(No Model.) 7 Sheets—Sheet 1.

# C. E. EMERY.

## METHOD OF AND APPARATUS FOR RATING TIME PIECES.

No. 451,181. Patented Apr. 28, 1891.

Fig. 1.

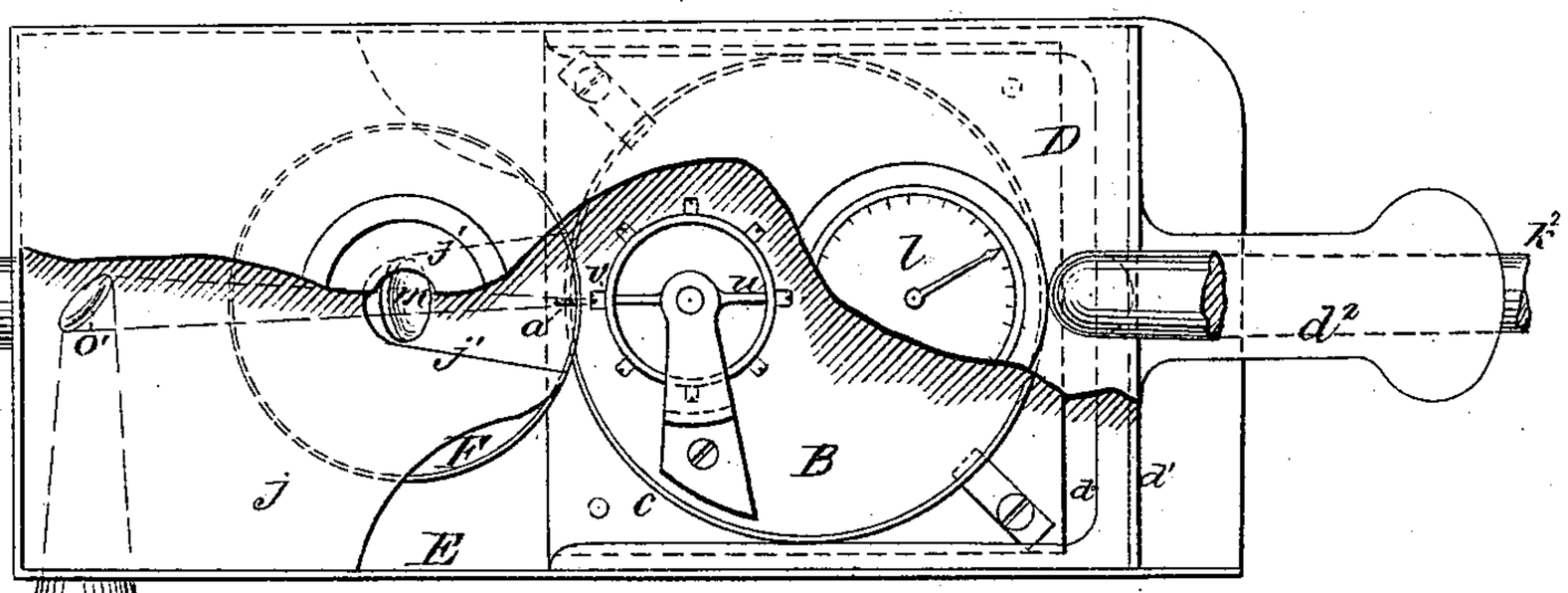


Fig. 34.

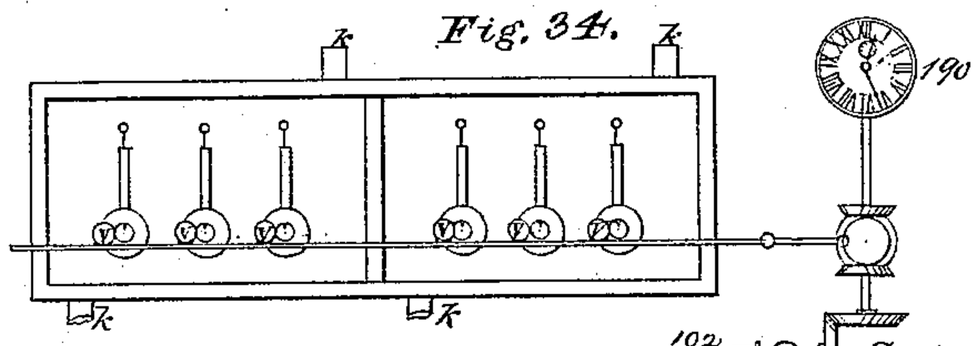


Fig. 2

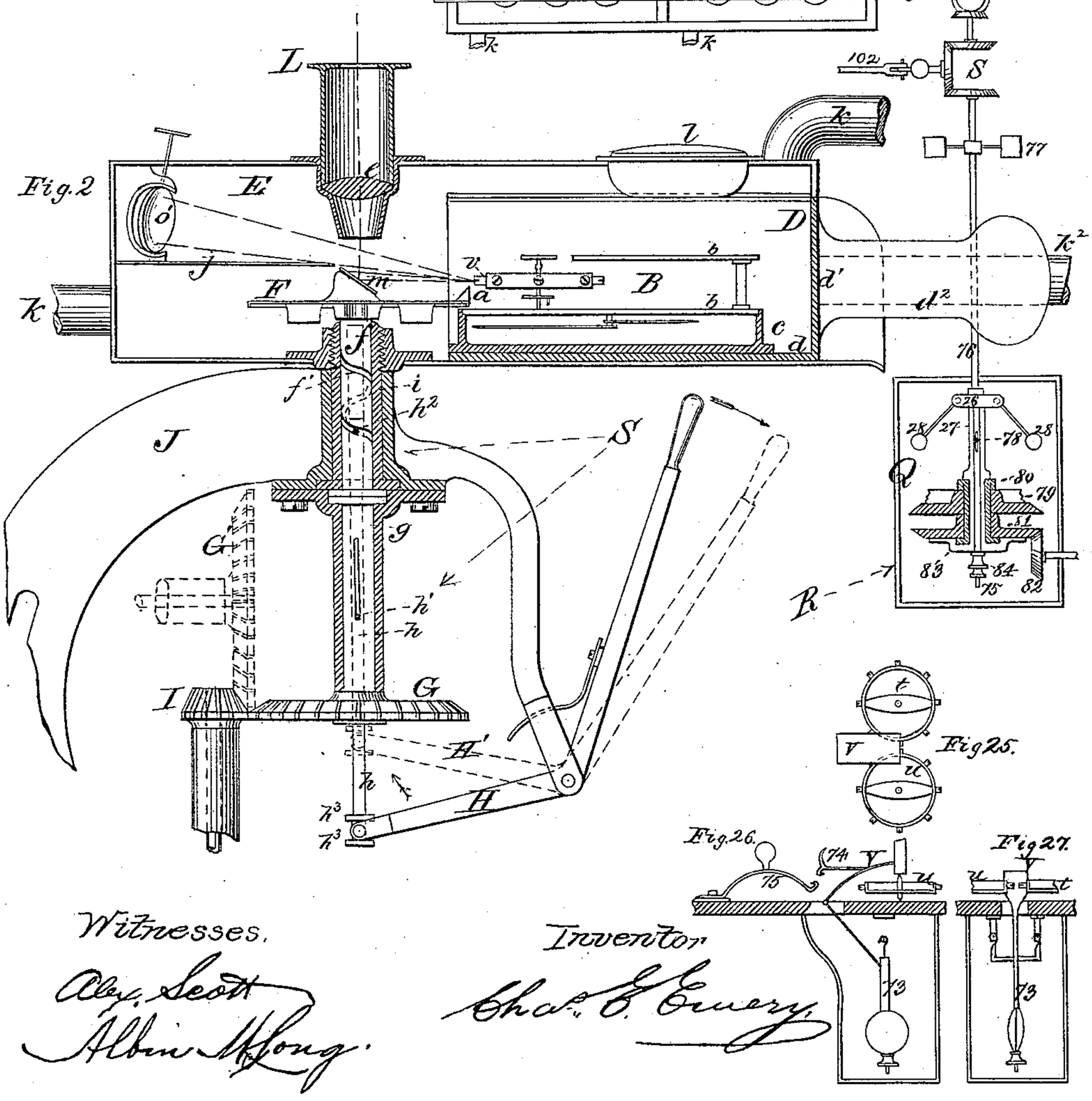


Fig 25.




Fig. 26.




Fig 27.




Witnesses.

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Chas. E. Emery.

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# C. E. EMERY.

## METHOD OF AND APPARATUS FOR RATING TIME PIECES.

No. 451,181. Patented Apr. 28, 1891.

Fig. 3.

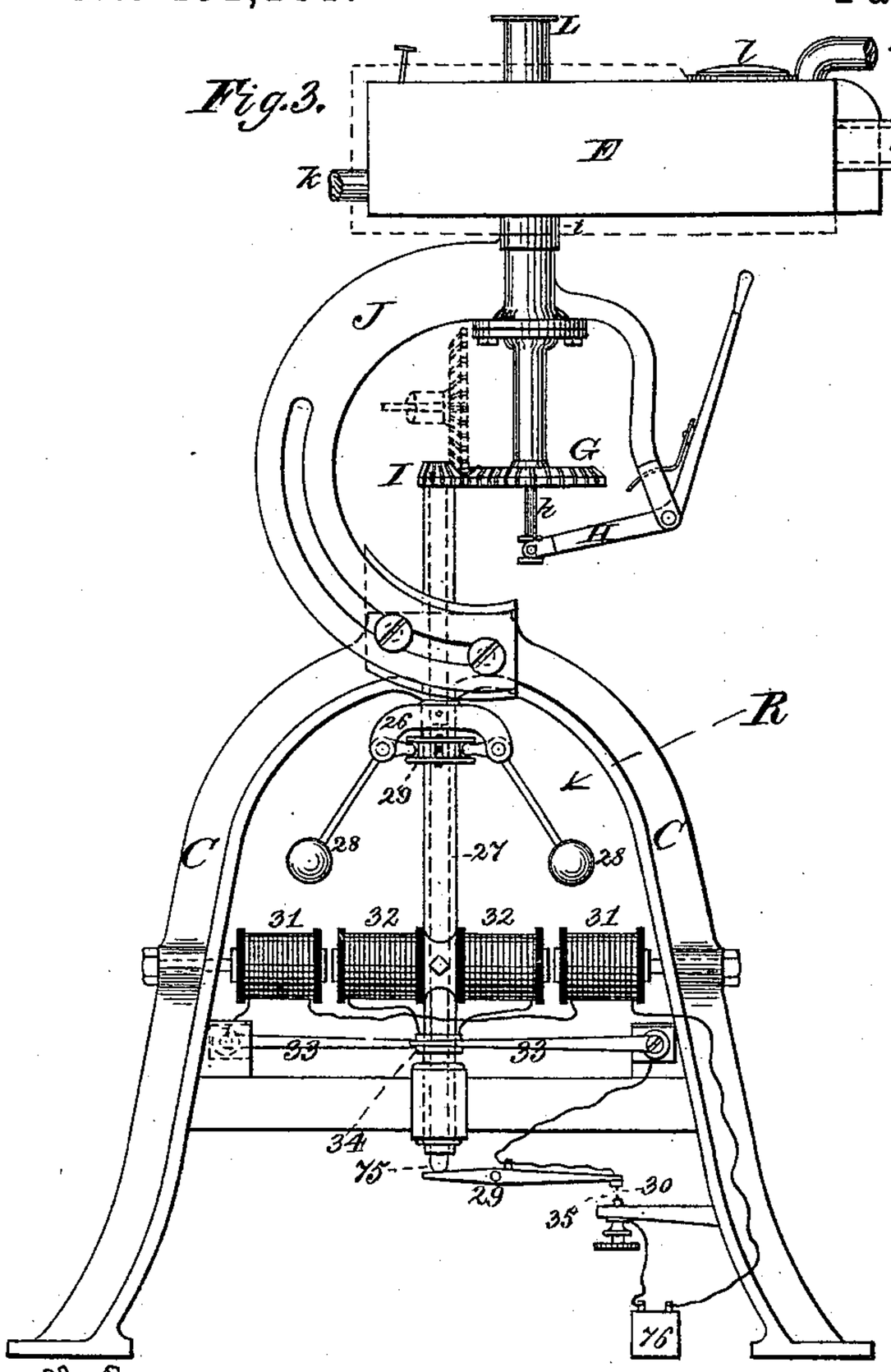



Fig. 4.

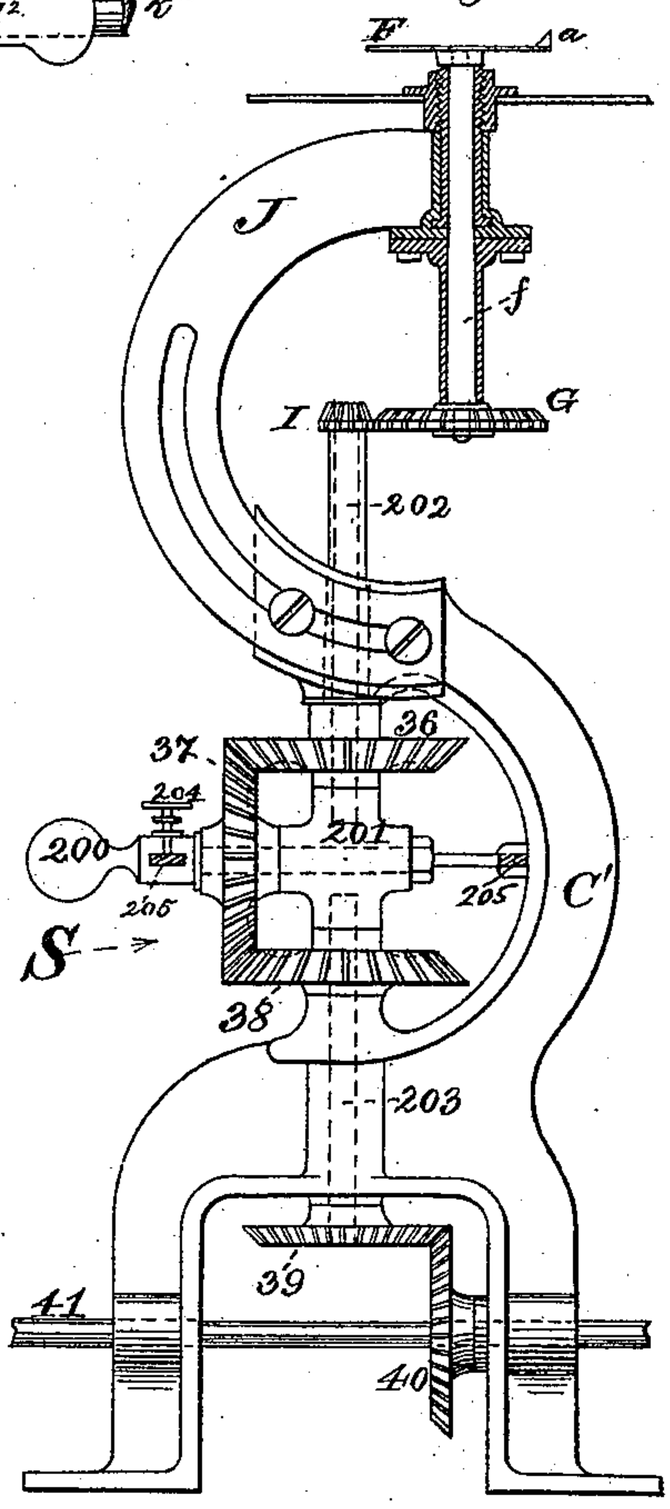
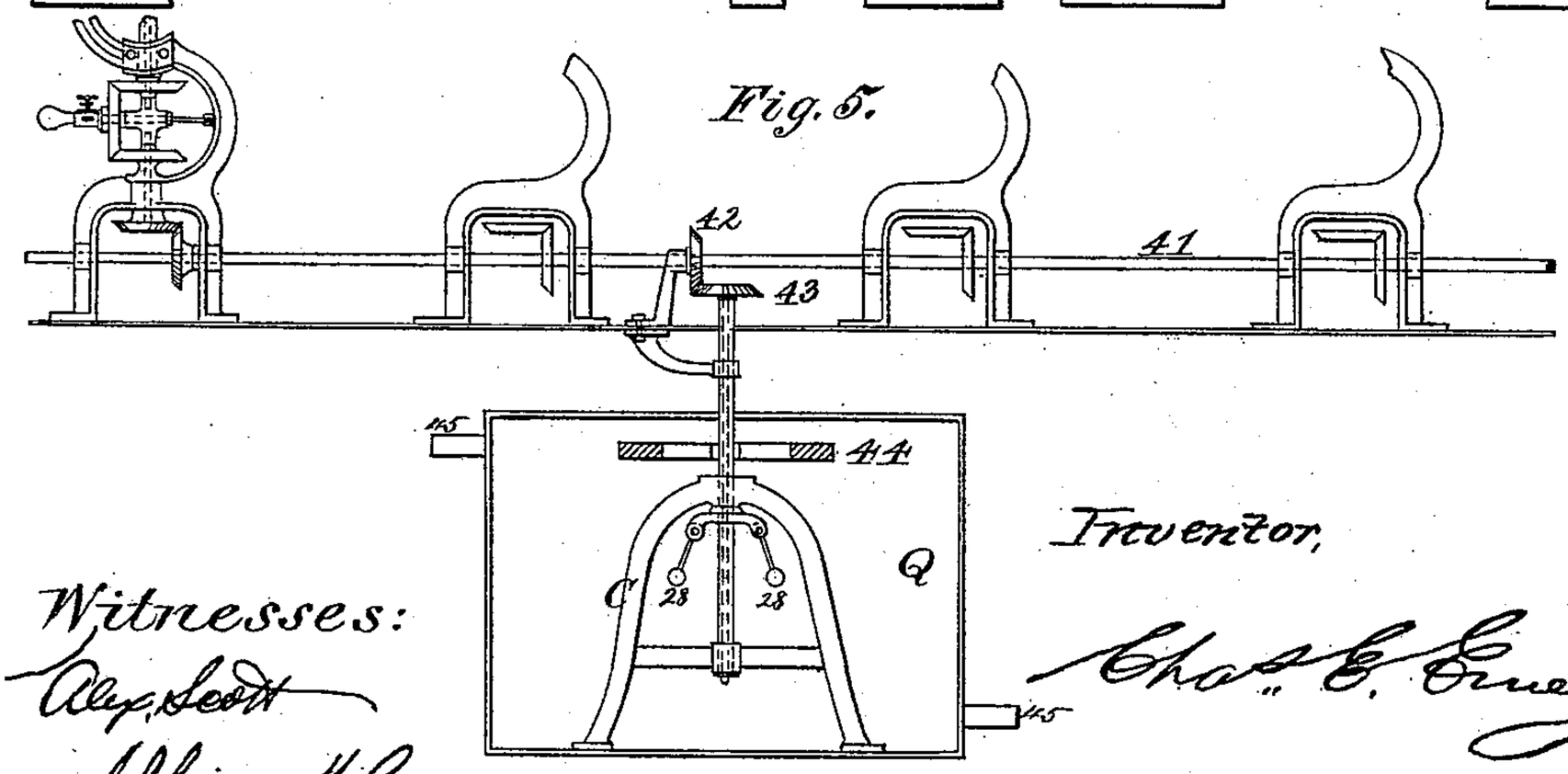



Fig. 5.




Witnesses:
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# C. E. EMERY.

## METHOD OF AND APPARATUS FOR RATING TIME PIECES.

No. 451,181. Patented Apr. 28, 1891.

Fig. 6.

