APPENDIX.

DESCRIPTION

OF THE

GALVANIC CHRONOGRAPHIC APPARATUS

OF THE

ROYAL OBSERVATORY, GREENWICH.

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THE practical introduction of Galvanic Chronographic Apparatus, in a form available for the purposes of an Observatory, is entirely due (so far as I am aware) to American Astronomers. The history of its successive steps of advance in the United States is given, with due reference to official documents, in the *Annals of the Astronomical Observatory of Harvard College*, Vol. I. Part I. It was from a letter of Dr. Locke to myself, dated 1849, January 13, that I first became acquainted with the system proposed by that gentleman; and from a letter of Professor Mitchel, dated 1849, July 10, that I received details of Professor Mitchel's method, though I was aware that his attention had been for some time directed to the subject.

The method of Dr. Locke contemplated the keeping a galvanic battery in constant action during those portions of time in which no signals (whether for clock-seconds or for moments of observation) were exhibited; the battery-action being suspended for the instant in which the signal is given. Professor Mitchel's method employed the battery only for giving the signal. This appeared to me preferable, both for diminution of the consumption of battery-elements, and for the superior distinctness of the signal. The fillets employed by Dr. Locke appeared to me entirely inapplicable to the uses of an Observatory, where more than 500 feet would be required for a single evening; they are not, however, essential to his principle. Professor Mitchel's specimens exhibited the second-signals as dots in a radial arrangement, the measures of time being taken along the circumferences of successive circles, and thus representing equal portions of time by different measures of space, according to the radius of the circle on which they fell. This appeared to me likely to lead to inconvenience; it is not, however, necessarily connected with the system.

On reviewing these matters, it appeared to me that the objects to be obtained, in order to make the principle of chronographic registration useful at the Royal Observatory, must be the following:—

1. The record must be made by dots or punctures, following each other in a spiral line upon a sheet of paper wrapped round a cylinder, which revolves, nearly or exactly, in a definite time of convenient period as referred to sidereal reckoning.

2. Means must be provided for interrupting at pleasure that movement upon which the sequence of spirals depends, and at the same time interrupting the action of the galvanic battery, in order that paper may not be unnecessarily consumed when observations are discontinued.

3. Means must be provided for distinctly separating the records of observations made before and after such discontinuance.

4. An important result would be attained if the regulation of the movement could be made so perfect, that the instrument itself, while maintaining the motion of the barrel, could itself be used as transit-clock.

5. Supposing this object to be not attained, it is still very desirable that the barrel revolve with great uniformity, in order that the punctures of different turns of the spiral corresponding to the same second of transit-clock-time but in different minutes, should be arranged in a straight line as nearly as possible parallel to the barrel-axis, for the sake of facility of reading.

With these guiding principles, the apparatus was arranged in the form which I now proceed to describe.

Figure 1 is a view of the whole apparatus from the south. (The dial-plate of the clock faces the east.) It is to be remarked that the barrel is protected by a jointed case of plate-glass, and that the clock and the pendulum are inclosed in boxes whose sides consist of glass pannels, and thus the whole which is represented in Figure 1 is actually at once visible to the eye, except only a part of the pendulum-suspension, which is indicated by dots.

A is the cast-iron platform which supports the whole of the apparatus except the pendulum. It is an inverted tray, strongly ribbed; its upper surface was planed by the planing-engine. The height of the upper surface above the floor of the room is 3 ft. 4 in.

B, B, are two of the four posts which support A. They are connected by diagonal braces below the range of this view.

C is a box, through which the clock-weight descends.

D, D, two standards, whose pedestals are screwed upon A, which support the anti-friction wheels on which the pivots of the barrel rest.

E, the Great Barrel, revolving in 2 minutes of sidereal time. It is of brass, and is covered with a layer of woollen cloth. A sheet of paper is wetted, and in this state is wrapped round the cloth, and its folding edges are united by cement; when the paper becomes dry, its surface is tight and smooth. To remove the paper, the cemented edges are wetted. Six similar barrels are provided, in order that when one is fully charged, another may be substituted for it without delay.

F is the toothed wheel of 300 teeth upon the eastern end of the barrel.

G, G, two standards which carry the support of the pinion that drives F, the two guides of the sliding pricker-frame, the two long screws which give motion to the pricker-frame, and the apparatus for ungearing the long screws, and for suspending the galvanic action.

H, the pinion of 30 teeth, revolving in 12 seconds, which drives the wheel F. It receives motion from the clock.

I, the spindle of H. It is not a spindle of a wheel of the clock, but is connected with a spindle of a wheel of the clock in the same line by a clutch, which acts at the beginning of the connexion by friction, and finally makes a firm union.

J, J, the two guides of the sliding pricker-frame.

K, the upper of the two long screws by which the pricker-frame is made to travel. The screw-thread is removed from a few inches of that end of the screw which is visible in this view, in order that, if from inadvertence the revolution of the screw should be permitted to continue after the arrival of the pricker-frame at the west end of the screw, the power of the screw to continue its longitudinal motion should cease, and there should be no danger of breaking the frame of the instrument.

L is a balanced winch for occasionally turning the screw K by hand, when it is not connected with the clock.

M, M, is a spindle of a wheel of the clock, connected with K, when necessary, by a clutch. It revolves in ten minutes.

N is the lower of the two long screws. It is connected (as regards rotatory motion) with K by toothed wheels on the outside of the western standard G, so that it necessarily revolves in the same time as K.

O, O, is the wooden frame of the box of plate-glass which covers the barrel.

P, P, &c. are brass hinge-pieces screwed to the plate-glass with intervening layers of vulcanized caoutchouc.

Q, Q, two handles fixed in the bottom of the lower piece of plate-glass. To open the box, the lower plate is turned upwards and over till its handles Q rest upon the upper plate, and then the two plates are turned up together into a vertical position, in which they are retained by a wooden hook, omitted in this Figure, but shown in Figure 2.

R is a system of four galvanic wires, by which power is given to the two galvanic magnets which drive the two prickers that make the punctures on the barrel. Two of the wires with one magnet have relation to the circuit which is completed at every second by the action of the transit-clock, and thus, by means of one of the prickers, impress on the barrel a puncture at every second; the other two are in the circuit which is completed by the touch of the observer's finger, and thus, by means of the other pricker, impress on the barrel a puncture at the instant of each observation. (It will be mentioned below that two wires, acting by one galvanic magnet and one pricker, are sufficient for both those offices, but that four wires and two prickers are convenient.) The wires pass over fixed bearers near the ceiling of the room, while their lower ends partake of the motion of the frame carrying the galvanic magnets and prickers, as it slides from one end of the barrel to the other. The descriptions attached to the four wires correspond to the nomenclature of attachments in the map of wires, &c. preserved in the Observatory.

S, a piece of wood attached to the ceiling of the room, with four rounded openings through which the wires pass.

T, a wooden case inclosing the four wires in their descent to the floor, on their way to the batteries in the basement, and to the subterraneous passage to the transit-room. One of them rises again to the gearing-rheotome X, and again descends through the floor.

V, the observation-rheotome, or small apparatus for interrupting or completing the circuit of the observation-current. There is a similar apparatus, the transit-clock-rheotome, beneath the platform A (not shown in the plates), for interrupting or completing the circuit of the current produced by the beats of the transit-clock; this is employed in the operation of ruling lines upon the barrel E.

W is one of the transit-clock-wires, which, having been led from the contact-spring in the transit-clock, rises up through the floor to the gearing-rheotome X.

X is the gearing-rheotome. It is so connected with apparatus, to be described below, that the same movement which puts the long screw K in connexion with the clock-spindle M, does at the same time complete the circuit through X; and when the connexion of K and M is broken, the circuit through X is also broken. The other wire which descends from X through the floor is not seen in this view.

The details of the clock will be described in the explanation of subsequent figures.

Y is the wooden frame of the glass case of the clock.

Z is the vertical spindle which is put in motion by the clock and revolves in two seconds.

a is the radial arm carried by Z, moving in a horizontal plane and acting on the pendulum-spike h.

b is the stone pillar which rises through the room to support the northern pivot of the polar axis of Shuckburgh's equatoreal in the room above.

c is the large cast-iron bracket which carries the suspension-piece of the clock-pendulum. It embraces two sides of the pier b, and is fixed to each side by a single strong screw.

d is a flat iron plate sliding upon the top of c, and adjusted horizontally by three screws, of which two are seen in the view. The suspension-piece of the pendulum is attached to its lower surface, and passes downwards through a large opening in the horizontal part of the bracket c.

e, a case inclosing the pendulum-suspension.

f, the suspension arches of the pendulum, to be described hereafter. The suspension-apparatus permits the pendulum to move in every direction.

g, the pendulum; it is a compensation pendulum, with steel rod and quicksilver in an iron cistern. Upon the steel rod there is a small sliding weight, for adjustment of rate.

h, the spike at the bottom of the pendulum cistern, on which the radial arm a of the clock acts; by this action the circular motion of h or the conical motion of g is maintained.

i, the wooden frame of the glass case which incloses the pendulum.

