



XXV. On instruments for measuring and recording earthquake-motions

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In a paper by Captain Abney and Colonel Festing, recently read before the Physical Society and printed in the *Philosophical Magazine* for June, on the Transmission of Radiation through Ebonite, reference is made to our original experiments; and the authors say that, judging from the figure accompanying our Note, they should think that the thickness of the ebonite prism traversed by the intermittent beam must have been about one fourth of an inch. We are afraid that that figure is liable to give this misconception; in drawing it we were merely paying attention to the directions of the incident and refracted beam, and not to the actual thickness of the ebonite, which was in fact very small indeed where the intermittent beam passed through it.

XXV. *On Instruments for Measuring and Recording Earthquake-Motions.* By THOMAS GRAY, B.Sc., F.R.S.E.*

[Plate III.]

I. *Rolling-Sphere Seismograph.*

THE instrument which I have called a rolling-sphere seismograph will be readily understood from the accompanying sectional drawing (fig. 1). A sphere of lead, iron, or any other heavy substance rests on a flat plate, B, made truly plane and furnished with three levelling-screws, L. An arm, A, fixed to the base, B, is so formed that a circular ring fixed to its end is held in a horizontal position with its centre vertically above the highest point of the sphere. This ring carries a species of spring universal joint, consisting of four very light bent springs, *j*, arranged at right angles to one another and meeting in a small round disk, *b*, at the centre. The lower end of the lever, *l*, passes through this ring *b*, and is fixed to it at such a point that its lower end, which is rounded, just fits a small hole in the top of the sphere S. Between S and *b* a small sphere, *s*, is fixed to the lever *l*, and is so proportioned that the lever *l*, when pushed at *b*, tends to rotate around a point a little above its lower end, thus diminishing the push on the sphere S. The springs *j* serve to allow the lever *l* to turn in any direction, and are made so light that they can only make the ball roll with a very long period. When thus proportioned they serve the purpose of a universal joint, and at the same time give a little stability to the parts, thus preventing the plate P, if it be put in motion, from causing the ball to roll over. The lever *l* is a rod of bamboo which is at the same time

* Communicated by the Author.

very light and rigid; at the upper end the rod is flattened and hinged just above the bend by a piece of tough Japanese paper glued to its upper side. This gives a very light, flexible, and sufficiently strong hinge. The plate P may be in a plane which, by proper starting-apparatus, will be set in motion at the beginning of an earthquake, or it may be taken as part of a roller or of a circular plate kept continuously in motion by proper mechanism.

This instrument possesses the advantage of being compact, of writing the actual motion, and of being capable of recording with approximate accuracy earthquakes of much greater magnitude than can be recorded by most of the instruments in ordinary use.

The multiplication given by an instrument of the sort may be determined experimentally; or it may be approximately calculated by taking a point O at a height equal to seven fifths of the radius of the large sphere S as nearly steady. In a locality where the motion of the ground is considerable, the lever l must of course be made to give little, or perhaps no multiplication.

In several instruments of this class which have been constructed for the observation of earthquakes in Japan, a segment only of the sphere S has been used, with an independent mass placed on a pivot at the centre of oscillation (arranged in this case to be above the centre of the sphere), and of such magnitude as to make the equilibrium nearly neutral. This method of construction allows the radius of the sphere to be much increased; but it introduces a difficulty of adjustment, a complication of parts, and generally a slight want of symmetry, which causes a little uncertainty in the interpretation of the records.

The static records* given by this machine are very interesting. These are simply enlarged representations of the motion of the earth; and are in many cases very curious, having generally a resemblance to the curves obtained when two harmonic motions, not in the same direction, are combined.

II. *Rolling-Cylinder Seismograph.*

In this instrument (fig. 2) a pair of hollow cylinders, C, C', made perfectly equal in thickness and in length by turning in a lathe, are placed, with their axes horizontal and mutually at right angles, on a smooth plane plate, P, furnished with levelling-screws, S. An arm, A, fixed to the plane, and therefore forced to move with it, passes over the top of one of the cylinders,

* That is, the records taken with the plate on which the motions are recorded at rest relatively to the earth.

and carries two recording-levers, l , l' . The lever l is pivoted at p and p' ; and its action can be readily understood from the figure. The lever l' is crank-shaped, and is hinged to a cross piece b , fixed to the front of the cylinder C' and to the arm A at p . This cross piece rotates as the cylinder rotates; and by properly adjusting its length and the ratio of the arms of the lever l , the multiplication can be made the same as for l . A drum carrying smoked paper (shown at D), or a circular glass plate, may be revolved in front of the plate, and hence a record of the different movements of the earth obtained.