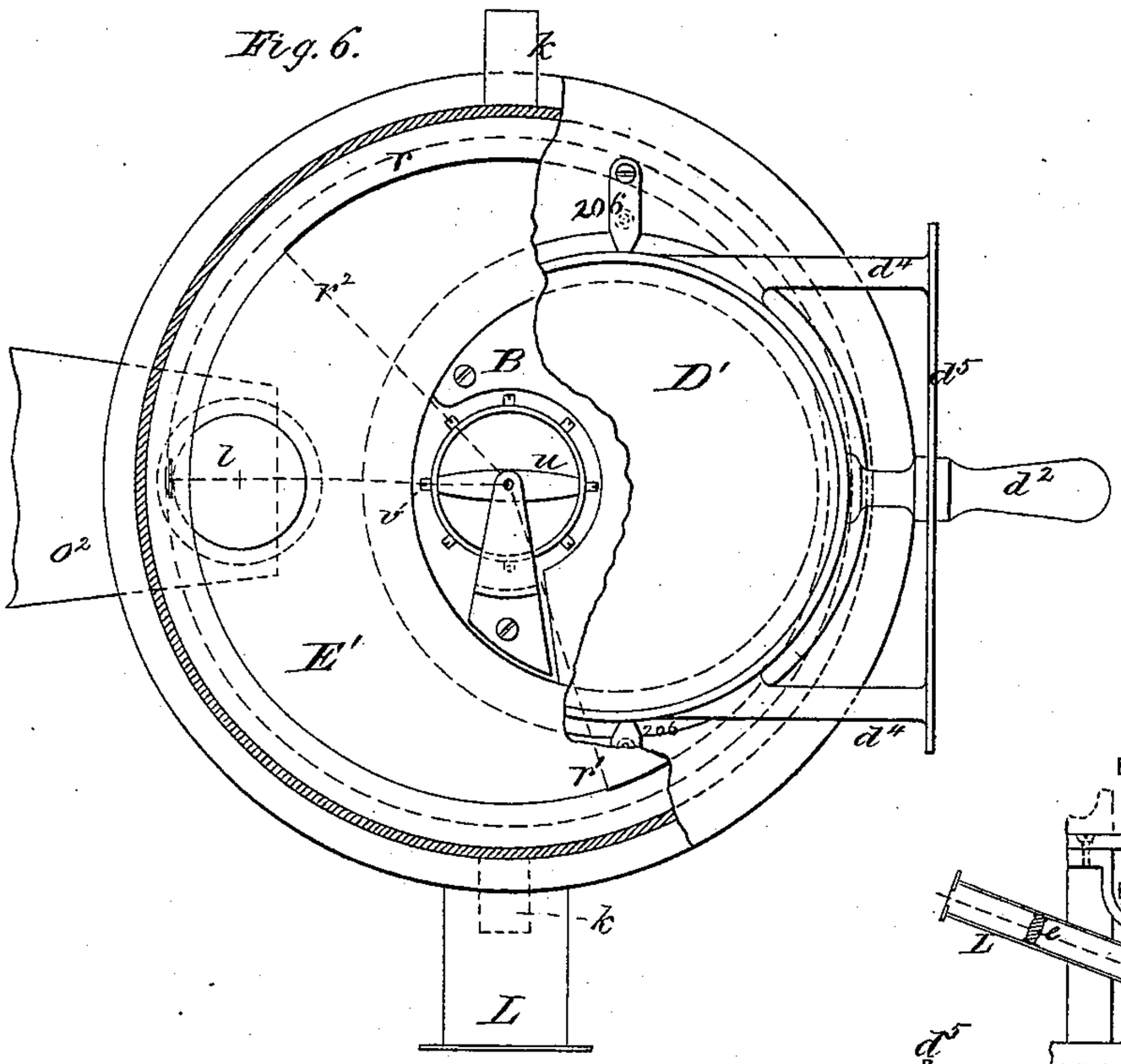


Fig. 7.

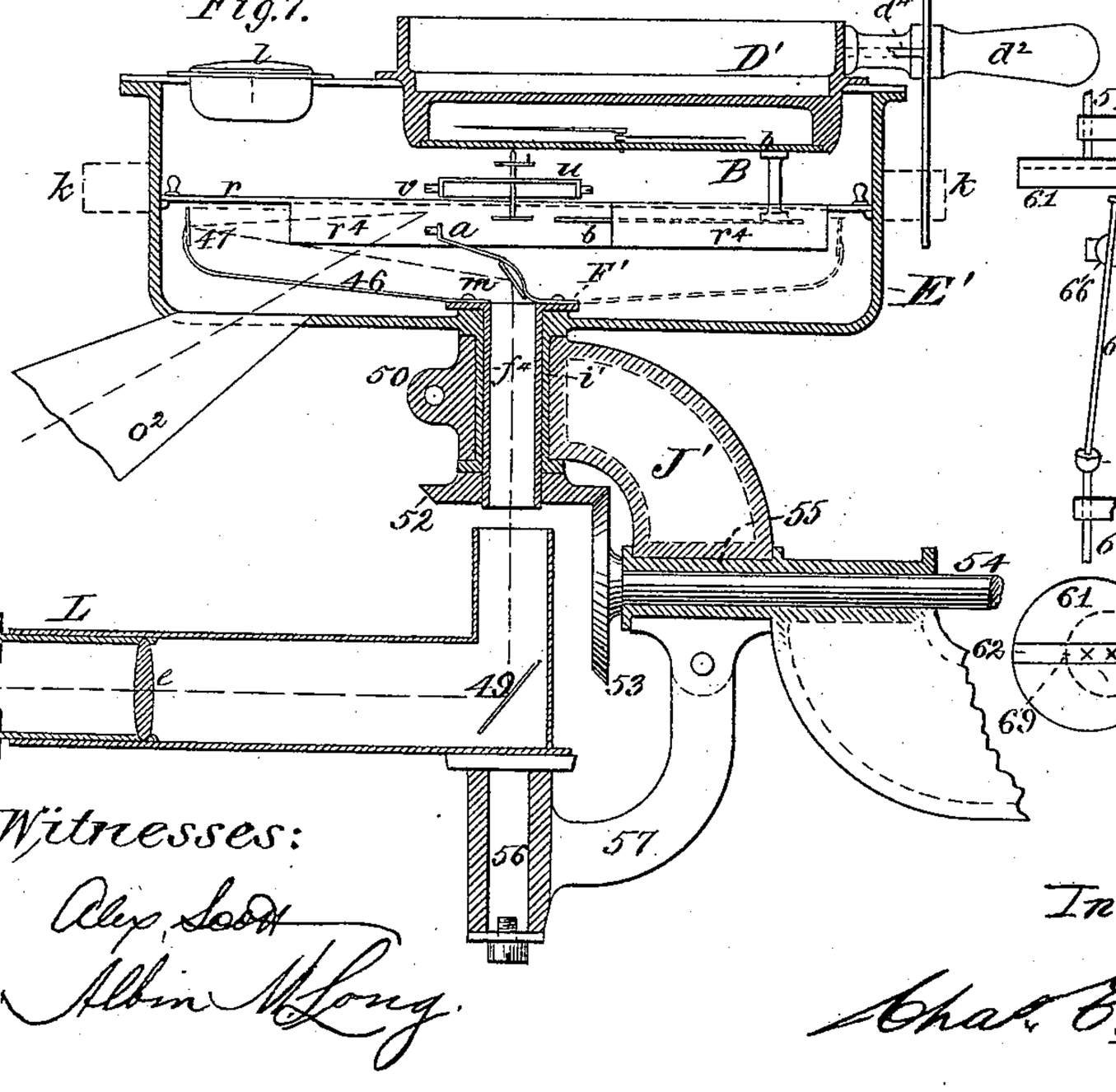


Fig 12.

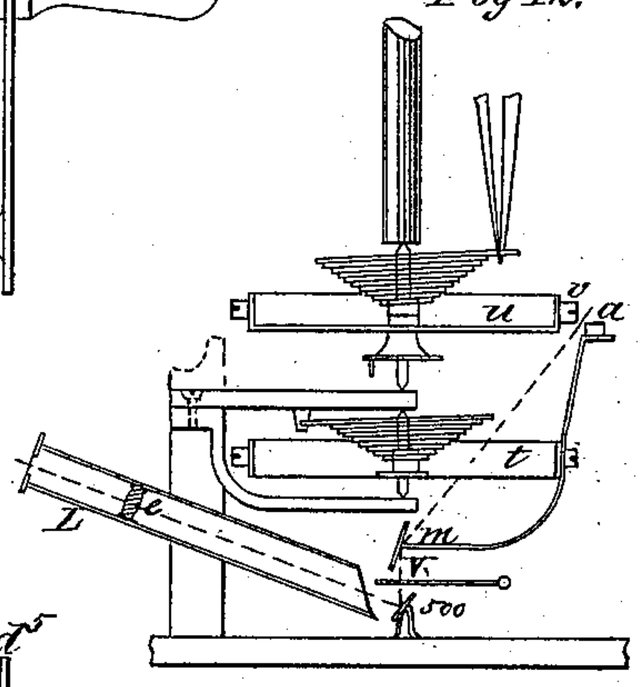


Fig. 10.

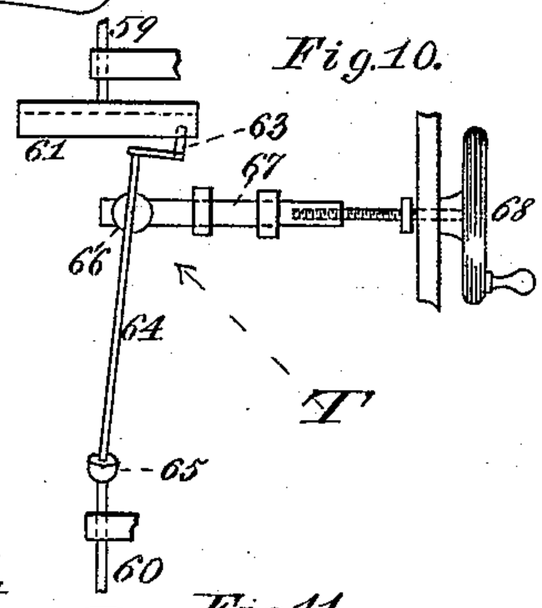


Fig. 11.




Witnesses:
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# C. E. EMERY.

## METHOD OF AND APPARATUS FOR RATING TIME PIECES.

No. 451,181. Patented Apr. 28, 1891.

Fig. 19.

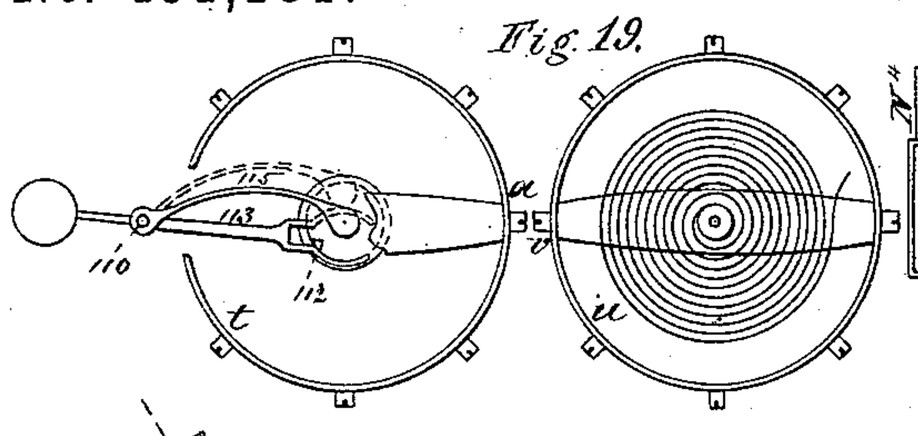



Fig. 20.

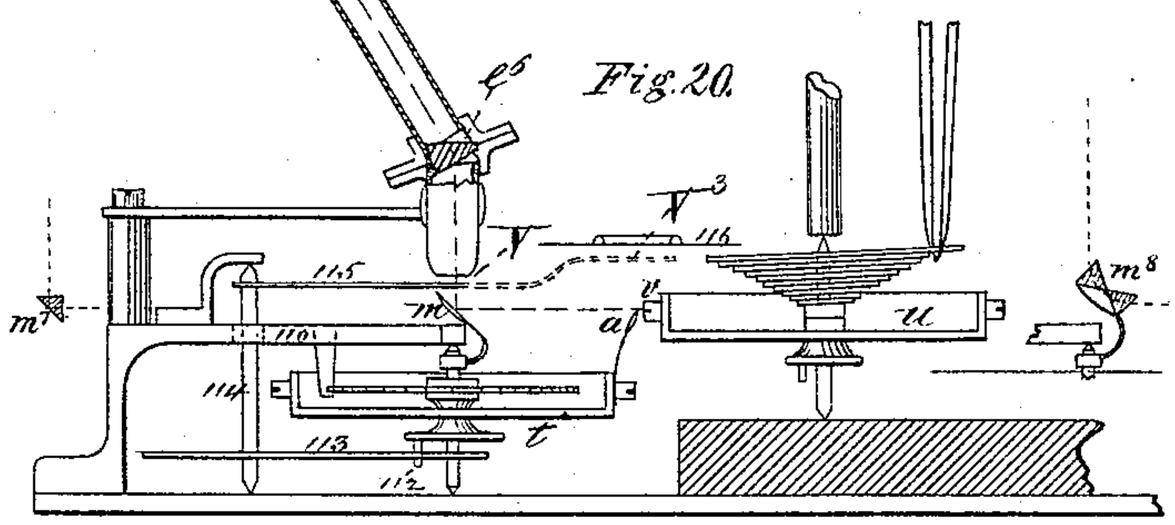



Fig. 8.

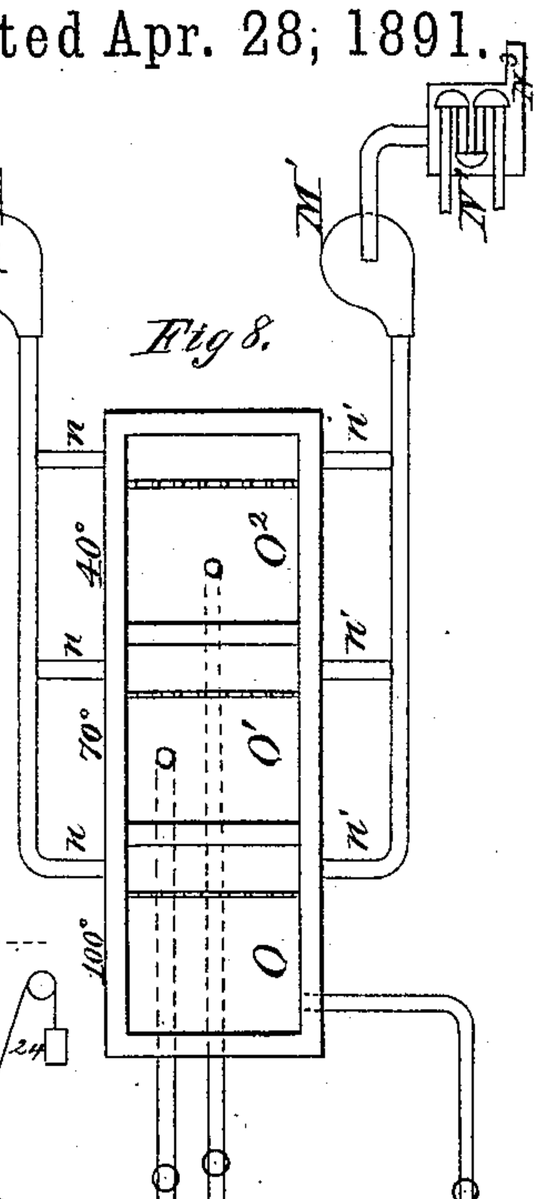



Fig. 21.

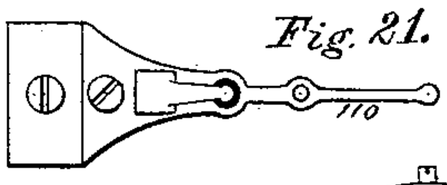
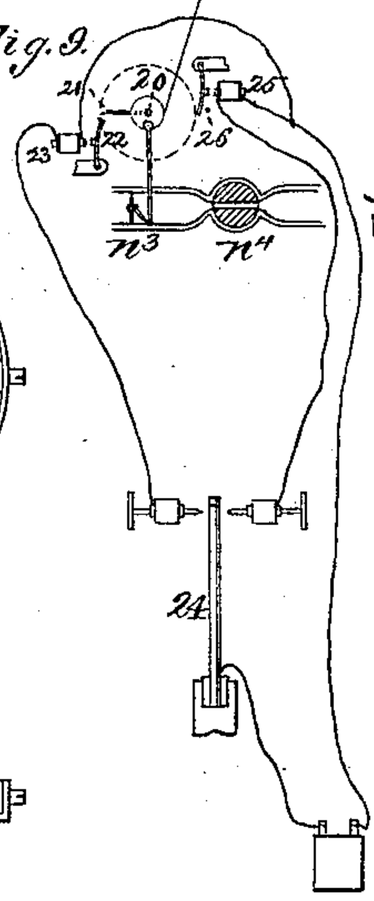



Fig. 22.




Fig. 9.



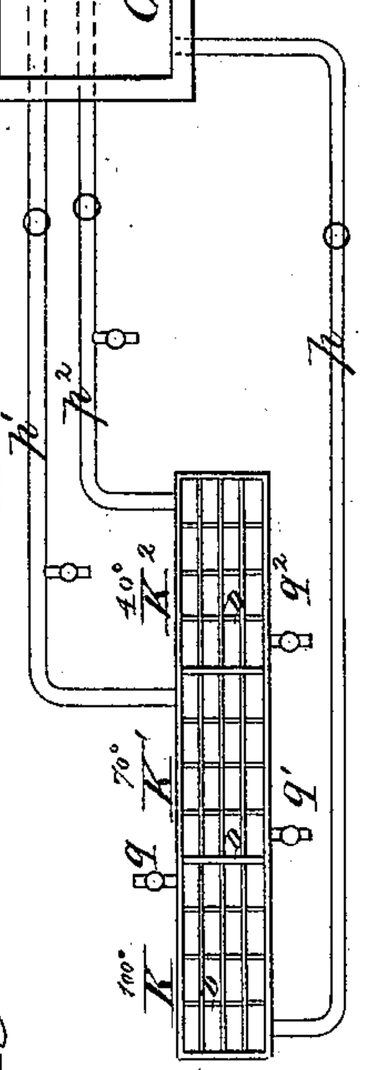




Fig 23.

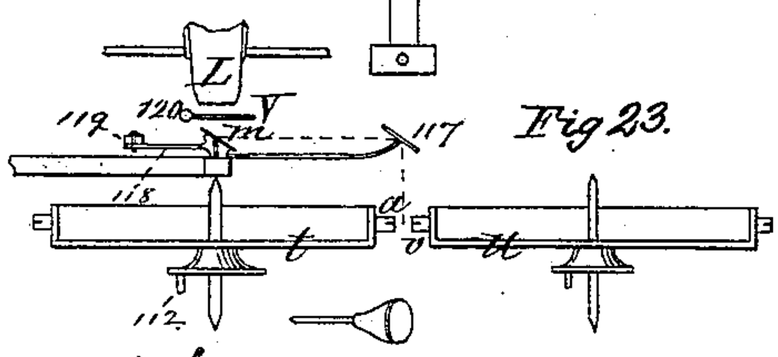
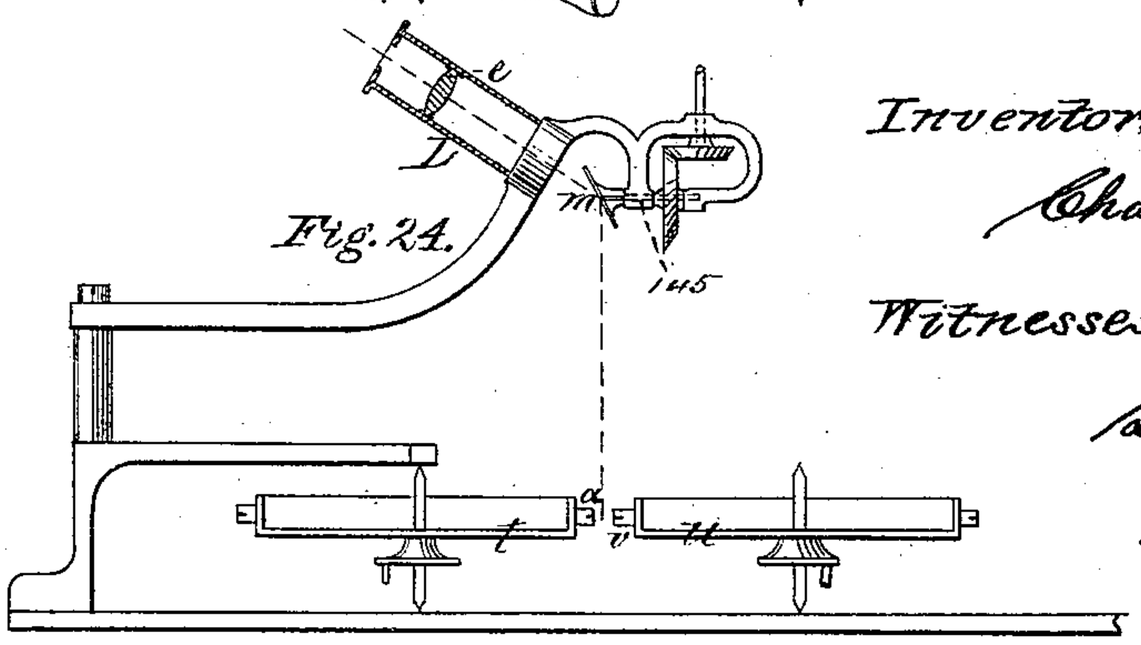



Fig. 24.

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# C. E. EMERY.

## METHOD OF AND APPARATUS FOR RATING TIME PIECES.

No. 451,181. Patented Apr. 28, 1891.