Figure 2 is a view of the apparatus from the east side.

k shows the position of the plate-glass-covering of the Barrel, when it is opened.

l, a wooden hook, for retaining the plate-glass in a safe position.

m, the dial-plate of the clock; it shows hours to 24, minutes to 60, and seconds to 60. The seconds-hand travels with a uniform smooth motion.

n, a small slider guided by two screws, partly hidden in Figure 2 by the dial-plate, but exhibited completely, and on a larger scale, in Figure 2 (*a*). Its explanation will be best understood from the following:—

o, in Figure 2 (*b*), the slider n as seen from above. In the process of ruling lines on the barrel, it is necessary to slide one of the clock-spindles lengthways, so as to ungear or detach its wheel from the pinion in which it acts. By withdrawing a locking-lever at the distant end of the spindle, the separation is permitted; and by pushing forward the slider n or o, whose inclined end acts on the near end of the spindle, the spindle is forced endways, and is retained in the position to which it is so forced; and the separation of the wheels is thus effected.

p, a lever, by pushing which in the longitudinal direction of the barrel-axis, the circuit is completed at the rheotome X, and at the same time K is put in connexion with M; or, by pushing in the opposite direction, the galvanic circuit and the spindle connexion are both broken. The lever is seen more completely in Figures 12 and 14.

q, a small piece of wood, attached by a hinge to the wooden frame of the cover of the barrel. When it is lifted, the lever p can be moved from one position (as that of completing circuit, &c.) to the other position (as that of breaking circuit, &c.), or *vice versâ*; but when q is dropped, the lever p is retained immoveably in the position (which ever it may be) in which it is placed. It is seen more clearly in Figures 3 and 12.

r, s, two brass cylinders attached to the clock frame, carrying two glass cylindrical vessels nearly filled with water.

t, v, two silken cords, passing over pullies. Their upper ends are fastened so as to act horizontally on the frame of the "intermediate wheel" in the chronometric governor, and their lower ends sustain weights in the water (conical cups carrying shot), the preponderance of one of which over the other defines, in the chronometric governor, the power which maintains the conical movement of the pendulum g.

Figure 3 is a representation of the apparatus as viewed from above.

w is a piece of plate-glass covering the greater part of the large opening in the back part of the roof of the box covering the Barrel.

x is a narrow opening which is left for the system of wires R to travel along, as the pricker-frame travels from one end of the barrel to the other.

A portion of the pricker-frame is seen imperfectly through w and x.

y, y, two screws acting in the plate d, and supporting the two primary suspension-springs of the pendulum. They are visible in this view through holes in the plate which covers d.

z, a small piece of wood attached to the box by hinges, by lifting which the gearing-rheotome X is discovered.

Figure 4 represents the principal train of the clock, as viewed from the east.

a is the weight-line-barrel.

b is the weight-line (a wire-rope). It supports the weight by a sheaf of two pullies (a single pully also being attached to the lower side of the platform A), and rises into the clock at *c*. The tension upon *b* is about 21 lbs., and it descends $8\frac{1}{4}$ inches in one hour.

c is the rising part or return of the weight-line. It is attached to the going-lever *m*, on which it acts with a tensile force as nearly as possible equal to that with which *b* acts upon *a*.

d is the barrel-ratchet of 48 teeth.

e, *e*, the barrel-clicks, their centers of motion being on the wheel *h*.

f, the going-ratchet of 80 teeth, forming part of the wheel *h*.

g, the going-click, whose center of motion is in the fixed clock-plate.

h, the barrel wheel of 96 teeth, revolving in 2 hours.

i, the pinion of 32 teeth, in which it works.

j, the second wheel of 48 teeth revolving in 40 minutes.

k, the lantern pinion of 12 teeth in which it works.

l, the sliding-frame which carries the center of motion of *i* and *j*.

m, the going-lever, on which the tension of the return of the weight-line *c* acts.

n, the center of motion of *m*, fixed in the clock-plate.

o, the guide fixed to the clock-plate, in which the end-rod of *l* slides; the other end of *l* being jointed to the lever *m*, and therefore requiring no guide.

The action of the lever *m*, slider *l*, and click *g*, is the following. As the clock continues going in the ordinary way, successive teeth of the ratchet *f* pass under the click *g*. The slider *l* is kept in position by three forces, namely, the pressure of the teeth of *h* against the teeth of *i* (as produced immediately by the weight-line *b*), the reaction of the teeth of *k* against those of *j*, and the pressure of the lever *m* (produced by the return of the weight-line *c*), acting to thrust the slider endways. The position taken by the slider under this action is definite; as, if it slide too far to the left, the moment of the action of *c* upon the lever *m* is increased, and tends to bring it to the right; or the contrary, if it is too far to the right. But when the winch is applied to wind up the cord, the pressure of *b* upon the wheel *h* ceases entirely. The pressure of *c* and *m* continue, and the portion of this pressure which is thrown upon the teeth of *i* pushes the wheel *h* backwards, till a tooth of *f* lodges against *g*. Then the rotation of *k* is kept up by the action of the teeth of *j*, in the movement which is caused by the pressure of *m* upon the slider *l*, and which carries *l* towards the right, the wheels *i* and *j* at the same time revolving in the bush which is fixed in *l*. The effect of this movement is that the wheel *j* does for the time revolve round that tooth which is in bearing on the teeth of the wheel *h* (now firmly fixed); and thus revolving, it maintains the motion of *k* as in the ordinary state. The line *c* during this time is descending. As soon as the pressure of the hand on the winch is relieved, *h* presses *i* and *l* to the left; and, as the moment of the action of *c* on *m* has been diminished by the change of position of *m*, the pressure of *h* on *l* overcomes it and forces the lever *m* to the left, raising the cord *c*, and restoring all to their original state.

It was intended at first to use a smaller pinion for *i* and a larger wheel for *j*, with the purpose of making the barrel *a* go for 8 days; and the lever *m* and guide *o* were accommodated to this. But it was found that an inconveniently heavy weight would be required, and the wheels were so changed as to make the barrel go 2 days only.

p is a wheel of 70 teeth revolving in 10 minutes. The spindle of this wheel is M, which is connected by a clutch with the long screw K.

q, the pinion of 7 teeth in which *p* acts.

r, a wheel of 40 teeth, revolving in one minute. This wheel carries the seconds-hand.

s, the pinion of 8 teeth in which it acts.

t, a contrate wheel of 48 teeth, revolving in 12 seconds. The spindle of this wheel is connected by a friction-clutch with I, the spindle of the large pinion H, which acts in F to drive the Barrel E. It is upon the near end of the spindle of *t* that the slider n or o acts. When the locking lever at the distant end of the spindle (to be hereafter described) is removed, and the slider n or o is forced, the contrate wheel *t* is pushed out of its gearing with the pinion *u*, but *s* is not detached from gearing with *r*, nor H from F, and thus the Barrel can be turned with great rapidity without any interference with the movement of the pendulum or the wheels immediately connected with it.

u, a pinion of 8 teeth with vertical spindle, revolving in 2 seconds.

v, a fly attached to *u*, consisting of a bar loaded at its extremities.

w, a bevelled wheel of 50 teeth on the same spindle.

x, the flat friction-plate on the same spindle. It receives the friction which, in a modification of the chronometric-governor, regulates the expenditure of power, and leaves a uniform force to act on the wheels that maintain the rotation of the pendulum.

y, the bevelled "intermediate wheel" of 50 teeth. Its center of motion is carried by the moveable frame on which the fine cords t and v act. In rotation round its center, it is driven by w.

z, a bevelled wheel of 50 teeth attached to the vertical spindle Z. It is driven by y.

α, α, α, three anti-friction wheels which support the upper part of Z. One of them is carried by a spring.

β, the cock which carries the upper pivot of u, x, and w, the lower pivot of Z, and the center of motion of the moveable frame that carries the center of motion of y. It will be remarked that there is no connexion between w and z except by the action of the "intermediate wheel" y; and that w and z revolve in opposite directions.

γ, the arch-head of the moveable frame, with a groove in which the cords t and v act. A hole which is seen in β is made for the purpose of allowing the end of the arch-head to pass freely through β.

δ, a cup loaded with a piece of lead, connected with the arch-head by a flexible spring, and travelling by means of a wheel upon the curved lever.

ϵ, the curved lever, to be described hereafter.

ζ, the near or eastern pivot of the curved lever. The axis of the curved lever is in the direction perpendicular to the clock-face.

ζ' is used in other figures to denote the distant or western pivot of the curved lever.

η, a counterpoise for the curved lever.

θ, the pressure-pin fixed in the lower side of the curved lever. This pin presses upon the friction-plate x. The amount of its friction depends on the position of the arch-head γ and the weight δ. When δ has travelled so far upon the curved lever as to be far removed from the axis of which ζ is the pivot, the pressure of θ upon the friction-plate, and the consequent friction, are so great as to stop the clock. When δ is nearly above the axis, as in the view, the pressure and friction are insignificant.

ι, ι, the two brass cups in water, partly loaded with shot, suspended from t and v.

Figure 5 is the dial-train.

κ, a pinion of 12 teeth, on the same spindle as k, p, and M, revolving in 10 minutes.

λ a wheel of 72 teeth, revolving in one hour and carrying the minute hand.

μ a wheel revolving in 24 hours and carrying the hour hand.

No further explanation is necessary.

Figure 6 is a view of the upper or regulating part of the clock, from the south.

