One cubic inch of water (as above) = grains $252{\cdot}286 \pm 0{\cdot}002$,

of which grains the imperial pound ($t = 62°$, $b = 30$ inches) contains 7,000.

IV. "On Wind Pressure upon an Inclined Surface." By W. H. Dines, B.A. Communicated by the Meteorological Council. Received June 12, 1890.

In accordance with a plan suggested in a memorandum drawn up by Professor Darwin, I have made the following experiments upon this subject, using for the purpose the large whirling machine of 56 feet diameter erected at Hersham.

The apparatus was made by Mr. Munro, and the general arrangement is shown in figs. 1, 2, and 3.

Fig. 1 gives a view as seen from the point towards which the pressure plate P is moving; fig. 2 as seen from the centre of the whirling machine; and fig. 3 as seen from a point vertically above it.

Fig. 1.

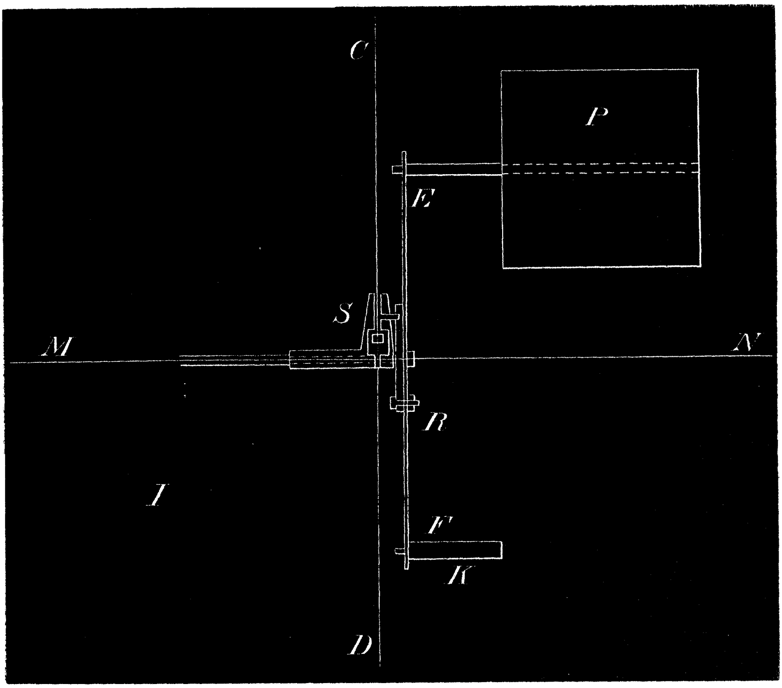


FIG. 2.

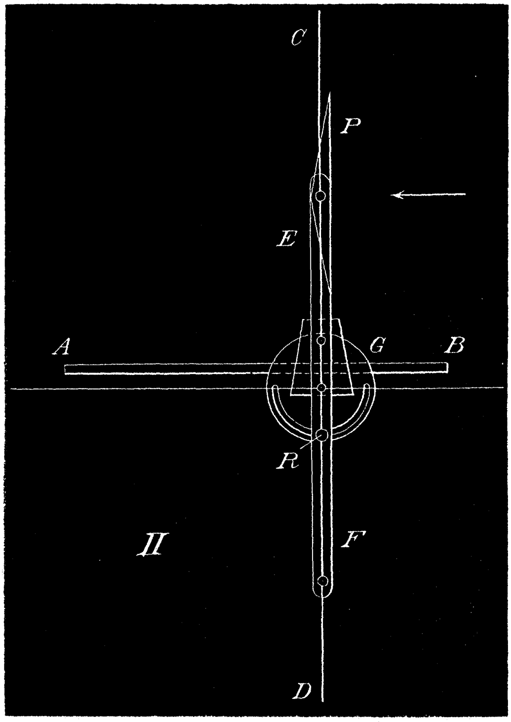
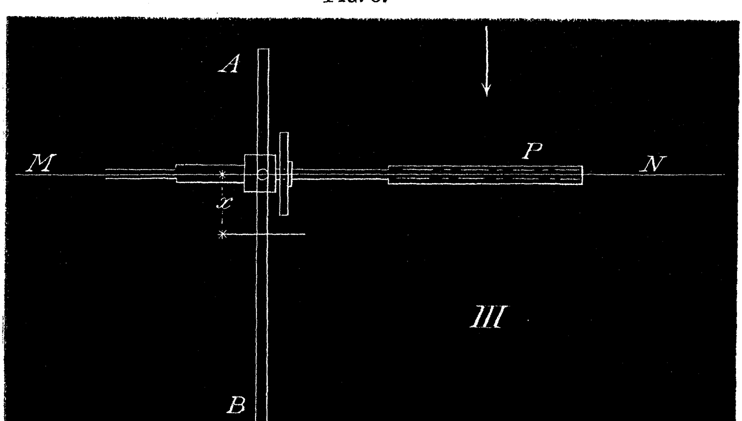


FIG. 3.



The moment due to the wind pressure is balanced by the moment of the centrifugal force due to the circular motion acting upon the bar AB. The axis MN, about which the pressure plate can turn, is coincident with the long arm of the whirling machine, and the axis of rotation CD of the bar AB is vertical, that is, parallel to the axis of the whirler, the bar itself being horizontal, and at right angles to the long arm. The moment due to the centrifugal force could be varied at pleasure by sliding the bar AB longitudinally through a slot, S, and thus altering the distance of its centre from its axis of rotation. The bar weighs 2 lbs., and is graduated in decimals of a foot; thus, if its centre of mass be placed at a distance x from its axis of rotation, the moment is $\frac{2v^2}{gr}x$ (ft. and lbs.).

This arrangement renders any determination of the velocity unnecessary during the experiments, since the wind pressure also varies as v^2, and therefore, as soon as x is known, the moment due to the wind pressure can be expressed in terms of v.

For reasons subsequently explained, it was found advisable to always work at about the same pace, and forty miles an hour was chosen as most convenient.

The pressure plate P of polished wood was 1 foot square, and, in order that the back might not present any irregular surface to the wind, it was made so that the section should be a very obtuse angled isosceles triangle, the altitude being $1\frac{1}{8}$ inches, and the supporting arm passing through the whole width of the solid wood. It was mounted with its centre 1 foot from its axis of rotation, and was balanced by a counterpoise weight, K, placed on the other side of the axis, the weight also making the arrangement symmetrical with regard to wind pressure.

The lever EF, on which the pressure plate was mounted, was clamped to a circular brass disc, G, with a graduated rim, the disc having its centre on the line MN, and being free to turn in its own plane about that line. The disc communicated its angular motion by a stud to the frame, through which the bar AB could slide, the frame and bar being pivoted, so that they could turn about the vertical axis CD, the motion being thus changed from a vertical to a horizontal plane. Of course, a stud being employed instead of a pair of bevelled wheels, a play of only a few degrees was possible. The lever EF could be clamped to the disc by a bolt and nut, R, in any position, and, since the motion was horizontal and the zero mark of the disc corresponded to a vertical position of the lever, the graduated disc afforded an easy method of giving to the angle of incidence of the air upon the face of the plate any desired value. The plate P, again, could be arranged so that the plane of its surface made any desired angle with the lever EF.

FIG. 4.

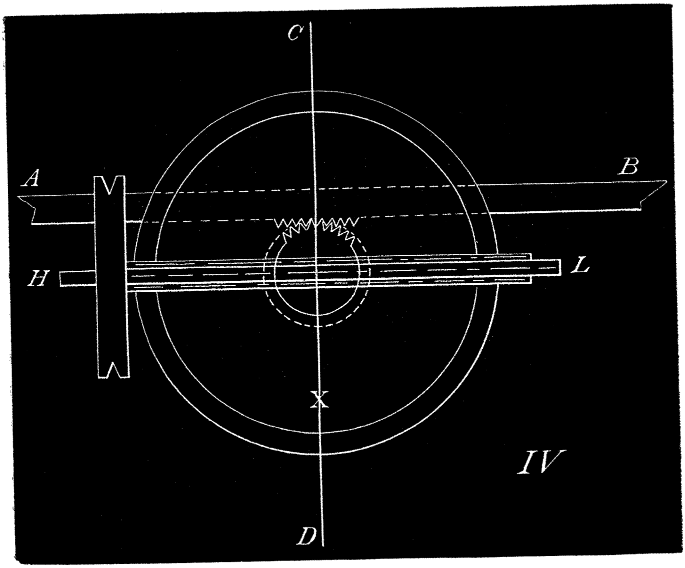
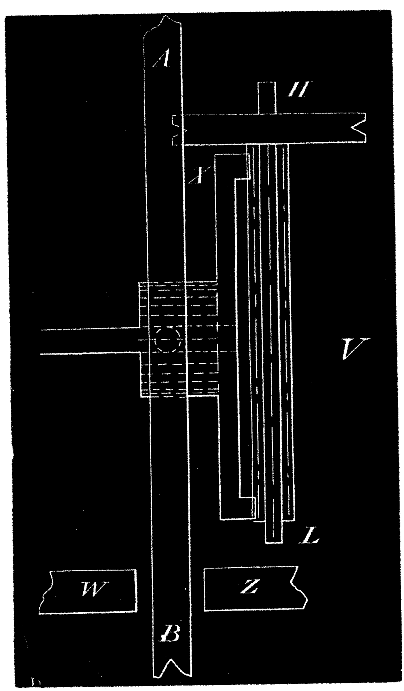


FIG. 5.



It remains to explain how the value of the moment corresponding to any position of the plate was measured. The bar AB was made to take up its position of equilibrium with the plate automatically, and the plan by which this was accomplished is shown in figs. 4 and 5.

The sliding bar AB had a rack cut on it, and the pivoted frame which carried it also carried a crown wheel, X, and pinion, the teeth of the pinion working into the rack cut on the bar. The fixed frame of the apparatus carried a long pinion and grooved pulley, HL. A band from a small windmill placed on the long arm caused this pulley to turn in one direction whenever possible.

The pinion LH was placed just in front of the crown wheel, and so near to it that when it was exactly parallel to the face of the crown wheel the teeth on both sides were engaged, and consequently the arrangement was locked, and no motion could take place, the driving band either slipping on the pulley, or the windmill ceasing to turn.

If, however, the frame carrying the crown wheel moved slightly round its axis CD, so as to bring the bar AB into contact with the stop Z, it is evident the teeth of the wheel on the side near H would become free from the pinion, and, the teeth on the side near L being more deeply engaged, the crown wheel would begin to turn, and would communicate a longitudinal motion to the bar AB, by means of the rack and pinion, causing it to move from B towards A. Contact with the stop W would cause the teeth on the side near H to become engaged, and consequently the wheel would turn in the other direction, and the bar move from A to B. Under these circumstances the bar takes up that position in which the moment due to the centrifugal force is exactly equal to the moment due to the wind pressure which it is required to measure; for that is the only position in which the bar can rest; any departure from the position of equilibrium being immediately followed by a readjustment of the position. Hence, to determine the wind pressure, it was only necessary to clamp the plate in position, to allow the steam engine to give a few turns to the whirling machine, to stop it, and then read off and enter the distance of the centre of mass of the bar from its axis of rotation.

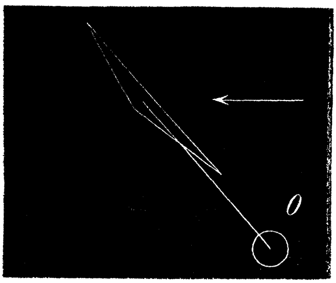
In practice two bars were used, one weighing 2 lbs., which could be placed in any position and clamped by hand; the other weighing $\frac{1}{4}$ lb., which, being worked by the automatic arrangement, made the final adjustment.

