DESCRIPTION OF AN APPARATUS FOR RECORDING BY PHOTOGRAPHY THE MOTIONS OF HORIZONTAL PENDULUMS.

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For several years I have been engaged in making continuous observations of the changes of level with horizontal pendulums, the motions of which were recorded by photography. A good deal of technical experience has been gained during these experiments, which made me think that a more detailed description of some parts of the apparatus than I have as yet given, might be useful to those who wish to undertake researches of a similar kind, in order to spare them unnecessary trouble.

I.—THE HORIZONTAL PENDULUMS.—As I have given a detailed description of this part of the apparatus in former publications I may be short about it here. In order to avoid repetition I will repeat the old notation.

- T_0 the time of oscillation of the pendulum in a *vertical* position.
- T the same in a *horizontal* position, ready for observation.
- i the inclination of the axis of rotation to the vertical.
- $2d$ the distance between the two pivots, which form the support of the pendulum.

s the distance of the centre of gravity from the line of rotation.

g the radius of curvature of the pivots.

a the distance between the pendulum mirror and the photographic paper expressed in millimetres.

r the scale value, *i.e.* the angular value of change of level in a normal direction to the pendulum, which corresponds with a displacement of 1 millimetre of the light-point on the photographic sheet.

With these notations we have

$$\sin i = \frac{T_0^2}{T^2} \text{ and } r = \frac{1}{2a \sin 1''} \sin i.$$

The suspension which I used consists of very fine steel-points, placed vertically one above the other, of which the upper one points away from and the lower one towards the centre of gravity of the pendulum. This is the most suitable arrangement, because the pressure exercised by the weight of the pendulum on the steel-points is a normal one, and there is consequently no inclination to slip in the pendulum. The latter rests with an agate cup on the steel-point, and owing to its inclined position but small friction is produced during the oscillations apart from the ordinary friction of rolling motion—which causes the amplitude of the swing to diminish in a quicker ratio than it is known to do in the ordinary pendulum. But numerous experiments have shown that this friction is much too small to prevent the pendulum from taking up exactly the position corresponding to the momentary level.

The stand which carries the support of the steel-points consists of a flat strong iron dish of cylindrical form, with three projections to receive the foot screws. The latter, which I will denote by the letters *A*, *B*, *C*, are at a distance of 435 millimetres from each other, one revolution is equal to 0.36 mm. in length, and corresponds with a change of level of the stand of 197″.1. These screws, which are *very carefully* worked, easily allow a change of level of 1″ merely by a turn with the hand, which is of the *greatest importance for easy adjustment* of the instruments.

In order to assure the perfect stability of the heavy iron stand, I used to fix the circular discs on which the screws rest in conical shaped grooves, on the surface of the pillar, with plaster of Paris. But I have lately noted some disturbances at Strassburg, where the cellar is exposed to large variations of temperature, which probably arose from this cause. As it is necessary to avoid any kind of strain in whatever part of the instrument, it is probably better to let the instrument stand perfectly free on the pillar, in order that it may give way to the effects of temperature.

Between the screws A and B, which we call *adjusting* screws, whilst C is the *sensitising* screw, a circular hole is cut in the side of the cylindrical dish which receives the lens. This is an ordinary bi-convex lens of 75 millim. diameter and about 4.6 meters focal length. Opposite and quite close to it, inside the dish, is the support for the pendulum, which is screwed to the bottom of the dish and consists of a strong frame. The pivots or steel points are screwed into two small horizontal shafts, which turn with considerable friction round their own axis and thus allow the regulation of the inclination of the pivots. The vertical distance between the axis of the two shafts is 68 millim., and as the pivots project about 2½ millim., the distance $2d$ is very nearly 70 mm., s is 100 mm., and the weight of the pendulum 42 grammes.

The pendulum mirror is placed very near the axis of the pendulum on the opposite side of its centre of gravity, so that when the pendulum is seen through the lens only the mirror is visible. Below it and on the same plane is another mirror of the same size, which is fixed to the bottom of the standard, and can be rotated from outside by a lever and screw round a vertical and horizontal axis. Both mirrors together form a square inscribed in the aperture of the lens. Each is about 20 mm. in height and 40 mm. in length.

It remains to be said that on both sides of the pendulum a vertical rod is fixed in order to prevent too large excursions, which might injure the steel points. One of these rods is rather long and provided with a small horizontal knife edge, on which the pendulum is hung with a little hole. When it is thus suspended the knife edge agrees as nearly as possible with the axis of rotation in horizontal suspension, and the value of T_0 can be easily determined with sufficient accuracy.