ν is an index, pointing to a graduation upon the arch-head, which gives a measure of the position of the arch-head, and of the consequent position of the weight δ, and of the friction which the pressure-pin θ produces on the revolving friction-plate x.

Figure 7 is a horizontal plan of the regulating part of the clock.
ζ' is the western pivot of the curved lever.

Figure 8 is a horizontal plan of the friction-plate and curved lever only.

Figure 9 is a horizontal plan of the arch-head and parts connected with it only.

The action of the regulating-part may now be explained. It must be understood that the weight hanging on the cord v is greater than that hanging on the cord t. Let the excess be W. This will have the effect of pushing the center of the intermediate wheel y towards the south with a force $n \times$ W, where n is the proportion of the radius of the arch-head to the distance of y from the center of the arch-head. In the ordinary state of things, with the arch-head resting tranquil, there must be a pressure $\frac{n \times W}{2}$ exerted by the teeth of w upon those of y, and a pressure $\frac{n \times W}{2}$ exerted in the opposite direction by the teeth of y upon those of z, which implies a pressure of $\frac{n \times W}{2}$ exerted by the teeth of z upon those of y in the same direction as the first; and thus all the forces sustained by y balance. But as we cannot assert that the magnitude of the weight acting upon the barrel a is such as to produce exactly the pressure $\frac{n \times W}{2}$ at the teeth of w, we must apply a weight to the barrel which will, unless it is reduced, produce a force *greater* than $\frac{n \times W}{2}$ at the teeth of w, and we must have some means of reducing that force on the teeth of w to the value $\frac{n \times W}{2}$. The means of reducing is given in the friction of the presure-pin θ upon the friction-plate x, produced by the weight δ. The arch-head therefore when tranquil must rest in one certain definite position, which draws the weight δ to such a position upon the curved lever, that the pressure of the pressure-pin θ upon the friction-plate x exactly consumes the excess of force derived from the weight-barrel, and leaves the due pressure $\frac{n \times W}{2}$ only to act on the teeth of y.

Suppose now, from inequality in action of the weight-line on the weight-barrel, friction in the train, resistance of the Great Barrel, or any other cause not higher in the wheel-work than w, the force which acts on w is suddenly increased, so as to accelerate the revolution of v, w, and x. The rotation of z will not be immediately affected, for it is connected by the arm a with the heavy pendulum, whose inertia is very great. Consequently the acceleration of the rotation of v, w, and z, will carry the wheel y and its center towards the north, or the arch-head towards the south; it will therefore draw the weight δ further along the curved lever so as to be farther from the axis $\zeta\ \zeta'$; it will therefore increase the pressure of θ upon x, and the consequent friction; and will thus reduce the power derived from the train of wheels till the remainder which acts upon y is diminished to its proper value $\frac{n \times W}{2}$; after which the arch-head will be tranquil.

It is easy to observe this effect by any arrangement which impresses either greater force or greater resistance on the wheel-train or Great Barrel. If the Barrel is put out of balance, by altering one of the adjusting-weights to be hereafter mentioned, the arch-head γ is seen to slide backwards and forwards under the index ν, the period of its oscillation coinciding exactly with the time of rotation of the Barrel.

By this arrangement, therefore, the maintaining power upon the wheel y is sensibly constant, and that upon the arm a, which immediately maintains the motion of the pendulum, is affected by the friction, &c., only of the wheels y, z, and of the anti-friction wheels α α α. The only resistance to the motion of the pendulum arises from the resistance of the air and the friction of the suspension. The inclination of the pendulum-rod to the vertical soon becomes such that these forces balance; and will frequently remain sensibly unaltered during many hours or days. It is, however, much affected by small irregularities in the friction of y, z, &c.

When we wish to increase the inclination of the pendulum, which is to be done by increasing the maintaining power upon the wheel y, the process is, not to alter the weight upon the barrel-line (supposed to be great enough or greater than is absolutely necessary), but to put a small shot into the northern cup ι. This overcomes the force actually exerted by w upon y, draws the arch-head towards the north, and causes δ to travel along the curved lever so as to diminish the pressure of θ upon x, and the consequent friction; and the force exerted by w upon y gradually increases till it becomes equal to the new or increased value of $\frac{n \times W}{2}$, after which the arch-head remains quiet, as before.

The object of suspending the cups ι, ι, in water, is to impede the sudden movement of the arch-head (which implies an irregular motion either of the pendulum or of the Great Barrel) without offering the slightest impediment to its slow movement.

Figure 10 is a horizontal plan of the upper part of the clock, showing the radial arms, &c.

Four arms are represented, of which two are mere counterpoises to the others. They have been planned with different intentions. The straighter arms, whose concave sides precede in the ordinary motion, were so shaped in order that the action of the pressing surface of a upon the spike of the pendulum, friction included, might be truly in the direction of a tangent to the circle described. The more curved arms, whose convex sides precede, were so shaped in order that, when the inclination of the pendulum is large, the friction might have some effect in diminishing the resolved part of the force of gravity on the pendulum (which, at large inclinations, is too great for isochronism); the arrangement has not been sensibly beneficial.

The small projections from the sides of a are lumps of solder which have been affixed for the purpose of measuring degrees of inclination of the pendulum-rod. The inclination usually maintained is about $3\frac{1}{2}°$.

Figure 11 is a perspective view from below of the suspension of the pendulum.

ξ, ξ, are two pieces of split metal, connected with the suspension plate d, through which the primary suspension-springs pass. These springs, however, are not supported by ξ, ξ, but by two screws y y, represented in Figure 3.

π, π, the two primary suspension springs.

ρ is an arched piece of brass suspended by π, π.

σ is a piece of brass arched in the opposite direction, and, as regards its horizontal plan, at right angles to ρ. It is firmly connected with ρ, and is in fact cast with it. It supports the secondary suspension-springs.

τ, τ, the two secondary suspension-springs.

υ, an arched piece of brass, suspended by τ, τ, in which the pendulum rod g is fixed.

The attachments of the springs are so adjusted that the top and bottom of the secondary springs are at precisely the same height as the top and bottom of the primary springs. It is evident that, by the combination of the flexures of the two pairs of springs, the pendulum is free to move in all directions, exactly as if it were suspended from the point which is the intersection of the line joining the top of π π, with the line joining the top of τ τ. The pendulum, in its motion, always turns the same side towards the north.

Figure 12 is a view, from the south, of the mechanism between the clock and the Great Barrel.

ϕ is the locking-lever to which allusion was made in the description of *t*, Figure 4. The end of the pivot of I rests against it. ϕ will be seen better in subsequent Figures.

χ is the center upon which ϕ turns.

ψ, is a notched circular plate or rude toothed wheel firmly fixed to I. The notches have no purpose but to receive the pins of the piece (2).

ω is a tube, sliding freely upon the spindle of the 12-second contrate-weeel *t*, but compelled by a pin in a slot to receive its rotatory motion.

It must be remarked that the end of the axis of the contrate-wheel abuts firmly against the end of I.

(1) is a long plate of brass firmly fixed to ω.

(2) is a plate in the transverse direction, firmly fixed to ω, carrying two pins at its ends which may fall into the notches of ψ. It will be seen better in Figure 13.

(3), (3), are long pins firmly fixed to (1).

(4), (4), are two screws, which have double-shoulder-bearing in (1).

(5) is a loose plate of metal similar to (1), but connected with nothing. It passes loosely over I, and over (3), (3); but the screws (4), (4), are tapped into it.

(6), (6), (6), (6), are four steel springs, to press the circular plate ψ. Two of them are fixed to (1), and two are fixed to (5).

The action of the friction-clutch may now be explained. If the screws (4), (4), be relaxed to the utmost, the plates (1) and (5) will be widely separated, and the action of the two springs (6), 6), attached to (1) will push the slider ω back, so that the pins of (2) will be withdrawn from the notches of ψ. In this state, there is no connexion between the slider ω or the spindle of the contrate-wheel on the one hand, and the spindle I on the other hand. The clock therefore will continue to go (without any sensible alteration of the inclination of pendulum and the rate, by virtue of the regulating apparatus) without giving motion to I, H, F, and the Great Barrel; or the Barrel may be lifted from its bearings, and another barrel may be substituted for it, (which operation will infallibly give motion to H and I,) without disturbing the wheels of the clock.

It is now required to put the Barrel in connexion with the clock. The attendant drives the screws (4) (4) alternately, as the motion of the clock brings them within his reach, driving them as nearly as possible by equal degrees. The four springs (6) (6) (6) (6) begin to embrace the plate ψ. Their friction at length becomes so great, that they gradually give motion to the Barrel. After a short time it is found that the hold is so complete, that there is no discoverable slip of the springs upon the plate ψ. Still, as accident might cause a slip, it is not proper to trust entirely to this frictional connexion. The screws (4) (4) are therefore driven still further, till the pins of (2) enter the notches of ψ, and then the connexion is perfectly secure. It is necessary to make the connexion in this cautious manner, on account of the great weight of the Barrel and Pendulum, the delicacy of the intervening wheels, and the probability that some would be broken if any sudden connexion were attempted.

The Barrel is always kept in motion and ready for use, except at the times of adjusting or changing the Barrel, &c.