Both these bars were graduated in decimals of a foot, and the plan adopted was to enter the distance of the centre of mass of the 2-lb. bar from the axis of rotation first, and then to enter the distance of the small bar, prefixing a + or − sign, according as the two centres were on the same or opposite sides of the axis. Dividing the second entry by 8, since $\frac{1}{4}$ lb. is $\frac{1}{8}$ of 2 lbs., and then adding it algebraically

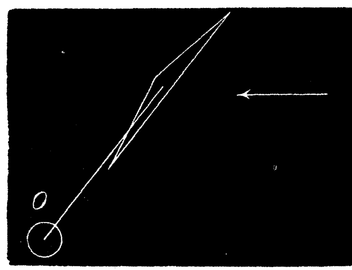
to the first entry, gave the distance from the axis at which a weight of 2 lbs. would cause equilibrium.

The change of the plane of the couple from the vertical to the horizontal was also accompanied by a change in the length of the arm of the couple in the ratio of 2 : 1, the apparatus being designed thus in order to reduce the weight of the sliding bar; and therefore the value of x, when found as above, had to be multiplied by 4, to give the distance in feet at which the centrifugal force acting upon 1 lb. would balance the pressure upon the plate.

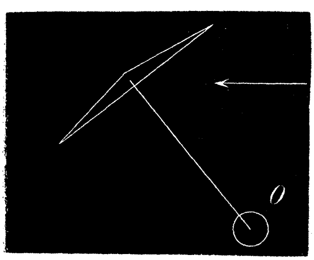
In the event of the small bar having run against its stops at either end, a fresh adjustment of the heavy bar had to be made by hand; but this seldom happened, except in the case of the first determination for a new position.



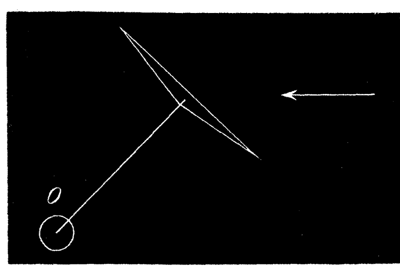
Position I.



Position II.



Position III.



Position IV.

The four typical positions are shown in the figures, and are referred to in the subsequent tables and remarks as Positions I, II, III, and IV. The following extract, taken from Professor Darwin's memorandum, shows how the normal component of the wind pressure and the position of the centre of pressure may be obtained:—

"It may be supposed that the couple, due to the wind pressure upon all the moving parts except the plate, may be eliminated, so

that the couple necessary to hold the plate in position alone remains to be determined.

"Consider the first and second positions of the plate or vane; since the wind meets the vanes at the same angles in both cases, the couples would be identical, if the centre of pressure were at the middle of the vane. But it is well known that the centre of pressure is nearer the forward edge, and hence the couples are unequal.

"If a be the distance from the centre of the plate to its axis of rotation, and if x be the unknown distance of the centre of pressure from the centre of the plate, and if P be the mean pressure estimated over the whole plate, and L_1 and L_2 the couples corresponding to the two positions, then it is clear that

$$\text{“}L_1 = P(a-x)\,;\ \ L_2 = P(a+x).$$

"from which we easily get

$$\text{“}P = \frac{1}{2a}\,(L_1+L_2),\ x = \frac{L_2-L_1}{L_2+L_1},$$

$$\text{“also } Px = \tfrac{1}{2}(L_2-L_1).$$

"Thus, this pair of experiments gives two of the things to be measured.

"Next consider the 3rd and 4th positions, where the experimental plate is clamped with its plane perpendicular to the arm, and where the inclination to the horizon is complementary to the angle of inclination in the 1st and 2nd positions.

"Suppose that T is the tangential force on the plate, and L_3 L_4 the couples in the two cases.

"Then it is clear that

$$\text{“}L_3 = Ta+Px \text{ and } L_4 = Ta-Px\,;$$

"from which we get

$$\text{“}T = \frac{1}{2a}\,(L_3+L_4).$$

"If we avail ourselves of the value of P and x, obtained from the 1st and 2nd experiments, we have

$$\text{“}Ta = L_3-\tfrac{1}{2}\,(L_2-L_1) = L_4+\tfrac{1}{2}\,(L_2-L_1).$$

"The 3rd and 4th experiments thus afford a redundant equation, and this may be expected to give a check on the consistency of the results with themselves."—An expectation unfulfilled.

For the purposes of comparison, the value of the moment of the 1 foot square pressure plate, when exposed normally, with its centre

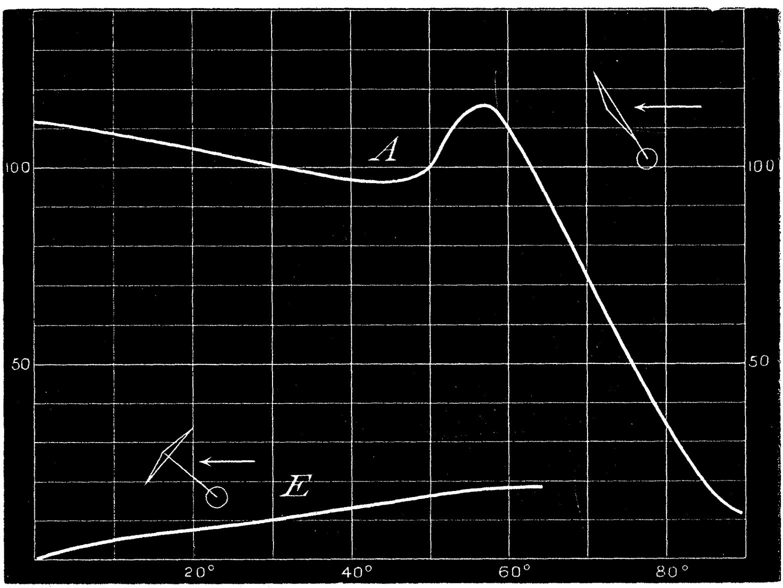
1 foot from its axis of rotation, and when corrected as far as possible for all sources of error, is given as 100, the values of all other moments being expressed relatively to it.

The actual value in terms of the velocity is given subsequently.

Square Pressure Plate.

Curves A and B show the relation between the angle of incidence and the moments for positions I and II, as deduced from the first uncorrected series of experiments, and curves E and F for positions III and IV (figs. 8 and 9). In taking the values of these moments there

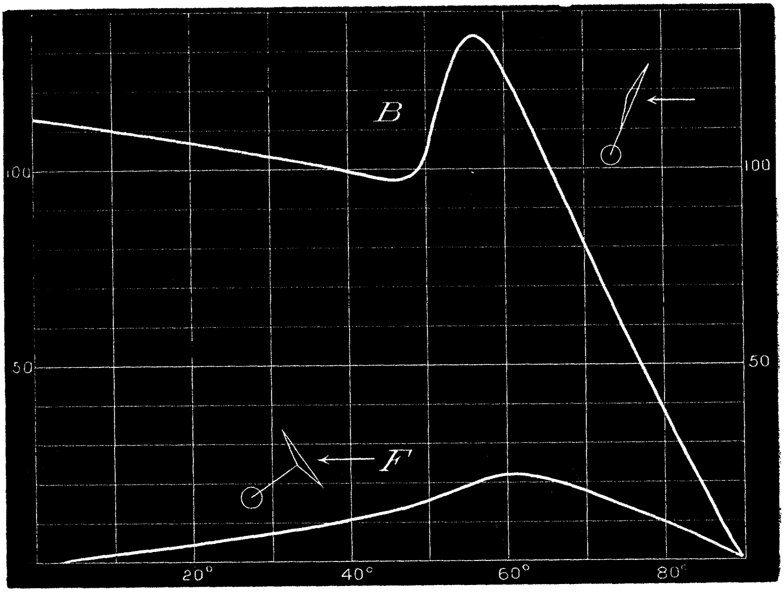
FIG. 8.—Diagram of Moments. Square Plate.



is one point of which we must not lose sight. The long arm of the whirling machine is not perfectly rigid, and gives way under the torsion produced by the wind pressure. Experiments made by hanging weights from the end of a lever showed that a force of 5 lbs. acting 1 foot from the axis caused a deflexion of 2°, and since this is about the moment caused by a velocity of 40 miles an hour, when the plate is exposed normally, the curves have been drawn on the supposition that a moment represented by 100 caused a deflexion of 2°, and that the other moments caused a proportionate deflexion.

It was on this account that it was found advisable to make all the experiments at one uniform velocity.

FIG. 9.—Diagram of Moments. Square Plate.



The actual results which have been obtained are all given in the following tables, in which no notice is taken of the torsional deflexion, although it has been taken into account in drawing the curves.

Position I.

Angle of incidence.	Values of moment.
10°	97, 105, 115, 107
15	106
20	108, 99
30	97, 102
40	97, 96
45	94
48	97
50	94, 91, 99
51	98
52	106
54	109
55	114, 113, 117
56	114
58	112
60	100, 103, 96, 109

Position II.

Angle of incidence.	Values of moment.
0°	109, 105, 111, 100, 110, 114, 127, 119, 119 (at top)
0	107, 100, 114, 108 (at bottom)
10	106, 108, 108, 108
15	110, 115
20	109, 102
30	103, 100, 97
40	103, 96
45	94
50	96, 95
52	105, 106
54	118, 106
55	124, 106, 107, 126, 123, 126

Position I—*continued.*

Angle of incidence.	Values of moment.
61	102
62	97
64	85
65	79
70	63
75	48, 52, 45
80	38, 39
85	25
90	9, 10, 12

Position II—*continued.*

Angle of incidence.	Values of moment.
56	124, 130
58	144, 151, 144
60	130, 126, 125, 119
61	128, 130
64	125
65	108, 120
67	106
70	73, 89, 85
75	64, 63, 64
80	39, 47
85	25
90	2, −5

Position III.

Angle of incidence.	Values of moment.
5°	0
10	3
15	7, 11
20	9
30	11, 10, 11
45	19
60	22, 15, 22, 15

Position IV.

Angle of incidence.	Values of moment.
5°	0
10	0
15	3, 3
20	4
30	9, 13
40	12
45	15, 14
50	20
52	17
55	21, 23, 24, 22
58	24, 24
60	24, 27, 23, 27, 27
61	24, 23
64	24, 22
65	24
67	24, 23
70	20, 21, 18
75	16
80	7
85	0

These tables give a negative value to the tangential component of the pressure when the angle is 60°, and they also make it appear that the central line of pressure is coincident with the central line of the plate until the angle of incidence exceeds 45°. Neither of

these conclusions seeming probable, it appeared advisable to obtain some independent information upon the point, and for this purpose the natural wind was used.

A light circular disc, of 8 inches diameter, was mounted so that it could turn freely in its own plane, and the lower half was cased in, so that it was completely sheltered. It was then exposed to the wind in various positions, its plane being always vertical, but inclined to the wind direction at different angles. The tangential component of the wind pressure, acting upon one side of the upper half of the disc, would tend to rotate the disc, but it was very seldom that the slightest motion could be obtained, although the friction was so slight that a few grains weight placed on the rim of the disc was sufficient to move it. It seems clear from this that the tangential component is so small that it may be neglected in comparison with the normal, and it has accordingly been considered equal to zero.

To find the position of the central line of pressure, the arrangement

FIG. 6.