*Fig. 15.*

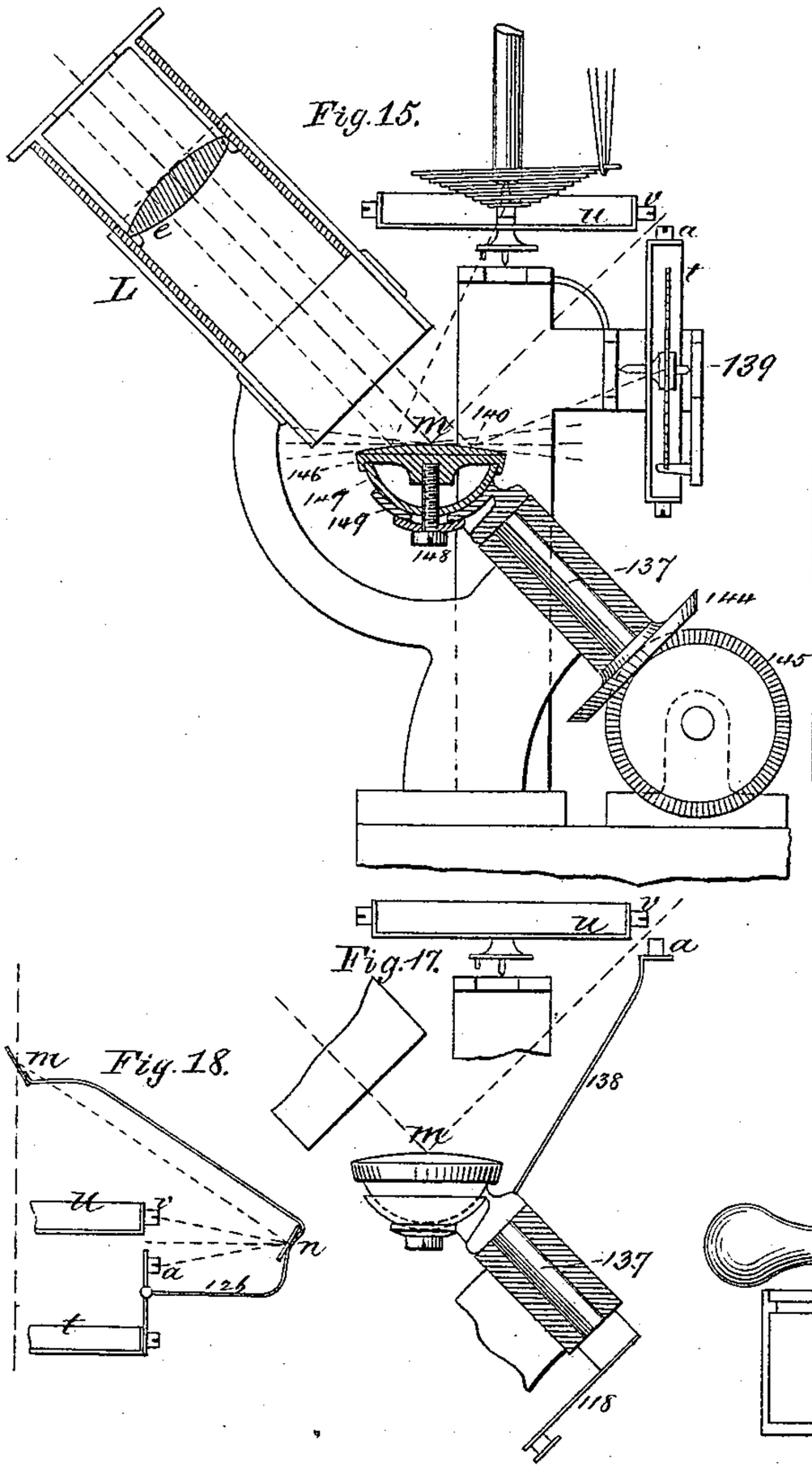



*Fig. 16.*

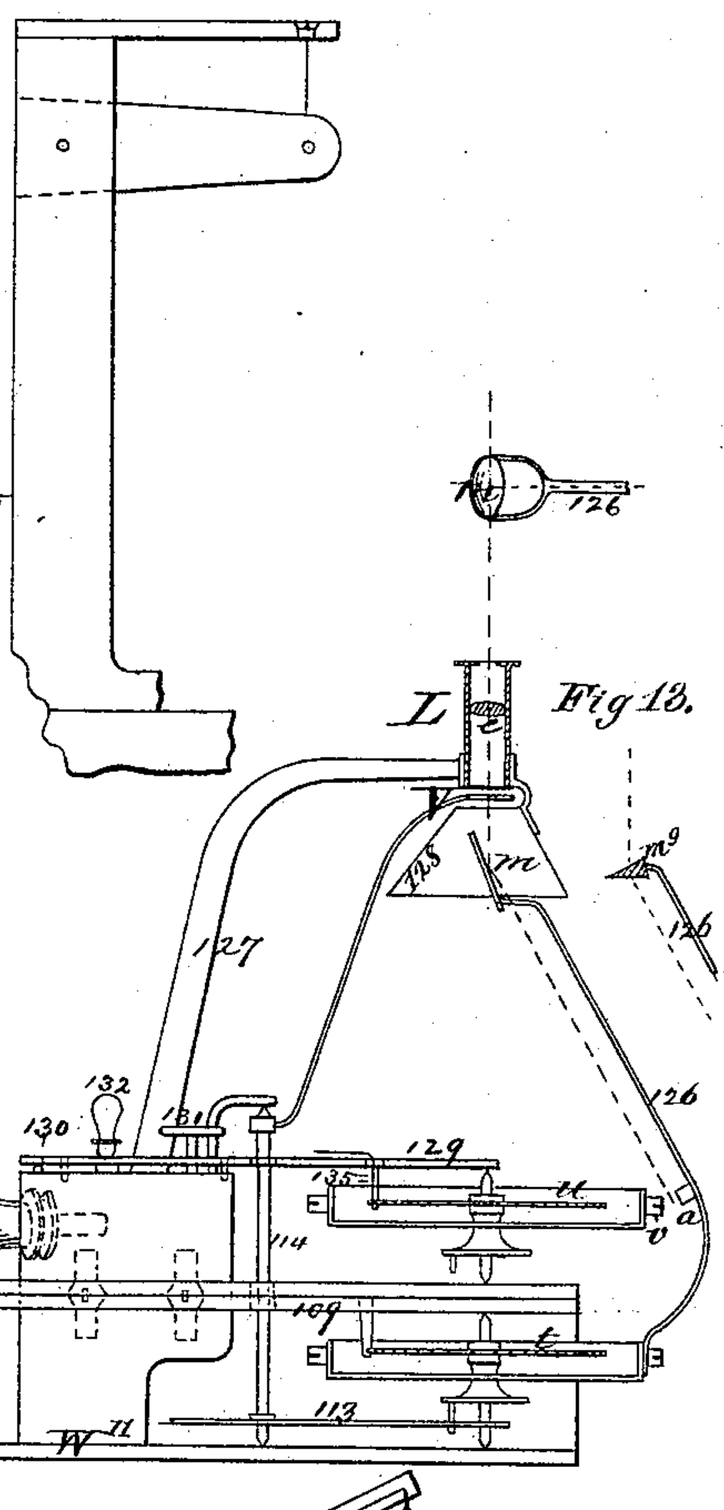
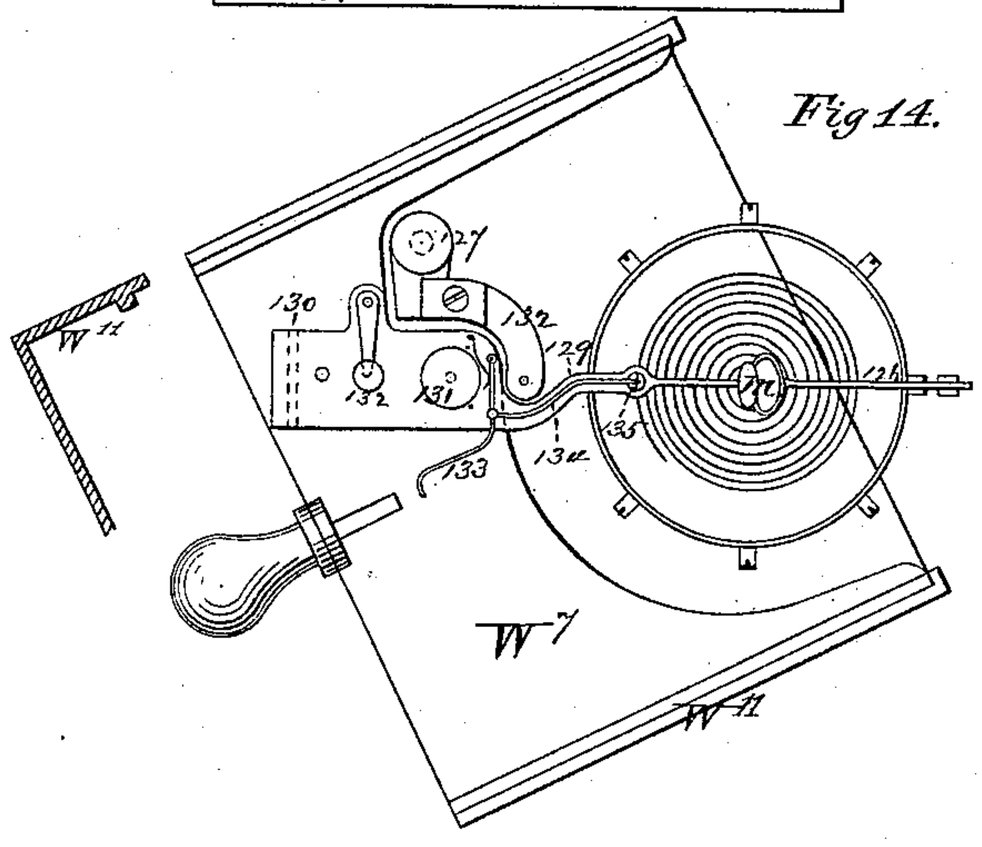



*Fig 14.*




*Inventor,*

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# C. E. EMERY.

## METHOD OF AND APPARATUS FOR RATING TIME PIECES.

No. 451,181. Patented Apr. 28, 1891.

Fig 28.

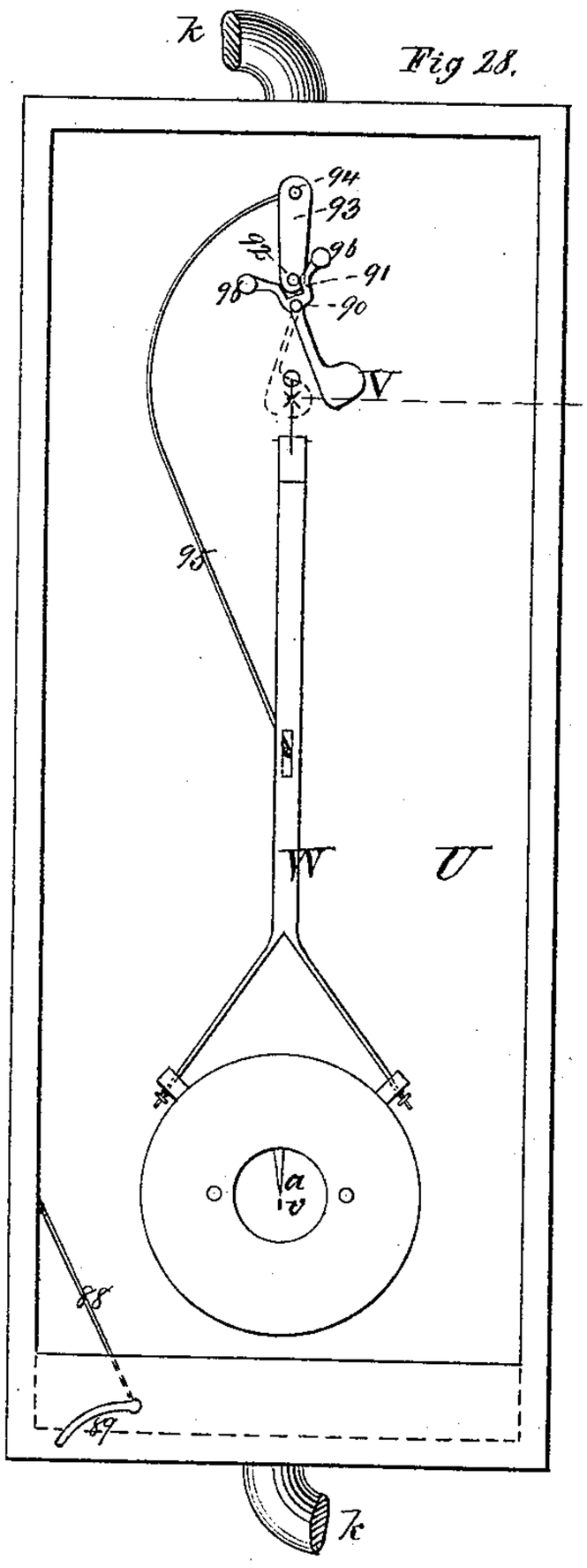



Fig. 29.

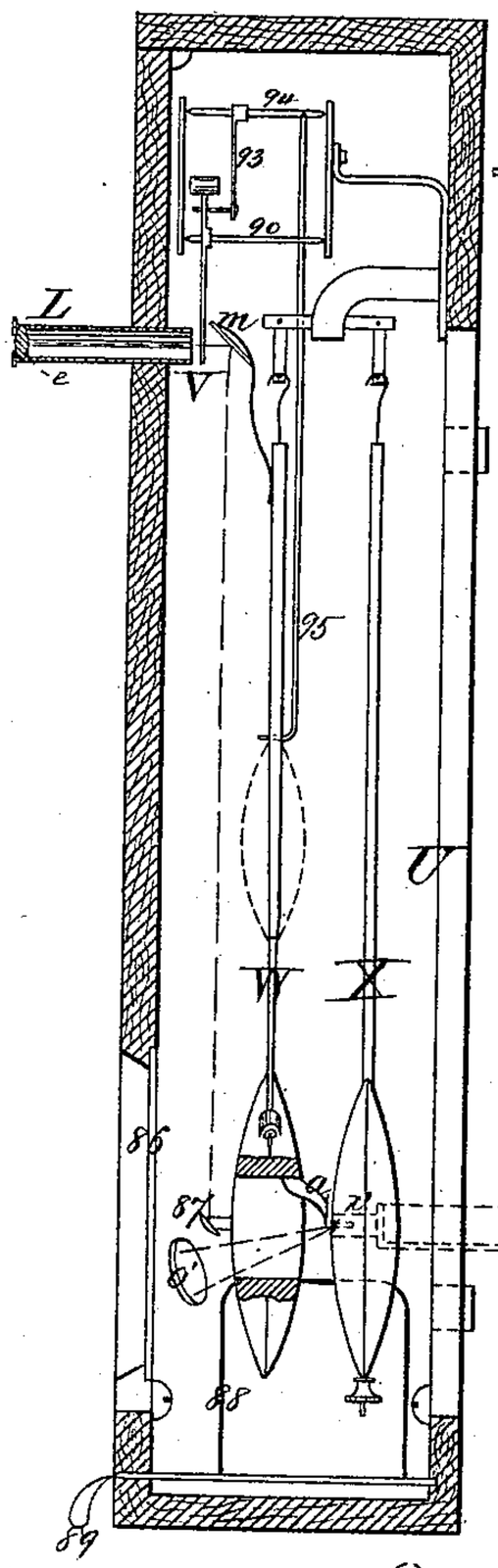



Fig. 33.

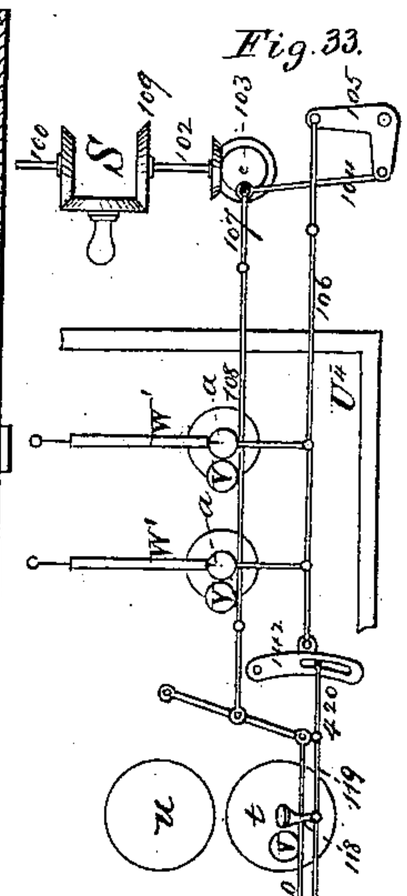



Fig. 30.

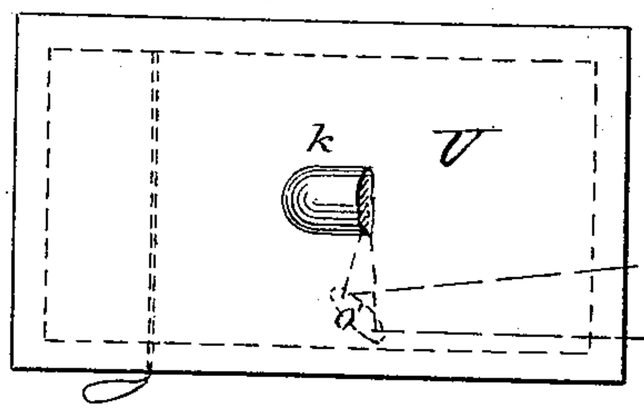



Fig. 31.

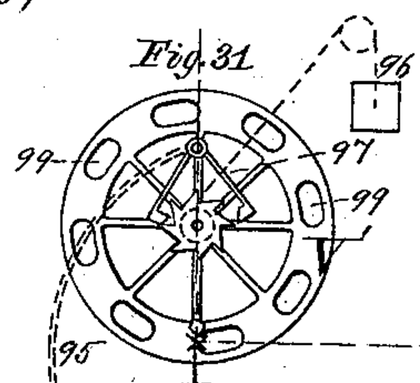
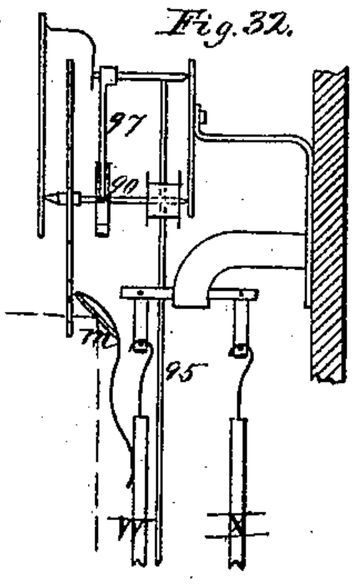



Fig. 32.




Witnesses,
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# C. E. EMERY.

## METHOD OF AND APPARATUS FOR RATING TIME PIECES.

No. 451,181. Patented Apr. 28, 1891.

Fig. 37.

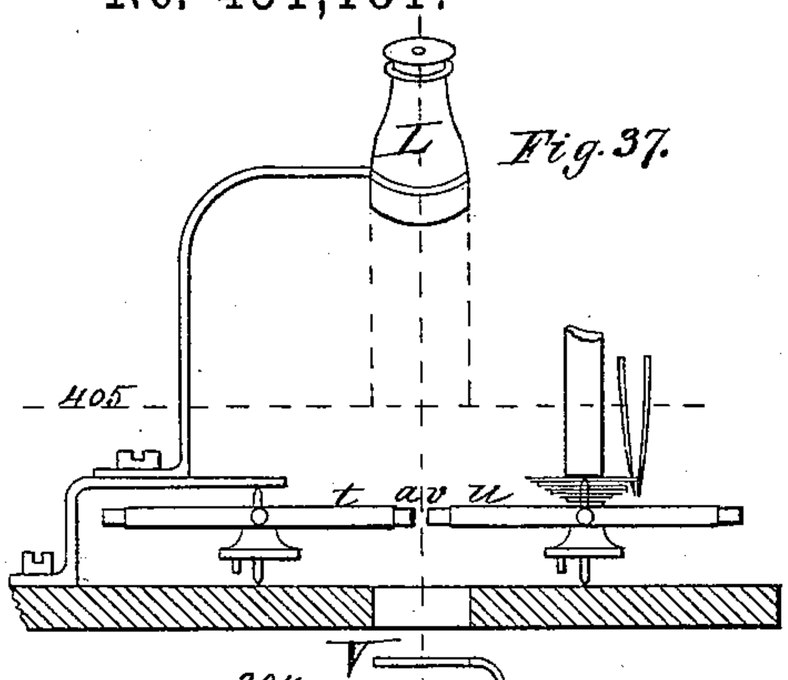


Fig. 38.

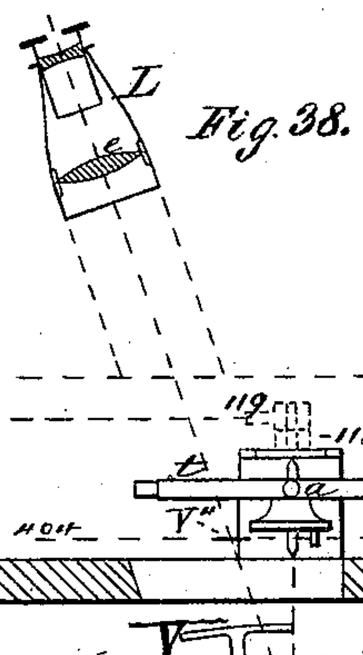


Fig. 36.