(7) is the sliding clutch-piece for connecting M, the spindle of the 10-minute wheel *p* of the clock, with the long screw K. The pin which compels (7) to receive the rotatory motion of M is not shown in the Figure, but it is to be understood as similar to that by which rotatory motion is given to ω. For making connexion with (8), (7) has a center-pin and a pin at the extremity of an arm.

(8) is the mushroom-head of the long screw K. It has a hole in the center, and a series of holes round the circumference (enlarged on the east side to a conical shape), better seen in a subsequent drawing (Figure 14). When the clutch-piece (7) is pushed towards (8), its pin engages in one of the conical holes, and thereby giving a small motion to the screw, if necessary, it soon enters the cylindrical part of the hole, and the long screw and the 10-minute spindle then revolve together.

(9) is a flat circular disk carried by the clutch-piece, on which the lever p acts to slide the clutch-piece.

(10) is a hook attached to the lever p for acting on (9), so as to withdraw the clutch-piece. The lever p itself makes the pressure on (9), which is required for thrusting the clutch-piece into connexion with (8).

(11) is a brass spring, forming the connecting part of the gearing-rheotome. It springs upwards, except when it is forced down by (14).

(12), a galvanic wire passing down through the floor, whence it rises under cover of the case T, passes through S, and descends (forming one of the collection of wires R) to the "Barrel Magnet A," which drives the Transit-Clock-pricker. It is connected with (11) by an ordinary terminal screw.

(13), a brass pin connected with the wire W.

(14), a block of wood carried by the lever p.

When the lever p is pressed towards the west, the block (14) forces (11) into contact with (13), and thus completes the communication between (12) and W. There is then no interruption of the galvanic circuit, of which (12) and W form part, except in the transit-clock, and there it is completed at every second of the transit-clock. It will be remarked that the same motion of the lever p, which forces X into contact with (13), does also establish the connexion between (7) and (8), or between M and K; so that, at the same instant at which the transit-clock begins its punctures, the screw K begins to revolve, carrying longitudinally the pricker-frame (to be described hereafter).

(15), three antifriction wheels carrying the axis of the 12-second wheel.

(16), two antifriction wheels carrying the pivot of the Great Barrel.

(17), the pivot of the Great Barrel.

Figure 13 is a perspective view of the friction-clutch, requiring no explanation beyond that which has been given above.

Figure 14 is a view, from the east, of the eastern standards, &c.

(18) is the head of the pin on which the lever p turns.

Figure 15 is a view, from the west, of the western standards, &c.

(19) is a toothed wheel attached to the upper long screw K.

(20) is a similar toothed wheel upon a fixed center.

(21) is a similar toothed wheel upon the lower long screw N.

By this arrangement, the two long screws turn in the same direction and with the same velocity.

(22) is one of the adjusting-weights upon a spoke of the Great Barrel.

Figure 16 is an end view of the Barrel from the east.

(22) (22) are the two adjusting weights at the opposite ends of the Barrel.

(23) (23) are the two fixed weights at the opposite ends of the Barrel.

For putting the Barrel in balance, there is provided a support, unconnected with this machinery, but bearing antifriction wheels exactly similar to those in this machinery, so that the movement of the Barrel when placed upon it is extremely delicate. The Barrel is turned till one of the weights (22) is in the vertical; and the other weight (22) is slid till the Barrel does not tend to move, and is then fixed; then the Barrel is turned till the second weight (22) is in the vertical, and the first weight (22) is adjusted in like manner. The barrel is then perfectly in balance in all positions.

Figure 17 is a view from the west (partly sectional) of the Pricker-Frame.

(24) is the foundation-plate of the Travelling Pricker-Frame. A large portion of its central part is cut away, to allow the two Barrel Magnets to project downwards through it. Near its upper and lower edges it is made thicker, to admit of its being bored and cut with internal screw-threads for the action of the screws K and N. The interval between successive folds of the same thread on either of these screws is 0·5 inch; and as the screw occupies ten minutes in turning, in which time the great barrel has made five revolutions; it follows that, in one revolution of the barrel, the Pricker Frame advances 0·1 inch. There are on each screw three parallel screw-threads. The extreme edges of the travelling plate are adapted to slide in chases in the long guides J and J.

(25) is a brass plate forming the upper portion of the bridge-piece, of which the side is not represented in this view, as it would in great measure conceal the Barrel Magnets. The feet of the bridge-piece are fixed by screws to (24).

(26) a piece of wood attached to (25), for insulating the connecting brass plates and terminals to which are attached the wires of R and the wires of the coils of the "Barrel Magnets A and B."

(27), (27), one part of the iron core of "Barrel Magnet A." The other part of the core is concealed by (27), and the other bobbin of "Barrel Magnet A" is concealed by the bobbin in sight. (27) is connected by a screw with (25).

(28), (28), similar parts of the core of "Barrel Magnet B."

(29), (30), (31), three brass cocks attached to (24), in which the pivots of the pricker-levers turn.

(32), the piece of iron carried by the "Pricker-Lever A," which is attracted by the core (27). It is represented in the Figure as if at this moment attracted by the effect of a galvanic current passing through the coils of "Barrel Magnet A."

(33), the pricker or conical point carried by the same lever as (32), which, in consequence of (32) being raised, is driven downwards so as to make a puncture upon the paper of the Great Barrel. The punctures given by (33) are those which correspond to seconds of the Transit-Clock, a current being sent through the coils of "A" by the completion of circuit, which is effected by a 60-tooth wheel on the arbor of the seconds-hand, forcing two slender springs into contact at every start of the seconds-hand.

(34) the piece of iron carried by the "Pricker-Lever B," which is attracted by the core (28). It is represented in the figure as not attracted at this moment.

(35), the pricker carried by the lever of (34), at present withdrawn from the Barrel. The punctures given by (35) are those which correspond to observations; a current being sent through the coils of "B" by the completion of circuit, which is made by the observer's touch either of a spring on the Transit-Circle, or of a spring on the Altazimuth.

(36), a clamping-piece for carrying a glass pen for ruling lines on the barrel. It is attached to the opposite side of the bridge-piece. It will be represented in another Figure.

(37), a spring for forcing (36) into a position which causes the pen to press upon the Barrel.

Figure 18 is a side view of "Barrel Magnet B," &c.

(38) is a weak spring, whose office is to separate (34) from (28), when the galvanic current has ceased. There is a similar spring for (32).

Figure 19 is a view of the pricker-frame from below, the barrel being removed.

The prickers (33) and (35) are separated in the direction transverse to the length of the screws, that is, in the direction of the Barrel's rotation, by a space as nearly as possible equal to the movement of the Barrel in one second of time (about 0·3 inch). In consequence, the fractional parts of the second of time in an observation are always accurately referred to the second of the transit-clock. The integer seconds also are duly recorded, in consequence of the counting of the transit-clock seconds being made to depend on the transmission of touch-signals through the pricker (35), as will be explained below.

The prickers (33) and (35) are also separated in the direction of the Barrel's axis, by a much smaller quantity (about 0·02 inch) sufficient to keep the punctures quite distinct.

Experiments have been made, on the advantage of dispensing entirely with one pricker, or dispensing entirely with one battery. But it was found that when one pricker only was used, there was risk of confusion of the transit-clock seconds with the record of observations; and when one battery only was used, the punctures, on occasion of two falling together, were inconveniently feeble.

Figure 20 is a view of the pricker-frame from the east, specially for the purpose of showing the ruling-pen and the mounting of the prickers.

(39) is the center upon which the clamping-frame of the glass pen turns. It will

be seen that the action of the spring (37) tends to force the point of the pen into contact with the Barrel.

The necessity for ruling the Barrel arises from this circumstance. When a sheet is taken from the Barrel covered throughout with punctures corresponding to clock-seconds, occasionally interspersed with punctures corresponding to observations, it presents to the eye such a confusion of dots that without some leading lines it is nearly impossible to interpret them. It was soon found desirable to rule lines which should be parallel to the line of dots, as following each other in the rotation of the Barrel, and affected by the slow motion of the pricker-frame. By the use of a pen carried by the pricker-frame this will be effected, provided that by means of the clutch-piece (7) the spindle M be put in connexion with K. Now in using fluid ink, it is convenient to perform the operation of ruling rapidly, and therefore it is convenient to use the locking-lever φ and the slider n or o in such a manner that the contrate-wheel t shall be detached from u, which will allow the clock-weight to turn the Barrel with great velocity, and will give the proportional speed of travelling to the pricker-frame which now carries the pen. Thus the pen will with great rapidity describe a spiral exactly similar to the spiral which is traced by the line of transit-clock-punctures.

But there is yet an inconvenience to be overcome. When, by means of the lever p, the spindle M is put in connexion with K, the galvanic circuit is at the same instant completed at X; and thus, during the rapid rotation of the Barrel, the pricker (33) would at every second be forced down to the paper of the barrel, and the paper would be torn and probably the pricker would be injured. To obviate this, the transit-clock-rheotome is provided (to which allusion is made in the description of V), and, the current being interrupted there, no injury arises from completing the circuit at X.

The material used for the lines is ink very much diluted with water. The entire sheet upon a barrel (about 500 feet of line) is usually ruled at one charge of the pen, and in a very few minutes.