In this instrument the principle of neutral equilibrium can be carried out to great perfection, as cylinders can be made with great accuracy. It seems probable, from the preliminary trials that have been made, that this arrangement may be improved by allowing a smaller cylinder to roll freely inside the large one. The advantage of this is the stability it gives, and the quickness with which the cylinder comes to rest in its new position after any motion.

An interesting modification of this machine might be made by placing two equal cylinders on a horizontal plate with their axes parallel, and placing on them a second horizontal plate so that its upper surface should always be in a plane through their instantaneous axes. This could be done by causing the plate to rest by means of arms on two pairs of smaller cylinders of proper dimensions, so disposed that each of the larger cylinders should bear at each end one of the smaller cylinders coaxial with the larger cylinder and projecting from it. A third cylinder placed on the upper plate with its axis at right angles to those of the first two would, for small motions of the earth, have a line in itself which would remain approximately at rest. Hence by proper registering-apparatus, perhaps similar to that adopted for my rolling-sphere seismograph, a record of the motion of the earth might be obtained.

The instrument is shown in the diagram as arranged for the registration of small motions; but it is easy to modify this arrangement so as to provide for the registration of motions ranging in amplitude from a fraction of a millimetre to several feet. All that is necessary is to arrange that, for very large motions, the multiplying-lever shall go out of action, allowing a direct-record arrangement to take its place. A very simple method of writing large motions would be to attach a fine point to the end of the cylinder at its centre, and allow this point to write on a plate placed in front of it and fixed to the base-plate P . For countries where the earthquake-motion is measured in centimetres instead of in millimetres, as is the case in Japan, an instrument of this form might prove of great

value, while by the arrangement shown in the figure it can be made to write any motion of sufficient magnitude to be appreciated.

The point p' is, of course, placed in the instantaneous axis, of which the position is easily found in the case of this instrument. Let h be the height of the instantaneous axis above the plate P , R the external radius, and r the internal radius of the cylinder, then

$$h = \frac{3R^2 + r^2}{2R},$$

from which it is easy to see that, in the case of a thin cylinder, the instantaneous axis is nearly on the inner surface of the cylinder. In the case of the instrument actually constructed, $R=8$ and $r=7$, and therefore

$$h = \frac{192 + 49}{16} = 15.06 \text{ nearly.}$$

III. *Pendulum Seismograph.*

About a year ago (Jan. 1880) I began to make experiments on horizontal levers pivoted at one end and loaded at the other, with the view of obtaining a body in approximately neutral equilibrium, which by its inertia would give a means of recording the motions of the earth during an earthquake. The levers which I used were about 30 centimetres long between the load and the pivots; and the load was generally about 5 kilogrammes. This mass remained steady even when an oscillatory motion of two or three centimetres was given to the pivoted end of the lever, if that motion was at right angles to the length of the lever. When the motion was oblique, however, there was a tendency for the mass to change its position, probably due to the direct impulses given to it not quite neutralizing each other. This change of position is not of vital importance if the successive motions be recorded on a moving plate; but as I was not at that time inclined to use clockwork in connexion with the machine, and it formed a great objection when a static record was used, I did not go further in the matter. The experimental machine, however, proved an excellent instrument for class-room illustrations of inertia; and as such I have since used it in my lectures on that subject. It is, of course, easy to give an arrangement of this kind sufficient stability to prevent permanent displacement; but when so arranged it has little, if any, advantage over an ordinary pendulum, and has some marked disadvantages.

I came to the conclusion at that time that the ordinary ver-

tical pendulum is the most convenient, and probably the most accurate, instrument for static records of earthquakes; and a machine, based on the pendulum principle, was described by me before the Seismological Society of Japan in March 1880; and a description with drawing is given in the 'Proceedings.' A description of that machine, and of some improvements I have since made in it, forms the subject of this part of my paper.

The machine consisted of an ordinary simple pendulum about 3 feet in length, the bob of which was of considerable mass. From the centre of inertia of the bob three threads radiated, and were attached to three light pulleys arranged at equal distances apart on the circumference of a horizontal circle having its centre at the centre of the bob. To these pulleys very light indices were attached, the points of which turned above graduated arcs, and showed the motion of the earth magnified twenty-five times. The three components were taken for the purpose of showing without ambiguity the direction of the motion, if it had a definite direction, and of giving information as to whether there was a multiplicity of directions of motion. This machine was of course only capable, under the most favourable circumstances, of giving the amplitude of the greatest motion, this being indicated by the permanent displacement of the pulleys and indices.