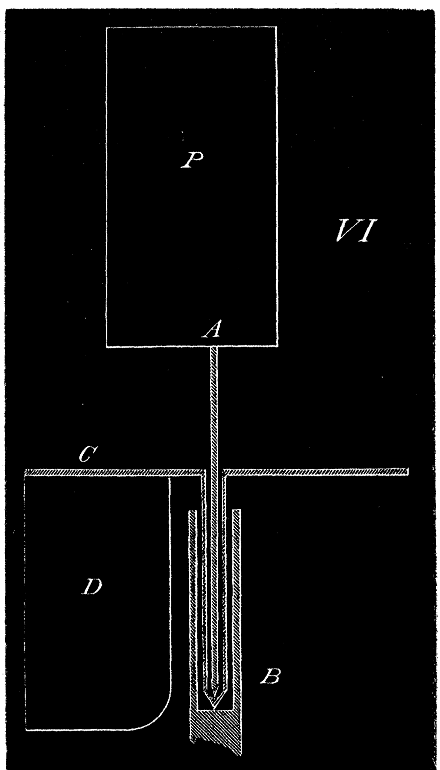
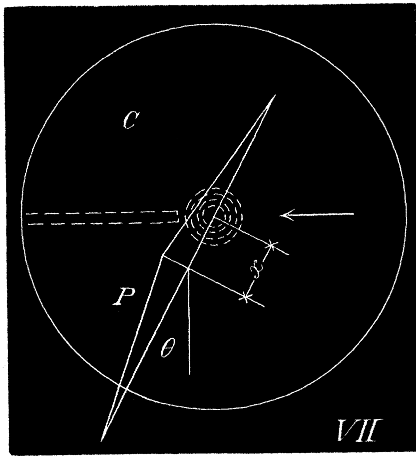


Fig. 7.

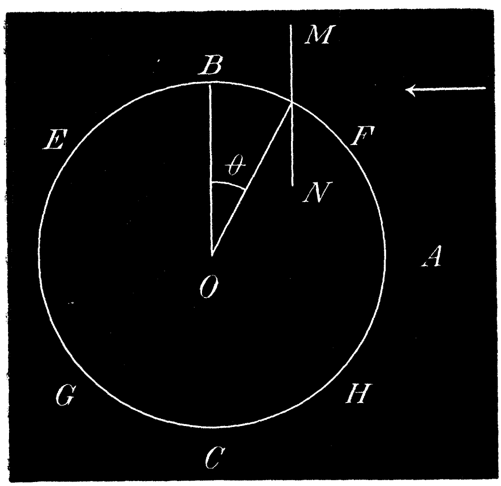


shown in figs. 6 and 7 was designed. A pressure plate, P, similar to the experimental plate, was mounted on a steel rod, AB, the line of the rod being on the face of the plate, and parallel to a vertical edge, but not necessarily passing through the centre of the plate. The rod was ground to a sharp point at its lower end and placed in a piece of brass tube with a plug at the bottom, on which the point rested, so that it could turn freely in the tube. On exposing this arrangement to the wind the plate could take up a definite position, the angle between the normal and the wind direction being dependent upon the distance of the centre of the plate from the axis of rotation formed by the steel rod.

It was not possible, however, to measure this angle, because the wind direction never remained steady for a sufficient time. To overcome this difficulty, a flat disc, C, was placed on top of the brass tube, and the tube itself was pivoted in another piece of tube. A definite line on the disc was kept facing the wind by a vane D, and the angle between the normal to the plate and this line was determined, as far as possible, for various positions of the steel rod relatively to the centre of the plate. A vertical section is shown in fig. 6 and a plan in fig. 7. In the following table the angle of incidence is denoted by θ, and the distance between the centre of the plate and centre of pressure by x. Exact relations between x and θ could not be obtained, but the following values are probably within a few degrees of the truth, unless the wind vane below the disc is influenced by the pressure plate. Whether this be so or not I have no means of judging.

$x = 0{\cdot}025$ foot	....	$\theta = 18°$
$x = 0{\cdot}050$,,	....	$\theta = 30$
$x = 0{\cdot}075$,,	....	$\theta = 45$
$x = 0{\cdot}100$,,	....	$\theta = 60$
$x = 0{\cdot}125$,,	....	$\theta = 70$
$x = 0{\cdot}150$,,	....	$\theta = 75$
$x = 0{\cdot}175$,,	....	$\theta = 78$
$x = 0{\cdot}200$,,	....	$\theta = 80$

Reverting to the whirling machine, the inconsistencies shown between the series of results for the different positions appeared to be due to an eddy from the frame of the apparatus, or at least that seemed to me the only feasible explanation. To test this, experiments were made on the machine with the plate MN in the position shown in the annexed diagram, the wind being supposed to come from the



right. If L be the moment about O in this position, the expression L sec θ, which is equal numerically to the force acting upon the plate when exposed normally, ought to be independent of θ, but such was not found to be the case. If a circle be taken with O for centre, and A be taken on the right, so that OA is the direction of motion of the apparatus through the air, and the points F, B, E be taken at 45°, 90°, and 135° respectively from A on the top, and H, C, G be corresponding points on the bottom part of the circle, then the value of L sec θ was found to vary in the following manner:—

At F the value was about 30 per cent. less than at E, the value increasing uniformly from F to E.

At H the value was about 15 per cent. less than at G, increasing uniformly from H to G.

At H and F the values were very nearly equal, F being slightly lower, but the difference was quite within the limits of an accidental error.

These results point clearly to an eddy from the frame of the apparatus, and it was owing to the accidental discovery that the pressure at C was 7 or 8 per cent. less than at B that I was led to try the effect of placing the plate exposed normally in various parts of the circle, as just explained.

Reference to fig. 1 will show how small a surface the frame presents to the wind; actually it is about 14 square inches, or only one-tenth of the surface of the pressure plate, and being as much as 15 inches laterally from the centre of the plate, it certainly seems surprising that it should exert so great an influence.

Observations to find the value of the moment about O for positions I, II, III, and IV were made indiscriminately in the top and bottom segments, before the existence of the eddy was suspected; but subsequent trial showed that the values in the case of oblique exposure were symmetrical about the line AO, excepting in the neighbourhood of the points B and C.

It is clear that the disturbance due to the frame is an important matter, and some attempt must be made to eliminate it.

Since the normal pressure upon the plate was found to increase uniformly from F to E, and also from H to G, it seems to be the least objectionable plan to assume that the moment when the plate is exposed obliquely varies in the same way. This assumption will, at least, bring the position of the central line of pressure, as deduced from positions I and II, more into accordance with the position which it is known to take up.

Also, since the normal pressures at H and F are practically identical, and these are presumably the positions where the eddy from the frame should have the least effect, I think it will be best to take the values of the normal pressure in these positions as the basis with which to compare all other pressures. It will be seen that this is equivalent to taking about 15 per cent. less than the value found at B, or about $7\frac{1}{2}$ per cent. less than the value at C, as the numerical value of the normal component.

Assuming that the tangential component is zero, we have now four ways of determining the normal component for any angle of incidence. They are (1) by combination of the corrected values found for positions I and II; (2) by combination of positions II and IV. These give also the position of the central line of pressure. If we take the position of the central line of pressure obtained from the experi-

ments with the natural wind, these values, combined with positions either II or IV, will give the normal component. It will be seen, on reference to the tables of values found for the various positions, that, in whichever way the curve be constructed, a very curious and sudden rise occurs between the angles of 55° and 60°. Curve C, fig. 10, for the normal component has been constructed by taking the values from positions II and IV, and curve D, fig. 11, by taking the position of the central line of pressure from the natural wind experiments, and then deducing the normal components from the values of the moment in position II. I can form no opinion as to which curve is the more likely to be correct. Some confirmation of the truth of these results is, perhaps, given by the fact that the greatest moment produced by the wind upon a Robinson cup does not occur when the arm is perpendicular to the wind direction, but when there is a considerable inclination, and the fact that a ship can sail at a good pace when its direction makes with the wind direction an angle considerably less than 90° is worth noting.

The position of the central line of pressure, as deduced from the experiments made on the whirling machine, is nearer the front edge of the plate than the position given by direct experiment with the natural wind. It will be seen that in both cases the distance of the central line of pressure from the centre of the plate increases more rapidly with the same change in the angle of incidence, as that angle increases in magnitude; but that the angle at which the acceleration becomes apparent is greater in the natural wind experiments.

The following results, showing the relation between x and θ (see preceding table), may be of interest; they are deduced from positions II and IV:—

$x = 0{\cdot}025$ foot	....	$\theta = 10°$
$x = 0{\cdot}050$,,	....	$\theta = 18$
$x = 0{\cdot}075$,,	....	$\theta = 26$
$x = 0{\cdot}100$,,	....	$\theta = 33$
$x = 0{\cdot}125$,,	....	$\theta = 39$
$x = 0{\cdot}150$,,	....	$\theta = 44$
$x = 0{\cdot}175$,,	....	$\theta = 49$
$x = 0{\cdot}200$,,	....	$\theta = 54$
$x = 0{\cdot}225$,,	....	$\theta = 58$
$x = 0{\cdot}250$,,	....	$\theta = 63$
$x = 0{\cdot}275$,,	....	$\theta = 67$
$x = 0{\cdot}300$,,	....	$\theta = 71$

Rough Surfaces.

The preceding results refer exclusively to a smooth polished plate. The effect of covering the face with sand-paper of medium coarseness,

Fig. 10.—Diagram of Normal Component.
From Positions II and IV.

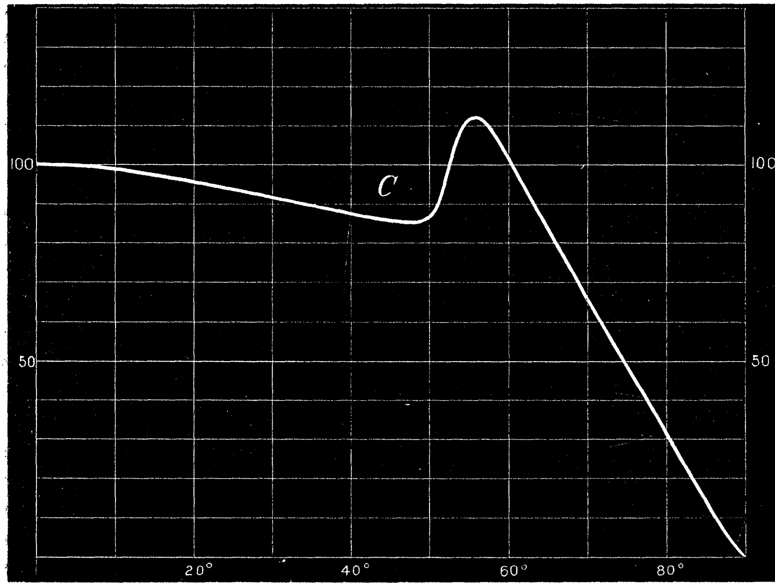
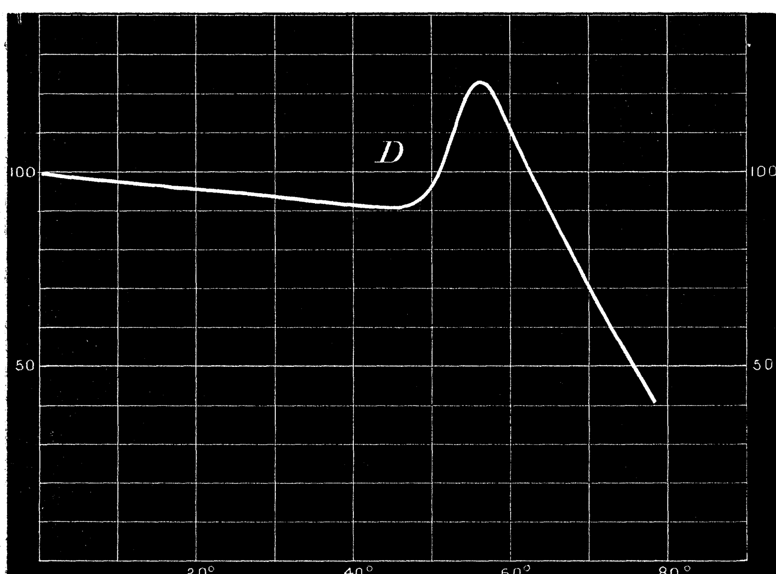


Fig. 11.—Diagram of Normal Component.
From Position II and Natural Wind Experiments.