In this view is exhibited the mounting of the prickers (33) and (35). They are carried by long slender springs, whose upper ends are attached to pieces of brass fixed to the pricker-levers. The springs, in both instances, are on that side of the pieces of metal towards which the Barrel is moving, and they press with a slight pressure of elasticity towards their respective pieces of metal. Although the springs are weak, they very well sustain the endwise thrust which is necessary for making a puncture on the paper. But when the point is lodged for a short time in the paper, the Barrel still moving drags the pricker with the paper (the flexure of the springs permitting it), and there is no scratch or elongation of puncture. The punctures in fact are well-defined round holes, in the position corresponding to the first blow of the pricker.

Figure 21 is a view of the 60-tooth wheel fixed upon the arbor of the seconds-hand of the transit-clock, and of the springs which it forces into contact at every second.

The view requires little explanation. It will be easily understood that the springs are attached to separate pieces of brass, insulated on dry wood, carrying separate terminal screws with which two of the wires of R are connected; and that there are adjusting screws to determine the position of the springs when the wheel-tooth is not acting on them. The parts forced into contact are a plate of platinum and a pin of platinum. The spark which is formed at contact here, when the circuit is complete at the transit-clock-rheotome and the gearing-rheotome, slightly burns the plate and transfers a small quantity of metal from one of the springs to the other; but several months pass before the galvanic communication is interrupted. The places of the two springs ought to be so adjusted that the action of the tooth of the 60-tooth wheel takes place after the action of the tooth of the 30-tooth escape-wheel upon the pallet of the clock-pendulum has terminated; then the resistance of the galvanic springs does not sensibly affect the arc of the clock-pendulum or the maintenance of the pendulum's vibration.

One tooth of the 60-tooth wheel, namely, that which forces the springs together when the second-hand starts to indicate 60^s, is cut away; and, therefore, one puncture is lost in every sixty punctures upon the Barrel, or two punctures are lost in every revolution of the Barrel; and, in consequence of the great exactness with which the Barrel performs its revolution in two minutes of sidereal time, two entire columns of punctures in the direction of the axis of the Barrel are suppressed. The method of interpreting these will be understood from the following description of the method of defining the zero of time which was used before the tooth of the 60-tooth wheel was shortened.

It was an instruction to the observer that at the commencement of some convenient decade of minutes, as for instance $15^h. 40^m$, he should by the touch-piece upon the Transit-Circle give the following observation-punctures. The intervals were to be one second. Remarking that 40^m contains four decades, he was to touch the touch-piece at 1^s, 2^s, 3^s, 4^s, then to wait for a few seconds, then to give fifteen touches for the 15^h. In this manner a record of certain hours, minutes, and seconds, was made on the Barrel, which left no difficulty in translating the record of every observation into hours, minutes, seconds, and fractions of seconds. The only danger of failure was this, that an unskilful observer might inadvertently commence his touches at 0^s, or 2^s, instead of 1^s, and might thus vitiate every record to the amount of one second.

The risk of error of a second was entirely destroyed by the instrumental suppression of the puncture of one of the seconds, and it only remained to ascertain what second is suppressed. Upon performing the operation just described, it was found that the second lost is 59^s. This arises from the circumstance that the two prickers (as has been mentioned) are separated by the space corresponding to one second of time, and, therefore, the record of transit-clock-punctures is (in reference to the observation-punctures) erroneous by one second. This seeming error is corrected by calling the suppressed second 59^s instead of 60^s.

The operation for recording the decades of minutes and hours is still necessary as before.

The battery for the Transit-Clock consists, at the present time, of fifteen cells, and that for the Observations consists of seventeen cells. The plates are of zinc and platinized silver, about four inches broad and seven inches deep; the acid used is the sulphuric acid of commerce diluted with about twenty times its quantity of water. The batteries are always charged and in connexion, and ready for use at any moment.

The two wires which communicate with "Barrel Magnet A" are interrupted by the battery and by the two rheotomes, and are then led in underground passages and along the area wall of the dwelling-house to the Observatory, where they pass under the floors to the slender springs in the Transit-Clock.

The two wires which communicate with "Barrel Magnet B" are interrupted by their battery and by one rheotome, and are led to the Observatory, where each of them bifurcates; one branch from each is led, by contact-rings on the conical axis of the Transit-Circle, to the touch-piece of the eye-end of the Transit-Circle telescope (as is fully explained in the description of the Transit-Circle), and the other branch from each is led into the South Dome, where the two branches are soldered to two insulated rings fixed upon the fixed horizontal circle, which are touched by two insulated springs carried by the revolving frame of the Altazimuth. Each of these springs communicates, by bifurcating wires, with two touch-pieces fixed upon the lower horizontal plate of the revolving frame, one adapted to use with Graduated Face of Vertical Circle Right, the other with Graduated Face of Vertical Circle Left.

The following notice will perhaps give a sufficient idea of the routine of use of this apparatus.

As the Barrel carries the record of observations made with two instruments (the Transit-Circle and the Altazimuth) which are usually employed by two different observers, there are prepared two cards, one inscribed, "In use for the Transit-Circle," and the other "In use for the Altazimuth." These cards are loosely tied upon the gearing lever p, and, when the apparatus is not in use, are thrown backwards out of sight. When an observer comes to begin observations, suppose with the Transit-Circle, he first turns the winch L about half a revolution, in order to separate the new series of punctures from the last which was left on the Barrel; then he presses the lever p to the west, and locks it in that position by the piece q. The "Barrel Magnet A" immediately begins to make the transit-clock-punctures. Then he places in front the card "In use for the Transit-Circle," and he goes to the Transit-Circle and makes observations by touch of the touch-piece, recording in a memorandum-book the name of each object and its approximate time. At some convenient time, he records hours and decades of minutes in the manner described above.

Suppose now that the Altazimuth Observer comes to commence his observations. He finds that p is already locked to the gearing-position, and he has therefore no instrumental movement to make, but he places the card "In use for the Altazimuth" also in front. He then goes to the Altazimuth and makes observations by touch of the touch-piece, recording always the name of the object and its approximate time, but he does not record hours, &c. (unless there be no observer at the Transit-Circle, in which case the Altazimuth Observer must go to the Transit-Circle for that purpose.)

Suppose now that the Transit-Circle Observer has finished his observations. He comes to the instrument, but finding the card "In use for the Altazimuth," he does not disturb p, but merely places his own card out of sight.

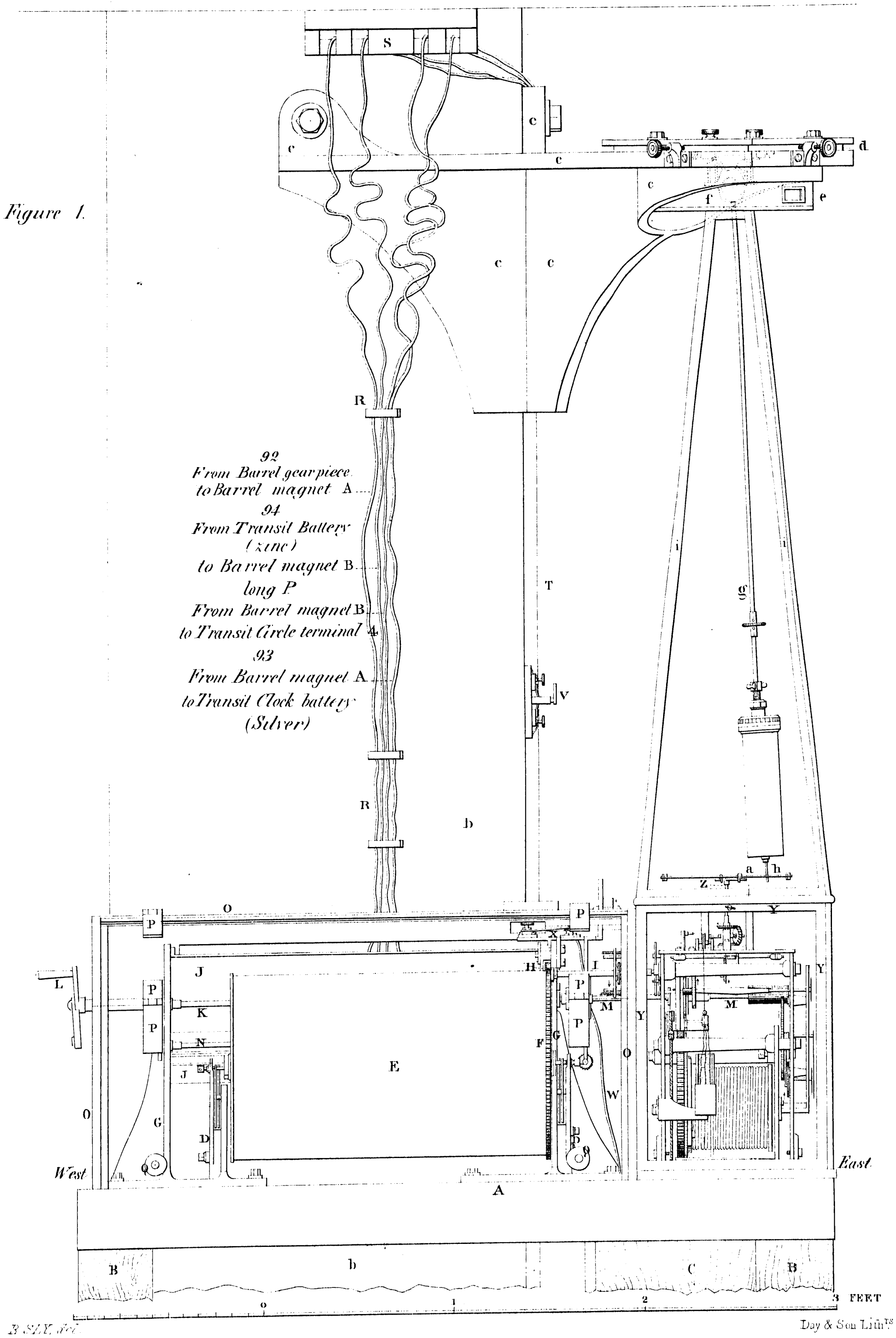
Finally, the Altazimuth Observer terminates his observations. He comes to the apparatus, and turns back his card "In use for the Altazimuth.' There is then no card in sight, and therefore it is his duty to press the lever p to the east, and to lock it fast in that position by q. The transit-clock-punctures and the advance of the pricker-frame cease immediately, and no unnecessary consumption of paper takes place.