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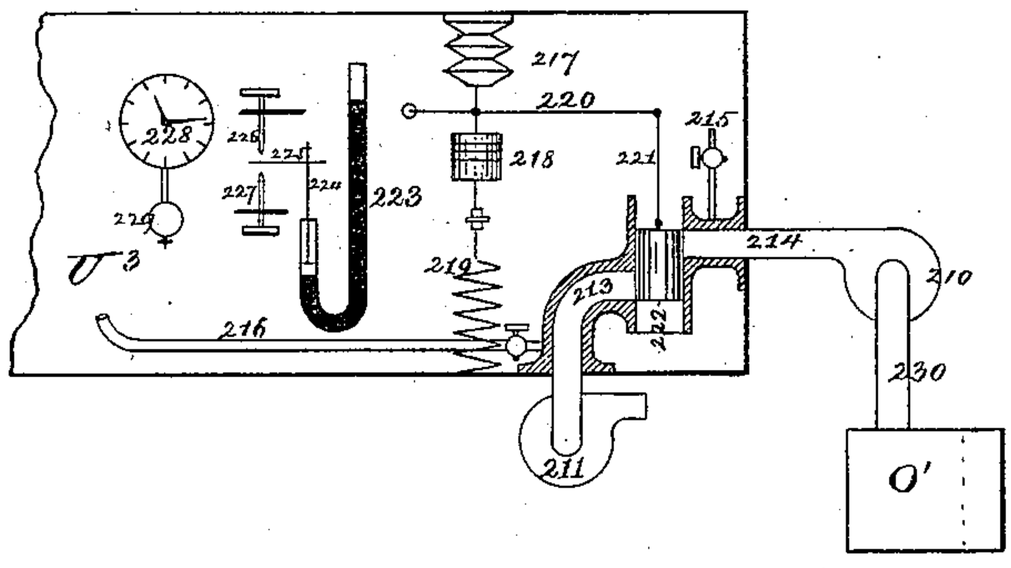
Witnesses,

Livingston Emery

George B. Pennell.

Fig. 35.

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# UNITED STATES PATENT OFFICE.

CHARLES E. EMERY, OF BROOKLYN, NEW YORK.

## METHOD OF AND APPARATUS FOR RATING TIME-PIECES.

SPECIFICATION forming part of Letters Patent No. 451,181, dated April 28, 1891.

Application filed May 2, 1890. Serial No. 350,256. (No model.)

*To all whom it may concern:*

Be it known that I, CHARLES E. EMERY, of Brooklyn, Kings county, New York, (office New York city,) have invented certain new and useful Improvements in the Method of and Apparatus Used for Rating Watches and Clocks; and I do hereby declare that the following is a full, clear, and exact description thereof, reference being had to the accompanying drawings, making part of this specification.

Section 1. The principal object of the invention is to produce a timing or time-comparing apparatus so delicate in its action that it may be determined in a few minutes whether a balance or pendulum is running faster or slower than a standard, even if the variation in rate be only a few seconds a day, so that changes necessary to adjust the rate may be made promptly, the comparison repeated at once and adjustments again made, as may be necessary, all as part of one continuous operation without waiting to run the watches or clocks at first for hours and finally a day at least between each adjustment, as is required at present.

Section 2. A further object of the invention is to provide means whereby in one apparatus the watches and clocks may be promptly compared under different temperatures and pressures and the former in different positions and the more delicate corrections due to these conditions be also made at once, requiring only a sufficient number of movements actually undergoing test to give time between the operations on each for the metal of the balances to assume the tension and shape due to the change of condition.

Section 3. To secure the desired delicacy of the time-comparing apparatus, which we will term a "comparator," it is necessary to be able to observe promptly the slightest variation in the motion of the balance or pendulum undergoing test from that of the standard with which it is being compared. The point to be observed on the balance or pendulum undergoing test will be called the "object-point" and the point on the moving standard with which the motion of the object-point is to be compared will be called the "comparing-point." These points jointly will be called "points of reference," and are preferably located on the rims of the standard balance or equivalent and of the balance undergoing test, so that the axes of both balances when at rest and the points of reference are in the same plane called the "plane of reference." Similarly the points of reference of pendulums would be fixed when they are hanging vertically opposite each other, so that the plane of reference will run through the points of suspension and points of reference. In either case the points of reference during operation cross the plane of reference when the balances or pendulums are moving at their highest velocity.

Section 4. The inventions embodied herein provide means for optically viewing a slowly-moving or stationary image of the points of reference when the latter are actually moving at their highest velocity, whereby any change of the relative positions of the two may be detected at once as readily nearly as if such points were actually moving in relation to each other with only their difference of velocity. This is accomplished somewhat on the principle used in equatorial telescopes to keep the axis of the telescope practically fixed on a given star, notwithstanding the motion of the earth. As the surface of the earth moves from west to east, the telescope is caused to swing around a polar axis from east to west with practically the same angular velocity. The same details and method of operation would evidently be applicable if the star were moving rapidly and the earth were stationary. To apply this principle in viewing minute objects, like the points of reference referred to, the observations are made through a mirror which receives such motion that the angle of incidence of its surface in relation to such points when practically coincident and the angle of reflection from such surface to the eye or line of sight will be the same or approximately the same, in which case the image of the moving points will appear stationary or moving so slowly that the relative motion of the two can be accurately determined. The mirror may be swung on an axis independent of that of either balance, when preferably the line of sight would be in the plane of the motion of

the points, or the mirror may be carried by one of the balances, when preferably the line of sight would be in the direction of the axis. The latter mode of operation will first be described in full, and may be illustated by supposing an observer situated at the center of the platform of a curriculum in rapid revolution and looking radially outward through an opera-glass. The view of objects off the platform would be indistinct on account of the relative velocity, although the observer was changing angle slowly; but if the glass were directed at the uplifted hands of two children riding side by side at the outer edge of the platform, where the actual motion would be rapid, the slightest movement of the hand of one in relation to that of the other could be observed because the optical axis of the glass would be moving at practically the same velocity as the children, and the difference of movement of the hands could as readily be distinguished as if no other movement were taking place. If the observer should put an inclined mirror in his chair at the center and then lie out on the stationary roof of the structure and look through his opera-glass downward in the mirror through a central opening in the roof, he would still see the image of the hands of the children and could watch their relative movements as well as if actually on the platform. Any particular point—for instance, the finger-nail of one finger of one of the children—could be brought in focus, when the image of it would appear absolutely still to the observer, although the point itself was moving rapidly through space. All the parts surrounding the central point in exact focus would appear in the image to revolve around the image of the point, but so slowly that the relative movements of parts near could be watched as closely as if there were no other motion than such relative movement. Objects off the platform would appear confused, as before; but if another platform were revolving at the same speed and with adjacent sides in the same direction alongside it objects on that would appear stationary at the moment of passing and the relative change of position of points on the two platforms which came nearly opposite at the moment of passing could be observed. In the same way the motion of the points of reference on two watch-balances may be observed at the time they are moving at nearly the same speed past the plane of reference by looking downward at an image of the same in an inclined mirror over the axis of one of the balances and moving with it. This principle is applied in a number of ways and with balances in a number of positions. Combinations of lenses and mirrors are provided, so that the slightest variation in the position of the points of reference when crossing the plane of reference may be detected, and by observations of successive vibrations it may be seen whether the object-point has moved ahead or has fallen behind the comparing-point. The delicacy of this method of operation is phenomenal. If the watch beat five times per second and the balance move through three hundred and sixty degrees at each beat, the main velocity will be five by three hundred and sixty degrees, or eighteen hundred degrees per second; but since the velocity is zero at the close of each vibration the maximum velocity, or that at the time the points of reference pass the plane of reference, will be about three thousand degrees per second, and if an ordinary observer can surely see a variation of ten degrees in the position of the points of reference this will correspond to an error of one three-hundredth of a second. If therefore a variation of ten degrees be discovered in one second, since there are eighty-six thousand four hundred seconds in a day, this error would correspond to (eighty-six thousand four hundred divided by three hundred equals) two hundred and eighty-eight seconds or 4.8 minutes per day; but if it required one minute to discover the same variation of ten degrees it would indicate an error of only one-sixtieth of two hundred and eighty-eight seconds or 4.8 seconds per day, or, if discovered in two minutes, to 2.4 seconds per day. Close observers would be able to discover a variation of five degrees, and would therefore be able to detect an error of 2.4 seconds a day in a single minute. Such observations are well within the requirements for temperature and position adjustments. In the more delicate operations the balances would require to be in place in the movements, so as to secure and retain very high velocities. A similar method of observation can be applied to balances when vibrated by hand; but more time will be required for very delicate adjustments, though the length of the spring can be fixed in a very short time within such limits that the exact adjustment can be obtained with the regulator.

Section 5. The inspection of the points of reference when in motion is accomplished optically by a combination of lenses and mirrors, which, with the movement to be tested and the standard, are in the complete form of apparatus preferably inclosed in a small case, through which air of different temperatures may be forced in making temperature adjustments, and which is so connected with the supporting and operating mechanism that it can be turned in different positions to test the movement for position. These tests are preferably made with the balance connected in the movement, which latter is mounted in a box adapted to form a drawer, which can ordinarily be kept in one of a series of drawer-cases, and there maintained at any desired temperature between the periods of comparison with the standard. In the specifications various forms of mechanism are shown, some adapted for the complete adjustment of a watch, others to accomplish parts of the results obtainable with the complete form. In some cases

a vibrating standard in the form of a balance resembling that to be tested is used, and in others a revolving standard is employed in which the point of comparison comes into view for every double beat of the balance to be tested. In all cases provision is made to cut off the view of the points of reference during the portion of the double beat in which motion is in a wrong direction. Adaptations of the same apparatus are applicable in rating pendulums. The invention involves a great number of details, which can best be set forth in connection with the description.

Section 6. In the drawings, Figure 1, Sheet 1, is a plan view, partly in section, of a comparator-case with a movement secured in a small drawer in such case. Fig. 2, Sheet 1, is a longitudinal section through the case and drawer and through portions of the comparator mechanism. Fig. 3, Sheet 2, is an elevation, on a smaller scale, of a complete apparatus embodying an external side view of the case shown in the previous figures. Fig. 4, Sheet 2, is a similar elevation of a modification of the parts shown in Fig. 3, with a different form of apparatus for securing angular adjustment and adapted for the use of a series of comparators operated by the same mechanism. Fig. 5, Sheet 2, is a view, on a still smaller scale, showing the general arrangement of the elements when such a series of comparators is used. Fig. 6, Sheet 3, is a plan view, partly in section, of another form of comparator-case in which an object-mirror revolves entirely around a watch-movement; and Fig. 7, Sheet 3, is a vertical central section through same with side view of some details. Fig. 8, Sheet 4, shows a general arrangement, on a small scale, of apparatus for circulating and regulating the temperature of the air used in making the comparisons for temperature adjustments. Fig. 9, Sheet 4, shows apparatus for automatically regulating the temperature. Fig. 10, Sheet 3, is a view of an apparatus for varying the angular velocity of a driven shaft in different parts of a revolution, to be used in connection with the revolving comparator above referred to. Fig. 11, Sheet 3, is a vertical elevation of the slotted disk shown in Fig. 10. Fig. 12, Sheet 3, is a vertical elevation, partly in section, of a vibrating apparatus with vibrating standard balance, showing one application of the principles of the invention to simple apparatus for ordinary vibrating purposes. Figs. 13 and 14, Sheet 5, are respectively a vertical elevation, partly in section, and a plan view of a modified apparatus for the purpose last above stated. Fig. 15, Sheet 5, is a vertical elevation, partly in section, of a modified apparatus, also for the same purpose; Fig. 16, Sheet 5, a transverse view, looking from the left, of the principal supporting-frame of the apparatus, shown in Fig. 15. Fig. 17, Sheet 5, is a vertical elevation, partly in section, of a fragment of a modification of the apparatus shown in Fig. 15. Fig. 18, Sheet 5, is a similar view of a fragment of a modification of the apparatus shown in Fig. 13. Fig. 19, Sheet 4, is a diagram plan view; and Fig. 20, Sheet 4, an elevation, partly in section, of still another modified form of apparatus for the purpose set forth in the description of Fig. 12. Fig. 21, Sheet 4, is a plan view of the balance-bridge of the same. Fig. 22, Sheet 4, is a plan view; and Fig. 23, Sheet 4, a vertical elevation, partly in section, of the principal parts of a modified apparatus for the purpose set forth in the description of Fig. 12. Fig. 24, Sheet 4, is an elevation, partly in section, of a modified apparatus for the same purpose. Fig. 25, Sheet 1, is a plan view, and Figs. 26 and 27, Sheet 1, are respectively side and front elevations, partly in section, of a vibrating apparatus for comparing balances with a cut-off operated by a pendulum. Fig. 28, Sheet 6, is a vertical elevation of a comparator-case for pendulums, combined with means for operating a cut-off. Fig. 29 is a side elevation, and Fig. 30, Sheet 6, a plan view of the same. Figs. 31 and 32, Sheet 6, are respectively front and side elevations of modifications of the cut-off apparatus shown in Figs. 28 and 29. Fig. 33, Sheet 6, is a diagram illustrating a method of operating cut-off disks and comparing-points from a prime mover. Fig. 34, Sheet 1, shows devices for the same purpose as the above in connection with a comparing-chamber and with apparatus for transmitting regular motion from a prime mover; Fig. 35, Sheet 7, an outline view, with parts in section, of apparatus for regulating the air-pressure. Fig. 36, Sheet 7, is a diagram showing the changes necessary in the angle of a vibrating object-mirror to keep in view objects moving in a plane at right angles to its face. Fig. 37, Sheet 7, is a fragmentary front view, partly in section, and Fig. 38, Sheet 7, a side view, partly in section and partly in outline, showing a combination of parts adapted for the use of a vibrating object-mirror not carried by a balance.

Section 7. The following are the names and designating letters of some of the principal details of the apparatus, viz: a comparing-point *a*, an object-point *v*, a comparator-disk F, a standard balance *t*, a balance for comparison *u*, a standard pendulum W, a pendulum for comparison X, a cut-off V, (section 21,) a mirror at the center *m*, an eye-piece L, a lens therein *e*, a drawer to contain a watch-movement for comparison D and D′, a comparator-case for a watch-movement E and E′, a watch-movement as a whole B, a comparing-chamber for clocks U, equalizing air-chambers O O′ $O^2$, cases for containing watch-movement drawers K K′ $K^2$, and pipes on comparator-cases for circulating air *k*. In addition to the above the following terms and designations will be used to express mechanical movements as a whole adapted for a particular purpose, as described in sections referred to, viz: a "regulated prime mover" R,

(Sec. 16;) an "angular adjusting apparatus" S, (Sec. 10;) "apparatus for varying the angular velocity" T, (Sec. 18.)

Section 8. In Figs. 1 and 2, Sheet 1, *u* represents a watch-balance mounted, preferably, in connection with the entire movement B, of which the plates *b b* are shown and are secured by clamps or other means in a fixture *c*, which in turn is fastened securely in the bottom of a drawer, (designated as a whole D,) of which *d* is the bottom plate, *d'* the end plate, and $d^2$ the handle. The drawer D moves from left to right upon the bottom between the sides and under ledges in a comparator-case (designated as a whole E.) F is a comparator-disk carried by a spindle *f*, the disk being provided at a point on its circumference with a comparing-point *a* and carrying at its center an inclined mirror *m*. L is an eye-piece, and *e* a magnifying-lens, with axis arranged in the line of the axis of the spindle *f* and of the comparator-disk F. The object-point in this case is represented by the screw *v*, which, as shown, stands opposite the comparing-point *a* when both are at rest and in a vertical plane passing through the axis of the balance and of comparator-disk F. The comparator-disk F, carrying comparing-point *a*, is to be revolved once for each double vibration of the balance and the points of reference are made to pass the plane of reference at substantially the same velocity either by adjusting the position of the comparing-point *a* in relation to the center of the comparator-disk F or by the use of an apparatus T for varying the angular velocity of the disk. (Sec. 18.) If, under such circumstances, the balance *u* and the comparator-disk F be put in motion, the image of the comparing-point *a* (seen through lens *e* in eye-piece L) will, when in proper focus, appear stationary, though the comparing-point itself is moving at a very high velocity, and momentarily during each double beat the object-point *v* will also appear stationary or moving at such reduced speed as to be seen. In the particular form of apparatus shown in this figure such object-point *v* will approach and recede from the comparing-point *a*, so as to change its relative angular velocity, and will therefore appear once during each double vibration to rapidly approach the comparing-point *a*, dwell slightly, and then as rapidly recede in a cusp-shaped path like that shown by a person's foot when viewed from below in walking on a grating; but an observer can detect during succeeding vibrations whether the points of the cusp traced by object-point *v* coincide with or gradually move to the right or to the left compared with comparing-point *a*. For instance, if the comparator-disk F be moving regularly to the left and object-point *v* appear gradually to move to the left of comparing-point *a* the balance will be running fast, and if observed point *v* should appear to be gradually moving to the right with reference to comparing-point *a* the balance will be running slowly, and vice versa. These variations can, as previously explained, (Sec. 4,) be promptly detected and adjustments made to vary the rate of the watch until the balance keeps time with the standard within a predetermined limit of error.

Section 9. The illumination of the comparing-point *a* and object-point *v* is secured by a light in the direction *o*, preferably provided with a condensing mirror or lens, or both, directing the rays upon a condensing-mirror *o'*, from which the rays are reflected and condensed upon the points of reference *a* and *v* when they pass the plane of reference. Any other system of condensing lenses or mirrors or other means of illumination may be adopted. To prevent the light from illuminating-mirror *o'* from falling upon the mirror *m* when the latter is turned toward the former, a disk *j* is placed just above the plane of revolution of mirror *m*, but with a sector removed on the lines *j' j'*, Fig. 1, corresponding to the angle in which it is desired to see the points of reference *a* and *v*.

Section 10. The hollow spindle *f* of comparing-disk F is operated by a spindle *g*, secured to a wheel G through a central rod *h*, provided with a driven pin *h'*, running in a longitudinal slot in the driving-spindle *g*, and a driving-pin $h^2$, engaging with a spiral slot *f'* in the spindle *f*. The wheel G is operated by a pinion I through a spur-gear on its edges when in the position shown in full lines, and through an attached bevel-gear, when, as hereinafter described, (Sec. 11,) the whole apparatus is revolved through ninety degrees, so that the wheel G takes the position shown by the dotted lines G'. H is a lever arranged with pins and rollers to engage between collars $h^3$ $h^3$ on rod *h*, and by moving the rod *h* longitudinally with the lever between the positions H H' the pin $h^2$ will, by its operation in the spiral groove *f'*, change the angular position of the spindle *f* of the comparator-disk F relatively to operating-wheel G, and with it the angular position of the comparing-point *a*, and evidently this change of angle may be made either when the parts are stationary or when the comparator-wheel F is in motion. In operation the pinion I would be given a motion from a regulated prime mover R, (Sec. 16,) such as would impart by the means shown to the disk F one revolution for each double vibration of a standard-balance. If, however, the comparing-point *a* in starting an observation pass the plane of reference at a different time than the object-point *v*, the disk F may while in motion be angularly adjusted by operating lever H, as described, so that both points of reference will pass the plane of reference at the same time when the lever H, being left in that position and held by a spring or catch the comparison can at once proceed, as above described. (Sec. 8.) In Fig. 4, Sheet 2, is shown a modification of the above apparatus. In this case the spindle *f* of the comparator-disk is

made continuous with the spindle of the wheel G, which, as before, receives motion from a pinion I, and the lower end of the spindle 202 of pinion I receives motion from a bevel-gear 36 thereon, which in turn is moved through another bevel-gear 37 at the left by a bevel-gear 38, carried on a spindle 203, which may be connected with spindle 27 of the electric motor, Fig. 3, Sheet 2, or, as shown in Fig. 4, with a bevel-gear 39, operated by any regulated prime mover. The bevel-gear 38 at the side runs loosely on a pin provided with a handle 200 at the left and secured at the right in a central cross 201. This cross is pivoted to and can freely revolve with handle 200 and bevel-gear 37 upon the ends of the upper and lower spindles 202 and 203, the bevel-gear 37 remaining in all positions in mesh with the bevel-gears 36 and 38. The handle 200 can be secured by a set-screw 204 upon a stationary arc 205. This arc is in this case a complete circle, which is secured at the right in jaws attached to frame C′, the circle being shown in section at the left in the shank of handle 200 and at the right in the jaws on the frame. The parallel lines show the continuation of the same circle beyond the section. By means of this arrangement, (marked as a whole S,) and which in this form will be recognized as a modification of the familiar "jack-in-a-box," the angular position of any point on gear 36 may be changed in relation to that of any point on driving-gear 38 by simply swinging the handle 200 around on the central spindles 202 and 203 as far as practicable without interfering with the frame C′, which action is evident if we suppose gear 38 to be held still and the handle 200 moved, when of course it will through gear 38 revolve the gear 36, and if all the gears are in motion an additional movement will be transmitted by handle 200, as well as if 38 were at rest. The change of the angular position of the bevel-gear 36 in relation to the driving bevel-gear 38 will also be transmitted through pinion I to wheel G, driving the comparator-disk F, and by properly proportioning the gear-wheels the comparator-disk F may be changed in angle through an entire revolution by operating the handle 200, though this would require that the pinion I be relatively larger in relation to wheel G than shown in this particular view. This apparatus, as well as that operated by the lever H in Fig. 2, Sheet 1, (Sec. 10,) will be referred to herein as "angular adjusting apparatus" (designated as a whole S) and embodied as an element in several combinations.