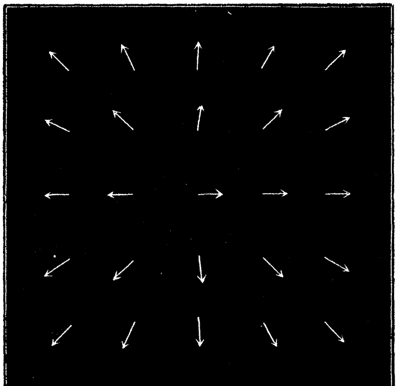
and also with coarse woolly flannel, was tried. So far as I could judge, the sand-paper made no difference in any position, and the flannel made no difference in the normal position. At the angle of maximum moment, the flannel causes a considerable change in the value of the moment. The mean of six experiments made in positions I and II gives a decrease of 21 per cent. in the value of the normal component (not the moment) when the face of the plate is covered with flannel. About the same decrease is caused by thoroughly wetting the face of the plate, probably because a series of ripples are set up, for just damping it has no appreciable effect. Experiments made with the flannel in positions III and IV show that it acts in two ways. It decreases the pressure, and brings the central line of pressure nearer to the centre of the plate; there is also a decided tangential component, but uncertainty about the effect of the eddy in the back positions (I and III) and want of time have prevented my making any attempt to determine the numerical value.

Distribution of the Stream Lines on the Surface of the Plate.

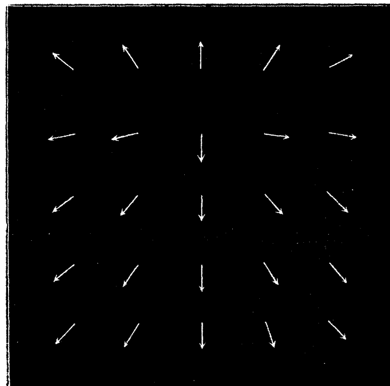
In accordance with suggestions made by Professor Darwin and Mr. Buchan on the occasion of their visit to Hersham on March 20th, an attempt has been made to map out the stream lines near the surface of the pressure plate for various angles of incidence.

For this purpose twenty-five small pins were driven into the face of the board in rows 2 inches apart, and a few short lengths of dark coloured silk were tied to the head of each pin. It was somewhat difficult to see the position taken up by the silk, but the accompanying diagrams give a general idea. Each diagram is the result of two drawings made at different times and compared afterwards, and in cases where the two drawings showed much difference a third trial was made. The pace was about 35 miles an hour, that being very near the limit at which the silk could be seen.

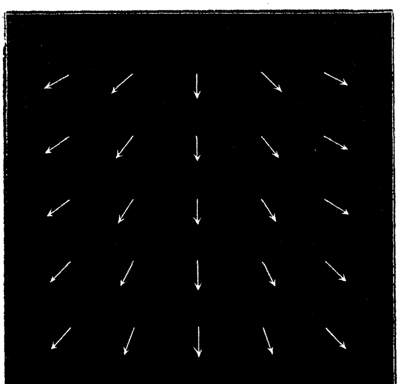
In each diagram the front edge of the plate corresponds to the top, and the left hand to the side nearest to the centre of the whirling machine. The arrows indicate the position taken up by the silk attached to the corresponding pin, and probably show the direction of motion of the air at the point within a few degrees. There is a general tendency of the arrows to incline to the right, which is no doubt due to the centrifugal force. The effect is no doubt indirect, and not due to direct action upon the silk, but to the action upon the comparatively still air, which, being driven to the right, in turn moves the silk. It was evident that in parts where the symmetry of the diagram was destroyed by a turning to the right, the motion of the air was comparatively gentle, this being seen by the inertness of the threads in those positions.



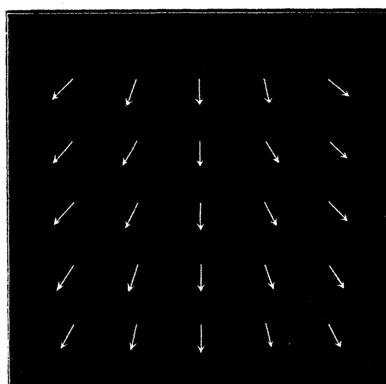
Front. 0°.



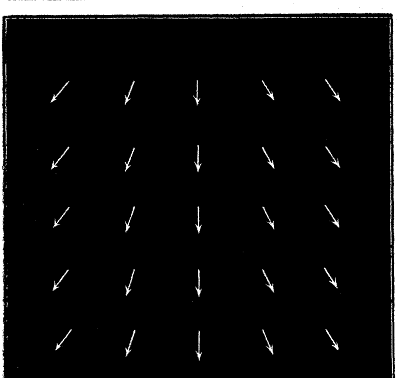
Front. 15°.



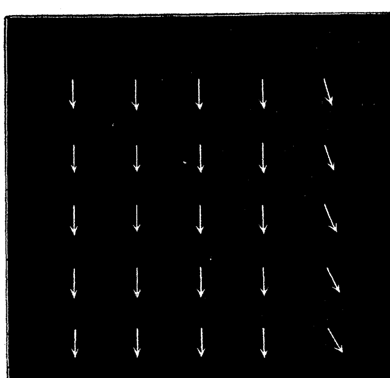
Front. 30°.



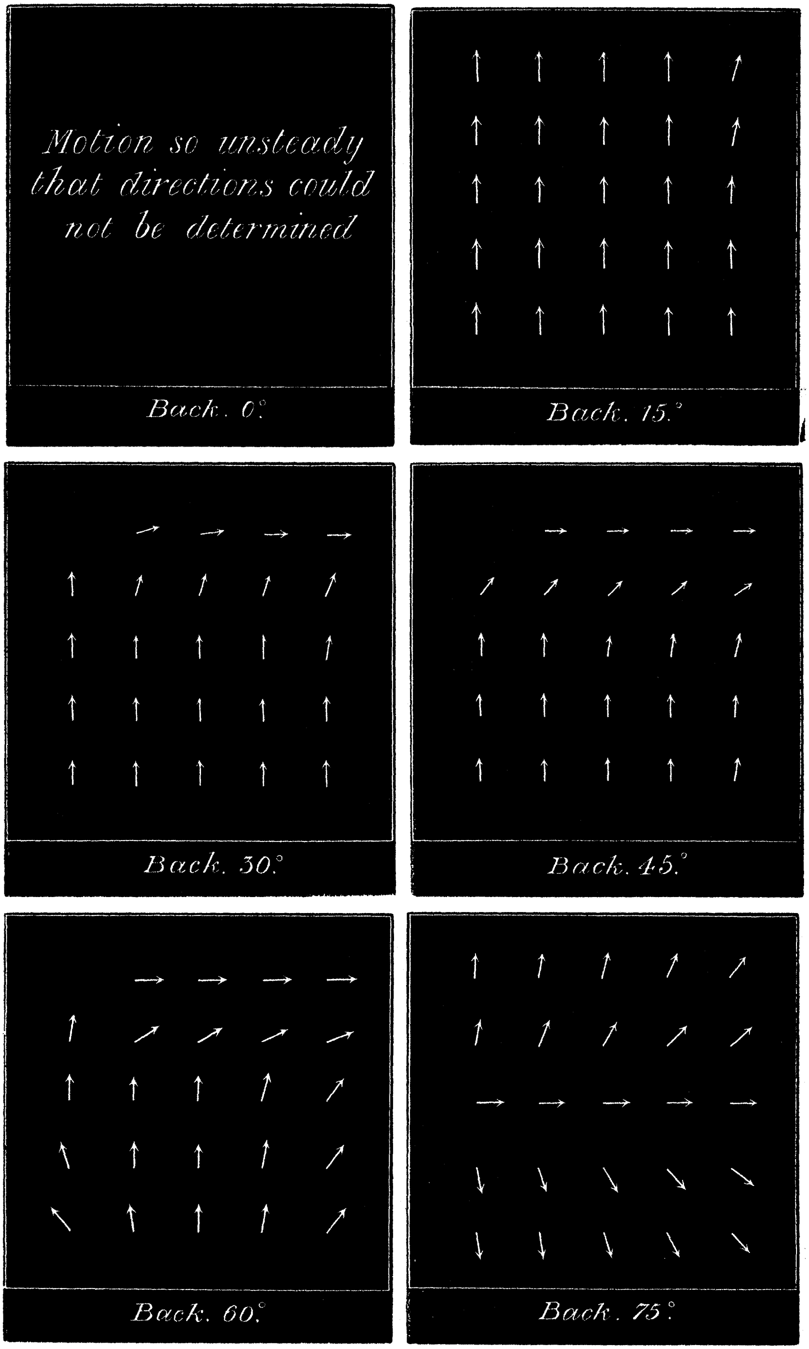
Front. 45°.



Front. 60°.



Front. 75°.


Motion so unsteady
that directions could
not be determined
Back. 0°
Back. 15°
Back. 30°
Back. 45°
Back. 60°
Back. 75°

No marked change in the distribution of the stream lines occurred on either the back or front of the plate at angles between 45° and 60°, several intermediate positions having been tried.

Until the angle of incidence exceeds 60° there is a region of still air at the back just behind the forward edge of the plate; the width of this seems to increase, but it remains at all events within 2 inches of the edge until the angle of incidence exceeds 60°. It is curious that at 75° the air should be at rest at the centre of the back of the plate, and pass off laterally in both directions. In all cases the motion on the front of the plate was quite steady. At the back, in the case of normal exposure, it was too unsteady to be determined; at 15° it was decidedly unsteady; but in the other positions there was no difficulty in seeing the position of the silk threads.

Effect of Temperature, Pressure, &c.

It will be seen on reference to the tables that very divergent results were sometimes obtained. Obviously experiments made under the same conditions of barometrical pressure, temperature, and wind ought to give the same values. In cases where a small change of inclination causes a considerable change in the moment, a discrepancy in the results is easily explained by supposing a small mistake to have been made in measuring the angle, but in many cases this explanation does not apply. Some natural wind ought to increase the mean pressure, but in so far as I can judge it does not do so to anything like the theoretical amount, that is to say, the pressure is not increased so much as the mean square of the relative velocity. Repeated experiments have shown that it is not possible to get a different result by altering the rate of the whirling machine, all speeds under 70 miles an hour, which is the greatest of which the machine is capable, giving results which show that the pressure varies as the square of the velocity. It must, however, be remembered that at low speeds the forces are too small to be capable of exact measurement.

Barometrical pressure has the result which might be expected, the pressure on the plate varying directly as the height of the mercury. A rise of temperature does not seem to make much difference, but, if anything, it increases the pressure. Experiments have been made through a range of about 40° F., from 28° F. to 68° F. The greater viscosity, I suppose, at the higher temperatures more than compensates for the decrease of density, for certainly, other circumstances being the same, the pressure is not less at 60° F. than at 30° F., and the lowest values ever obtained were in a thick fog with a temperature below the freezing point.

No determinations of the dew point have ever been made in con-

nexion with the experiments, but I think that damp air is conducive to a high, and dry air to a low, relative pressure.