On the next morning, the superintendant of the Transit Department detaches the friction-clutch by gradually unscrewing (4), (4), takes out the Barrel, and places it upon a wooden stand in which its pivots are supported with the axis in an inclined position, so that its rotation is like that of the Polar Axis of an Equatoreal. He sits before this, and turns the Barrel to bring different punctures under his view; the light then falls upon all in the same way, and the reading is free from error as regards direction of illumination. First he identifies and marks in ink the time-zero signals, and by means of these he writes the hours and minutes corresponding to each commencement of a minute, as well as the seconds at the top of each column of seconds. Then he identifies the first transit-wire-observation in each transit, and writes the name of the object observed. Lastly, he reads off in hours, minutes, seconds, and tenths of seconds (the latter being taken by means of a divided scale of paper) the time of every transit-observation, which an assistant enters into the proper book for reduction. The Barrel is then restored to its place, and, by driving the screws (4) (4), the friction clutch connects the Barrel with the clock, and all is ready for new observations.

When several of the Barrels are fully charged with observations, the paper is wetted at the overlapping edge at which the cement is applied, the edges are separated, each sheet is taken off, the successive sheets are tied together in packets of a month each, and these packets are preserved in drawers.

CHRONOGRAPHIC APPARATUS, ROYAL OBSERVATORY, GREENWICH. PLATE 1.

Figure 1.



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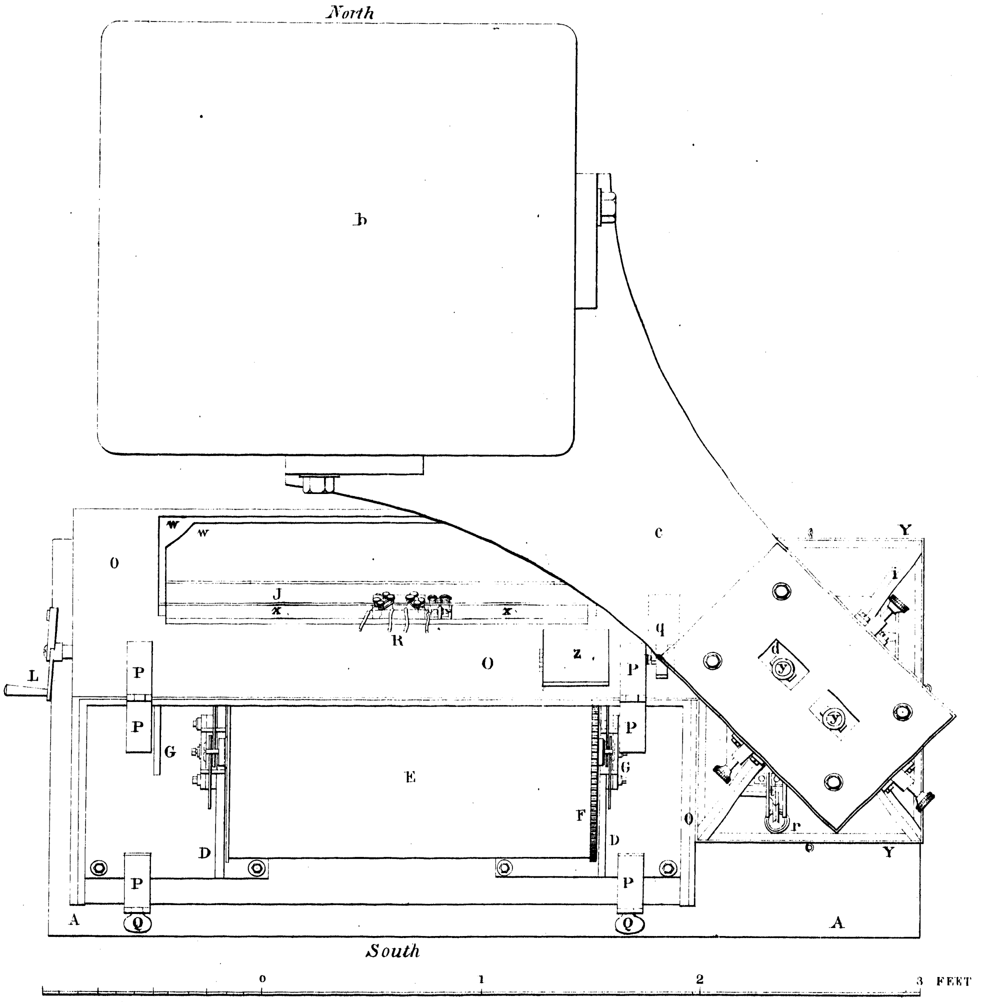
Day & Son Lith^rs to the Queen.

CHRONOGRAPHIC APPARATUS, ROYAL OBSERVATORY, GREENWICH. PLATE 3.

Figure 3.



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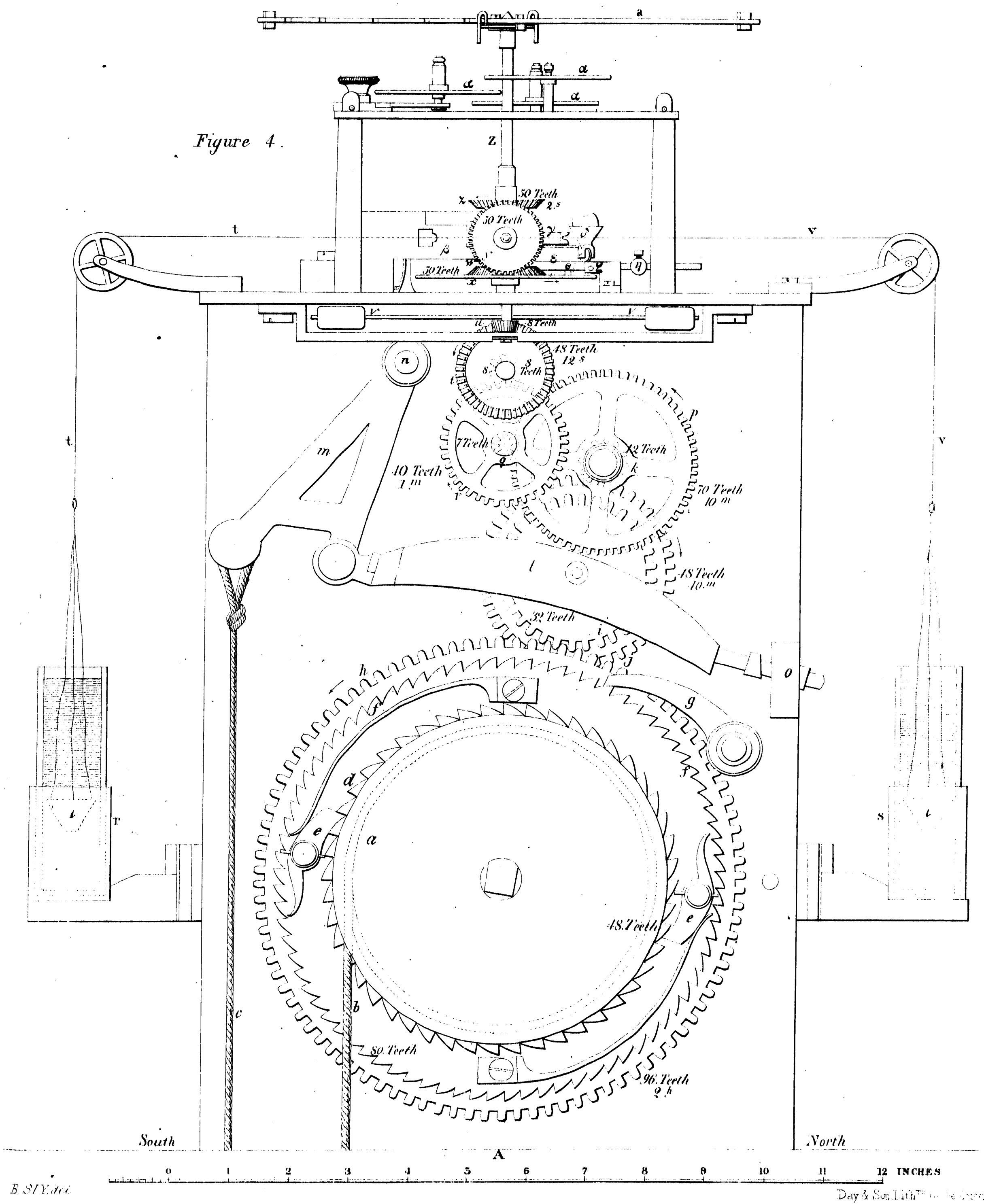
Day & Son Lithrs to the Queen.

