secondary or auxiliary compensation.*—As the ordinary compensation balance is not capable of being manipulated so as to remove this residuary error, various devices have been added to it for producing a separate and additional adjustment to accomplish that purpose—some acting in cold, some in heat, and some at all temperatures. This additional compensation is called secondary or auxiliary compensation, and balances provided with them are termed balances with auxiliaries. These, however, are generally added only for some special requirements, (258,) and have not come into any general use in instruments sold for purely commercial purposes, being mostly unstable, and therefore unreliable for a permanent action, besides their cost being greatly increased. As the number of these devices is probably several hundred, acting on all sorts of principles, and by all sorts of means, it is impossible to give directions for constructing or adjusting even the more prominent makes. Frequently the conditions of success are known only to the makers, or could only be ascertained by many experiments and failures. It will generally be found more profitable and satisfactory not to meddle with auxiliary compensations or unusual constructions at all, unless the workman has skill and experience enough to make them himself. In that case, he would probably be able to study out the principles of the particular device before him, without any further instruction than his knowledge of the theory of compensation. His experience will then have taught him both wisdom and *caution* in making alterations. The average workman would do well to confine his practical operations to the primary compensation, or adjustment of the ordinary compensation balance, and, before going any further than that, he should again read and remember the advice in the last paragraph of the introduction to these articles.

APPENDIX.

METHOD OF COMPARING TIME CLOSELY.

In setting your watch to seconds, do it by stopping the balance. I have seen those who claimed to be fine workmen twisting the seconds-hand forwards and backwards as if it were merely an ornament to the dial. The seconds-hand, when properly placed, should be firmly secured upon its pivot, so that it cannot be acccidentally shifted. If it is loosened up for setting, it must be afterwards pressed down again, which will frequently cause an error of one or two seconds, and perhaps the watch is stopped. Or, it may go on too far, and must be pried off again, making another error, etc. The quickest and best way is to put a stiff smooth bristle in a light handle, (peg wood will do,) stop the watch when the seconds-hand is just on the 60, by placing the bristle on the balance, which should be drawn around far enough to start instantly with a good motion when the bristle is raised. Then set your minute and hour hands.

All trials and observations should begin and end when the seconds-hand on your regulator is at the 60, unless the seconds-dial of your watch is imperfectly spaced off; if so, then at the nearest 60 upon that. I have found the following an excellent way to mark the exact time. Supposing that you have a regulator with a visible pendulum beating seconds, you place a thin diaphragm, say of tissue paper, in front of the pendulum, so as to obscure it somewhat, except at the very end of each vibration, when the edge comes into full view. The pendulum is plainly visible all the time, but at the end of each vibration it suddenly appears brighter. The paper can be either inside or outside of the clock case.

You now stand facing the clock at a little distance off, holding your watch nearly in line with the pendulum. Thus while you are looking directly at your watch, the image of the pendulum will also be clearly seen, with the sudden brightening at the exact end of each swing. This is better than listening to the "tick," as that may be faint or drowned out by other noises.

But in order to know when the regulator hand is exactly at the 60, you commence at the 5th second beforehand, and count the seconds backwards, thus: Looking at the clock, when its seconds hand reaches 55 seconds, you say "Five;" then look at your watch, as above described, and each "brightening" marks the time of another second. Counting either aloud or mentally, you say "Five—Four—Three—Two—One—Now!" lifting your bristle at the "Now," if you are setting your watch.

But it is in comparing the watch with the clock that this idea is most useful. For you can look closely at your watch, and at the same time you know the exact second upon the regulator. If your watch has, say, five beats to the second, (18,000 per hour,) you can also count the beats for fractions of a second, provided your seconds-dial is accurately spaced. At the "Five," you place your finger nail on the glass over the dial, drawing it steadily back as the seconds-hand approaches it. At the next seconds-mark you pass after the "One," you begin and count the beats between that and the "Now," then hold your finger at that spot and take your time to satisfy yourself fully of the number of the second. For instance, from the seconds-mark there were three beats to the "Now," and that mark was 13 seconds. So the "Now" was at $13\frac{3}{5}$ seconds. This counting backwards is also useful when one person observes the clock, and another the watch, or for calling the time to a person some distance off, for the latter has constant warning of the gradual approach, as well as the arrival, of the exact instant. Always number your seconds; even if it is the last fraction of the last second, name it correctly: $59\frac{4}{5}$ seconds. This habit, once acquired, you are safe; but if you say so many seconds "before" or "after" the 60, you will frequently make mistakes, in spite of all your care, from being confused by customers forgetting "which was which," counting the wrong way to the nearest figure, etc., etc.

DEMAGNETIZATION OF WATCHES, (232.)

Watches worn by students and others in technical laboratories are often rendered useless by being magnetized by the magnets used in such places. Magnets kept in the house often create equal mischief by being laid near watches, and much time and expense are sometimes needed to demagnetize them before they can be made to work. A serious case of this kind of injury recently led Prof. A. M. Mayer, of the Stevens Institute of Technology, Hoboken, to experiments which resulted in a very simple method of demagnetization. The magnetized watch was laid upon a table in the neighborhood of a common compass-needle. Each hour on the face was then placed in turn before it to discover the location and intensity of the magnetism in the watch. The movements of the compass showed the north and south poles to be located (say) at the figures V and XI, while the neutral points were at VIII and II. The watch was then held in a horizontal position before a large bar magnet, the south poles of each being together. A gentle tilting motion was given to it for a moment, and, on trying the watch again before the compass, a sensible decrease of magnetism was observed. The processs was repeated till the sensitiveness of the watch at that pole was nearly extinguished, when the same thing was tried with the north pole of the watch. After a few trials and comparisons, the magnetic influence was found to be removed, and the watch readily resumed its work.—*Scribner's Monthly.*

MAKING COMPENSATION BALANCES, (238.)

At a meeting of the British Horological Institute, on December 6th, 1876, Mr. V. Kullberg referred to the liability of balances to "set" or change their shape after running for a while, as stated in section (244,) and then observed as follows:

"In order to prevent irregularity from such causes he suggested soldering, as he had done in his early days at Jurgensen's. He did not use soldered balances now, owing to the prevailing fashion of melting, but could not help thinking that a soldered balance was free from some of the drawbacks resulting from melting. Brass required considerable heat to fuse, much more than was considered good for steel; the steel would be therefore liable to be burnt. Another reason was that the particles of the brass in cooling, or at the point when they become solid, were prevented from coming into contact owing to the brass surrounding steel, a metal which contracts in cooling less than brass, and for these reasons soldering would theoretically seem to preserve the two metals the most. Then by using drawn wire bent up and turned to fit the steel block, a texture of the brass would also be obtained, with a grain running along the rim, much superior to the melted crystallized brass. If soldered balances had failed, (as everything thoughtlessly done would fail,) it must have been through an injudicious carrying out of the process. If a solid brass ring were turned out to fit the steel block nicely when cool, as soon as it was heated in soldering the brass would expand, and at the point of fusion of the solder there would be a gap between the brass and steel as wide as the thickness of the brass in a finished balance. Besides giving plenty of room for blisters, the difference of expansion of the silver and brass on opposite sides would make a worthless balance. He had prevented this by using a pair of tongs which supported the balance during the process of soldering, and, at the same time, by means of a wire, squeezing the brass close upon the steel at the fusing point, and twisting the steel round by means of a couple of holes drilled in it, so that all blisters were driven out, and the brass and steel closely cemented with the strength of the silver. It was true that, with soldering with silver, the steel would be so little heated as to obtain its greatest softness, and such balances, unless hardened, were softer than melted balances, owing to the steel not being burnt."