On some days the values will not vary to more than 1 or 2 per cent. throughout; on others, under apparently precisely similar circumstances, variations of 10 or even 15 per cent. will occur within a few minutes. It is perhaps possible that these changes may be due to variations in the viscosity of the air caused by a change in the dew point, or they may be caused by a circular eddy due to the wind coinciding in position with the path of the pressure plate. The latter supposition seems the more probable, but, if so, it ought to appear sometimes in experiments with velocity instruments, and I have tried several air meters many times, and never detected anything approaching to a variation of 10 per cent. It must be remembered, however, that a change of 5 per cent. in the velocity would produce a change of 10 per cent. in the pressure.

These variations give an immense amount of trouble, because it is imperative that an experiment should be repeated many times before the mean value is considered correct.

Actual Pressures.

The actual value of the pressure for any velocity is obtained thus.

In the normal position, the pressure for which has previously been denoted by 100, equilibrium was obtained when the moment due to the centrifugal force was 1·33 (ft. and lbs.). The bar was 27 feet $9\frac{1}{2}$ inches from the centre of the whirling machine, and the centre of the pressure plate 29 feet $1\frac{1}{2}$ inches; hence, since the centre of the pressure plate was 1 foot from its axis of rotation, the pressure P is given in lbs. by the equation

$$P = \frac{1\cdot33 \times v^2}{27\cdot8 \times 32\cdot2},$$

when v is the velocity of the bar in feet per second.

This gives

$$P = \frac{1\cdot33 \times 27\cdot8V^2}{32\cdot2 \times (29\cdot1)^2},$$

when V is the velocity of the plate.

Changing to miles per hour, we have

$$P = \cdot0029v^2,$$

which gives about $18\frac{1}{2}$ miles per hour as the velocity at which the pressure is 1 lb. per sq. ft.

This is, I believe, a lower value than has been previously given.

The older books on engineering give $P = 0{\cdot}005v^2$, but more recent books give $P = 0{\cdot}003v^2$.

It is a lower value than the one determined at Hersham last year, but I had then no suspicion that the frame of the apparatus would influence the result. It is, however, borne out by the values obtained last year for smaller plates, and the experimental evidence which shows that a decrease of pressure per sq. ft. occurs as the size of the plate is increased.

The following particulars may also be of interest; the method by which they were obtained is described in a paper read before the Royal Meteorological Society in May, 1890. At the centre of the plate when exposed normally the increase of pressure at a rate of 60 miles an hour is equal to 1·82 inches of water, and the decrease at the back, also at the centre close to the plate, is equal to 0·89 inch of water. These values were found with the plate at the point B (see preceding diagram), and, taken in connexion with the fact, discovered I believe by Mr. Curtis, that the pressure in front decreases from the centre outwards, agree fairly well with the value for the pressure obtained in that position.

Long Narrow Vane.

Experiments have also been made with long narrow strips instead of with a square plate. The size chosen was 4 feet long by 3 inches broad, the surface thus being the same as the square plate.

Observations were made at angles of 10° apart, in positions I and II, both with the shorter axis inclined to the wind, and also with the longer axis.

There was a difficulty in mounting these strips so that the supporting arm should not cause any disturbance of the motion of the air over the strip, and still be sufficiently rigid to support the pressure. The thickness of the wood was $\frac{3}{8}$ inch, and the edges were feathered off. It will be seen that when the strip was exposed so that its shorter axis was inclined to the wind the longer axis was necessarily parallel to the long arm of the whirling machine, and its centre 2 feet from the end of the lever. Under these circumstances the velocity would be nearly 4 per cent. greater, and the pressure from 7—8 per cent. greater, than upon the square plate for the same rate of rotation of the whirling machine. This has been taken into account in drawing the curve G.

The support was obtained by a piece of flat iron, $1\frac{1}{4}$ inch by $\frac{3}{16}$, which passed half way along the back of the wood, the end of the iron being bolted to the lever.

The values of the moment for position I were found to be greater than for position II, doubtless on account of the eddy from the

frame, and accordingly the values for position II only were used for drawing the curve.

Rectangle 4 feet by 3 inches.

Shorter Axis inclined to the Wind.		Longer Axis inclined to the Wind.	
Position II.		Position II.	
Angle of incidence.	Values of moment.	Angle of incidence.	Values of moment.
0°	132, 126, 127, 128, 135	0°	126, 129, 125, 126
		10	141
10	128, 132	20	153
20	135, 126	30	167, 156, 159
30	130	40	156
40	125, 123	50	118
50	114, 120	60	84, 93
60	99, 100, 102	70	36
70	72	75	25, 26
80	37	80	11
90	−6	90	11
Position I.		Position I.	
20	133	10	114, 116
40	131	20	93
50	120, 126, 117	30	73, 77
60	120	40	66
		50	54
		60	38, 36, 39
		70	24
		80	24
		90	12

The curve G, fig. 12, therefore shows the moment about O, rather than the normal component of the pressure, but, the strip being only 3 inches broad, the departure of the central line of pressure from the centre of the strip cannot cause any very serious difference. The actual pressure upon a surface of this kind is much greater than upon an equal surface when collected in a compact form, such as a square or circle, the difference in this case being more than 20 per cent. This is quite in accordance with previous experiments that have been made on the subject.

The dotted line shows the value of the normal component given by Lord Rayleigh, the curves being made to agree at the beginning and end. The agreement between the theoretical and experimental curves would be more marked if both gave the same quantity, for the moment

FIG. 12.—Long Strip. Diagram of Moments.
Shorter Axis inclined to the Wind.

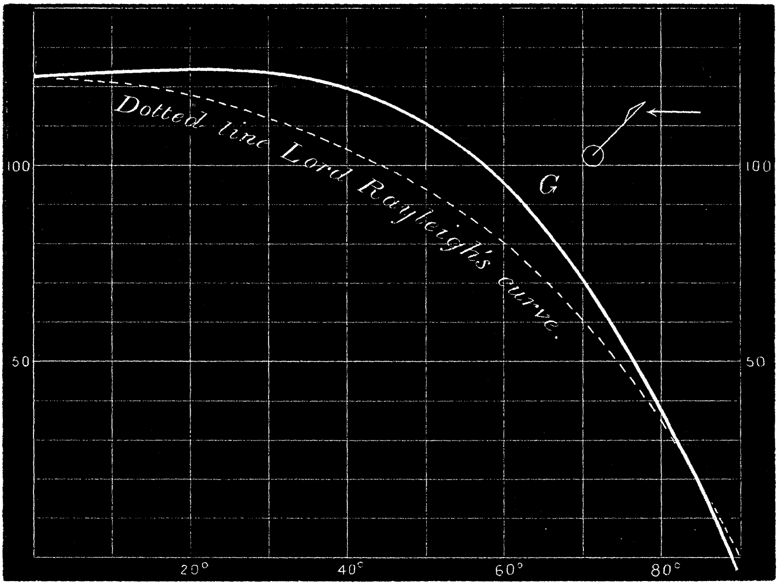
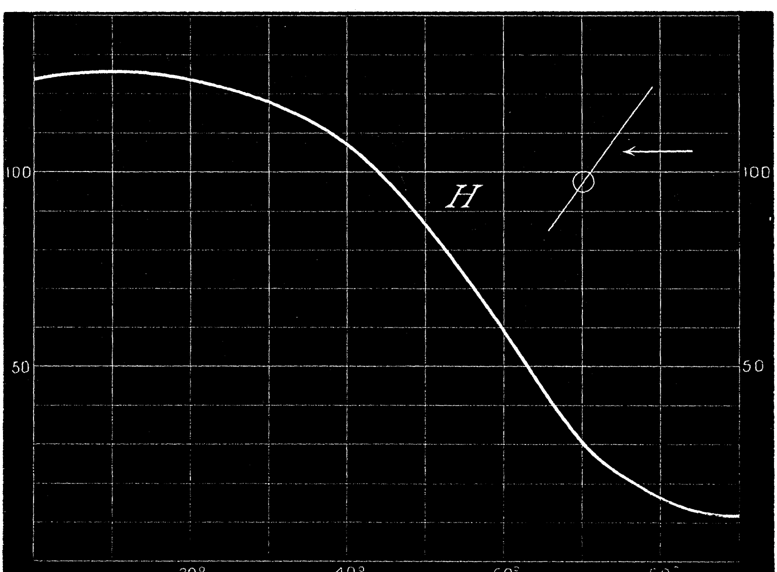


FIG. 13.—Long Strip. Diagram of Normal Component.
Longer Axis inclined to the Wind.



in the intermediate positions is necessarily greater numerically than the normal component.

Curve H, fig. 13, gives the normal component of the pressure upon the same strip of wood with the longer axis inclined to the wind. In this case the wood was mounted 1 foot from the lever (EF, fig. 1) and parallel to it. The curve is drawn from the values of the moments in positions I and II, want of time having prevented my making observations in positions III and IV. The curve shows the normal component, and not the moment, and the distances of the centre of pressure from the centre of the strip are given in the following table, x and θ having the same meanings as before:—

$x = 0{\cdot}10$ foot	....	$\theta = 10°$
$x = 0{\cdot}24$,,	....	$\theta = 20$
$x = 0{\cdot}36$,,	....	$\theta = 30$
$x = 0{\cdot}40$,,	....	$\theta = 40$
$x = 0{\cdot}37$,,	....	$\theta = 50$
$x = 0{\cdot}39$,,	....	$\theta = 60$

It is probable that the flattening of the curve about the angle of 50°, and the corresponding departure from symmetry in the relation between x and θ for that angle, is accidental. The curve is obviously wrong at 90°, where the normal component should be zero, but I have sought in vain for any explanation of this, and can only put it down to the eddy from the frame, which has caused so much trouble in other ways. It is not due to any want of balance, so far as gravity is concerned. Several trials have been made during the course of the experiments to see whether the sliding bar would come to the zero mark when the plate and balance weight were removed from the apparatus, and it has always been found to do so with very fair accuracy. Care has been taken to see that the moving parts were properly balanced for weight, and although the pressure upon the plate, and consequent deflexion, has no doubt slightly altered the balance while the apparatus was moving, the error so caused is very trifling, at least so far as the foot square plate is concerned.

In conclusion, I must say that I am sorry not to have been able to clear up the different inconsistencies better, and not to have been able to draw the curves for the normal component with a greater certainty of their being accurate.

FIG. 1.