CHRONOGRAPHIC APPARATUS, ROYAL OBSERVATORY, GREENWICH. PLATE 4.

Figure 4.



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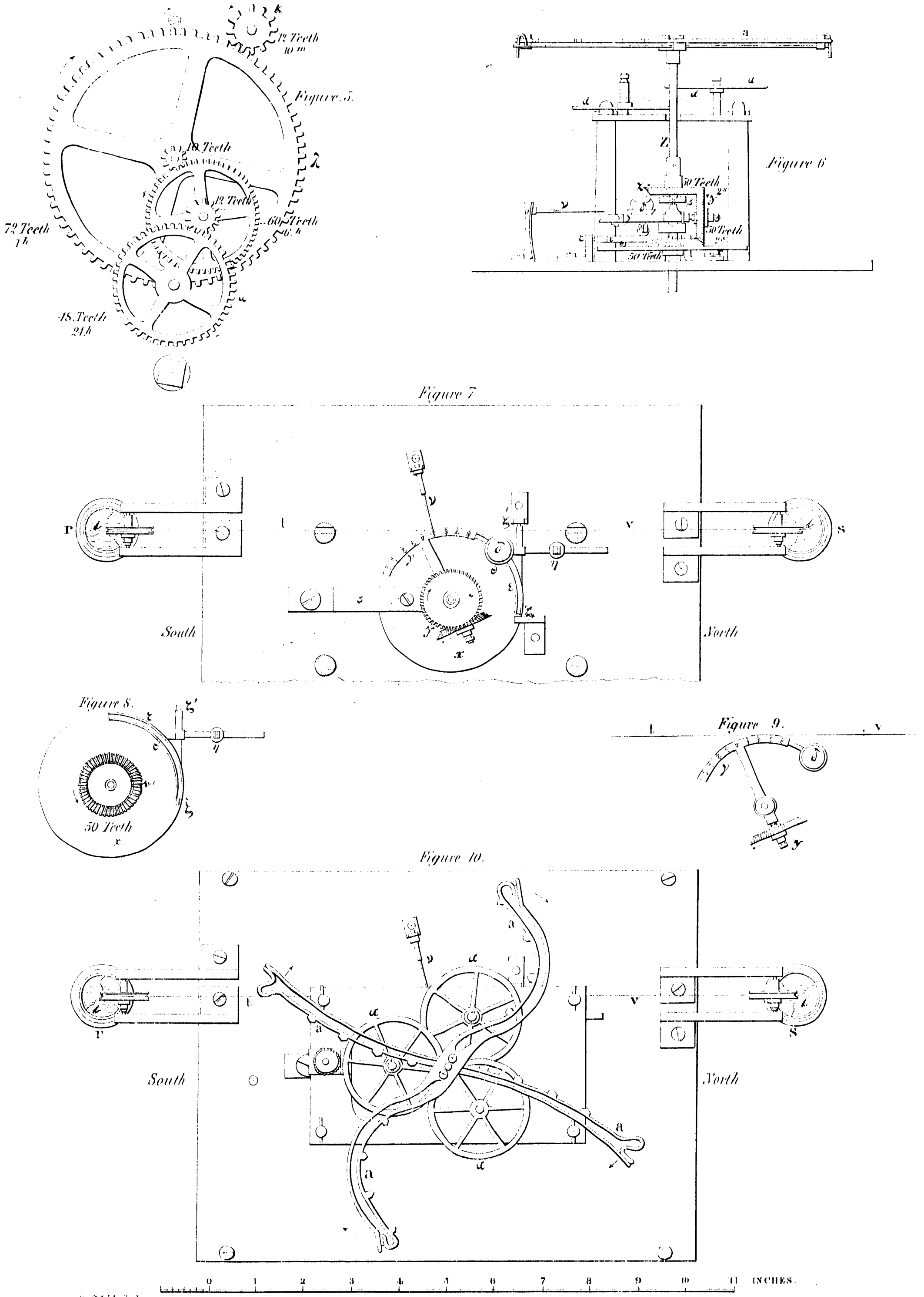
Day & Son, Lithrs to the Queen.

CHRONOGRAPHIC APPARATUS, ROYAL OBSERVATORY, GREENWICH. PLATE 5.



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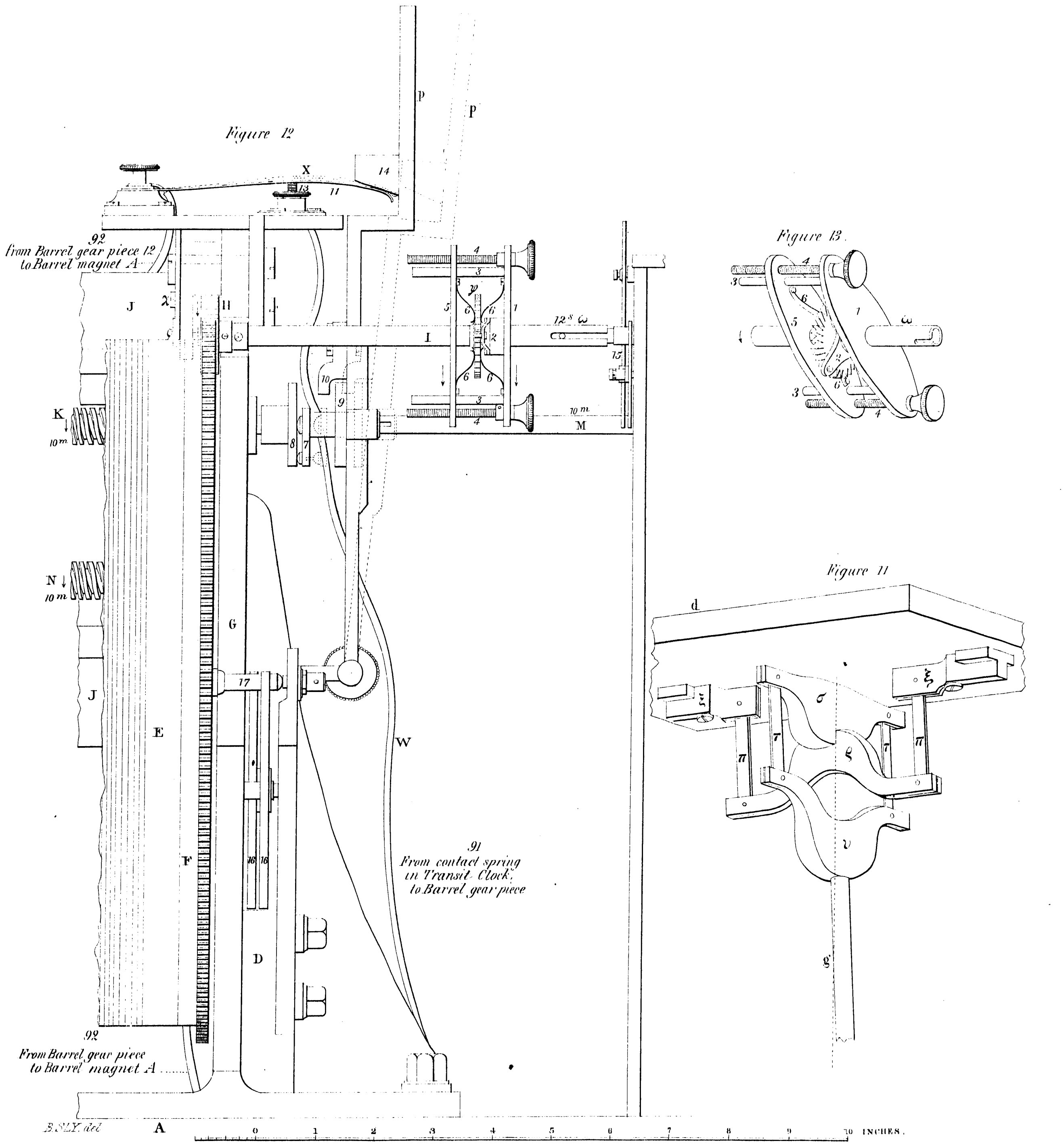
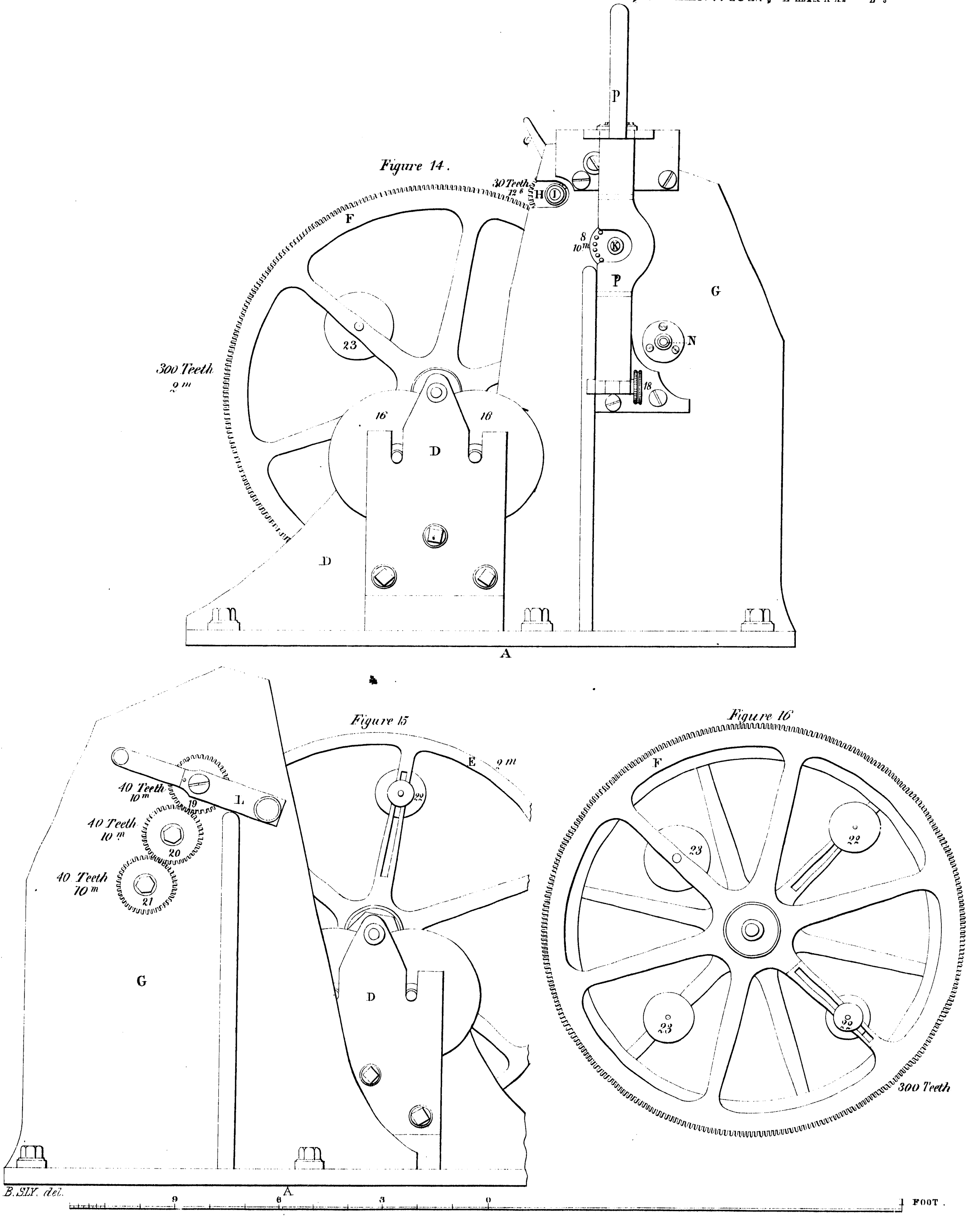
CHRONOGRAPHIC APPARATUS, ROYAL OBSERVATORY, GREENWICH. PLATE 6.