The only difficulty which presented itself during the observations—as far as regards the pendulum alone—is caused by the *imperfect shape of the steel points.* Instead of being absolutely sharp points, they end in a curved surface, the radius of which, *g*, was several times examined with a microscope and generally found to be between 0.01 mm. and 0.02 mm. It appears that sharper points can easily be made by the instrument maker, but through the handling of the pendulum, when suspending it, and the pressure of the suspended pendulum, however small its weight may be, the sharpness of the point is nearly always destroyed. I believe that the preservation of very sharp points during the unavoidable process of suspending the pendulum, as long as steel is used, is a mere matter of chance.

In the case of absolutely sharp points, the axis of rotation of the pendulum coincides with the straight line joining the points. This line preserves its position in space—as long as there are no changes of level in the stand—even when the pendulum itself is caused by the small and nearly ever present vibrations of the soil to shift a little on the points. I have observed cases of distant earthquakes in which this shifting must have been quite considerable, as could be gathered from the displacement of the light point on the photographic sheet. Let *e* be the linear horizontal displacement of the line joining the points of contact between the steel-points and agate cups, counted in the plane vertical to the plane of the pendulum, then the angle w through which the pendulum moves is given by the equation

$$Agw = \frac{e}{s}$$

Let w' be the displacement of the light point in millimetres, then $w = \frac{w'}{2a \sin 1''}$. Thus in every case it is easy to find the the value of e. For instance, during the earthquake which happened in South-east Europe on the 8th of April, 1893, and was recorded by the hor. pendulum at Strassburg, w' was 13.5 mm., and 1 mm. being $= 56''$, w is $= 12'6$, $e = 0.37$ mm. This is perhaps the large displacement of the axis of rotation with regard to the pendulum that took place during the several long series of observations which I have made.

With such small displacements—and it is evident that the construction of the pendulum does not permit much larger ones to take place—it is easy to demonstrate that *the value of T is not influenced in any sensible degree by the shifting,* whether the points of contact with the agate cups move in the same or in opposite directions at the upper and lower suspension. Strictly, this conclusion only refers to the case of absolutely sharp points. But owing to the small range of oscillation with which we have to do in the present application of the hor. pendulum, we are justified in considering the blunt point as part of a sphere with the curvature g, and in this case the axis of rotation always passes through the céntre of this sphere and thus preserves an unaltered position in space.

If the shape of the blunt points is not so regular as supposed, theoretical conclusions show that a *real displacement* of the axis of rotation in space may be the effect of a shifting of the pendulum. In this case, the value of T is altered, and with it the scale value r. During my own observations, only *one* case happened in which a sudden change of T was distinctly noted, and this was probably during the earthquake which I mentioned above. The amount of change in T, however, was so considerable that it seemed quite impossible for me to attribute it to the shifting of the pendulum, however irregular the shape of the steel points may have been. I prefer to believe that it was caused by a sudden release of strain in the instrument, which had been exposed to a very great change of temperature, and took up its new state of equilibrium in consequence of the strong vibrations to which it was subjected during the earthquake.

The above remarks show that it is of importance to watch constantly the changes in T by making observations at regular intervals. Of course T is subjected to variations anyhow, because changes of level take place in the direction of the pendulum plane as well as in any other. But generally these changes are small enough—supposing a sufficient interval of time to have elapsed since the erection of the pillar to allow a mean value of r to be used for the reduction of a long series of observations. I believe that *one* determination of T once a month will nearly always be found sufficient. If two successive values are found to differ considerably from each other, and if there is no indication of a strong change of level during the interval, the mere aspect of the curves will probably always suffice to find the moment in which the disturbance took place. But from my own experience I have reason to believe that such an occurrence will be very rare.

Practical experience shows that in sensitising the instrument with the screw C, and with high values of the period of oscillation T, a point is soon reached when the pendulum becomes unstable. The value of one revolution of the screw being known, one will find that this point is reached some time *before* the axis of rotation coincides with the vertical. The degree of sensitiveness obtainable, which fluctuates with the value of T, is dependent on the angle $\frac{g}{a}$. If the points are very blunt, g is large, and it will be found impossible to make T larger than a certain value without destroying the equilibrium of the pendulum, however careful one may be in the use of the adjusting screws A and B. But if g is small, much larger values of T can be obtained without causing the above mentioned disturbance.