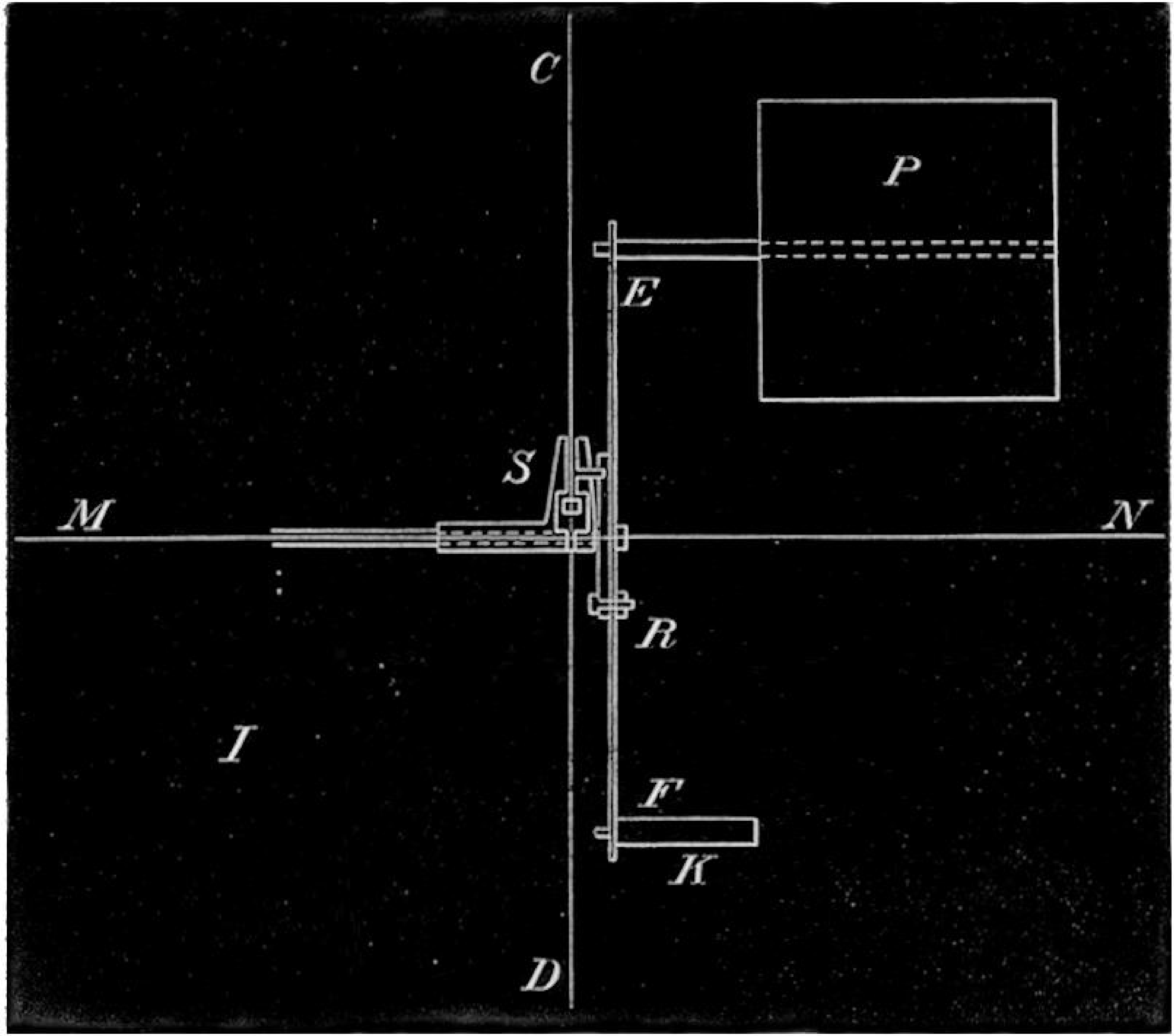


FIG. 2.

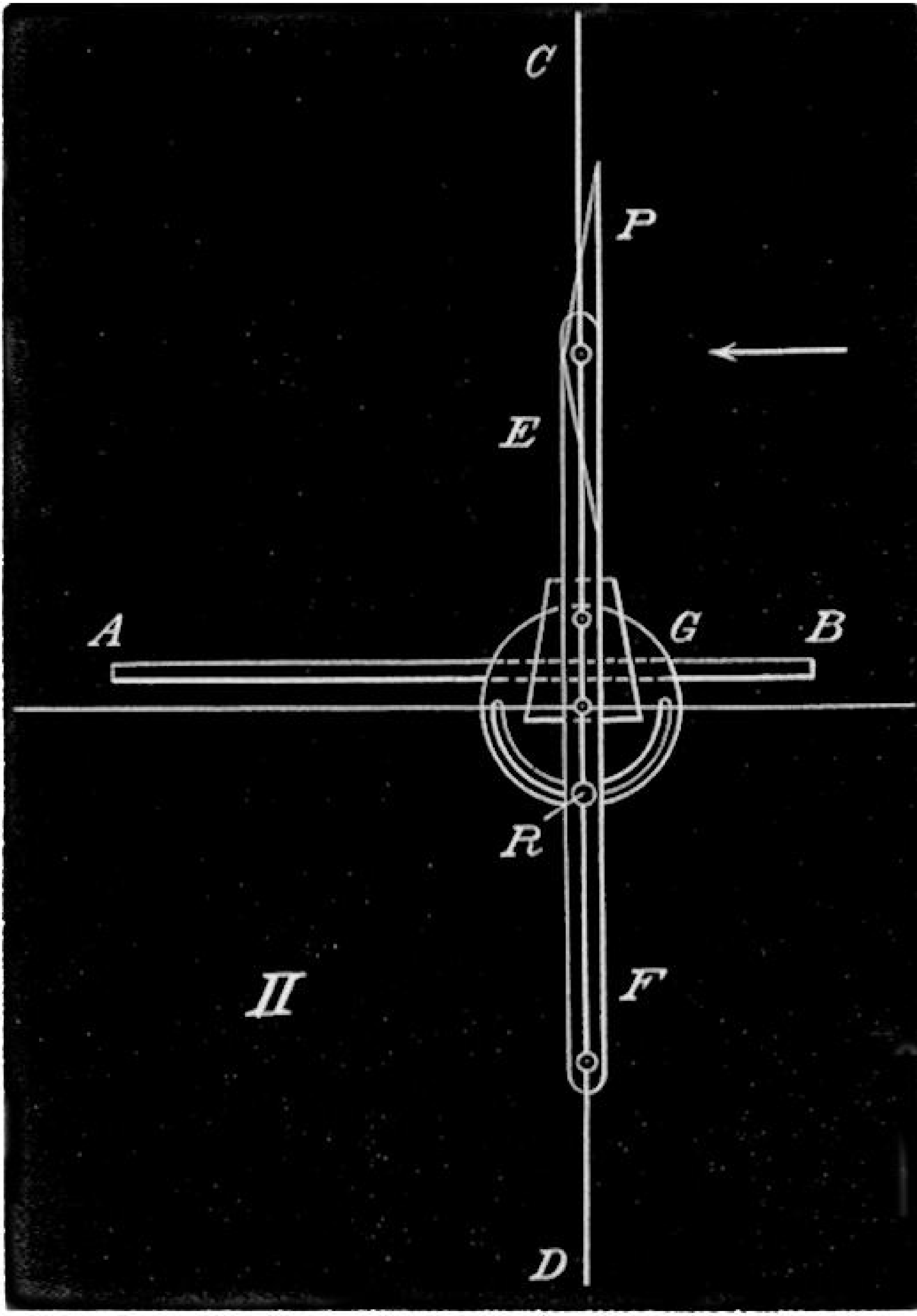


FIG. 3.

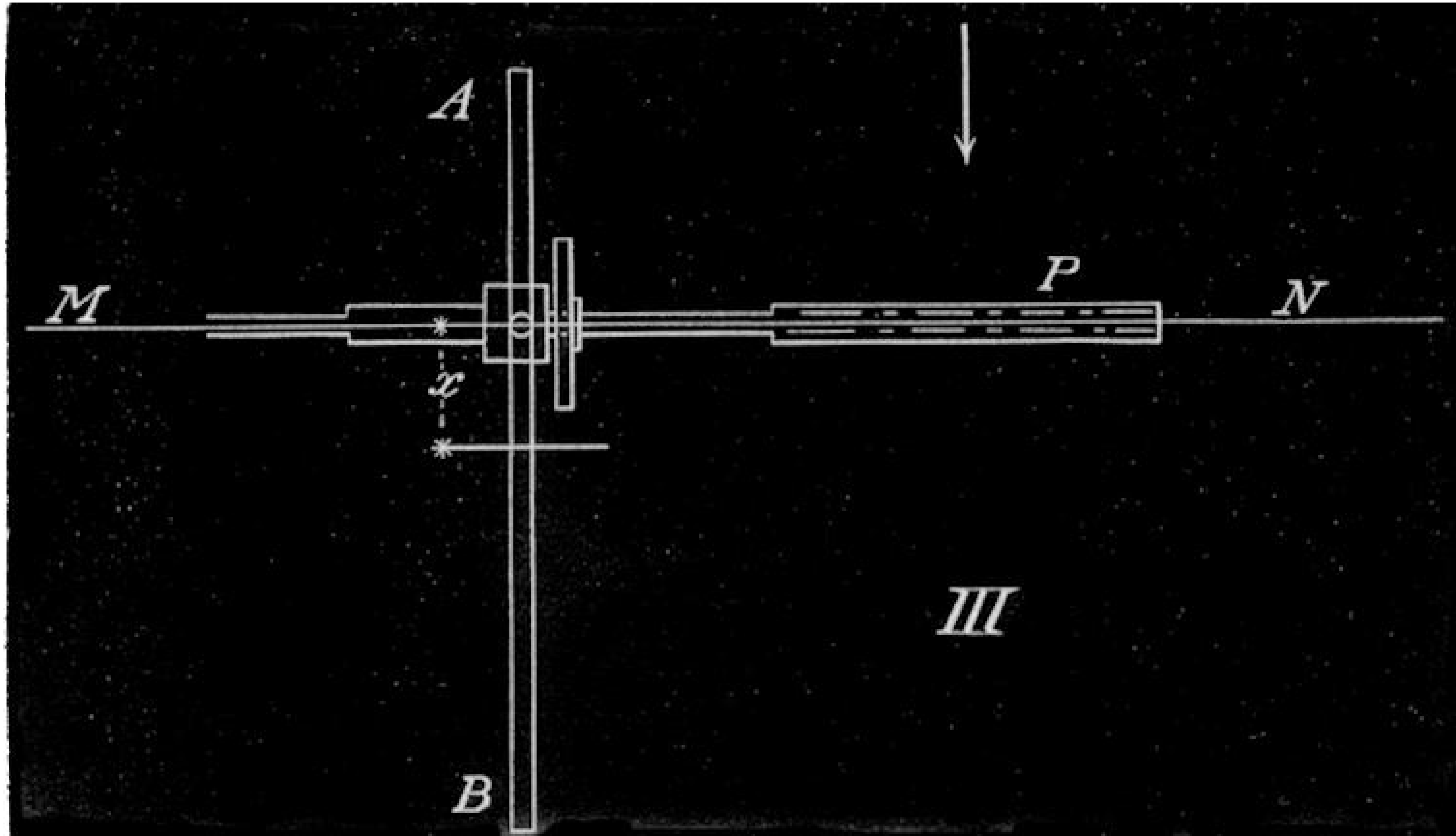


Fig. 4.