Section 11. The customary position of the comparator-case E is shown in Fig. 3, Sheet 2, in which the rate of the balance would be tested with the movement on the flat with the face or "bezel down," as shown in Fig. 2, Sheet 1. To test the rate on the flat "bezel up," it is simply necessary in this particular apparatus to withdraw the drawer D and turn it over, as the parts are so proportioned that the object-point *v* will be at the center of the drawer in either flat position of the movement. To provide for testing in vertical positions, the case E, as shown in Fig. 2, Sheet 1, is secured to a spindle *i*, which swivels in an eye in the end of a curved supporting-arm J, which, as shown in Fig. 3, Sheet 2, swings through an arc of ninety degrees in corresponding curved brackets in the top of a frame C, provided with screws or other means to secure such curved arm J in either extreme position. In the position shown the spur-teeth on wheels I and G are in gear; but when the arm J is swung around its center (at the junction of the pitch-circles of the spur and bevel gears) through an arc of ninety degrees the bevel-gear teeth on pinion I engage with those on G in the position of the dotted lines, the spindle *i*, supporting comparator-case E, becomes horizontal, and the spindle of the case may be turned in its bearing in the boss on the end of curved arm J, so that the position of the movement will correspond with pendent up or down or right or left, the customary positions used in testing watches in vertical positions, and comparison made in either position without other adjustments except as to the location of the lamp for illumination, which must be adjusted for each position unless hung on the apparatus or in the form of a gas-jet or electric light with connecting flexible pipes or wires. The provisions for circulating air, hereinafter described, can readily be adapted to all the changes of position.

Section 12. To provide for temperature adjustments air-nozzles *k k* are provided on the comparator-case E, in one of which air, either hot, cold, or of medium temperature, may be blown through a conducting-hose and pass out of the other, either through a conducting-hose or into the room. Such an opening—for instance $k^2$—may be in the handle $d^2$ of the drawer D. In some cases, however, it is better not to blow the air directly on the movement, but rather to produce and maintain the desired temperature by conduction through the metal of the drawer. For delicate movements the drawers may be made practically air-tight and the balances viewed through glass, or in any case the case and seasoning-chambers may have hollow walls, between which fluid of any kind at a regulated temperature may be circulated to produce and maintain the desired temperature in the case and chamber. In adjusting the temperature it is proposed to maintain the movement at the desired temperature by circulating air of that temperature through the case E, when by observing the rates at two extreme temperatures and any intermediate temperature desired the balance may be adjusted to correspond and tested again and again until made satisfactory. In practice it is proposed to erect near the apparatus three or more cases of drawers K, K′, and $K^2$, Fig. 8, Sheet 4, provided with drawer-openings of proper size to

receiver drawer D, Fig. 1, Sheet 1, and to provide a sufficient number of drawers to entirely fill the openings, also one spare one to contain the movement actually undergoing test. The cases of drawers are to be maintained at the different temperatures it is desired to employ—for instance, severally at 40°, 70°, and 100° Fahrenheit. In Fig. 8, Sheet 4, M and M′ represent pumps or fan-blowers, one M drawing air over ice in a chamber N through an inlet $N^4$, the other M′ drawing air over a stove or heating-coil in a chamber N′ through an inlet $N^3$. The outlets of the blowers are connected by suitable pipes and branches provided with valves $n$ $n'$ with equalizing-chambers O O′ $O^2$, which are severally connected by discharge-pipes $p$ $p'$ $p^2$ with the cases of drawers K K′ $K^2$, and such cases are provided with outlet-valves $q$ $q'$ $q^2$. In operation cold air discharged by the blower M and hot air discharged by the blower M′ can by regulating the valves $n$ $n'$ be mixed in any desired proportion in the right-hand compartments of the chambers O O′ $O^2$ and be passed through screens or deflecting-plates to the main portions of the chambers, and from there be conveyed through the pipes $p$ $p'$ $p^2$ to the several cases of drawers K K′ $K^2$. It is proposed to make the partitions between the drawers of cases in skeleton form, so that air blown in the cases can circulate over the entire surfaces of the drawers and finally escape by the outlets $q$ $q'$ $q^2$. For instance, O may be the hot room connected to case K and sufficient hot air admitted to maintain both at a temperature of 100°. Similarly room O′ and case of drawers K′ can by properly mixing the air be kept at a temperature of 70°, and room $O^2$ and case of drawers $K^2$ can by supplying a sufficient quantity of cold air be maintained at a temperature of 40°. The hot air discharged at $q$ or cold air at $q^2$ may in turn be conducted through a hose to the inlet $k$ of the drawer E, Figs. 1 and 2, Sheet 1, and return from outlet $k'$ of such drawer through a hose to the suction of the proper blower to prevent waste of heat or ice, or the return may be omitted and the circulating air be allowed to escape into the room through one of the branches $k$ on comparator-case E. This case may receive air at an intermediate temperature of, say, 70° by connecting the same with outlet $q'$ or to any point on the pipe $p'$ leading from chamber O′. Evidently, also, the desired temperature of comparator-case E may be obtained by direct connection to such one of the rooms O O′ $O^2$ as is maintained at that temperature or to any of the pipes or connections leading therefrom.

Section 13. The temperature of the air circulated through case E, Fig. 1, may be ascertained by inspecting a thermometer $l$ of any kind inserted in such case. To prevent discomfort in handling the comparator-box E, Fig. 1, Sheet 1, Fig. 3, Sheet 2, and to prevent too rapid change of temperature due to exposure to the air, such box or any of the apparatus desired may be covered with nonconducting material—for instance, in the space inclosed by the dotted lines surrounding box E in Fig. 3, Sheet 2.

Section 14. The temperatures may be maintained at the desired point in the chambers O O′ $O^2$ by automatic apparatus of customary form—such, for instance, as is used in hatching devices. One method of doing this is shown in Fig. 9, Sheet 4, in which $n^4$ represents one of the valves $n$ $n'$. A simple butterfly-valve $n^3$ is provided in the same pipe, and may be operated through an external arm by a crank on a shaft 20, which is given a tendency to revolve at the top from right to left by any motive force—for instance, the weight 24, shown connected to a drum on shaft 20. An arm 21 on this shaft is detained in the position shown by the armature 22 of an electric magnet 23, so that in the position shown the valve $n^3$ is closed. 24 represents a bimetallic plate or the end of the curved tube (filled with fluid) of a metallic thermometer or any equivalent device in which motion is caused by change of temperature, such device being distinguished herein in general as a thermometer or bimetallic thermometer, though no scale is required if adjustment be made with an ordinary thermometer. In the arrangement shown 24 moves in one direction for heat and in the other for cold. In one case, through the electric connections indicated, it closes an electric circuit to move the armature of electro-magnet 23, thus releasing arm 21 and allowing shaft 20 to revolve half a revolution until arm 21 thereon is detained by the armature 26 of an electro-magnet 25, and thereby opening valve $n^3$, and in the other case closing an electric circuit to electro-magnet 25 and causing armature 26 to release arm 21 and permit the motive force to close valve $n^3$ again. By placing a bimetallic thermometer 24 in each of the equalizing-chambers O O′ $O^2$ a number of combinations may be made to adjust the temperature of each as desired. For instance, in the hot-chamber O the valve $n$, admitting cold air, may be nearly closed, and the valve $n'$, admitting hot air to that chamber, be operated by apparatus similar to that described, governed by a bimetallic thermometer. A similar arrangement would answer also for the equalizing-chamber O′ for the intermediate temperature; but evidently this temperature can be maintained in summer, when the temperature is higher than 70°, by simply admitting cold air through a valve $n$ under the control of a thermometer to keep the temperature down, when by placing the ice-chamber well above the point where the cold air is to be delivered such air will fall by gravity and circulate throughout the apparatus without a blower. In winter, when the normal temperature is lower than that desired, the temperature can be maintained by simply admitting hot air under the control of a thermometer through a valve

$n'$ to keep the temperature up, and if the heating devices are sufficiently below the point where the hot air is to be delivered it will circulate without a blower. In either case the air can be drawn through the apparatus by a heated chimney. Regulation of heat may also be made by shutting off a gas-jet or closing the damper of a furnace heating the air to be circulated. Similar methods of operation may be employed when the out-door temperature available is extreme for either of the other equalizing-chambers. Ordinarily to maintain the low temperature in chamber $O^2$ it would be found most convenient to admit a small quantity of warm air by regulating the valve $n'$ by hand and then operating the valve $n$, admitting cold air through apparatus governed by a thermometer in the chamber coupled and arranged so that as the temperature rises cold air will be admitted and as it falls will be excluded. In other cases evidently two bimetallic thermometers may be used in each chamber, one connected to the hot-air inlet and arranged with suitable apparatus to admit hot air when the temperature falls below a certain point, the other thermometer arranged to govern the cold-air inlet and to admit cold air when the temperature rises above a certain point, and if the two thermometers are set with a slight difference the temperature will be maintained at some mean point. The arrangement of equalizing-chambers O O′ $O^2$ would be used also in connection with the testing of clocks for temperature, the pipes $p$ $p'$ $p^2$ being led to cases or rooms in which the clocks are located, as described hereinafter. The general arrangement herein described for circulating air at a regulated temperature through comparing-chambers or other fluid at a regulated temperature through hollow casings surrounding such comparing-chamber, though in detail very similar to apparatus used for heating and cooling rooms for other purposes, introduces, when applied to the regulation of clocks and watches, as described, a novel system of great advantage. Heretofore watch-movements have been put alternately in hot and cold chambers, from which such watch-movements were necessarily removed to the work-benches of the operatives or adjusters in various parts of the building, or at every point where watches were adjusted furnaces and refrigerators were necessarily located. With this arrangement there need be but one general arrangement for heating, and in connection therewith apparatus for refrigerating the circulating fluid, all of which can be located in or near the room supplying the power and be attended to as part of the general apparatus, like the engine, the heating apparatus, the electric-light apparatus, &c., and from such apparatus for circulating fluid at a regulated temperature pipes be conducted to any part of the building where it is desired that testing operations be conducted, and branches be led directly to the work-bench of each operator on this class of work—for instance, to each comparator of a series shown in fragmentary view in Fig. 5, Sheet 2, and a more detailed view of one of which is shown in Fig. 3 on same sheet.

Section 15. In operation all the drawers would be in place in the several cases K K′ $K^2$ and one spare one be provided, so that if adjustments of movements running in the cold were being made in a particular comparator the drawer removed from the comparator-case E would be put in place of one removed from the drawer-case $K^2$, which latter would be put in the comparator-case and the movement tested. The comparator-case would at that time be connected with the case of drawers from which the movements were being taken. This operation would be repeated for each temperature desired and adjustments made between the trials. If movements were sent away for adjustments, necessarily spare drawers or stoppers would be put in place of those removed from the drawer-case.

Section 16. In the lower part of Fig. 3, Sheet 2, is represented an electric motor for operating the comparator-disk through the gears I and G previously described. The spindle of the pinion I runs through a long bearing connected rigidly to the upper part of frame C, and such spindle connects in a yoke 26 with a hollow governor-spindle 27, provided with a lower bearing in the cross-bar of the frame. The yoke 26 is secured to spindle 27 and carries governor-arms 28 28, provided with short arms turned inward and connecting with a sliding sleeve 29, which sleeve, through a pin moving in a slot in spindle 27, connects to a regulating-spindle 75, extending through the governor-spindle 27 and below the bottom of the same and bearing upon the short end of a lever 29, which at the other end is provided with a metallic point 30 to open and close an electric circuit. 31 31 are fixed electric magnets, and 32 32 electric magnets revolving with spindle 27. 33 33 are brushes insulated from the frame, with their free ends bearing on a commutator 34 on spindle 27, arranged in customary ways to make and break the current passing through the revolving magnets 32. The current from the electric battery 76 passes through the coils of fixed electro-magnets 31, thence through the left-hand brush 33 to the commutator 34, thence through the coils of the revolving electro-magnets 32, and out upon the brush 33 at the right to the point 30 on lever 29, and the operation is such that when the speed of the apparatus slacks the balls 28 28 of the governor will fall toward the center, lifting the governor-spindle 28, so that the point 30 will be depressed and come in contact with fixed point 35 and close the circuit, when the electric engine will increase its speed until the balls 28 again move out and break the circuit at 30. The height of the point 35 is made adjustable to permit slight variations of speed by varying the height of the balls in relation to the points

of suspension. In the lower part of Fig. 34, Sheet 1, is shown an apparatus to be connected to a prime motor and used as a substitute for the electric motor shown in Figs. 3 and 5, Sheet 2. Q is an inclosure for the governing apparatus corresponding to that similarly designated in Fig. 5. In Fig. 34 there is, as in Fig. 3, a governor with balls 28, mounted in a yoke 26, secured to a hollow spindle 27. The balls are provided with arms turned inwardly to operate a central rod or spindle 75, and the yoke 26 is connected to a shaft 76, which may be connected to any apparatus it is desired to operate—for instance, that shown in Fig. 34 or the spindle of pinion I in Fig. 3. In Fig. 34 the spindle 27 is continued downward and arranged to turn freely inside a sleeve 80, secured to a bevel-gear 81. The sleeve 80 of gear 81 revolves in a bearing in a frame 79. The bevel-gear 81 is kept in motion at a speed which should at all times slightly exceed that to be given the governor-balls 28 by a prime motor of any kind from which motion is to be transmitted in any mechanical way—for instance, through a bevel-gear 82. A disk 83 is carried by adjusting-nuts 84 on central spindle 75, and is by a splined or square rod and hole arranged so as to turn therewith and yet permit longitudinal motion from the adjusting-nuts 84. The upper part of spindle 75 carries a driving-pin 78, running in a slot in the hollow spindle 27 of the governor. In operation, when the speed of the governor is reduced the balls fall, pulling up the central spindle 75 and bringing disk 83 in contact with the under face of the bevel-gear 81, which imparts a certain degree of motion by friction to the disk, spindle, and governor until the latter is brought up to speed or a trifle higher, when by the expansion of the balls 28 the disk 83 is released from contact with wheel 81. In practice the balls will generally maintain a position so that the pressure of the disk 83 on bevel-wheel 81 will be just sufficient to drive the governor to speed. The shaft 76, operated by the governor, may carry vanes 77 to act on the air and produce a slight resistance to steady the apparatus, and, if desired, a fly-wheel like 44, Fig. 5, Sheet 2, may also be used. Either form of apparatus above described will be found convenient for obtaining motion at a regulated speed, though any other regulated prime mover—such as a steam-engine with a delicate governor—may be employed. Such an apparatus is referred to in general herein as a "regulated prime mover," and designated as a whole R.

Section 17. Fig. 4, Sheet 2, also shows a part of a modification of the driving apparatus of a revolving comparator, designed to operate several machines from the same prime motor. The wheel 39 may connect to pinion I and comparator-disk F either through the jack-in-the-box arrangement shown in Fig. 4, or evidently its spindle 203 may be connected directly to the spindle of the pinion I in Fig. 3, where the angular adjustment is differently provided for. As shown in Fig. 4, the bevel-gear 39 is operated by a gear 40 on a shaft 41, corresponding to the shaft of the same number in Fig. 5, which, as shown, operates a number of machines, of which fragmentary views are shown. The shaft 41, through bevel-gears 42 and 43, is operated by a vertical shaft carrying a governor regulating any form of prime motor—for instance, the electro-magnetic engine shown in Fig. 3. 44 is a fly-wheel to assist in keeping the speed uniform. The governor apparatus, independent of the type of prime mover, is preferably arranged in a separate room Q kept at uniform temperature—for instance, in the basement of a building, or provided with connecting-pipes 45 45, connected with the apparatus for circulating air. (Shown in Fig. 8, Sheet 4.) In this way a series of comparator-disks may be operated simultaneously at the desired speed from a prime mover, the governor of which is adjusted for temperature by running in air of a uniform temperature. A uniform air-pressure may, if desired, also be maintained by connecting the chamber Q with apparatus for securing the same. (Sec. 24.)

Section 18. The maximum velocity of an object-point on a balance necessarily varies with the amplitude of vibration, for the reason that long and short arcs are made in the same time. If the balance undergoing test be compared with another balance with the same amplitude of vibration, the velocities of the points of reference across the plane of reference will be the same, whereas when a revolving comparator is used the velocity of the comparing-point, without special provision to the contrary, will be constant independent of the amplitude of vibration and maximum velocity of the balance which is being compared with it. To overcome this difficulty, means are provided to vary the angular velocity of the comparing-point as it passes the plane of reference. Such point must necessarily make an entire revolution in the time of the double beat of a standard balance; but its angular velocity may vary in different portions of its revolution. This can be accomplished by placing anywhere in the driving connections an apparatus familiar in the arts, like that, for instance, used on some machine-tools and in some forms of sewing-machines; but as in the present case the variation in angular velocity must be adjustable at will while the spindles and wheels are revolving, a method of accomplishing the object is shown in Figs. 10 and 11, Sheet 3, in which 59 and 60 are revolving shafts in the same line, shaft 59, carrying a disk 61, provided with a slot 62, in which runs a crank-pin 63 on the end of a short shaft 64, connected to shaft 60 by a universal joint 65 and supported at 66 in a ball-joint bearing adjustable transversely in relation to the disk 61 by a slide 67, operated in any customary way—for instance, by a

screw provided with a hand-wheel 68. The effect is that when the center of the shaft 64 is made to coincide with that of 59, the crank-pin 63 and attached parts not only make the same number of revolutions in a given time as the disk 61, but have the same angular velocity throughout each revolution. When, however, shaft 64 is thrown to one side, so that the crank-pin travels in the path shown by the dotted lines, Fig. 11, the crank-pin 63 will be moved quite rapidly when near the outer boundary of the disk in the position 63, Fig. 11, and quite slowly when in the opposite position (designated 69) near the center of the disk. Apparatus for varying the angular velocity is designated, as a whole, T, and so referred to in various combinations. An equivalent for the same, applicable to a vibrating point of comparison, is described in Section 29 and similarly designated T.

Section 19. When an apparatus T for varying the angular velocity is employed, if the balance be swinging through a very small arc at the time of comparison, the comparator-disk may be adjusted to run at a correspondingly slow velocity across the plane of reference, and when the balance is swinging through long arcs in the same time the comparing-point may by the use of the apparatus be given a greater velocity at the time of the observation. The apparatus T can be applied in Figs. 1 and 2, Sheet 1, by simply lengthening out the spindle $f$ of comparator-disk F and applying the apparatus between the arm J and case E, so that the variation in angular velocity will be made in a fixed relation to the comparing-point $a$ and not modified by the means of securing angular adjustment S. In such case a bent arm should be extended upward from the arm J to carry an additional bearing for spindle $f$ near the comparator-case E, when the two bearings will correspond to those on shafts 59 and 60 in Fig. 10, Sheet 3. The apparatus T, for varying the angular velocity, can be conveniently applied anywhere in the operating connections of the form of comparator shown in Figs. 6 and 7, Sheet 3, yet to be described, providing it be put between an angular adjusting apparatus S (Sec. 10) and such comparator. When such apparatus T is used to transmit motion to a comparator-disk, the connecting-gearing should be arranged to run at the same or a multiple of the speed of the disk, and in general the comparing-disk F should either make one full revolution for each double vibration of the balance or a number of revolutions in the same time. So, also, a comparing-point $a$ may be on a balance making a number of vibrations during the double vibration of the balance to be compared, so long in either case as the view is cut off by a cut-off apparatus V, yet to be described, (Sec. 21,) at all times except when the comparison is being made.