The improvements on this machine, to which I now call attention, are, first, a method of rendering the pendulum dead-beat, and, second, a modification of the mode of fixing the pointers to the pulleys.

A well-known objection to pendulum machines is their tendency to acquire a swinging motion during the earthquake, this of course causing their indications of extent of motion to be untrustworthy*. I have found, after a considerable number of trials, that this objection can be almost wholly overcome by a very simple process. Let a rod be adjusted in such a way that it can slide freely in a vertical direction through holes in two plates, one above and the other below the centre of the bob, but as near to its centre as possible. Load this rod until, with its sharp point touching a glass plate, it offers sufficient friction to bring the pendulum to rest after one half-swing, when the initial displacement is about that of the largest earthquake likely to occur. A load of 30 grammes will be found sufficient in Japan for a 3-foot pendulum; the bob of which weighs 10 kilogrammes. With this simple addition to the pendulum its swinging will be almost wholly avoided, and

* See Professors Ayrton and Perry's paper, "On a Neglected Principle in Earthquake Measurements," *Phil. Mag.* Aug. 1879.

the amplitude-indications rendered nearly absolute. It may be objected that this friction will cause the amplitude for each individual motion to be shown too small. But I find on trial that the permanent displacement which this is capable of producing is almost inappreciable, and that the displacement due to a motion of the glass plate backwards and forwards at a period nearly corresponding with the period of the pendulum is not very great, even if two or three times repeated.

The improvement in the mode of attaching the pointers was called for by the fact that, even with the lightest pointers which could be conveniently made, the rotational energy imparted to them by the shock made them swing too far round. This I got over by hanging the pointers by a bifilar suspension from the lower side of the pulleys. When the pulleys and pointers are so arranged, the pull on the pendulum can be made almost infinitesimal; and yet, since the indices are not forced to move with the pulley, but rather tend to check its motion, the indications are very nearly accurate.

I may remark that the indications of these machines, a considerable number of which have been in use for some time, tend to show that there is no definite direction of movement, or, in other words, that the successive impulses contain vibrations in different azimuths. No doubt much of this is due to the existence of direct and transverse vibrations, such as we may expect from the theory of vibrations in elastic solids.

Besides exercising a controlling power on the pendulum, the friction-point can be made to describe very interesting curves on the glass plate if it be previously smoked. These curves in some of the larger earthquakes have indicated a very complicated motion of the earth.

IV. *Double-Lever Seismograph**.

In the course of my experiments on the horizontal-lever arrangement, I was informed by Prof. Milne, to whom I had shown my experiments, that a very similar arrangement had

* This paper is for the most part extracted from an account of a seismograph constructed on the principle described, which was communicated to the Seismological Society of Japan at its meeting on January 26, 1881. The only differences between the instrument here described and that figured in the 'Transactions' of the Society, are some variations in size and in details of construction which have been suggested by experience. The instrument there described was made very small, the horizontal levers and frame carrying them being all surrounded by the ring R, which had in that case an internal diameter of about 12 centimetres. It was found inconveniently compact, and was besides difficult to construct accurately. As the instrument now described is almost wholly of wood, its first cost is very small.

been for some time used by Prof. Chaplin at the Tokio University. I have since heard from Prof. Chaplin that he obtained the idea from a Zöllner's pendulum. Prof. Chaplin was no doubt the first in this country, perhaps the first anywhere, who applied this certainly valuable arrangement to the measurement of earthquake-motion. While talking over my experiments, Mr. Milne expressed a strong desire to have a direct record of the earthquake from some such arrangement; but a suitable mode of obtaining it did not then suggest itself. Since that time, however, it has occurred to me that two levers hinged together will not only give this arrangement, but will avoid at the same time one very serious source of disturbance, namely the shock which the mass receives in consequence of the direction of motion not being at right angles to the direction of the lever. Acting on this idea, I made a sketch of the arrangement described in this paper, and showed it to Mr. Milne, who at once offered to give the instrument a trial if I did not care to do so. In consequence of this, one of these instruments has been in course of construction for some time, but unfortunately has not yet (March 23) been finished sufficiently for exhibition to the Society.

The principle and form of this machine will be readily understood by reference to fig. 3. A post, P, resembling in all respects a light gate-post, is fixed firmly in the ground; and to it a species of gate, A, is hinged in a manner almost identical in form with that usually adopted. The hinge, H, is capable of being moved backwards and forwards, its position being regulated by the nut, N, and from side to side, its position in that direction being regulated by two screws, s, put in from opposite sides of the post. These adjustments are all that are necessary, after the instrument is properly constructed, to allow neutral equilibrium to be obtained. The lower pivot H rests against the bottom of a conical hole cut in such a way that the pressure will be along the axis of the cone. The upper hinge H is a knife-edge resting against the side of a round hole. The hinges H', H' are exactly similar in construction to H, H.