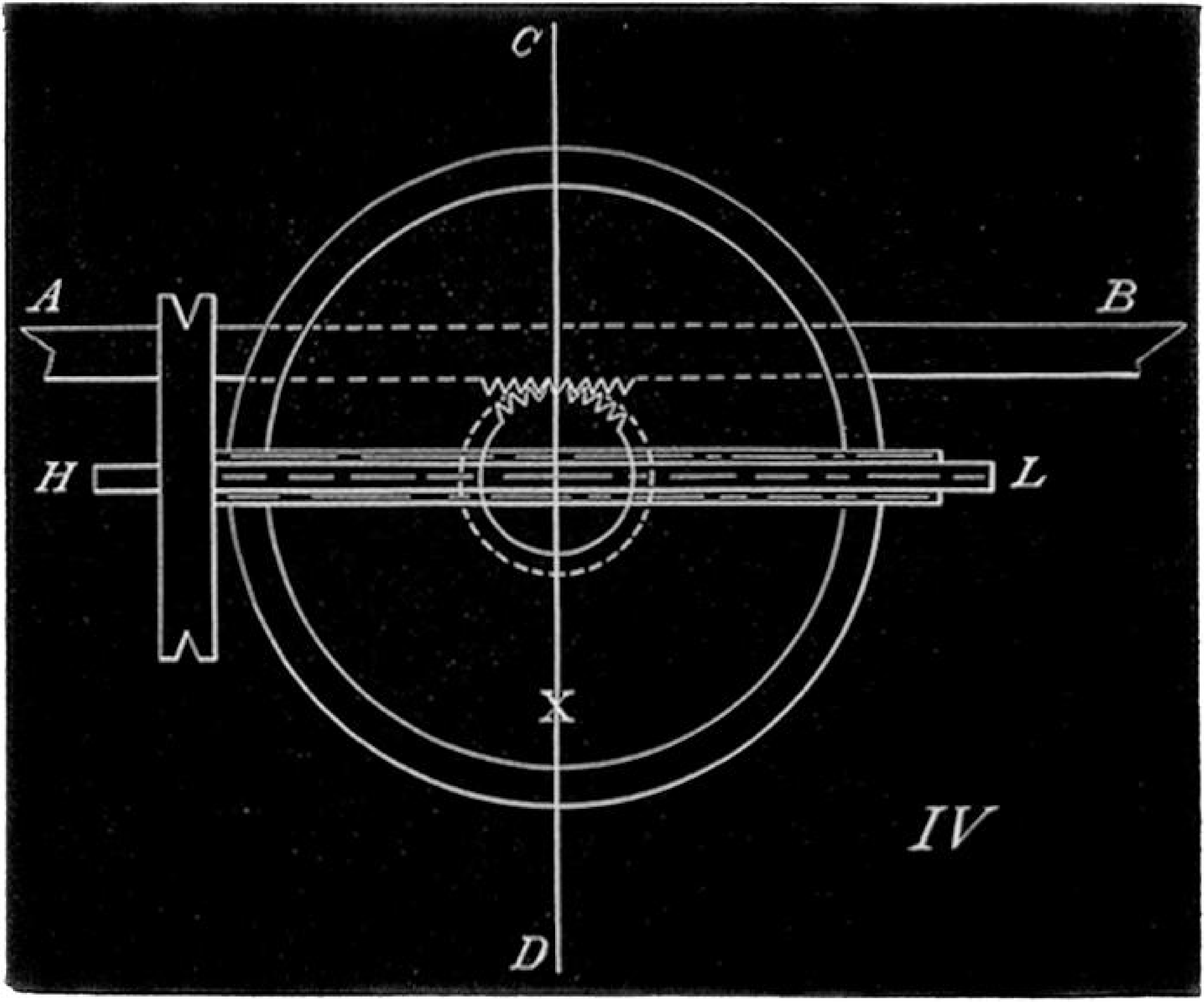
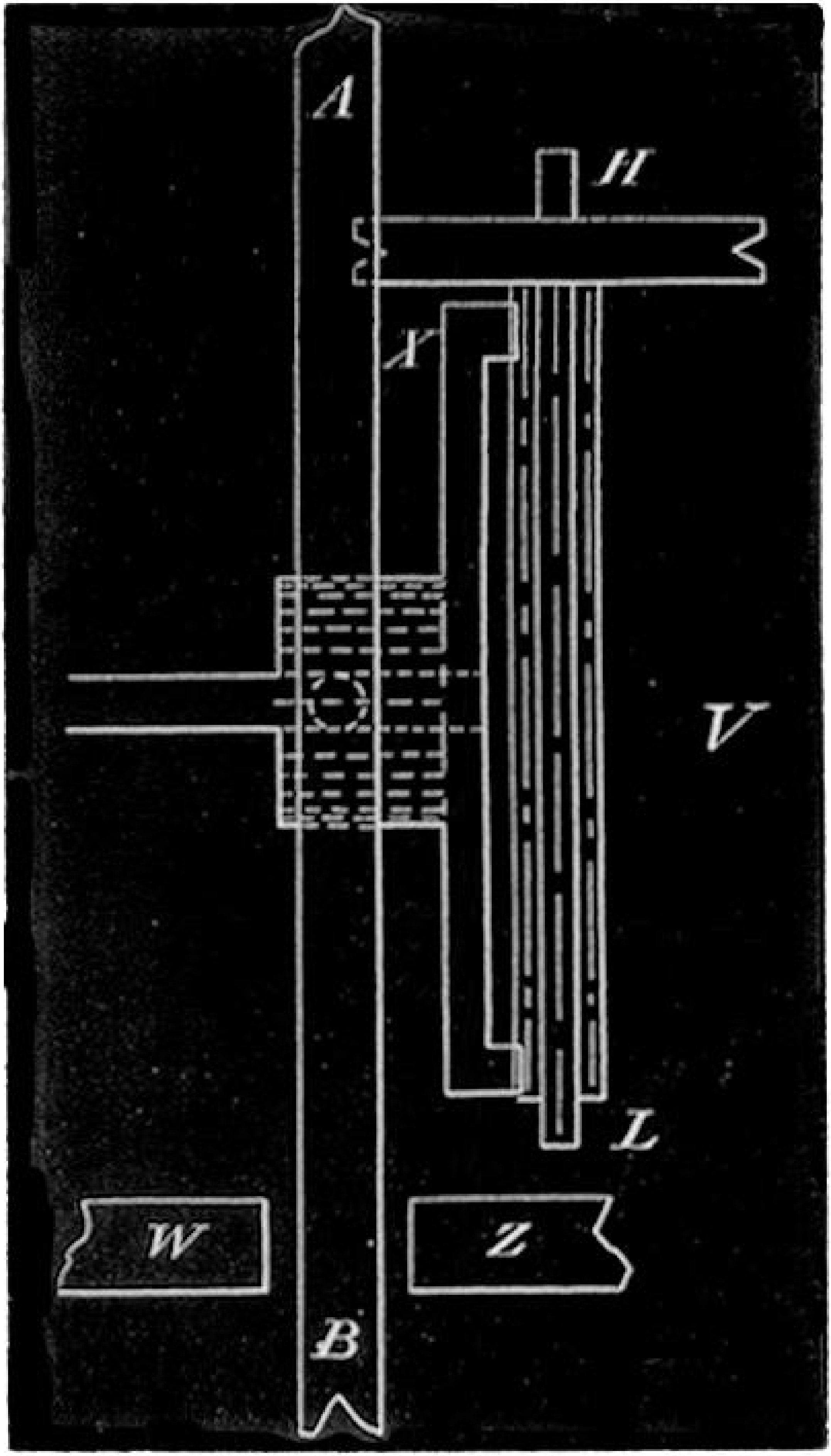
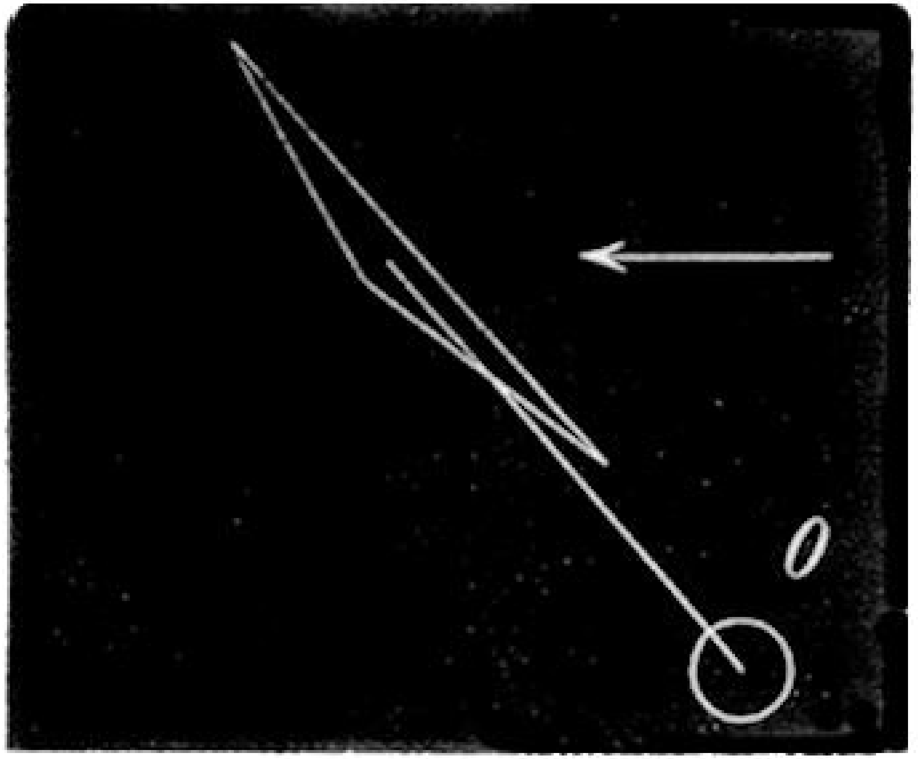
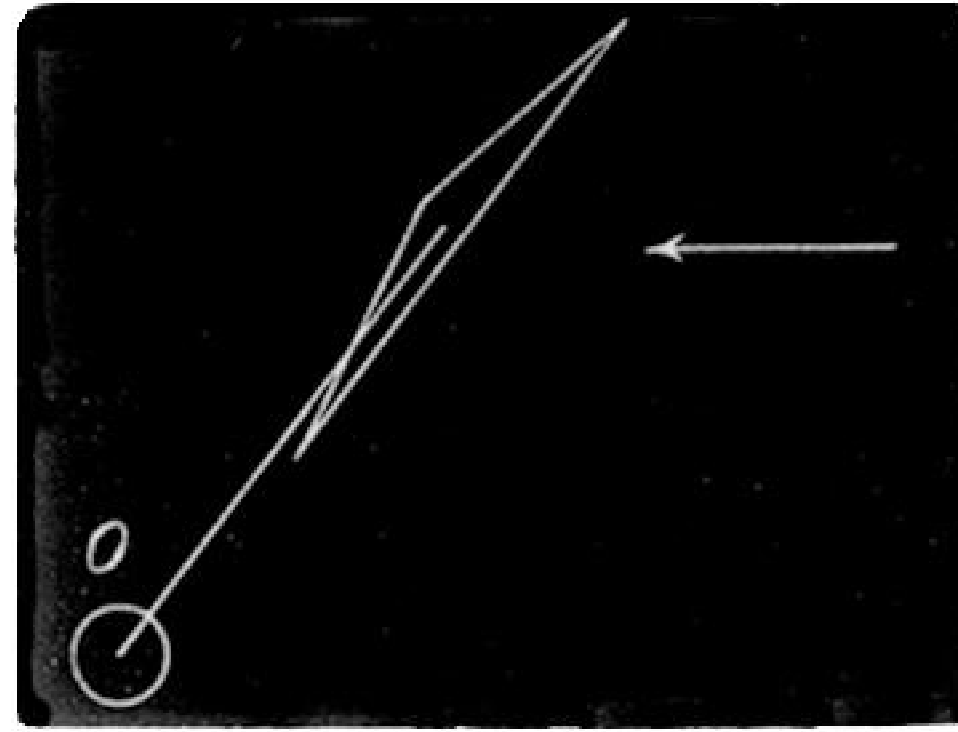


FIG. 5.