As it is impossible to increase the sharpness of the points beyond a certain limit, or to protect them entirely from the flattening effect of the pendulum's weight, it may for some purposes be useful to increase the distance $2d$, which is 70 mm. in the instruments used by myself. With this distance and a value of $T_0 = 0^s.4046$, T could be raised to $18.^s3$ without any great difficulty at Strassburg. Very nearly the same T, viz. $18^s.45$, were obtained by myself at Potsdam, but these high values could not be retained for the continuous record, owing to the very large motions of the pendulum. In fact, with $T = 18^s.45$, and a distance $a = 4220$ mm. as it was at Potsdam, 1 mm. displacement of the light point is only $0''.012$, thus a change of level of $1''$ would cause the light point to travel across half the breadth of the photographic sheet (20 mm.). It is evident that this is a sensitiveness more than sufficient for ordinary purposes. But for some investigations, like, for instance, the study of earth pulsations, or in case the instrument should be used for determining the density of the earth by deflections, it might be useful to attain a still higher degree of sensitiveness. I have shown that this is quite possible, even with the ordinary steel points, by making the distance $2d$ or the length of the axis of the pendulum sufficiently large.

Some remarks about the lenses and mirrors used will be added below.

II.—The Lamp and its Stand.—If the source of light is placed at a distance equal to the focal length of the lens, the reflected image is formed in the same plane, which is most convenient for regulating the apparatus. For all my experiments the lamp was close to the side of the photographic sheet, and both the slit and its image were at the same distance from the plane of observation. S (Fig. 1) is a strong iron stand

so-called "earth pulsations" are probably [illegible] in which a table *T* moves up and down and is clamped by the screw *a*. *C* is a spacious light-tight and sufficiently ventilated case, made of sheet iron, with a tube, *l*, on one side containing the vertical slit *s* of 20 mm. length, and a door on the other side. *C* is fastened on *T* by the screw *c c*. When *T* is clamped, the case *C* can still be moved a little by loosening these screws; *d* is a short tube, which surrounds *b*, and on which a long tube can be fitted in case it should be desirable to exclude the dispersed light emanating from the slit. (See the figure.)

During the first experiments, petroleum lamps with a flat burner were used, and the narrow edge of the wick was turned towards the slit. Precautions were taken that the flame should allways occupy the same spot with regard to the slit, because, owing to the great distance of the lens, a small displacement would easily produce a sensible loss of light in the image. I had two lamps which were changed every half day, and unless the old lamp had lost much of its intensity from burning 12 hours, no trace of the changing was visible on the curves. It is necessary to watch the new lamp for a few minutes after it has been placed in the box, because the flame soon rises higher under the effect of the high temperature. Although all precautions were taken, many difficulties arose from the lamps. This was especially the case when, during my observations at Teneriffe, I had to use oil of inferior quality. It happened several times that the lamp was found burning quite low, and in one or two cases soot had filled the glass tube and chimney, which caused the petroleum to boil.

All these difficulties were removed by the use of benzine instead of petroleum.* During nearly 1½ years' continuous observation at Strassburg no interruption of any kind has been caused by the lamps. The following is a description of a very simple form of lamp, which Prof. Kortazzi, who has been

* Which as I heard had been before used with good success by Dr. Eschenhagen at the Magnetical Observatory at Potsdam.

using it for nearly two years at Nicolaiew, was kind enough to give me:—On prend un réservoir (Fig. 2.) quelque flaron assez ferme, avec un bouchon de liége; par ce bouchon on fait passer un mince tube de verre avec la mèche; le diamètre intérieur du tube ne doit surpasser 1.5 mm. et son bout doit s'éléver à 2-3 cm. au dessus du bouchon, pour que celui-ci ne s'echauffe pas trop. Le bout de la mèche n'atteient pas le bout superieur du tube à 2-3 mm; en changeant cette distance on peut régler l'intensité de la flamme. Le long du bouchon *b* il faut faire une mince coupure *c*, un canal pour que l'air puisse entrer dans le reservoir. Il est bien entendu qu'en versant du benzine la lampe doit être éteinte et le reservoir et le bouchon ne doient être mouillées, autrement, en approchant l'allumette au tube, ils peuvent s'enflammer. Si le benzine est pur, la lampe peut servir 2-3 mois sans aucun nettoiement, après quoi on peut briser un morceau du tube (4-5 mm.) couperla partié bruhè déla mèche et en même temps faire sortir le tube un peu plus haut du bouchon pour avoir le flame à le hauteur exigeé."

In cases where two or more horizontal pendulums have to be observed at the same time, it will be necessary to use the light of the flame in several directions. If these lie close together, *one* slit is sufficient, with a suitable lens placed between the slit and the flame. Though the light of the simple flame has always proved to be sufficient to leave an impression on the photographic paper, even when the pendulum was swinging during an earthquake shock, it would be possible to gather more light on the pendulum mirror by applying a suitable combination of convex mirrors and lens inside the lamp case. Either such an arrangement or a stronger source of light would be necessary if the movements of the horizontal pendulum known as earth pulsations are to be recorded in detail on quickly moving paper.