Day & Son Lithrs to the Queen.

CHRONOGRAPHIC APPARATUS, ROYAL OBSERVATORY, GREENWICH, PLATE 7.



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Day & Son Lithrs to the Queen

CHRONOGRAPHIC APPARATUS, ROYAL OBSERVATORY, GREENWICH. PLATE 8.

Figure 17.

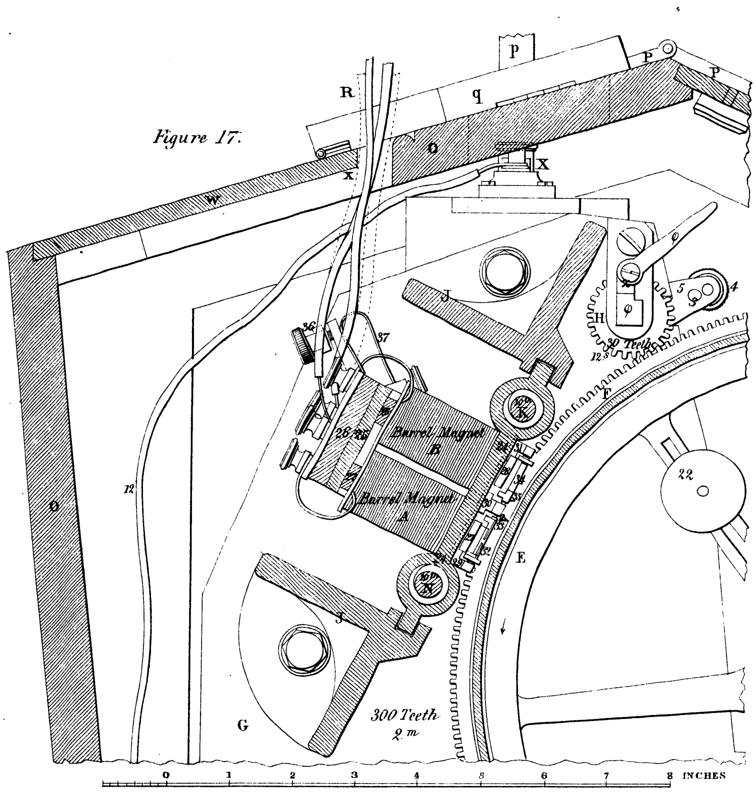


Figure 18.

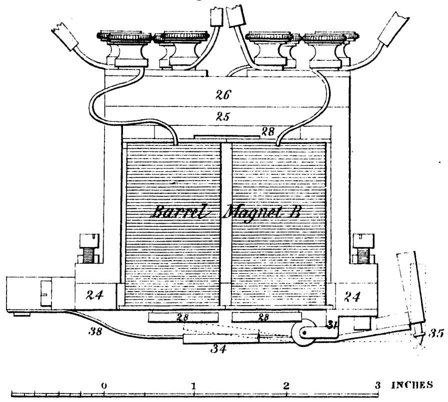


Figure 20

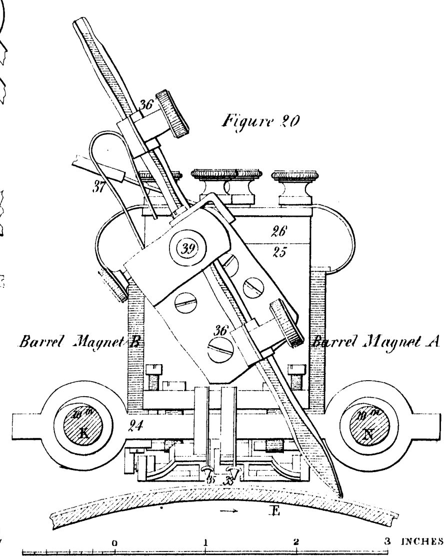


Figure 19

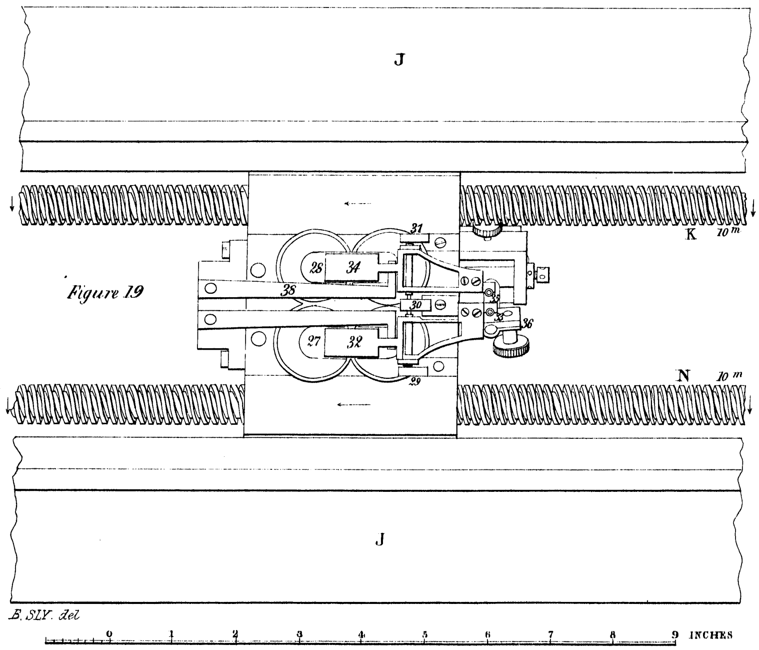
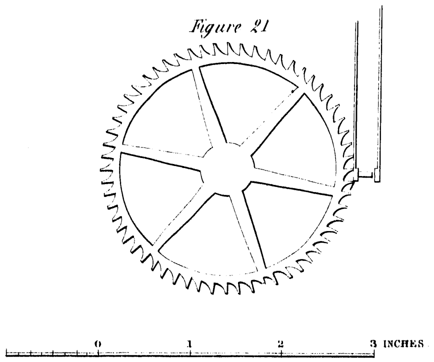


Figure 21



E. SLY. del.

Day & Son Lith^{rs} to the Queen.