The gate A is 15 centim. long. and 60 centim. high; the central piece is a round bamboo tube of about 4 centim. diameter, and the cross pieces hard wood firmly fixed to the central piece. By adopting a symmetrical form like the above, the proper positions of the hinges H, H' are readily calculated, while the tubular form of the vertical piece gives great torsional rigidity with small weight. The front gate, B, is similar in form but in every way lighter, as it does not require to withstand a twisting force such as acts on A. The lower half

of B is slightly different, a light bracket being introduced for the purpose of raising the ring R, and allowing room for the registering-lever. The ring R is pivoted so that it can turn round a vertical axis, thus rendering more definite the point which remains steady. A stiff bar, *b*, fixed to the post P at one end, carries the universal joint in which the writing-lever, *l*, turns. This universal joint consists of four very light bent springs, fixed at the lower end to a round ring, and at the upper end to a small disk through which the lever *l* passes, and to which it is soldered. The four springs are arranged at right angles to each other, and offer a slight elastic resistance to the rotation of the lever *l*, and consequently of B and A. This resistance is made so small that the period of oscillation of B is very long. The reason for using this peculiar form of joint is to prevent a gradual displacement of R by the top of *l* when the plate on which *l* writes is kept moving by clockwork. The static friction, even with the precaution taken in this machine, will probably be much greater than the pressure of *l*; but a slight motion might take place during the shaking. The ideas of calculating the positions of H and H' are taken from Prof. Ewing's paper "On an Astatic Horizontal-Lever Seismograph," communicated at last meeting to this Society, or rather from a conversation which I had with him previous to the reading of that paper. I have generally been in the habit of finding approximately the steady part by experiment; and in many cases this is almost the only satisfactory method*.

In using this instrument, the two gates A and B are adjusted so that their planes are accurately at right angles to each other, each inclined at an angle of 45° to the front of the post P. The gates are so made that when in this position the lever *l* is vertical. At the lower end of the lever *l* a thin sewing-needle, *n*, slides up and down through two small loops. Under this needle the plate *p*, smoked to receive the record, is placed. If it is desired to separate the different motions, *p* must be moved by clockwork.

V. On a *Conical-Pendulum Seismograph*.

In a paper on "Steady Points for Seismographs," communicated to the Seismological Society of Japan in March 1881,

* In the small instrument which I described before the Seismological Society, the levers were so light and small compared with the ring R that no determination of the exact proper positions of the axes were made. That instrument promises to act very fairly as a seismograph; but I expect the instrument just described to act better, because of smaller friction, due to great height, finer and more scientifically arranged hinges, and greater length of arm.

I suggested that a conical pendulum would probably be found a good arrangement for registering one component of the motion of the earth during an earthquake. Since that time an instrument on this principle has been made; and as it has been found to be very suitable for this purpose, a short description of it may be interesting.

The instrument is shown in plan and elevation in fig. 4. In that drawing P is a post which is intended to be fixed firmly in the ground, and may project above it from a foot to a foot and a half. W, W are weights fixed to the ends of the cross bars b, b , each pair forming the bob of a conical pendulum. The suspending wires, t, t , of these pendulums are attached to cross pieces, c, c , slotted and made to slide under clamping-screws, s, s . By sliding the cross pieces c, c backwards and forwards and turning them round to one side or other, the point of suspension can be adjusted until it is vertically above the point p at which the small cross arm a rests. This cross arm a serves the double purpose of causing the bob of the pendulum to move in a circle, if it moves at all, and of forming the short arm of the lever l , which is used for writing a component of the motion of the earth. When the pendulum is adjusted in the way just described the bob is evidently in neutral equilibrium in any position; and hence any error due to oscillatory motion is avoided. Since, however, it is desirable that the instrument should have a small amount of stability, it may be made to have a long period of oscillation round a definite point by adjusting the point of suspension a little forward, or by fixing the top of the suspending wire and allowing its torsional rigidity to control the motion of the bob.