III.—The Recording Apparatus (S. Fig. 3).—The general plan of this is shown in Fig. 3; *a* is a strong iron plate, which is placed on a little wooden table. It has two holes, *b* and *c*, which correspond with holes in the table-top and allows the string of the weight and the pendulum to pass; *d* is the case containing the clockwork; *e* is the dial-plate, which is visible through a circular opening of the wooden box *f*, which covers the whole apparatus and is held tight by the little blocks *g*, projecting from the ground plate; *h* is an horizontal slit of about 25cm. length and 4cm. height. A sort of frame surrounds the slit, on which a wooden tube can be fitted in the same way as on the lamp case. The box is blackened inside, and the lid can be taken off without moving the box itself. The winding of the clock-work is also done from outside; *i* is the cylinder of 20cm. length and 55cm. circumference. Its axis, which passes into the box of clockwork on one side, is held by the support *k* on the other. One revolution is completed in about 50 hours, 1 hour corresponding to a linear movement of very nearly 11mm. The cylinder is not absolutely fixed on its axis, but can be turned with considerable friction. This is a very convenient arrangement, for with it the change of paper can be made in a very short time without in the least disturbing the clock-work; *l* is a cylindrical lens of a little more than 20cm. length, 25mm. breadth, and 5 cm. focal distance. This lens, placed parallel to the surface of the paper in the same light as the axis of the cylinder and its support, is provided with the necessary corrections to give it the proper position.

Between the lens and the cylinder, but close to the surface of the latter, passes a wire, which is bent round the sides of it and is attached to the lever *n* on the side of the clockwork, whilst it is led round to the point *o* on the other side. This wire frame, which moves up and down round the line oo′o′, belongs to the arrangement for the automatic record of time; *p* is a little screen, which generally hangs a little below the light-point, but is lifted once every hour to cut off the light during an interval of 5m. I shall now describe this part of the instrument, which was designed by Mr. Wauschaff, the well-known instrument maker of Berlin. It will be remembered that two beams of light are reflected towards the photographic sheet, one from the mirror attached to the pendulum, the other from the fixed mirror below. The lens *l* compresses the images of the slit into two brilliant points of light, of which the fixed one can be brought to the edge of the cylinder by the aid of its corrections. The little screen *p* is then moved on the wire so as to occupy the same position.

Figs. 4 and 5 are sections normal and parallel to the axis of the cyclinder. *S* is a circular disc fitted on to the end of the shaft of the hour-wheel projecting from the clockwork and held by the screw *d*. On the side turned towards the cylinder, *S* carries two little knobs, *b* and *c*, the form and position of which is visible. Fig. 4, *a*, is a lever with its centre at *o* and connected with the wire frame *m* mentioned above. It is weighted on one side, and this weight would be sufficient to lift the lever, and with it the frame, until it meets with a resistance at *u*, if it were not pressed down by another weight *w*; *e* is a second lever placed below *a*, and *f* is a piece attached to it which projects upward and carries a little screw, the top of which rests on the lever and presses it down on to the support *w*. As shown in the figure by the two strong curved lines, two fine strips of steel (watch-spring) are attached by a set of screws to the levers *a* and *e*, which come into contact with the knobs *b* and *c* once during every revolution of the disc *S*. The process then is as follows:—When there is no contact *a* rests on *w*, and *e* on *a* by the screw at *f*, and the screen *b* is below the light point. The rotation of the disc *S*, which takes place in the direction of the arrow, first brings the knob *b* into contact with the steel-strip on *a*. By passing along *above* it, *b* prevents the lever *a* from rising when the weight of *e* is removed. This latter is the case as soon as the knob *c*, after touching the lower part of the lever *e*, gradually begins to lift it* as it moves along.

As soon as *b* reaches the end of the steel-strip, the lever *e* swings upward, and the light-point is cut off by the screen *p*. This lasts 5 minutes, when *b* passes off the lower strip, thus causing *e* to fall back and to draw *a* with it. Thus the beginning and end of the interruption are entirely instantaneous. The length of the strips and the position of the knobs are so chosen that it lasts exactly 5 minutes. By loosening the screw *d* and turning the disc *S*, the beginning of the interruption can be made to coincide with any desired point of the dial plate.

The supports for the two levers, as well as the screws *u*, *v*, *w*, are fixed on the outer side of the clockwork case. It is scarcely necessary to say that all the parts of the apparatus just described ought to be made as light as possible and carefully balanced.

Returning to the cylinder *i*, we have to describe the arrangement for clamping the paper which is shown in section in Fig. 3; *a a* are two long rods of brass, which run across the cylinder and can be turned round their own axis. When the little pins are pushed upwards, there is room between the rods and the cylinders, paper can be introduced and clamped, and, owing to the form of the rods, made to fit tightly to the surface of the cylinder. For the sake of an easy and quick changing of the paper it is of some importance that the sheets should be carefully cut to shape. A small ridge running across the cylinder between the two rods, against which one end of the sheet is pushed, would perhaps facilitate the laying on of the paper and prevent its taking the position of a spiral or not fitting tightly to the cylinder, which often causes a loss of time. These little details may appear trifling, but in work of this kind, where all manipulations have to be done half in the dark and must often be entrusted to subordinate assistance, every little convenience must be considered as a gain.