Section 20. Figs. 6 and 7, Sheet 3, show a modification of the comparator illustrated in Figs. 1 and 2, Sheet 1, designed to overcome an objection to that form of comparator, due to the fact that since the axis of the balance $u$ and of the comparator-disk F do not coincide in Figs. 1 and 2 the velocity can only be the same at one point of the revolution of the comparator and approximately the same for very limited angles on either side of that point. In Figs. 6 and 7 the balance $u$ to be tested is set in a movement B, of which the plates $b$ $b$ are shown, and the latter attached to the bottom of a circular holder D′, which, as shown, is arranged with its bottom protruding eccentrically through the top of a circular comparator-case E′, and secured thereto by clips 206 or other suitable means. The holder D′ is, however, provided outside of case E′ with a handle $d^2$ and guides $d^4$, so that such holder may be turned upside down and pushed into a drawer-opening, (the same as the holder D, Figs. 1 and 2, Sheet 1,) and the opening in drawer-case closed by an attached plate $d^5$, when the operation in relation to such holder D′ and its attached watch-movement B will be the same generally as that for the drawer D, Figs. 1 and 2. The case E′, Fig. 7, is attached to a hollow sleeve $i'$, with which it may be revolved in a bearing in a boss on the frame J′. The holder D′ is so set in the case E′ that the axis of balance-wheel $u$ is in line with that of the sleeve $i'$. Within the sleeve $i'$ runs a hollow spindle $f^4$ of a comparator-disk F′, which is provided with a comparing-point $a$, corresponding in size and in distance from the center with the screw $v$, forming the object-point on the balance $u$. The comparator-disk F′ also carries an arm 46, provided at the end with a mirror 47, set in the same axial plane as comparing-point $a$, which mirror receives an image of the points of reference $a$ and $v$ and transmits it to a central mirror $m$, also carried by the comparator-disk F′, which reflects the image through the hollow spindle directly to an eye-piece in some cases, but generally upon a third mirror 49, where it is viewed by a magnifying-glass $e$ in an eye-piece L. The several mirrors 47, $m$, and 49 may form parts of a multiple magnifying-glass or of a compound microscope. The sleeve $f^4$ is operated by an attached bevel-gear 52, operated by a second bevel-gear 53, the spindle 54 of which is to connect to a regulated prime mover R, (Sec. 16,) running at the proper speed through angular adjustment apparatus S, (Sec. 10,) and apparatus for varying the angular velocity T, (Sec. 18,) as desired. As shown, spindle 54 has a bearing in a stationary sleeve 55, upon which is pivoted the arm J′, in which the sleeve $i'$ of the comparator-case E′ is journaled. The eye-piece L, with attached tube carrying mirror 49, is shown pivoted at 56 in an arm 57, attached to the arm J′, the result being that the arm J′ may be turned around the sleeve 55, so that the case E′ will carry the face of the watch-movement B up or down to make tests "bezel up" or "bezel down;" or the case E′, with

sleeve $i'$, may be swung around in eye 50 of frame J′ to make tests pendent up, down, right or left. So, also, comparator-case E′ may be partially revolved with sleeve $i'$ in bearing-boss 50 to secure angular adjustment of the object-point $v$ to the comparing-point $a$, instead of using the angular adjustment apparatus S (Sec. 10) to bring the comparing-point to the object-point. This method of adjustment by swinging the comparator-case is not of general application as it will change the vertical positions of movement when spindle $i'$ is horizontal, but the swinging comparator-case is the equivalent of apparatus S when spindle $i'$ is vertical on either plan shown in Figs. 6 and 7 or in Figs. 1 and 2. In either of the positions of the comparator-case E′, Figs. 6 and 7, the eye-piece L may be set at various angles by swinging it on pivot 56. In the operation of the apparatus shown in Figs. 6 and 7 the object-mirror 47 revolves around the pendent movement and in full view of the balance when not obstructed by the watch-movement or other means, as explained hereinafter. The plane of reference is fixed near the center of the least obstructed space—for instance, as shown, between the balance-bridge and the horn of the back plate of movement—and since the object-mirror 47, carried by comparator-disk F′, turns on an axis coincident with that of the balance the image in mirror 47 of the object-points $a$ and $v$ is nearly stationary for a larger arc, and comparisons can be more readily and closely made than with the apparatus shown in Figs. 1 and 2. It is desirable, however, to limit the view to a portion of the revolution of the comparator-disk when the balance is moving in one direction and with nearly maximum velocity. This is accomplished by means of a movable ring $r$, resting on a ledge in the comparator-case E′, such ring being provided with a pendent apron $r^4$, which intercepts or cuts off the view of the points of reference $a$ and $v$, except through an arc $r'$ $r^2$, where the pendent apron is cut away. The gap thus left may be adjusted by turning the ring $r$; but, as illustrated, the comparator-arms are supposed to be moving at the bottom from right to left, so that the object-mirror 47 contains a fair view of the balance as soon as it passes the balance-bridge and follows it around to the plane of reference, supposed to be where the object-point $v$ is shown in Fig. 6, and the end of the screen or apron $r^4$ can be adjusted so that the view will be cut off soon after passing this plane and before the velocity of the balance is reduced materially. This form of apparatus has many advantages; but there is an objection to the number of mirrors necessarily employed, which absorb a great deal of light. The illumination is secured through an opening $o^2$ by means of a lamp and condensing lens or mirror, as is found most convenient for use. The arm 46, carrying mirror 47, may be curved in the horizontal plane, so that its shadow will not interfere with the illumination at the instant of observation. As before, tubes $k$ and $k$ are provided for the circulation of air at any temperature desired in making temperature adjustments.

Section 21. Many modifications of these elaborate forms of apparatus are available to perform a part of the several operations referred to, in some of which the comparing-point makes a full revolution, as has been described, and in others has a vibrating movement, as if located on a standard balance. In the latter case, however, it is desirable that the comparison only be made with the balances moving in one direction to avoid confusion, and the means used to accomplish this are available even in connection with ordinary vibrating apparatus, and when applied overcome one of the principal difficulties in teaching operators to vibrate balances. No confusion occurs with the form of apparatus shown in Figs. 1 and 2, for the reason that the comparator makes a full revolution for a double vibration of the balance, and the object-mirror $m$ receives an image of the balance only during motion in one direction and the view is cut off during the return movement, for the reason that the mirror is directed away from the balance. In Figs. 6 and 7 the balance would be in sight when not obstructed by the parts of the movement, were it not for the screen $r$ shown, which cuts off the view except in the vicinity of the plane of reference. It is proposed in all cases to provide equivalent means for cutting off the view during one vibration, so that the operator will only see the points of reference during the other vibration. A method of doing this when two balances are employed, which illustrates particularly the principle involved, is shown in Figs. 25, 26, and 27, Sheet 1, in which, for instance, $t$ is the standard balance provided, as is customary, with a hair-spring, and $u$ the balance to be adjusted to run with the standard balance by varying the length of the hair-spring. Starting the balances together, so that contiguous screws are moving in the same direction, ordinarily if $u$ run faster than $t$ a screw on the same forming the object-point which is caused at first to coincide with one on $u$, forming the comparing-point, would be at the left during a vibration in one direction and at the right during a vibration in the other. As all the movements are very quick, this causes the greatest confusion to beginners and some people never can learn to vibrate. By, however, providing a screen or "cut-off," consisting of a plate V, plane or curved, which is automatically thrust in the line of sight during the vibration in one direction and removed so that the screws can be seen during the vibration in another direction, the difficulty is removed and less skillful operators may learn to vibrate balances. In the plan shown the plate V is curved and connected by a rigid arm with a pendulum 73 under the table timed to vibrate the same as the stand-

ard balance. A hook 74 on cut-off plate 72 may be made to engage with a fixed catch 75 to keep the plate V out of the way while fixing a balance in position; but after starting the balance the catch 75 may be released and the pendulum will start its vibrations, when, if the operator is sufficiently skillful in making the start, the points of reference will only be seen when moving in one direction and the view cut off when moving in the other. The evident objection to this arrangement is the skill required to start the pendulum exactly right after first overcoming the difficulty of starting the two balances alike. The first difficulty is overcome by operating the cut-off plate V by a motor giving the required number of vibrations per minute through an apparatus S for producing angular adjustment, (Sec. 10,) by the use of which the phases of the movement of the cut-off can be made immediately to so correspond with those of the balances that the points of reference will only be seen when moving in one direction. Apparatus for this purpose will be hereinafter described (Sec. 29) in connection with an application of the same principle in comparing two pendulums or a pendulum and a balance.

Section 22. A pendulum may be rated for time, temperature, and barometer on the principle stated herein by vibrating it in connection with a standard pendulum or equivalent in a case, room, or other inclosure, through which air may be circulated to give the desired temperature and pressure. In Figs. 28, 29, and 30, Sheet 6, U represents a case for this purpose containing a standard pendulum and one to be observed, and provided with pipe connections $k$ and $k'$ for circulating air. The case may be enlarged to a room in which clock-movements complete may be set up, and a standard pendulum or a disk or point moving synchronously with such pendulum be caused to vibrate opposite the pendulum of each movement. A face view of a standard pendulum W is shown in Fig. 28 and a side view in Fig. 29. At the rear of the standard pendulum W is hung the pendulum X to be rated, which can be put in place and removed through a door in the rear of the case. The standard pendulum W is preferably provided with an opening through its center, as shown, in which is secured a comparing-point $a$, moving close to the ball of the pendulum X, and upon the latter a mark $v$ is to be made as an object-point. An image of the points of reference $a$ and $v$ is formed in an object-mirror 87, secured to the standard pendulum, which mirror reflects the image upward to another mirror $m$, set opposite the center of motion, and the image therein is viewed through an eye-piece L, provided with a magnifying-glass $e$, as in other cases. A lamp for illumination is provided in the direction $o$. The rays are reflected and concentrated by a condensing-lens $o'$ on the points of reference. A pane of glass to observe the operations from the front is represented at 86. A thumb-piece 89, operating a rock-shaft carrying a bent wire 88, is used to start the two pendulums together. Evidently as the two pendulums vibrate an image of the comparing-point $a$ and mark on pendulum or object-point $v$ will be seen in eye-piece L, the point in focus on the same appearing stationary and points at a distance appear to be moving slightly in radial lines around the same, so that any variation in movements in the two can be readily detected, except that the point which is faster will be at the right of the other during the vibration in one direction and at the left during the other, introducing the same kind of confusion referred to in Section 21 with reference to vibrating balances. To obviate this difficulty a cut-off V is provided in the form of a disk attached to an arm swinging on an arbor 90, which also carries a fork 91, operating in connection with a pin 92 on the arm 93, carried by a spindle 94, receiving motion through a crutch-rod 95 from the standard pendulum. 96 96 are small weights, which act as would their equivalent, a small weight above the center, to counterpoise the cut-off disk and to shift the center of gravity, so that the cut-off V will remain in either direction when shifted by the pin and fork. The cut-off V is so adjusted in reference to the vertical and the width of fork and other parts so proportioned that as the pendulum when moving to the right passes mid-position the pin 92 will, as shown, engage with the fork 91 and swing the cut-off opposite the point of suspension, where it will remain until the pendulum returning from the right has passed the center of its movement to the left, when the pin will again engage with the other side of the fork and shift the cut-off V back to the position shown by the full lines, where it will remain while the pendulum completes its movement to the left and passes its middle position in moving to the right. The effect is that the cut-off V is interposed in the line of sight between the piece L and mirror $m$, cutting off the view as the pendulum passes mid-position in one direction, but is swung away, leaving the view unobstructed as the pendulum passes the center in the other direction. The cut-off may be arranged to cut off the line of sight periodically either where the same runs horizontally, as shown, or where it runs vertically to the other mirror. An equivalent effect can also be produced when artificial illumination is used, as shown in this case and in Fig. 1, by having cut-off plate V cut off the illuminating-beam, and thereby darken or in effect cut off the line of sight during the movement in one direction. A modification is shown in Figs. 31 and 32, same sheet, in which a disk V′, mounted on an arbor 90, is given a tendency to move to the right by a train or other means represented by a cord and weight 96, and an anchor 97, operated by crutch-rod 95 from the rod of the standard pendulum T, allows the wheel V′ to turn like

an ordinary escape-wheel. This wheel V′ is provided with openings 99, so arranged in connection with intermediate spaces in the face of the wheel that the image in mirror *m* will be seen from eye-piece L as the pendulum moves in one direction and the view of such image be cut off as the pendulum moves in the other. The operation is on the same principle as described in relation to watches. The pendulums being started together, it will soon be seen whether pendulum X is vibrating faster or slower than W, and at normal temperature the height of the ball on X would be shifted to change the rate. By circulating hot and cold air through pipes *k* and *k* the rates at different temperatures may also be observed and devices for securing compensation of temperature (not shown) adjusted to correspond with the observations. Similarly, if the pendulum X be erected in connection with a movement and compared, adjustments for barometer may be made by changing the pressures of the air admitted at *k* or *k′* at constant temperature. Evidently a balance shown in dotted lines at *u*, Fig. 29, Sheet 6, may be rated by comparing it with the motion of the comparing-point *a*, or the balance may be the standard and the point *a* or equivalent be carried by the pendulum to be rated.

Section 23. A series of pendulums may, if desired, be hung in a large box or room and rated with comparing-points moved synchronously with a standard by an external force, which may also operate the cut-offs. Fig. 33, Sheet 6, shows an arrangement for this purpose. $U^4$ shows a corner of the room. 100 represents a shaft operated by any regulated prime mover R, (Sec. 16,) and through a "jack-in-the-box" gearing or any angular adjustment apparatus S (Sec. 10) operates through driven wheel 109 and shaft 102, directly or through bevel-gears, the crank-disk 103, which, by means of a connecting-rod 104, bell-crank 105, and jointed rod 106, operates the lower ends of dummy comparator-pendulums W′ W′, provided with comparing points *a*. A connection 107 leads off at right angles to 104 from the same or a similarly-set crank 103 and moves a rod 108, which carries cut-off targets V V, which are moved in front of the comparing-points *a* as the comparator-pendulums W′ W′ swing in one direction and to one side as such points are swung in the other direction. This arrangement is designed for direct comparison without the mirrors shown in Fig. 29, same sheet. If such mirrors be used, the disks V would simply be operated mechanically across the line of sight in the position of V, Fig. 29, or at any point where the line of sight would be interrupted thereby—for instance, on a line between mirrors *m* and 87, or in this or other applications, so as to obstruct the illumination from mirror O′ or equivalent. This mechanism is intended to be operated in connection with the pendulums of ordinary clock-movements placed behind the dummy pendulums W′, and the comparator-point *a* of the particular dummy pendulum then in use would on commencing the comparison be made to coincide with an object-point mark on the pendulum of the clock being compared by means of an angular adjustment apparatus S, the comparison made, the rate adjusted by the operator or an attendant, and another pendulum operated upon while the first is attaining a steady rate. A somewhat similar arrangement is shown in Fig. 34, Sheet 1, in which a rotary motion is given to a series of cut-offs or comparators from a prime motor below upward through an angular adjustment apparatus S, shown in the jack-in-a-box form and provided with a rod 102, (to be connected at right angles to the position shown,) carried along the face of the cases, so that it can be operated at any point. Both comparators and cut-offs may be included in the apparatus as before. At 190, Fig. 34, a clock-dial movement is shown operated by the comparator-gearing, which should indicate the same time as a standard clock. In this figure pendulums which may or may not be erected with clock-movements are shown arranged in different rooms, one of which may be used as a hot room and the other as a cold room, alternately, *k* being the air connections, as in other cases.

Section 24. To provide for testing clocks and, if desired, watches under different barometric conditions, the comparator-chamber may receive air with a plenum of pressure from a chamber kept under constant temperature by connection to the outlet of a blower M or M′, Fig. 8, Sheet 4; or the comparator-chamber can be arranged to receive a reduced pressure or partial vacuum by connection to the inlet of such a blower, each connection being provided with a valve for automatically regulating the outflow in one case and the inflow in the other. The valve first above referred to may operate on the principle of a check-valve loaded to the pressure desired, and the valve in the second case be provided with a weight tending to open it, but which will permit it to shut when the pressure is reduced below the point required. In such an apparatus the actual pressure will vary with the atmospheric pressure at the time; but this may be overcome by operating the valves referred to by a large aneroid barometer placed within the pressure-chamber. A special arrangement for regulating the pressure is shown in Fig. 35, Sheet 7, in which $U^3$ represents a section of a chamber in which the pressure or any other tests desired are made, such room being arranged to receive any desirable number of clock or watch movements, of which 228 represents a clock with pendulum 229. In the right of the room is represented the special machinery for regulating the pressure. O′ represents one of the rooms shown in Fig. 8, Sheet 4, maintained at a constant temperature, the air from which, under the pressure of the blow-

ers M and M′, is conducted through a pipe 230 to the port 214 of the chamber of the valve 222. If the pressure from the blowers M and M′, Fig. 8, is insufficient, another blower 210, Fig. 35, Sheet 7, may be employed to draw the air from the chamber O′ and deliver it to 214. 211 represents a suction-blower discharging into the air, which, through a suitable pipe, is arranged to produce suction in a port 213 of the same valve 222. This valve is so arranged that ports 213 and 214 are closed at the same time. 213 is opened into the chamber $U^3$ by an upward movement of the valve, and 214 opened into the same chamber by a downward movement of the valve. 217 represents an aneroid barometer of the multiple-diaphragm type, the internal vacuum being balanced by weights 218, and in part, through an adjusting-screw, by a spring 219. The barometer, as shown in outline, operates the short arm of a lever 220, which, at the end of the long arm, is articulated to connection 221, operating the valve 222. In operation, weights 218 and spring 219 may be adjusted so that the valve 222 will stand in mid-position at any desired pressure within the limits of the apparatus, (shown by a mercurial or other barometer 223 in same chamber,) when if the pressure in chamber $U^3$ rises the diaphragms of barometer 217 will be compressed, thereby raising valve 222 and putting the chamber in communication with the suction-blower 211, so that the excess of pressure will escape. If, on the contrary, the pressure fall, the diaphragms of barometer 217 will not sustain the load imposed by weights 218 and spring 219 and the valve 222 will descend and air be admitted through port 214 to restore the normal pressure. If the blowers be capable of producing a suction or pressure varying two inches from that of the atmosphere, comparisons may ordinarily be made in chamber $U^3$, between the limits of about twenty-eight to thirty-two inches of mercury, which is more than will customarily be required in practice. In order to insure a draft of air from the chamber O′ at all times, a certain amount of air is to be admitted to chamber $U^3$ through a pipe 215 or equivalent, regulated by a cock, and a certain amount of air is also to be drawn out of chamber $U^3$ through a pipe 216, also regulated by a cock, which pipe is carried to an extreme point in the chamber, so as to insure circulation, when evidently at all times, even when the barometer inside the case is set to exactly the same pressure as the air outside, the pipes 215 and 216 will produce circulation to maintain the temperature, for the automatic arrangement will require the blower 211 to draw out through pipe 216 and port 213 as much air at least as is forced in through 215. A very small barometer 217 may be used to cause the movements of the lever 220 or other connecting part to operate the valve 222 indidirectly—for instance, by means of a screw operated by a prime mover through the familiar "mill-governor;" or the lever 220 may touch electric points, so that the valve 222 will be operated by electricity, as in the mechanism shown in Fig. 9, Sheet 4, (Sec. 14.) So, also, a float 224 may be placed in the short leg of a mercurial barometer 223, connected electrically to a battery to form a "ground" and, through an arm 225, touching one or the other of the adjustable contact-points 226 227, complete electric circuits through magnets, (substantially in the same way as the thermometer 24 in Fig. 9, Sheet 4,) and thereby operate the valve 222, Fig. 35, in the same way that valve $n^3$ is operated in Fig. 9; or the mechanism in Fig. 9 may simply operate the clutches of a mill-governor, which through a screw or equivalent operates the valve 222 more gradually. For tests of pressure above the atmosphere evidently the blower 211 may be omitted and the discharge from port 213 be directly in the air, and for tests below the pressure of the atmosphere only blower 211 is necessary, and air can be drawn through 214 from any source. One blower can evidently at different times be arranged to produce either suction or pressure at the point desired, or any form of pump may be used instead of either of the blowers described or shown in either of the figures. It is evident, also, that the blowers M and M′, Fig. 8, Sheet 4, may be omitted by connecting the pressure side of a single blower to both the nozzles $N^2$ and $N^3$, the suction of such blower being connected with the external air.

Section 25. Parts of the several operations possible with the complete forms of apparatus shown in Figs. 1 to 6, inclusive, Sheets 1, 2, and 3, may be accomplished with special machines embodying such portions of the principles as are applicable to the operations desired to be performed. Figs. 19, 20, and 21, Sheet 4, represent poising apparatus, *t* being a standard balance, and *u* a balance of which the hair-spring is to be made the right length to cause the balance to vibrate with the standard. In Fig. 20 a small collar on the staff of the standard-balance *t* carries through a bent arm a mirror *m* above a narrow bridge 110. An image is made in this mirror of the comparing-point *a*, attached also to the standard balance, and of an object-point *v* on the balance *u*, which image is viewed through an eye-piece L, being magnified by a lens $e^6$, which may be a prismatic lens, as shown, if desired to bend the line of sight to one side for convenience. The standard balance in this case carries a pin 112, operating in connection with a fork on a lever 113, to vibrate a staff 114, provided at its upper end with an arm 115, carrying a screen or cut-off V in the line of sight to mirror *m;* or, if the mirror be omitted and the points of reference be viewed directly, the cut-off may, as shown in dotted lines in Figs. 20 and 22, Sheet 4, be extended to $V^3$, so as to move over the space between the balances and obstruct an opening in a cover-plate 116, through which the points of

reference on the two balances may be seen direct if caused to move through very small arcs. A modification is shown in Fig. 23, same sheet, in which the two balances *t* and *u* are placed at the same level and the points of reference viewed through an object-mirror 117 and a mirror *m* at the center. Both mirrors are carried by an arm 118, pivoted over the axis of the standard balance and operated through a connection 119 by a regulated prime mover R (Sec. 16) through an angular adjustment apparatus S, (Sec. 10.) L represents a fragment of an eye-piece, and V a cut-off operated through a rod 120 from the same prime mover. Evidently the mirror *m* in Fig. 20, Sheet 4, may be operated in the same way as the corresponding mirror *m* in Fig. 23, same sheet, or vice versa, and the cut-off in either case can be operated the same as in the other. The vibratory motion of the arm 119 and the proper movement of the cut-off V may be secured through the intervention of an apparatus like that already described in relation to the adjustment of pendulums, and such an arrangement is shown in connection with Fig. 33, Sheet 6. In this case rotary motion is imparted by a prime mover R (Sec. 16) through an angular adjustment apparatus S to the crank-disk 103, which gives motion in manner previously described to rod 106 to operate standard object-points and to rod 108 to operate independent cut-offs. The rod 106 may connect directly to rod 119, operating one or more arms 118, corresponding to arm of same designation in Fig. 23, or rod 106 may be articulated to and operate a swinging lever 142, Fig. 33, provided with a slotted opening in which a pin in the end of connection 420 may be raised or lowered to vary the amplitude of movement, and through connection 119 the angles through which arms 118 are swung. (See Sec. 28.) The cut-off rod 108 may directly or through a lever shown operate a rod 120, carrying cut-off disks V corresponding to those similarly designated in Fig. 23, Sheet 4.