The only points where friction acts in this machine are p, p' ; and since the pressure on these points is small, they can be made very fine and almost frictionless. In this respect the conical-pendulum machine has a decided advantage over most other machines of a similar nature, such as hinged-horizontal-lever machines. The levers l, l are arranged so that they come out at an angle of 45° to the direction of the component they are intended to measure, and parallel to each other. This arrangement is adopted for the purpose of getting the record of the two rectangular components side by side. When the record is made in this way, the direction of motion of the earth can be much more easily determined than if they were recorded at different points of the same drum or revolving plate. The question of change of phase-relation between the two components can also be much more easily investigated with this arrangement. Another advantage which this apparatus possesses, is the very small mass required for the moving parts,

and the very great mass which can be put into the weights W without increasing the friction, the only change required being that the wire t should be lengthened. The question of massiveness in the portion whose inertia gives the writing-power is important, as the multiplication which can be used is practically proportional to this mass. Very large multiplication is not generally necessary for earthquakes of ordinary magnitude; but there is a large class of tremors which have a great interest to investigators; and these may be recorded by giving a multiplication of, say, from twenty to fifty, according to the degree of minuteness aimed at. Of a considerable number of machines which I have devised and tried, I think this is decidedly the most sensitive; and it is probably the most sensitive and at the same time accurate recording-instrument now in use.

It is of course to be understood that, in connexion with this seismograph, some form of clockwork arrangement must be used for the purpose of supplying a moving surface on which the different motions of the pointers are to be recorded. When such an arrangement is adopted, the horizontal amplitude and direction and the period of each individual motion are recorded, the period of course being reckoned from the rate at which the drum is moved by the clock. The records are most convenient for use when taken on smoked glass or transparent smooth paper, because in that case, by simply varnishing the plate or paper sheet, the record can be preserved and used as a negative for obtaining photographs.

VI. *Hydrometer Vertical-Motion Seismograph.*

Some time ago I made several attempts to obtain an instrument capable of recording the vertical movements in an earthquake shock. I propose in the present paper to describe two of the most successful of these attempts.

My first attempt in this direction was suggested to me by observing the motion of a Nicholson's hydrometer when immersed in a liquid and slightly displaced from its equilibrium position. The period of up-and-down oscillation of such an instrument can, by varying the thickness of the stem, be made almost any length desired. I therefore proposed to use an enlarged hydrometer, with the lower basket removed and ballast placed in the bottom of the hollow foot. For the sake of ease of regulation I attach the upper end, by means of a thread, to a pulley through the centre of which, at right angles to its plane, a wire has been passed and then soldered. This wire is stretched between two springs, and can be twisted round its own axis, thus allowing the force of torsion to regu-

late the position of the float. An instrument of this kind was made for water as the floating medium, and gave results which justify the assumption that, by causing it to write on a moving plate, it is capable of giving valuable information as to the magnitude of the vertical movement. This instrument has, however, the disadvantage of being very large, and consequently inconvenient; and I propose therefore to use mercury instead of water. Fig. 5 indicates a form which may be adopted in such a case.

Referring to the figure, F is a varnished, or otherwise protected, lead float placed in a wood or iron vessel, V , filled with mercury. A fine wire is fixed to the lower end of the float, and, passing loosely through a hole in the plate p , serves to prevent the float from turning round. A weight, W , sufficient to completely submerge the float is applied to the stem above the surface of the mercury. To the upper end of the stem a wire or thread, W , is attached, which is passed through a small hole in the top of the vessel V , and then over the pulley l , to which the index, i , is attached. With this arrangement the period of vertical oscillation can be made very long; and consequently each individual motion of the earth can be recorded on a moving surface, such as a drum D , relatively to an undulating line due to the slow up-and-down movement of the float. By using the pulley l , the sensibility of the instrument is made constant for any position within the range of the motion.

VII. *Compensated Spring Astatic Seismograph for Vertical Motions.*

The following is a description of another instrument which I have contrived for registering vertical motions, and which seems well adapted for that purpose. A description of it, with some account of my experiments with various arrangements leading to the form adopted, was given at the meeting of the Seismological Society of Japan, on the 28th of April of this year. The instrument is shown in fig. 6, which is a section through the frame, and shows in elevation the acting parts of the apparatus. A vertical spring, S , is fixed at its upper end by means of a nut, n , which rests on the top of the frame F , and serves to raise or lower the spring through a short distance as a last adjustment for the position of the cross arm A . The arm A rests at one end on two sharp points, p , one resting in a conical hole and the other in a V-slot; it is supported at B by the spring S , and is weighted at C with a lead ring, R . Over a pin at the point C a stirrup of thread is placed which supports a small trough, t . The trough t is pivoted at a , nas

attached to it the index i (which is hinged by means of a strip of tough paper at h , and rests through a fine pin on the glass plate g), and is partly filled with mercury.