IV.—The Adjustment of the Instruments.—In all my ex-

* In the figure, *e* is already lifted and *b* is just about to slip off the strip to allow *e* to go upwards.

periments I was obliged to use recently constructed pillars for installing the horizontal pendulum. This should be avoided wherever it is possible, because it appears that such pillars, however small they may be, require a very long time for setting. At Strassburg, for instance, a bracket was fixed into the large pillar of the transit instrument in November, 1891, but I have reason to believe that even in the summer of 1893 it had not yet taken up its definite position with regard to the pillar. When possible, a single block or a combination of blocks without mortar or cement, should be used where there is no *old* brick-work foundation. For the lamp and recording apparatus, wooden tables are quite sufficient, precaution being taken to ensure their invariable position. When the focal distance of the lens for chemical rays is not exactly known, it must be determined beforehand by trial. For this purpose I used to widen the slit as much as possible and to take photographs of its reflected image at varying distances. From these the sharpest picture was chosen. If a and b are the distances of slit and image from the lens, we have the focal length $f = \frac{2\,a\,b}{a + b}$, and as a and b do not differ much from f, we have b-x as the distance at which the front-side of the cylinder has to be placed when $a+x$ is the distance of the slit.

When the pendulum is sensitized and the recording cylinder is in its proper place—when its front is normal to the mean direction of the rays of light—the cylindrical lens is first removed and the two images of the slit are brought to the same height on the middle of the cylinder by changing the height of the lamp-stand and using the corrections of the fixed mirror.

The period of oscillation can then be observed by noting the passages of the movable range through the fixed image. It is necessary to note the *amplitudes* of the swing by clamping a paper scale on to the cylinder, for I have found that T can be expressed by the formula $T + g\alpha$, in which α is the linear value of the amplitude. The correction ga is rather large, and may not be omitted when an exact determination of T is necessary, especially when the oscillations are large.

When the cylindrical lens is adjusted and the fixed light-point brought back to the edge of the cylinder and placed above the little screen, the instrument is ready for observation.

I have once been obliged to place the lamp and recording apparatus in a room which was used as a laboratory during the day, whilst the pendulum stood in an adjoining room separated from the first by a door with two openings. In this case a curtain was hung round the table carrying the recorder, and a wooden tube was laid to join the box and the door. The second opening of the door by which the light of the slit entered the neighbouring room was only sheltered by a screen from the light of the window. Although I often worked for hours in the laboratory by the light, whilst the instrument was working, the above precautions were quite sufficient to protect the paper from getting tinted, except in one or two cases, when light entered from below through the holes of the table plate. In a cellar I believe it is always possible, by using a simple curtain, to dispense with a dark room when the changing of paper is made at night. The careful regulation of the apparatus before the commencement of a long series of observations, especially with regard to the sharpness of the curves, and the working of the clockwork is also of great importance. When this is done, any intelligent servant can be brought to do all that is necessary to keep the instrument in good working order, excepting the regular determinations of T. The changing of lamps and paper require very little instruction. Some attention, however, is required not to let the light-point pass away from the cylinder when the deflections of the pendulum are large. In this case it has to be brought back to the middle of the paper by turning one of the adjusting screws. It would be an easy thing to lay a rod between the recording apparatus and the pendulum, and thus to effect the necessary corrections without approaching the pillar. An arrangement of this kind will be mentioned below.

The above remarks presented themselves to me, because to ensure an *uninterrupted series* of continuous observations, when not made under the auspices of an observatory, it is of greatest importance that they should not require the constant presence of a scientific observer. With the above apparatus the ordinary routine work can be entrusted to a trustworthy servant, *because the instrument itself exercises a constant control*, and this is a point of some importance, especially in the case, where the work is undertaken by a private person, who does not wish to be always bound.

V.—THE PAPER, ITS DEVELOPMENT, ETC.—The paper which I first used was from the English Manufactories of Morgan and Kidd, Kew Foot Road, Richmond. The price is 10/- per quire of 24 sheets, 20 cm.×55.5 cm. Later on I employed a paper manufactured by Dr. Stolze & Co., Charlottenburg, Westend, (near Berlin), Kirschen-allee 21, which though a little more expensive, is far more sensitive than Morgan and Kidds. In fact, the curves which Dr. Eschenhagen at the Magnetical Observatory at Potsdam has managed to get with this paper, leave nothing to desire. They are as dark and sharp as a line drawn by a fine pen. This paper bears the *mark F*, the sheets are only 19 cm. broad and the price is 0.55 mark (1 mark=1 sh.) per sheet. The finest details, such as earth pulsations, were never so well shown as on the photographs taken with this paper.