Section 26. In Figs. 13 and 14, Sheet 5, *t* and *u* are the two balances, as before. A light arm 126, attached to the standard balance *t*, carries an object-point *a* opposite the screw *v*, forming the comparing-point of the balance *u*. The arm 126 carries also at the center of motion a mirror *m*, in which an image of the points of reference is formed and viewed through the magnifying-glass *e* in eye-piece L. 128 is a screen to cut off light from the sides and is notched to receive a cut-off V, which is operated by an arm on a staff 114 by means of a lever 113, as in Fig. 20, Sheet 4. A feature of this construction is that the balance to be tested is placed in a drawer $W^7$, which carries a block surmounted by a bent narrow bridge 129, which rests at one end on a round support 130, at the other on the point of a set-screw 131, and is held down by a spring-button 132. 133 is a lever operating a rod 134, with end bent down and operating in connection with a stationary point to form a pair of jaws 135 to take the place of a stud. By operating the lever 133 the rod 134 is moved, opening the jaws and releasing the hair-spring, so that it can be shortened or lengthened and subsequent observations taken on another screw, or the collet turned a little on the staff to bring the comparing-point opposite the object-point at the position of rest. The base-plate $W^{11}$ carries the standard balance *t* and bridge 109 of same, also cut-off staff 114 and an arm 127, supporting the eye-piece L. The balance *u* being carried by the drawer $W^7$, the latter can be pulled out of the machine and a new balance put in place without disturbing the parts above mentioned, the spring-catch 132 releasing or securing the bridge by a single movement, and end shake being regulated by set-screw 131. Fig. 18, same sheet, is a modification of devices shown in Fig. 13, in which the light arm 126 has two branches, one carrying an object-point *a* below the comparing-point *v* on the other balance, the other carrying an object-mirror *n*, which reflects the images of the points of reference to a field-mirror *m* at the center, where it is viewed as before. The operation in either case would be substantially the same as described in relation to other figures.

Section 27. Fig. 15, Sheet 5, is still another modification, in which *t* and *u* are the balances, as before, the latter being horizontal, so that the spring may be conveniently held by fixed or hand pliers, and the other vertical, so that the line of sight may be at a point intermediate between the two. *m* is a mirror carried at the center of motion by a revolving spindle 137, operated by the gearing shown or in any mechanical way from a regulated prime mover R (Sec. 16) and angular adjusting apparatus S, (Sec. 10.) The image of the points of reference is viewed by a magnifying-glass *e* in an eye-piece L, as in other cases, though in this case the magnifying-glass is arranged so that it may be adjusted to and from the mirror to suit the eyesight of the observer. The operation of the mirror *m* is like that of the mirror *m* in Fig. 1, Sheet 1, with the advantage that the motion of the two balances is more nearly concentric and the departures from the line of sight are the same for each, so that there will be less difficulty in determining their angular departure from each other. To keep the points of reference a longer time in the field, the mirror *m* is made cylindrical transversely to the plane of reference, the effect of which is that the lateral components of the movements of the points of reference (to and from the eye of the observer in the drawings) are reflected to the magnifying-glass in the eye-piece without distortion; but the components showing the departure of such points from the plane of reference are reduced in the image on account of the convexity of the mirror, and the field of the latter is thereby in-

creased. For instance, the object-point *a* in moving angularly through ninety degrees, so as to appear opposite the center at 139, would without this provision have shown a motion through the projection of the semi-diameter of the balance and be out of the field with proportions shown; but on account of the convexity of the mirror its image will be reflected at the point 140 nearer the center of the mirror than a correct projection, and therefore in the field. A similar movement of the comparing-point *c* will be also transmitted nearer the center on the other side of the mirror, where it will be seen in the object-glass. A modification is shown in Fig. 17, same sheet, in which the standard balance *t* is omitted and in place thereof an object-point *a* is carried by an arm 138, attached to spindle 137, which also carries the mirror. Upon the lower end of the spindle is placed a rock-arm 118, which is to be connected to a regulated prime mover R, (Sec. 16), giving a reciprocating movement, and there is to be provided in the connections an angular adjustment apparatus S (Sec. 10) to bring the phases of the motion of the points of reference together. Instead of using lever 118, rotary motion may be imparted to the spindle by gear-wheels—such as 144 145 in Fig. 15—by making the frame in such shape as to permit the object-point *a* and carrying-arm 138 to make an entire revolution. For convenience of adjustment the mirror *m*, Fig. 15, is cemented to a plate 146, forming the cap of a hemispherical piece 147, which fits in a similar segment of a sphere 149, formed on the end of the spindle 137. A screw 148, bearing through a hemispherical washer on the spherical head 149 of the spindle, attaches directly to the cap-plate 146, and by slightly slacking the screw the mirror may be rocked in any direction for angular adjustment, but without changing the optical axis, as the center of the sphere is at the center of the face of the mirror. It is proposed to use this method of adjustment wherever practicable in adjusting mirrors of any form used in any form of the apparatus.

Section 28. Another plan of arranging the optical apparatus to show the image of the points of reference practically at rest, corresponding closely in operation to the illustration given in Section 4, in reference to viewing the heavenly bodies, is illustrated in the diagram Fig. 36, Sheet 7. In this figure, $a^5$ $a^6$ $a^7$ represent three positions of an object-point, an image of which is to be reflected from a mirror *m*, so as to be seen by the eye held stationary at or in the direction 300. Bearing in mind the principle that the angles of incidence and reflection must be equal if the axis of vision or eye 300 be situated ninety degrees from the central point $a^6$ with relation to the center of the mirror *m*, the mirror would, at an angle of forty-five degrees, or with its face substantially in the line 301 301, reflect the image of the point $a^6$ to the eye, and when the object-point is at $a^7$, if the face of the mirror be adjusted so that the angles of incidence and reflection will again be the same or with its face substantially in the line 302 302, the image $a^7$ will again be reflected to the eye, and if the object-point be at $a^5$ and the mirror be moved so that the angles of incidence and reflection will again be equal or with its face substantially in the line 303 303, the image will also be reflected to the eye as before. It appears, therefore, in this case, as well as in relation to the mirrors *m* previously described, that the image of a moving body viewed through a mirror can be kept in the axis of vision by changing the angle of the mirror coincidently with the motion of the body, so as to maintain the angles of incidence and reflection in relation to the surface of the mirror equal at all times. In general, under conditions last above shown, the change in the angle of the mirror will be only one-half of that made by the object in reference to the mirror, whereas in the cases previously described, where the line of sight coincides with the axis around which the mirror is rotated, the angle of movement must be the same as the angular change in the position of the object, though in both cases the angular velocity of the rays from the object-point to the mirror is the same, and the difference in the angular movement of mirror required is simply due to the difference in the direction to which the image is reflected. In both cases the general principle of operation is the same—viz., the image of the moving points of reference is optically brought to rest, or nearly so, whereby the difference in the motion of the two can be readily observed. An application of this method of operation is shown in Figs. 37 and 38, Sheet 7, in which, as before, *t* is the standard balance and *u* the one to be compared with it, the latter being shown with staff and hair-spring so supported that the latter can be conveniently oprated upon to change its length. The rocking mirror referred to is designated *m*, and is connected to and preferably, but not necessarily, arranged in line of the axis of a spindle 304, operated by a rock-arm 305 through a connection 306. The mirror *m* is arranged at such angle and given such motion that the image of the points of reference will be reflected through an eye-piece L, which, for convenience, is erected with its axis in a plane passing between the two balances, but sufficiently at one side of the plane of reference to give a clear view of the mirror. The eye-piece L in this case is shown (see Fig. 38) as provided with two glasses—viz., a magnifying-lens and an adjustable concave lens—which together practically form an opera-glass, through which the image in the mirror may be seen at a greater distance than with an ordinary magnifying-glass, it being understood that in all cases the particular form of optical apparatus would be adapted to the conditions by an expert.

Section 29. As shown, the connection 306, operating mirror *m*, is provided with a handle 321 and articulates with a block 307, which may be slid up and down in a slot in an arm 308, vibrating on a fulcrum 313, and operated in any convenient way—for instance, through an arm 310 and connection 311—by a crank-pin in a disk 103, which corresponds to the disk, similarly designated in Fig. 33, Sheet 6, and is to be operated by a regulated prime mover R, (Sec. 16,) through an angular adjusting apparatus S, (Sec. 10,) as in other cases. The same or an equivalent crank-pin is arranged to operate an independent cut-off through suitable connections. For instance, the parts shown in skeleton—viz., the connecting-rod 314, bell-crank 315, connecting-rod 316, and arm 317, vibrating on a fulcrum 318—may operate a cut-off arm 319, carrying at its upper end a cut-off disk V, arranged to obstruct the line of sight between the eye-piece L and mirror *m* during the vibration of the points of reference in one direction and to move out of the way during the other phase of the double vibration. In general, however, a moving cut-off disk may be avoided by simply contracting the opening in the bed-plate or any intervening disk, so that only about half the balance can be seen from the position of the mirror. The stationary limiting edge of the opening will then appear to move and cut off the line of sight during about half the vibration, the same as at $r^2$ in Fig. 6, Sheet 3, or at $j'$ in Fig. 1, Sheet 1. The operation is precisely the same as in other cases. When the mirror is adjusted properly, the object-points will, at least during the central portion of their vibration, appear at rest or so nearly at rest that their relative positions and any change therein may be observed and corrections made accordingly. To provide for changing the amplitude of the angular vibrations of the mirror so that the relative velocity of the rays forming the image will be the same substantially as that of the points of reference, the spindle 304 has a bearing in a lever 320 or equivalent, whereby by operating a handle 321 thereon the mirror may be raised and lowered while it is being vibrated. The handle 321 should be provided with some form of spring friction or catch to hold it in any desired position. This arrangement varies the angular velocity of the rays forming the image by changing the distance at which the moving object is viewed, and if such adjustment be insufficient an actual adjustment of the angular movement of mirror can be made by varying the height of the block 307 in the slotted arm 308, it being understood that the block would be provided with friction apparatus to hold it in any desired position. 307 is a sleeve or turn-buckle connecting the two parts of rod 306 by right and left hand threads, and can be operated to change the length of such rods slightly, thereby varying the angle of the mirror *m* more delicately and promptly than it can be done by changing the angle at which it is mounted, as with mirror *m*, Fig. 15, Sheet 5. The whole apparatus above described for varying the amplitude of movement is designated T, the same as the apparatus for varying the angular velocity, (Sec. 18,) for evidently the two devices perform the same function in adjusting the angular velocity of the mirror to that of the points of reference when crossing the plane of reference, so that the image appears to be at rest, one form being simply adapted for a vibrating comparator, the other for a revolving one.

Section 30. The general methods of operation last above described in relation to Figs. 37 and 38 may readily be applied to any one of the forms of apparatus previously described by simply arranging the mirror in each case so as to reflect the image in a plane at right angles to the axis of motion and changing the position of the eye-piece accordingly. The object-point may be either on a rotating standard or a vibrating one, and in any case the object and comparing points may be so near each other as to form an image in the same mirror, or so related that each will form an image in an independent mirror, and the two images be reflected directly or indirectly to the same eye-piece, as in the mariner's sextant. Instead of vibrating the mirror *m*, it may, by suitable connections to spindle 304, be revolved, in which case the desired velocity at the time of crossing the plane of reference can be adjusted within certain limits, when the connections permit, by operating the handle 321 to vary the distance of the mirror from the object; or such adjustment may be made by the use of the form of apparatus for varying the angular velocity T, (shown in Fig. 10, Sheet 3, Sec. 18,) located at some point in the transmitting connections. The vibrating mirror described in relation to Figs. 36, 37, and 38 may be readily applied in comparing pendulums in any of the modified forms suggested. The simplest adaptation would appear to be to the form of apparatus shown in Fig. 28, Sheet 6, in which a mirror may be secured to the spindle 94 with its face parallel to the axis of the same and reflect an image of the comparing-points *a* and *v*, to the right or left in Fig. 28 or to the top in Fig. 29, by arranging comparing-point *v* so that it can be seen from above and clearing the way underneath, or applying the mirror a litttle to one side of spindle 94 to the crutch-rod 95, where the vertical motion will create little disturbance, in which case the effect will be exactly as if Fig. 36 were inverted. So, also, the spindle 94 and attached mirror may be below the points of reference, as in Fig. 38, and still be operated by the crutch-rod. Of course any form of magnifying-glass—such as the opera-glass combination—could be applied in the line of sight, and it would be necessary to cause the crutch-rod to engage with the pendulum at such distance as to cause the mirror

to vibrate through an angle about one-half that moved through by the pendulum, when the mirror is at such distance from the object-point that the amplitude of movement of the object-point and of the incident ray from the same to the mirror will be substantially equal.

Section 31. The object-point *a* in Figs. 37 and 38 may be operated from a regulated prime mover—in fact, the same one used for operating the mirror—in any convenient way, and the cut-off V may be operated as shown in Fig. 38, or by a motion derived from the apparatus carrying the object-point *a*. For instance, if in Fig. 23, Sheet 4, mirrors *m* and 117 be considered as omitted and in said figure and in Fig. 38, Sheet 7, 118 in the former represent a side view and in the latter an end view of a lever, which for this operation is to be considered attached to the staff of a balance *t* beneath it, then such balance becomes a comparator-disk corresponding to F in Fig. 1, Sheet 1, and may be vibrated through an arm 118 by a connecting-rod 119. With the arrangement of parts shown in Fig. 38 this vibration may be secured by operating the rod 119 through connections shown in dotted lines—viz., a double-ended lever 403, articulated at the top to 119, provided with a fulcrum-spindle at 402 and articulated at the bottom at 401 to a link connecting it to the bottom of the lever 305 at 400. Ball-joints or equivalent bearings will be required at the ends of the top link 119. In this way it will be seen that the comparator-disk carrying the object-point *a* and the swinging mirror *m* will be vibrated together, and this vibratory motion may be applied in the arrangement shown by connecting the end of adjustable rod 306 to 401, instead of 400, to any other lever secured to the fulcrum-spindle 402 of lever 403, or to any combination of machinery connected therewith. Again, referring to Fig. 23, Sheet 4, if the lever 118, when connected to balance *t*, then forming a comparator-disk, be also provided with a roller and pin 112, operating in connection with a fork in lever 113, as in Figs. 19 and 20, same sheet, such staff 114 may also carry a cut-off disk, which, when the arrangement is applied to Fig. 38, may obstruct the view from the eye-piece L to mirror *m* at any convent point—for instance, through a disk $v^4$, attached to an arm located in the same plane as the fork on line 404 404.

Section 32. The general arrangement of apparatus shown in Figs. 37 and 38, Sheet 7, in Fig. 24, Sheet 4, and in Fig. 15, Sheet 5, can be adapted for use in a case similar to E, Figs. 1 and 2, Sheet 1, or E′, Figs. 6 and 7, Sheet 3, either when the object-point is rotated or vibrated by a prime mover, or when the balance of a watch-movement is employed as a standard, by so arranging the operating connections that mirror *m*, operating on the principle shown in Fig. 36, will have the proper motion in relation to the points of reference conveyed to it through swinging joints on the principles stated in relation to Figs. 1 and 2, Sheet 1, and Figs. 6 and 7, Sheet 3. The arrangement described in Section 31 will be found convenient for such application, in which the vibrating mirror and comparator-disk carrying the object-point are vibrated from the same prime mover, as in such case there can be arranged outside of the case E or E′, in connection with a regulated prime mover R (Sec. 16) and angular adjusting apparatus S (Sec. 10) the apparatus T for varying the amplitude of the vibratory movement, as described with relation to Fig. 38 (Sec. 29) and Fig. 33, Sheet 6, (Sec. 18,) and the vibratory motion be imparted to the spindle 402, Fig. 38, Sheet 7, through the arrangement of joints and spindles shown either in Fig. 2, Sheet 1, or Fig. 7, Sheet 3. Such an application can be understood by an inspection of Figs. 37 and 38, Sheet 7, without further increasing the number of figures. The modified apparatus for operating the standard balance or comparator-disk and the mirror coincidently, described in section 31, may be inclosed in a case corresponding to E, Fig. 1, with sides located substantially on the dotted lines 405, Fig. 38, Sheet 7, when the balance *u*, Fig. 37, would preferably be inserted in a watch-movement secured in a drawer D, Figs 1 and 2, and be put in from the right in Fig. 37, which would be from the front in Fig. 38. All the moving parts would then be operated by a connection to rock the spindle 402, giving vibratory motion to the lever 403. This can be done by making such spindle 402 correspond with an extension of $f^4$, Fig. 7, Sheet 3, in connection with which, if the case were attached to the sleeve *i*′, as in said Fig. 7, it could be revolved with it entirely around in one plane and through arm J′ revolved entirely around sleeve 55 in another plane at right angles to the first, so as to be entirely universal. The motion could be conveniently applied by articulating connection 306 in Fig. 38 to an arm on the spindle 54, Fig. 7. The connection of such arm to the spindle 54 would necessarily be made through a clutch or set-screw, permitting an angular movement of the spindle within the arm when the case E is revolved, since the revolution of the case would necessarily throw the vibrating levers out of adjustment, and readjustment of the arm-vibrating spindle 54 to a mark or equivalent on said spindle would be required for each position. This adjustment, though not serious, can be avoided by putting the whole of the apparatus T for varying the amplitude of movement, Fig. 38, (Sec. 29,) within the case, or so that it will be included within dotted lines 405 406 of that figure. The spindle of the crank-disk 103, Fig. 38, would then be connected like $f^4$, Fig. 7, Sheet 3, and rotary motion communicated through the swinging joints and sleeves shown in said Fig. 7. With this arrangement the change in angle due to revolving the case could be readily corrected by an angular adjusting apparatus

S, (Sec. 10,) located in the connections to the driving-shaft 54, Fig. 7, Sheet 3. It should be understood that while such angular adjusting apparatus S is not available to keep vibrating levers in relative position while the case is being rotated, if they be used as above, still its use is essential after adjustment of the levers in order to bring the phases of the vibrating comparing-point to correspond with those of the object-point on the balance to be tested.

Section 33. Fig. 24, Sheet 4, shows a modified poising apparatus in which the position of the mirror may be readily modified to suit either general method of operation. In these figures *t* and *u* are, as before, the two balances. The image is formed in a mirror *m* and viewed through an eye-piece L, the axis of which is to coincide with the center of the mirror, whether mounted at the angle shown or otherwise, as referred to hereinafter. The mirror *m* is secured at the center to and revolved or vibrated by a spindle 145, (shown in this case as parallel to the balances,) and may receive motion through the bevel-wheels shown or through a rock-arm from a regulated prime mover R (Sec. 16) through an angular adjusting apparatus S, (Sec. 10.) If the axis of the eye-piece L be arranged in the line of the axis of the spindle 145, or horizontally in the drawings, the operation will be on the same principle as that shown in most of the figures—for instance, Figs. 1 and 2, Sheet 1—and if the mirror be turned so that its surface will coincide with or be parallel to the axis of the spindle 145 and the eye-piece be located in a cross-plane passing between the two balances the operation will be as shown in Figs. 37 and 38, Sheet 7. With the eye-piece located as shown in Fig. 24, Sheet 4, the operation is a combination of the two general methods. The image of the points of reference in the mirror *m* will be reflected along the surface of a cone, the axis of which corresponds to that of the spindle 145, and the angular velocity of such spindle and mirror may be adjusted by an apparatus T to bring the image of the points of reference at rest, or nearly so, when passing the plane of reference, the same as in other cases. When the mirror is revolved, as provided for in the illustration, the apparatus T for varying the angular velocity would be in the form shown in Fig. 10, Sheet 3, (Sec. 18;) but if instead thereof the mirror be vibrated the amplitude of the vibrations should be varied by an apparatus T of the form shown in Figs. 37 and 38, Sheet 7, and a cut-off in this case would also be required. Similarly the general arrangement of parts shown in Fig. 15, Sheet 5, is well adapted for the various methods of operation described in relation to Fig. 24, Sheet 4.