The reasons for this mode of suspension are :—First, the arm A , by allowing the spring to be held stretched by means of a lever and weight instead of by a weight directly applied, increases the period of free vertical oscillation of the spring and weight. For let ϕ = angle turned through by the arm A from its normal position at time t , e = consequent elongation of the spring, E = total normal elongation of the spring, l = length of long arm of lever A , l' = length of short arm of A , g = force of gravity in unit mass, T = period of vertical vibration, M the mass of the lead weight R ,—then, supposing ϕ small, the lever A very light, and the mass of R collected at its centre of inertia, and neglecting the influence of the trough &c., we have for the equation of motion,

$$\frac{d^2\phi}{dt^2} + \frac{g}{E} \frac{l'}{l} \phi = 0,$$

and therefore

$$T = 2\pi \sqrt{\frac{E}{g} \frac{l}{l'}}.$$

From this we see that the period increases as the square root of $\frac{l}{l'}$; and hence an advantage in length of period is gained by attaching the string as shown. A disadvantage, of course, is that a smaller mass (in the ratio of l' to l) is required to produce a given normal elongation of the spring than if the weight were applied directly.

Secondly, the mercury in the trough t acts as a compensator to prevent the ring R moving when the top of the spring is moved through a distance short compared with the distance between the pivots on the trough t . The action of this part is as follows:—When the plane carrying the spring S is raised and lowered, the point a rises and falls, but in consequence of the inertia and slow period of R the point C remains behind. In consequence of this the end of the trough t falls and rises relatively to a ; and the mercury, running backwards and forwards, puts more or less force on the point C , and hence tends to keep this point stationary.

If the length of the trough be x , the distance between the pivots y , and the width w , then for a rise of a through a distance h we have the centre of gravity of a prism of liquid of depth h moved from the centre of the trough to a point $\frac{x}{3}$ from

the end. This gives a displacement equal to $\frac{1}{6}x$, and therefore an increase of weight on C = $\frac{1}{6}\frac{x}{y}hw\delta$, where δ is the density of mercury in this case.

Now the increased elongation of the spring, c remaining stationary, is $\frac{l_1}{l}h$; therefore the increased force is

$$\frac{l_1}{l}h\frac{W}{E},$$

where W is the normal force on C. Hence we have

$$\frac{l_1}{l} \cdot \frac{W}{E} = \frac{1}{6}\frac{x}{y}w\delta$$

for an astatic arrangement. In this equation x , y , w , and δ may vary; but y is generally determined with reference to a convenient multiplication, and δ will generally be either the density of mercury or of a liquid whose density is approximately unity. Hence, x or w being decided on, the other is determinate.

The case in which the arm A is not used can evidently be got from the above by putting $\frac{l_1}{l} = 1$. This arrangement with a long spring is, no doubt, best when the vertical displacement is likely to be great. A round tube has an advantage over the rectangular form of trough t for small motions, as it can be arranged so as to render the system astatic when t is horizontal, but to acquire stability when slightly displaced. For large displacements, however, the rectangular form, when of suitable depth, is no doubt best.

Instruments of the class here described are not to be relied on for static records, owing to the ease with which a large displacement can be given to the lever. For such purposes an instrument with a somewhat short natural period, controlled by some kind of frictional resistance, acts best.

Before the above method of compensation suggested itself to me, I had attempted compensating by placing the axis B below the line joining p and c . This method has the disadvantage, that generally a mass, either that of the weight or the spring, has to receive a motion of translation in order that the point C may remain at the same height. There is also another disadvantage, namely that after a small displacement the equilibrium becomes unstable.

Several other methods have suggested themselves to me—such as allowing the ring R to roll backwards and forwards, on a properly proportioned axis, in a curve at the end of the

lever. This would produce compensation by lengthening the arm pc when the lever inclined downwards, and shortening it when it inclined upwards. Another method would be to attach one end of an independent string at the point B and the other end to a point p , so that, if the arm A was deflected, a couple would be introduced tending to keep it deflected. This method would have the advantage of ready adjustment, by means of a screw attached to the end of the compensating-spring. I do not consider any of these methods so nearly perfect or so simple as that which I have given prominence to in this paper; but the main object has been to call attention to the principle of compensation for such instruments.

XXVI. *The Microphonic Action of Selenium Cells.*

By Dr. JAMES MOSER*.