The treatment is exactly the same as that of dry plates, and it is unnecessary to say that ruby light must be employed during the development. The dishes required can be made of iron plate and covered with Japanese lacquer. They last a long time, but now and then the varnish must be renewed.

The sheets are first soaked in water and then placed in the dish with the developer. This is the ordinary iron developer (1 part iron solution with 5 parts solution of oxalate of potassium) *without any addition* of bromide of potassium) in which they are left until the curves are sufficiently black. Afterwards rinse the paper, and to avoid its colouring, place it for a few minutes in a water bath containing a few drops of sulphuric acid (1 : 1000). Fixing and washing is the same as with plates, but the paper ought to remain at least 10 min. in the fixing solution and must be carefully washed,† if not it soon takes a yellow colour. This, however, is not of much importance, because it does not affect the reading of the curves.

The developing process causes a shrinking of the paper. Dr. Eschenhagen told me that he had found it as much as 1°/₀ in some cases. This quantity can be easily determined by marking a distance, or better, by photographing a glass scale on the undeveloped paper and measuring it again after the developement. We did this once or twice at Strassburg without finding any appreciable difference.

The readings of the ordinates of the curves are taken with a glass scale, which consists of a long horizontal line at the lower edge‡ and 5 vertical lines in the middle of the plate, the distance of which was made equal to the average length of 1 hour (viz. = 11.04 mm.). These vertical lines are crossed by horizontal lines, for which I first had a distance of 5 mm. (because during the first trials the curves were rather broad) which I afterwards diminished to 2½ mm. When the curves are very fine (¼ of a millimetre broad) like those obtained by Dr. Eschenhagen at Potsdam, a scale of 1 mm. lines can be

† Before fixing, the paper must not be touched with anything that has been in contact with the hyposulphite, because this causes ugly stains. The old developer can be kept in a bottle and used again with an equal quantity of fresh developer.

‡ Dr. Eschenhagen recommends a double line between which the base line of the photograph is brought. Messrs. Reinfelder & Hertel. Tell me that the price of a silvered mirror of 4·5 metres focal length by 2½-3 mm. thickness and 40 mm. diameter, is 15 shillings.

taken instead, and I do not believe that even with such a small scale the readings of a certain point, where taken with sufficient care, and with the naked eye, would differ more than 0.1 mm.

Besides the vertical scale there is a scale on the base line with 1 div.=6 min. The accuracy of the time readings depends greatly on the sharpness of the light points. Both sides of the 6 mm. intervals ought to be perfectly alike, but I have not yet succeeded in attaining that. In the time readings, account has to be taken of the fact that the two light points are never exactly at the same height. The correction which is constant can be determined best by closing the slit of the lamp during a known interval of 5 min., which does not coincide with the automatic interruption.

VI.—The Mirror, Lenses, Prices, etc.—It is scarcely necessary to say that the mirrors ought to be of the *very best quality*. When they are silvered on the front side, which I believe to be an advantage, it is necessary that the glass or box covering the pendulums should be very nearly air-tight. It is therefore advisable to take the ordinary precautions‖ against such an effect, at the same time it is neccessary, in order to protect the silver from the effect of sulphur vapours, to add a piece of blotting paper soaked with Acetate of Lead. With these precautions a pair of mirrors silvered on the front face were used 15 months without interruption at Strassburg and without any loss of polish.

On the suggestion of Dr. Eschenhagen, I have made an experiment with *concave mirrors*. A single circular mirror of about 50mm. diameter was first ground and afterwards cut into two, and the part intended for the pendulum was ground down to the smallest possible thickness in order not to increase the weight of the pendulum. These mirrors gave very satisfactory results, but they have several disadvantages: (1) the two halves do not retain exactly the same focus, (2) it appears

‖ Calcium chloride or sulphuric acid are placed inside the case.

that the images of the light points, though very small, are not sufficiently regular, and (3) considering the very small size of the mirrors they could not be made with as large a focal distance, as I desired. I have reason to believe that the same results can be obtained by the ordinary plane mirror.

In an article entitled "Einige Bemerkungen zur Aufzeichnung der Variationen des Erdmagnetismus," by Dr. M. Eschenhagen at Potsdam (5. Meteorologische Zeitschrift, December, 1892,) the author proposes the use of a mirror with three rectangular faces which are inclined to each other at a small angle. This angle depends on the distance between the mirror and the photographic paper and is so chosen that when the light point reflected from the middle face is about to pass over the edge of the paper, either one or the other of the two reflected images passes on to it. The distance of the paper was 1.7 metres, and the angle between the faces 3°, whilst each had a size of 12×16 mm. Thus in recording the deflections of the needle an angle of 9° was covered. It is evident that some arrangement might be used for the horizontal pendulum, if in considering the average range of the oscillations and the larger distance between the paper and mirror is found sufficient. Anyhow, the application of such a triple mirror would considerably reduce the number of cases in which corrections to the pendulum itself are necessary.