Section 34. Fig. 12, Sheet 3, shows still another modified poising apparatus, in which the position of the mirror may be readily modified to suit either general method of observation. In this figure *t* and *u* are the balances, as before, the latter being placed above the other, where it is convenient of access. An object-point *a* is carried by the standard balance *t*, near the comparing-point *v*, such object-point *a* arranged at right angles to the arm of the balance, and the hair-spring of such balance made permanently conical, so that the points of reference may be seen from below through one of the openings in the balance. As shown, an image of the points of reference is formed in the mirror *m*, carried by the standard balance, reflected to stationary mirror 500, and observed through a magnifying-glass *e* in an eye-piece L, when the operation will be the same as in many of the other figures, particularly Fig. 13, Sheet 5. The method of operation described in relation to Figs. 37 and 38, Sheet 7, (Sec. 28,) would be applied to Fig. 12, Sheet 3, by arranging a mirror with its face coincident with or parallel to a spindle carrying the same and having its axis located substantially in the line of that of the eye-piece L, as shown in said Fig. 12, in which case the image would be observed from the front as the figure is drawn.

Section 35. A prism may in many locations be substituted for a mirror *m*, and may be made achromatic when the dispersion is sufficient to affect the clearness of the image. A prism in the form of a right-angled triangle may be substituted directly for a mirror by placing the hypotenuse in the position of the face of a mirror. For instance, $m^7$, at the left of Fig. 20, Sheet 4, may be substituted for the mirror *m* in that figure, when the rays passing through one plane side of the prism will be reflected from the hypotenuse through the other and the action be precisely the same as that of an ordinary mirror. When the angle through which the rays are to be diverted is comparatively small, as is the case with the mirror *m* in Fig. 12, Sheet 3, and Fig. 13, Sheet 5, the principle of refraction may be brought into play. For instance, a prism $m^9$ (shown in a detached view to the right in Fig. 13) may be substituted directly for the mirror, the dotted lines showing the direction of the rays and corresponding to such lines in the main figure. In both of the above applications the prism would have the same motion imparted to it as a mirror. For instance, the prism $m^7$, at the left of Fig. 20, would be attached to the staff of the balance *t* by a fixture similar to that carrying the mirror *m*, and prism $m^9$ in Fig. 13, Sheet 5, would be attached to the standard-balance *t* by an arm 126, like that shown in connection with the mirror *m*. Greater angles of diversion may be obtained by a combination of prisms. In a detached view at the right of Fig. 20, Sheet 4, a fixture similar to that carrying the mirror *m* in the main figure is shown supporting two prisms together, (designated $m^8$,) arranged with an angle on one adjacent to one on the other. In this arrangement the rays of light from the points of reference, supposed to be at the right, will first

be deflected nearly parallel with the base or upper right-hand face of the first prism, then nearly parallel with the line joining the centers of the two prisms, then diagonally upward nearly in line with the base of the left-hand prism, and finally emerge substantially in a vertical line to the eye-piece, which, as in Fig. 20, may be directly over the axis, or the rays be diverted by a stationary prism $e^6$, which prism may either be non-magnifying and the image be magnified by a lens in the eye-piece L or may be a combined prism and magnifying-glass. The effect of the double prism $m^8$ is to cause the rays to bend on the sides of a polygon, so as to appear in the small view to follow on the arc of a circle. The view $m^8$ is not intended to show the exact angles or number of prisms required, but only to illustrate the principle. A prism such as described or a combination of prisms is herein considered the equivalent of a mirror $m$ when combined in substantially the same way and producing substantially the same result.

Section 36. Referring to Fig. 3, Sheet 2, it is evident that the electric motor shown at the base may connect directly or through an annular adjustment apparatus to the spindle of the comparator without the adjustable arm J or any moving joints whatever, and then the whole apparatus, including the comparator-case E and the motor, be changed in position as a whole or swung around supporting universal joints attached to any parts of the system which do not carry through them any moving parts, and in this way the watch-movements be run in different positions. In such case it would be necessary only to provide flexible wires for running the motor and flexible pipes for carrying the supply of air, which could be carried through the joints, if desired. Similarly two watch-movements may be placed in the comparator-case, one as a standard, the other to be compared, and the case provided with means for viewing a substantially stationary image of the moving points of reference, when the case with the movements and other apparatus as a whole can be changed in position as desired. The method of operation in either of the above cases, so far as the rating of watch-movements is concerned, would be the same as if the apparatus were used in the exact form shown in the figures.

Section 37. When the motor is of a kind like an electric or friction motor that can be checked by overloading, the angular adjustment apparatus S may be omitted in the form shown, and the phases of the movements of the comparing and object points be brought together by simply applying friction to any of the connections driven by the motor. For instance, in Fig. 3, if the connection from wheel G to comparator-disk be continuous and the spindle $h$ be omitted, the lever H could be operated to press against the bottom of the wheel G and produce friction, retarding the motor until the comparing-point met the object-point, when by releasing the friction the former would again run to speed. Evidently, also, the movement of the lever H could at the same time break the circuit operating the electric motor to facilitate the operation. In such such case if the comparing-point were but little behind the object-point it would have to be thrown back nearly a full revolution, which would make no difference in result. The general method of operation last above described would, so far as the rating of time-pieces is concerned, be the same as if the special mechanism S described in Section 10 were provided.

Section 38. The different forms of apparatus above described, though differing in appearance and somewhat in detail, may be classified together, from the fact that all contain one or more of the several distinguishing features, which are necessarily combined together to form a complete apparatus. It will be observed that, for instance—

First. Most of the forms of mechanism shown in the different figures embody in general a time-comparing apparatus, called herein a "comparator," provided with means to hold a balance or pendulum to be tested, upon which any distinguishing feature or a simple mark may form an object-point, provided, also, with a moving comparing-point with proper operating apparatus synchronized with a standard clock to which the movements of the balance or pendulum under test can be referred, and provided, also, with means for producing and viewing a substantially stationary image of the moving points of reference.

Second. In most cases devices above referred to are used by which an image of the points of reference is optically brought to rest, or so nearly to rest that the difference in the motion of the two may be observed even when both are moving at their highest velocity, such means involving the use of a moving mirror or prism preferably at or near the center of motion of a balance, disk, or arm, also of subsidiary mirrors, prisms, or lenses, or other optical apparatus to facilitate obtaining a fair view under different conditions and to magnify the image to permit close observations.

Third. In general there is used some form of cut-off by which the comparison may be confined to one phase of the vibratory movement.

Fourth. In connection with the comparator in its most complete form methods of artificial illumination are necessary.

Fifth. Angular adjustment apparatus is in most cases provided, whereby the comparing and object points may on beginning an observation be caused to pass the plane of observation at the same time even when in rapid movement.

Sixth. Means are usually provided to mod-

ify the velocity of the comparing-point to correspond approximately to that of the object-point when passing the plane of reference.

Seventh. In the use of the comparator as a whole means are necessarily provided by which it may be arranged and supported in different positions, so as to ascertain the position errors of the watch-movement under comparison. To accomplish this the comparator is preferably mounted on a series of universal joints which may be made hollow and any motion brought from an external source by means of revolving or vibrating shafts be conveniently carried through the same. The method of operation is, however, the same when motion is not brought from an external source and the comparator as a whole is changed in position.

Eighth. Provision is also made for comparisons under different conditions, as to temperature and pressure, which requires that the comparator be in an inclosed case provided with pipe-connections for receiving air or other fluid under the proper temperature and pressure.

Ninth. The watch-movements in general are severally attached to small drawers, which may be kept in a case of drawers maintained at the proper temperature, in the same way as the comparator-case, so that the movements may in a sense be seasoned or accustomed to the change of condition before comparison.

Tenth. The maintenance of the temperature and pressure involves apparatus for heating, cooling, and circulating air, and for regulating the same.

Eleventh. The general result is that a watch or clock movement may be rated for time, temperature, barometer, and position as required by merely running it in connection with a comparator for a very short time, making the necessary adjustment, permitting the movement to again run until it attains a uniform rate, and then making any further adjustment found necessary, all as part of one continuous operation, without the delays and without requiring nearly the great number of movements undergoing test that are necessary in ordinary practice, where each movement must be run a day or more between each adjustment.

Section 39. The present application includes general combinations of devices for performing the several operations above referred to and one arrangement of mechanism in each case to produce such result. Alternative arrangements of various details are given to aid in understanding the various principles involved, many of which will form the subject of other applications. In grouping the elements of the claims the comparator as a whole is considered independent of the particular way of operating the comparing-point, whether by a balance or mechanism within or exterior to the comparator-case and the apparatus S, (Sec. 10,) for producing angular adjustment, and that T, (Sec. 18,) for changing the angular velocity, are considered as forming the same elements in the general combinations, whether applied to a rotary comparator or a vibrating one, the result accomplished—viz., the bringing together and equalizing the velocities of the comparing and object points in starting an observation—being the same in each case. It will be observed that when the comparing-point is either revolved or vibrated by external mechanism the cut-off is preferably operated by the same mechanism. For instance, with the revolving comparator in Fig. 1 the cut-off is made by the mirror turning away from the points of reference. In Fig. 3 the object-mirror runs behind a screen, thereby forming a cut-off, and in Fig. 38 the cut-off, though independent in form, is operated from the same revolving spindle 103 as the mirror *m*, which spindle also moves the comparator-disk in several of the forms of apparatus described. It will also be observed that the apparatus required to operate this cut-off is kept in the same form when a vibrating balance is used as a standard, and that such cut-off-operating apparatus is also of great value when combined with ordinary vibrating apparatus without special optical attachments of the kind herein provided for.

Section 40. The word "balance," as used in the claims hereof, is intended to include a complete balance and hair-spring with means for holding the same, so that the balance will keep in vibration after once being started, the same as a pendulum vibrating under the influence of gravity. The word "standard" is used in the claims in a general sense to include either of the devices herein described for carrying a comparing-point—such, for instance, as a balance provided with a comparing-point and hair-spring or a comparator disk or lever carrying a comparing-point and moved by some external force—it being understood that means for holding the same so that they will be operative are included in all cases.

What I claim as my invention, and desire to secure by Letters Patent, is—

1. In combination, to form a comparator or time-comparing apparatus for rating timepieces, a comparing-point carried by a moving standard, a balance to be rated, provided with an object-point, means for holding the standard and balance, and optical apparatus to form and transmit to the eye of an observer a substantially stationary image of the moving points of reference, substantially as and for the purposes specified.

2. In combination, to form a comparator or time-comparing apparatus for rating timepieces, a comparing-point carried by a moving standard, a regulating member of a timepiece to be rated, provided with an object-point, means for holding the standard and pendulum, and optical apparatus to form and transmit to the eye of an observer a substan-

tially stationary image of the moving points of reference, substantially as and for the purposes specified.

3. In combination with a comparator provided with a comparing-point carried by a moving standard, a balance to be rated, provided with an object-point, means for holding the standard and balance, and optical apparatus to form and transmit to the eye of an observer a substantially stationary image of the moving points of reference, a cut-off device to cut off the view of the points of reference in one direction, and suitable mechanism for operating such cut-off, substantially as and for the purposes specified.

4. In combination with vibrating balances *t* and *u*, a cut-off V and suitable apparatus for operating the same, substantially as and for the purposes specified.

5. In combination with a comparator for rating time-pieces, provided with a comparing-point, and a balance to be rated, carrying an object-point, and with optical apparatus to form and transmit to the eye of an observer a substantially stationary image of the moving points of reference, a disk or equivalent carrying such comparing-point, a regulated prime mover R, and suitable connections for operating such disk from such prime mover, substantially as and for the purposes specified.

6. In combination with a comparator for rating time-pieces, provided with a comparing-point, and a balance to be rated, carrying an object-point, and with optical apparatus to form and transmit to the eye of an observer a substantially stationary image of the moving points of reference, a disk or equivalent carrying such comparing-point, a regulated prime mover R, a cut-off V, and suitable connections for operating such disk and cut-off from such prime mover, substantially as and for the purposes specified.

7. In combination with a comparator for rating time-pieces, provided with a standard carrying a comparing-point, and a balance to be rated, carrying an object-point, and with optical apparatus to form and transmit to the eye of an observer a substantially stationary image of the moving points of reference, a regulated prime-mover R, a cut-off V, and suitable connections for operating such cut-off from such prime mover, substantially as and for the purposes specified.

8. In combination, a balance to be tested, provided with an object-point, a standard disk or equivalent carrying a comparing-point, and an apparatus S, arranged and operative to secure angular adjustment of the comparing-point relative to the object-point, substantially as and for the purposes specified.

9. In combination, a balance to be tested, a standard disk or equivalent carrying a comparing-point, a regulated prime mover R, and an angular adjustment apparatus S in the connections for operating the comparing-point from the prime mover, all arranged and operating substantially as and for the purposes specified.

10. In combination, a balance to be tested, a standard disk or equivalent carrying a comparing-point, a regulated prime mover R, a cut-off V, an angular adjustment apparatus S, and suitable connections for operating such disk and cut-off through such angular adjustment apparatus from such prime mover, substantially as and for the purposes specified.

11. In combination, a balance to be tested, a standard carrying a comparing-point, a regulated prime mover R, a cut-off V, an angular adjustment apparatus S, and suitable connections for operating such cut-off through such angular adjustment apparatus from such prime mover, substantially as and for the purposes specified.

12. In combination with vibrating balances *t* and *u*, a regulated prime mover R, a cut-off V, and suitable apparatus for operating such cut-off by such prime mover, substantially as and for the purposes specified.

13. In combination with vibrating balances *t* and *u*, a regulated prime mover R, a cut-off V, an angular adjustment apparatus S, and suitable apparatus for operating such cut-off by such prime mover through such angular adjustment apparatus, substantially as and for the purposes specified.

14. In combination with a comparator for rating time-pieces, provided with a comparing-point, and a balance to be rated, carrying an object-point, and with optical apparatus to form and transmit to the eye of an observer a substantially stationary image of the moving points of reference, a disk or equivalent carrying such comparing-point, a regulated prime mover R and apparatus T for varying the angular velocity, and suitable connections for operating such disk from such prime mover through such apparatus T, substantially as and for the purposes specified.

15. In combination, a balance to be tested, a standard disk or equivalent carrying a comparing-point, a regulated prime mover R and an angular adjustment apparatus S, and an apparatus T for varying the angular velocity, arranged in the connections for operating the comparing-point from the prime mover, substantially as and for the purposes specified.

16. In combination with a comparator for rating time-pieces, provided with a comparing-point, and a balance to be rated, carrying an object-point, and with optical apparatus to form and transmit to the eye of an observer a substantially stationary image of the moving points of reference, a disk or equivalent carrying such comparing-point, a regulated prime mover R, a cut-off V, an angular adjustment apparatus S and apparatus T for varying the angular velocity, and suitable connections for operating such disk and cut-off from such prime mover through the apparatus S and T, substantially as and for the purposes specified.

17. In combination with an eye-piece and the points of reference of an apparatus for rating time-pieces, a moving mirror or equivalent and mechanism for operating the same, all arranged to transmit to the eye-piece a view of the points of reference when in motion, substantially as and for the purposes specified.

18. In combination with an eye-piece and the points of reference of an apparatus for rating time-pieces, a mirror located at or near a center of movement, and operating mechanism arranged to impart to such mirror such movement in relation to the points of reference that a substantially stationary image of such points of reference when passing the plane of reference will be transmitted to an eye-piece, substantially as and for the purposes specified.

19. In combination with a comparator for rating time-pieces, provided with means for holding a balance or pendulum to be tested, and provided with a standard balance, pendulum, or equivalent carrying a comparing-point, and provided, also, with a regulated prime mover R for operating such standard, means for adjusting the relative angular positions of the object and comparing points, and a handle *h* for operating such means when the parts are in motion, substantially as and for the purposes specified.

20. In combination with an object-point on a balance or pendulum to be tested, and with a comparing-point on a moving standard, a mirror or prism so arranged in relation to such comparing-points and an eye-piece and receiving such motion from or coincidently with the motion of one of such points that the mirror will maintain the angles of incidence and refraction between the mirror and the points and the mirror and a stationary eye-piece substantially constant during the period of observation, thereby producing a substantially stationary image of the moving points of reference, substantially as and for the purposes specified.

21. In combination with a comparator for rating time-pieces, provided with a balance or pendulum to be tested, carrying an object-point, and provided with a standard carrying a comparing-point, and provided with a vibrating mirror for use in optically viewing an image of the points of reference, a crank 103, connected with a prime mover, a slotted lever 308, an adjustable radius-arm 321, and necessary connections for operating the mirror from said prime mover through said crank and slotted lever and connections, substantially as and for the purposes specified.

22. In combination with a comparator for rating time-pieces, provided with a balance or pendulum to be tested, carrying an object-point, and provided with a standard carrying a comparing-point, and provided with a vibrating mirror for use in optically viewing an image of the points of reference, and provided with a cut-off V, a crank 103, connected with a prime mover, a slotted lever 308, an adjustable radius-arm 321, and necessary connections for operating the cut-off V and mirror from said prime mover through said crank and slotted lever and connections, substantially as and for the purposes specified.

23. A comparator for rating portable time-pieces, in combination with an inclosing case and with joints supporting the same, and with external operating mechanism connecting with the comparator through such joints, substantially as and for the purposes specified.

24. In an apparatus for rating time-pieces, and in combination with a comparator provided with a moving standard and means to receive a movement of which the balance is to be rated, a fixture to receive such movement, so constructed that it may be secured in the comparator-case and may be used as a drawer in a seasoning-case, substantially as and for the purposes specified.

25. In an apparatus for rating time-pieces, and in combination with a comparator provided with a moving standard and means to receive a movement of which the balance is to be rated, a fixture to receive such movement adapted for ready connection with a comparator-case, and provided with a suitable handle, by means of which the movement and fixture may be transferred without directly handling it from a comparator to a chamber maintained at constant temperature, substantially as and for the purposes specified.

26. In apparatus for rating watch-movements, a case of drawers provided with openings for separate movements, in combination with attached pipes and blowers for circulating air at a regulated temperature through the case and about the movements, substantially as and for the purposes specified.

27. In combination, a pendulum or balance to be tested, a standard carrying a comparing-point, optical apparatus to form and transmit to the eye of an observer a substantially stationary image of the moving points of reference, an inclosing case, conducting air-pipes, and apparatus for circulating air of a regulated temperature or pressure through such case, substantially as and for the purposes specified.

28. The method of rating time-pieces for temperature, which consists in subjecting them severally or in multiples to the different temperatures desired in inclosures conveniently located and maintained at the desired temperature by the circulation of fluid at a regulated temperature from a central plant, and comparing such time-pieces with a standard or standards at convenient locations separated from but connected in a system with the apparatus for producing such temperatures, substantially as and for the purposes specified.

29. The method of rating time-pieces for barometric changes, which consists in subjecting them severally or in multiples to the

different pressures desired in inclosures conveniently located and maintained at the desired pressure by the circulation of fluid at a regulated pressure from a central plant, and comparing such time-pieces with a standard or standards at convenient locations separated from but connected in a system with the apparatus for producing such pressures, substantially as and for the purposes specified.

30. In combination with chambers for mixing air of different temperatures to be circulated mechanically for rating time-pieces, a regulator receiving its initial movement from the temperature of the air circulated, arranged and operated substantially as and for the purposes specified.

31. In combination with a chamber to receive time-pieces to be compared with a standard and rated under different air-pressures, means for supplying air at a different pressure from that of the atmosphere, a valve for regulating the movement of such air, and a barometer for directly or indirectly operating such valve, combined, arranged, and operating to maintain a regulated pressure in such chamber substantially as and for the purposes specified.

32. In combination, a balance or pendulum to be rated, provided with an object-point, a standard provided with a comparing-point, and a mirror or equivalent for condensing light from a suitable source upon the points of reference when passing the plane of reference, substantially as and for the purposes specified.

33. The method of rating time-pieces under different temperatures and pressures, which consists in comparing the same with a standard inclosed therewith in a chamber maintained at the desired temperature and pressure by the circulation of fluid, substantially as and for the purposes specified.

34. The method of rating time-pieces for temperature, which consists in accustoming the same to such temperature in a room or equivalent and transferring the same to a comparing device maintained at substantially the same temperature, substantially as and for the purposes specified.

35. The method of rating the balance or pendulum of a time-piece, which consists in comparing the motion of a point on the same with that of a point on a moving standard through optical apparatus designed and arranged to form and transmit to the eye of an observer a substantially stationary image of such points when in rapid motion, substantially as and for the purposes specified.

36. The method of rating a watch-balance for temperature, which consists in subjecting the same to different temperatures and comparing for each temperature the motion of a point on the same with that of a point on a standard by observing an image of such points optically transmitted to the eye so as to appear to be at rest or so nearly so that the relative movement may be ascertained, substantially as and for the purposes specified.

37. The method of rating a watch-balance for position, which consists in placing such movement in different positions and comparing in each position the motion of a point on the balance with that of a point on a standard by observing an image of such points optically transmitted to the eye so as to appear to be at rest or so nearly so that the relative movement may be ascertained, substantially as and for the purposes specified.

38. The method of producing a substantially stationary image of the points of reference on a balance or pendulum to be tested and a moving standard, which consists in arranging and operating a mirror, prism, or equivalent optical apparatus to so divert the rays forming the image that the latter will appear substantially stationary when it reaches the eye, substantially as and for the purposes specified.

39. In time-comparing apparatus, the method of bringing together the phases of the movements of a balance or pendulum with those of a standard by angular adjustment of the standard while in motion, substantially as and for the purposes specified.

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