WHEN I began these researches on the Transformation of the Energy of Light into that of Sound by the Photophone, I held the opinion which is still common, that there are two kinds of photophones and three forms of light-rays. My experiments led me to the conclusion that there is only one way in which light acts photophonically. The effect of radiation on selenium-cells is, in fact, the same as that exerted on the majority of solid, liquid, and gaseous bodies used as non-electric photophonic receivers. Though rays may have different wave-lengths, all rays are the same in kind. There are not three kinds—heating, luminous, and chemical, but one and the same ray may have heating, chemical, and luminous effects.

In February last, when I began these experiments, I believed that the photophone could inform us as to the direct correlation between light and electricity. A current circulating around a beam of polarized light changes the plane of its vibration. Hence we are led to conjecture that there may exist further relations between light and electricity, and that, as the electric current or lines of magnetic force affect the beam, so, inversely, the beam may influence the electric current or the magnetic lines of force; and we may conjecture that such influence may manifest itself in the photophone.

I therefore tried to change the magnetic condition of an iron plate by light. I hoped, for instance, to get an electric current in the coil of the telephone at the moment when

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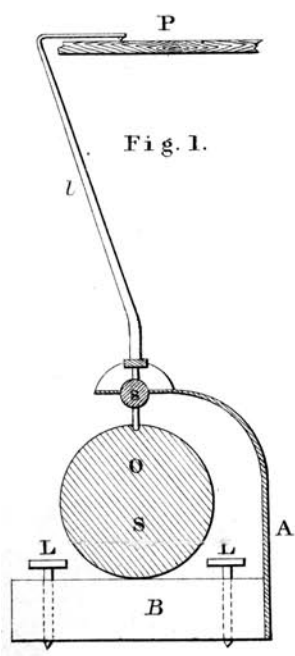


Fig. 1.

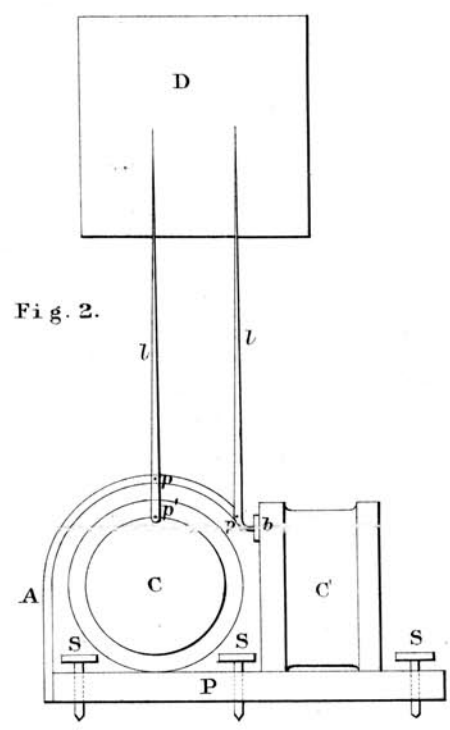


Fig. 2.