From the same point of view, an idea which presented itself to me when thinking about the combination of two pendulums may appear of interest. For a complete study of the changes of level as well as of the small earthquakes, it is necessary to observe *two* instruments at right angles. By placing a large prism before one of the lenses and extending the diameter of the ray of light emanating from the slit by the help of a lens placed between the slit and flame, *one* lamp and *one* recording cylinder are sufficient to record the movements of both pendulums. But the following arrangements affords a greater advantage (Fig. 6.) :—Let P^1 and P^2 be two pendulums placed in the

N.S. and E.W. plane on the surface of a pillar, and let ordinary plain glasses, *g*, take the place of the lenses. At *c*, where the planes of the pendulums meet, a box is mounted containing three vertical mirrors inclined to each other at an angle of $22\frac{1}{2}°$ with a lense, *L*, before them. Through *L* the light enters from the slit, which is in the direction of S., and is reflected from the mirrors 1 and 2 towards the pendulum mirrors I. and II.; and back again on the same way, 3 is the fixed mirror, which serves as reference and for marking the time. Of course the mirrors must be so arranged that they do not interfere with each other. A tube on each side connects the mirror box with the pendulum glasses. The use of these mirrors affords the great advantage that by making them rotate it is possible *entirely to avoid touching the pendulum apparatus*, as long as the deflections are not inconveniently large. By attaching a gear with a long rod to the mirrors, the necessary corrections can be applied from a distance. To observe the constant *T* from time to time I have always found it sufficient to walk close to the side of the instrument, which immediately caused it to swing. In the above case an india rubber tube might be connected with the instrument, by which a fine air current is directed against the pendulum. The instruments used by myself were provided with such an arrangement, but I did not make any use of it during the records, because I feared it might cause a disturbance by producing aircurrents which would be prevented by inserting a valve close to the instrument.

The lenses used were ordinary achromatic lenses of 75 mill. diameter, and about 4.6 m. focal length. Dr. Eschenhagen thinks that the light points can be made considerably sharper by cutting off the outer rays with a circular screen, but this of course has not much meaning, when rectangular mirrors are used. The above named lenses as well as the long cylindrical lenses for the recording apparatus and the mirrors were all made by Reinfelder and Hertel (the well known optical firm of

Munich, Mitterer Strasse). Perhaps it will be useful to mention the prices. They are as follows:—

Circular lens, 75 mm. diam. about 4.6 m. focal length	£. 1.
Cylindrical lens 210 mm. long. 25 mm. broad 5 m. focal length*	£. 2.
Glasses with parallel plane surfaces, quiet perfect per square inch	£. — 6.s.
When used without optical arrangement	£. — 4.s.
With silvered surface, per square inch.........	£. — 1s. extra.

The price of one whole outfit, consisting of one horizontal pendulum (by Repsold †) one lamp, with stand and one recording apparatus (by Wanschaff) including the optical parts was very nearly £50.

The lamp does not require more than ¼ of litre of benzine per day, for which I paid 20 pf. at Strassburg. Thus with paper and chemicals, the cost of one day's record is sixpence. It would be useless to say anything about the sums required for the first installation of the instrument, because they entirely depend on the locality chosen for the observations as well as on other circumstances. But the above will be sufficient for a first estimate.

* The price of these lenses is rather high, because they required special preparations owing to their great length.

† I hear from Mr. Repsold that they have raised the price of the horizontal pendulums, which was £25 to £35.

Fig 1

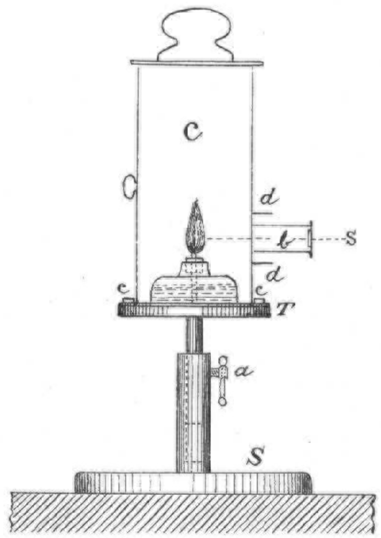
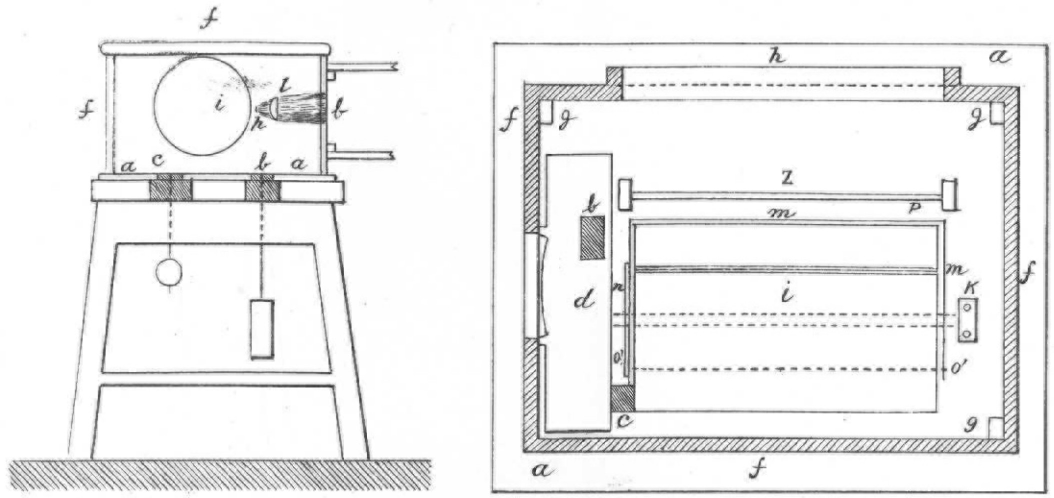


Fig 3



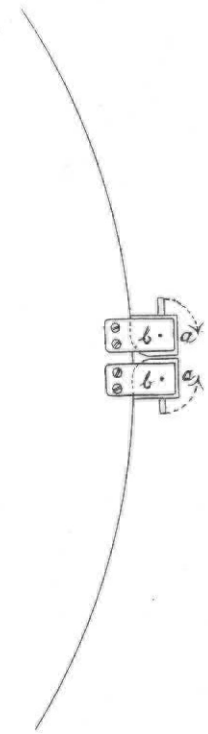


Fig 4

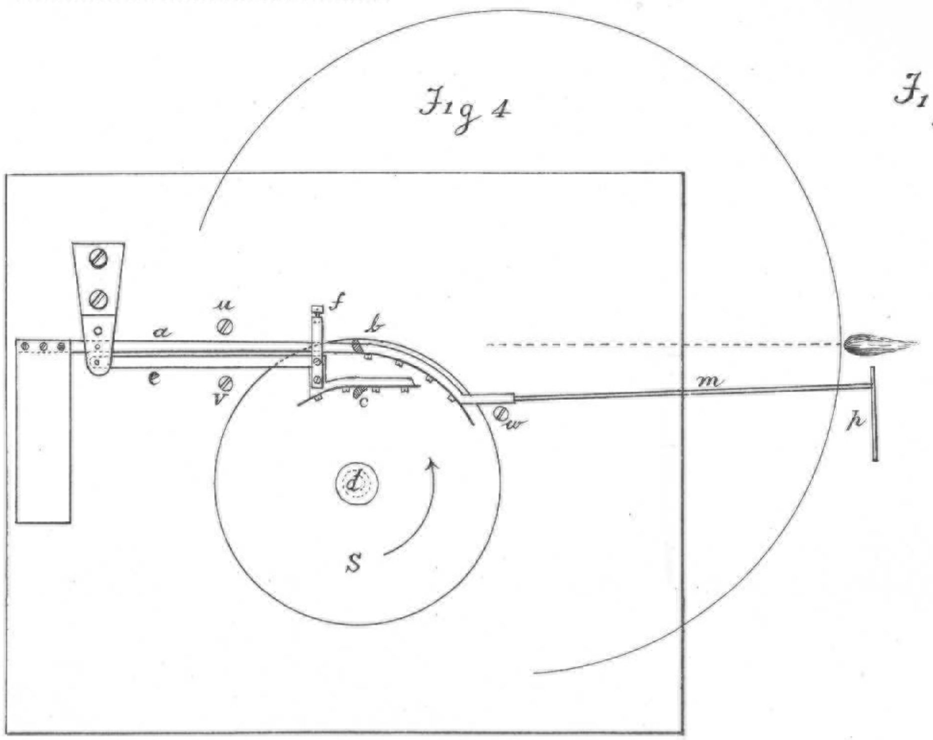


Fig 5

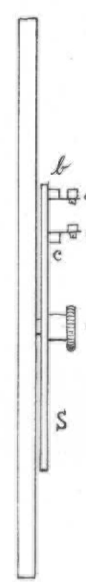


Fig 6