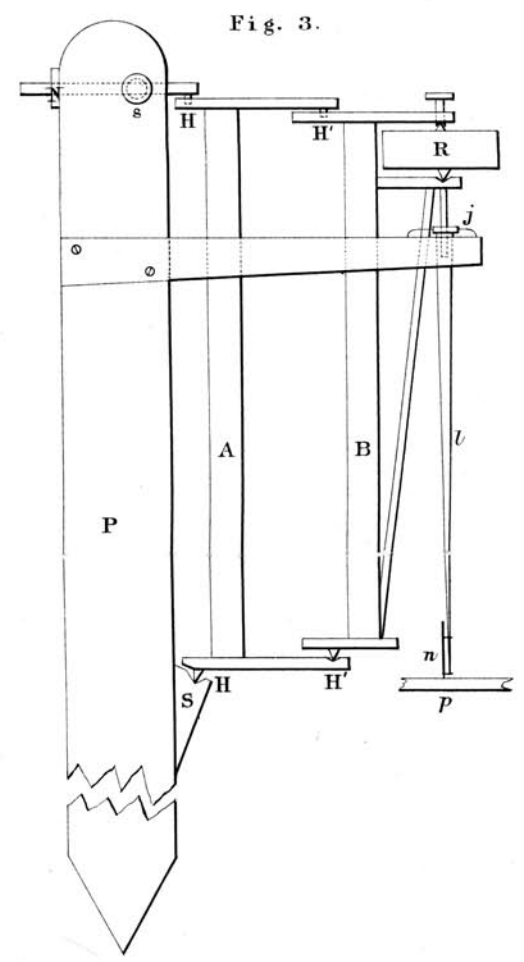
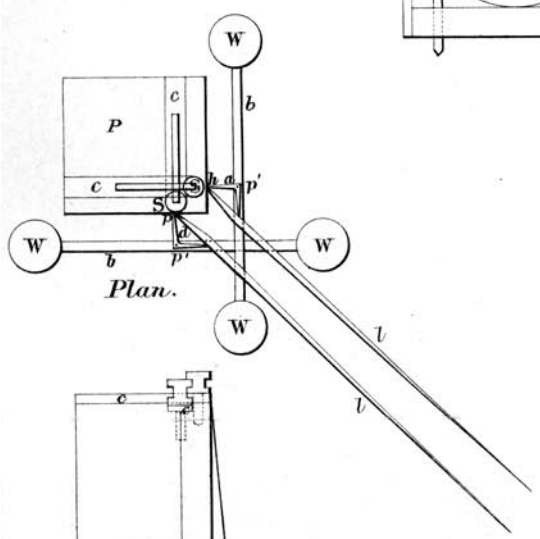
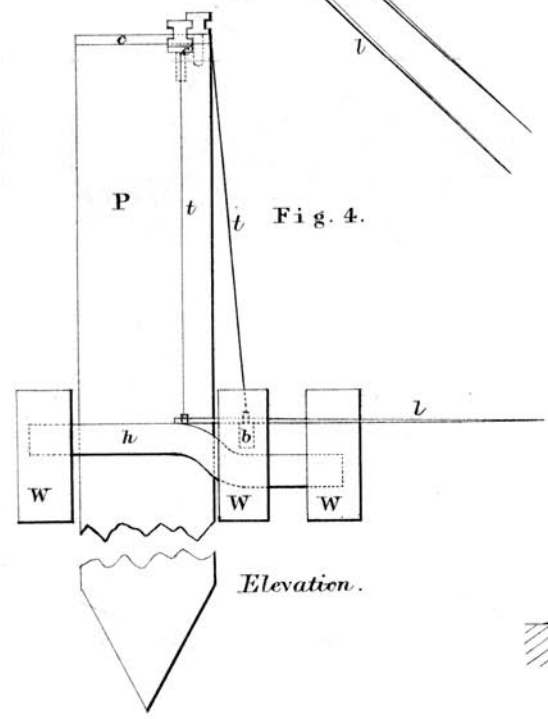


Fig. 3.



Plan.



Elevation.

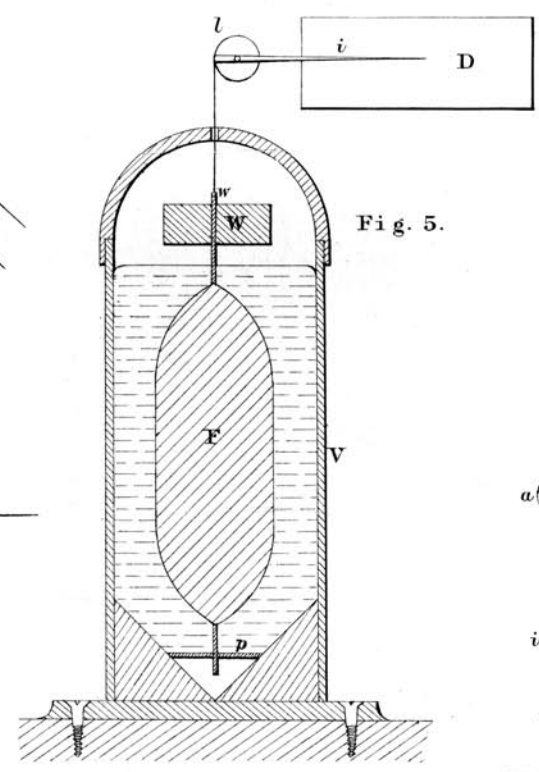


Fig. 5.

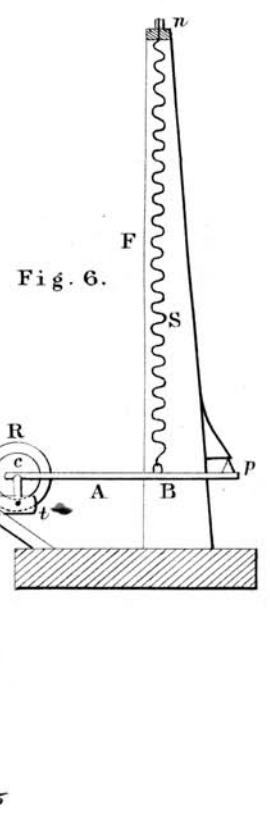


Fig. 6.