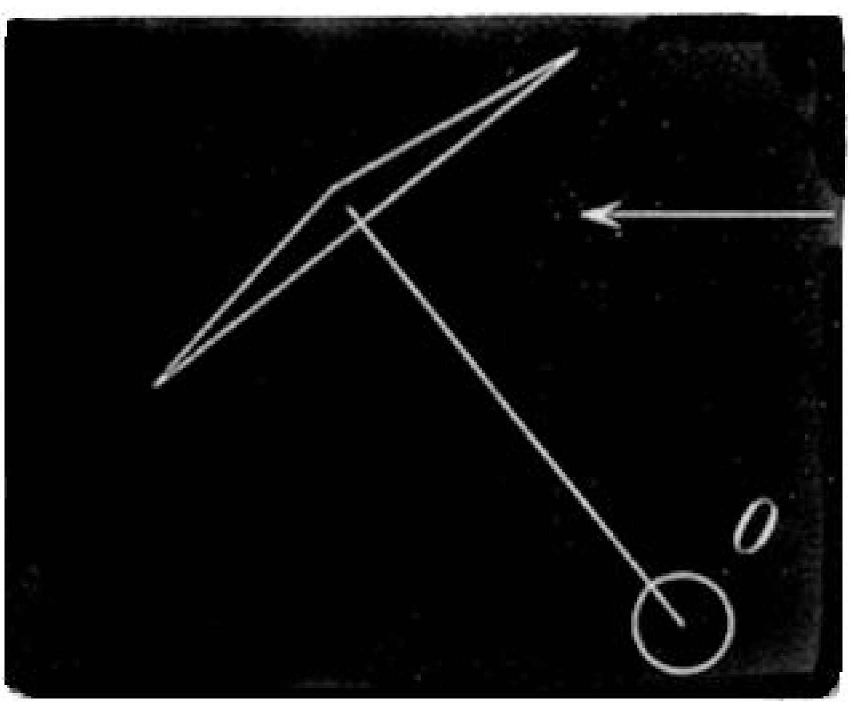




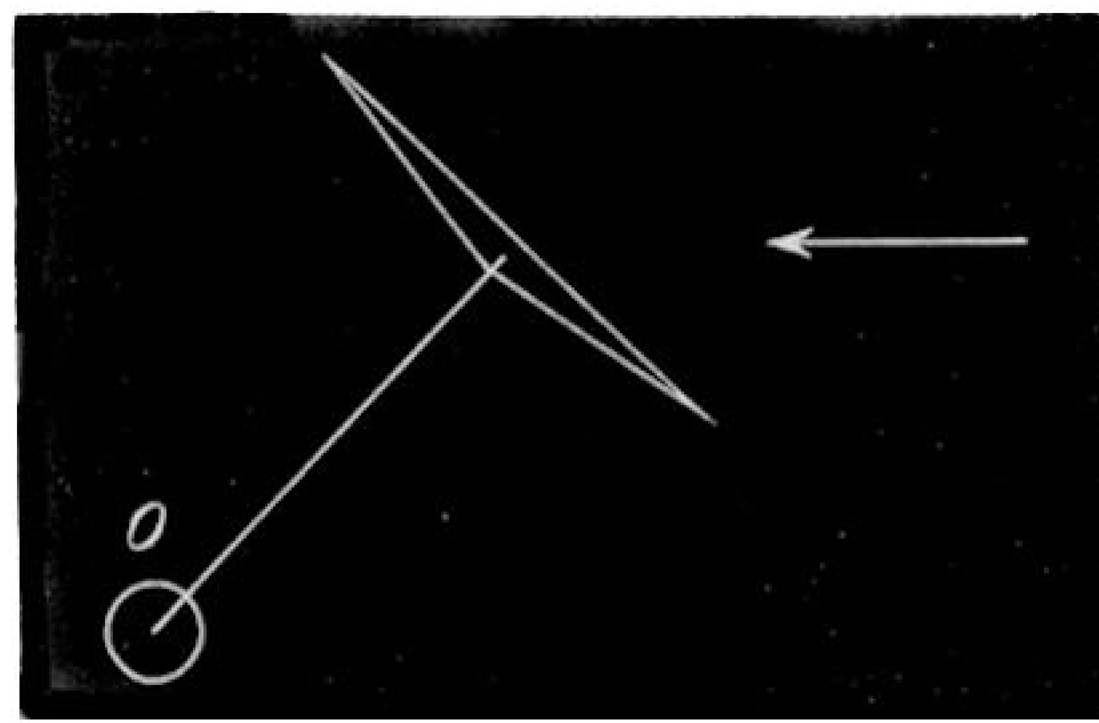
Position I.



Position II.



Position III.



Position IV.

FIG. 8.—Diagram of Moments. Square Plate.

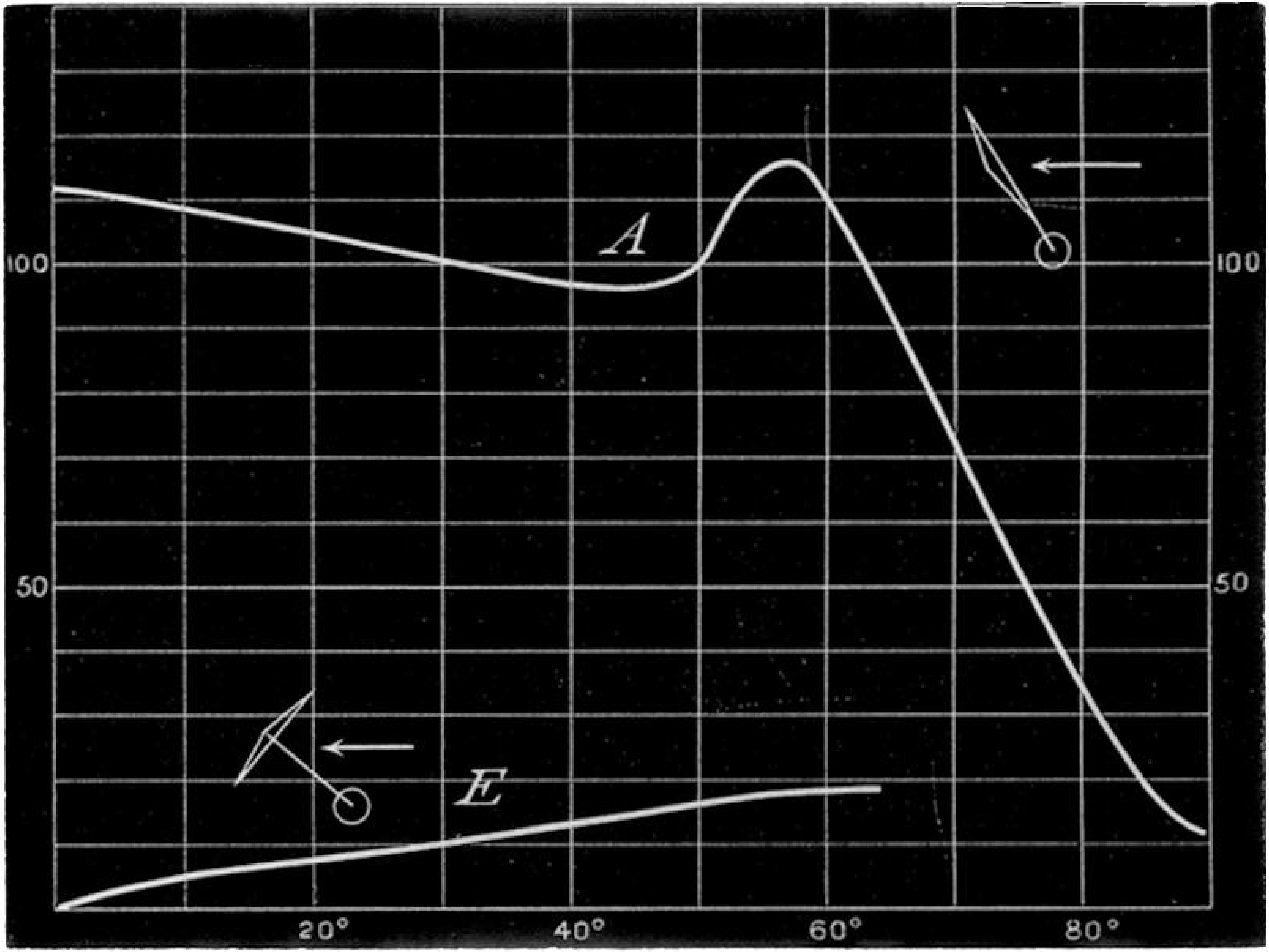


FIG. 9.—Diagram of Moments. Square Plate.

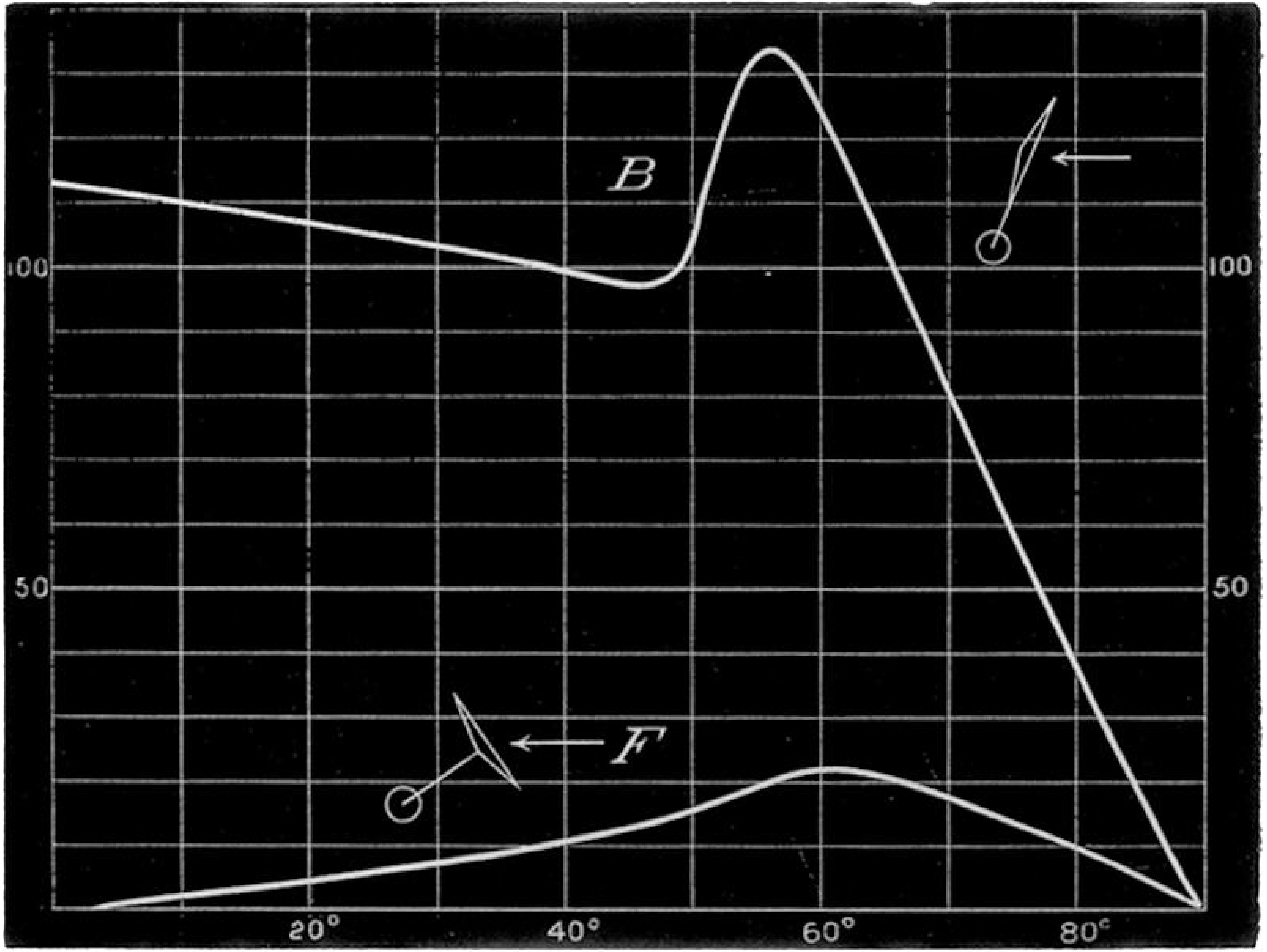


Fig. 6.

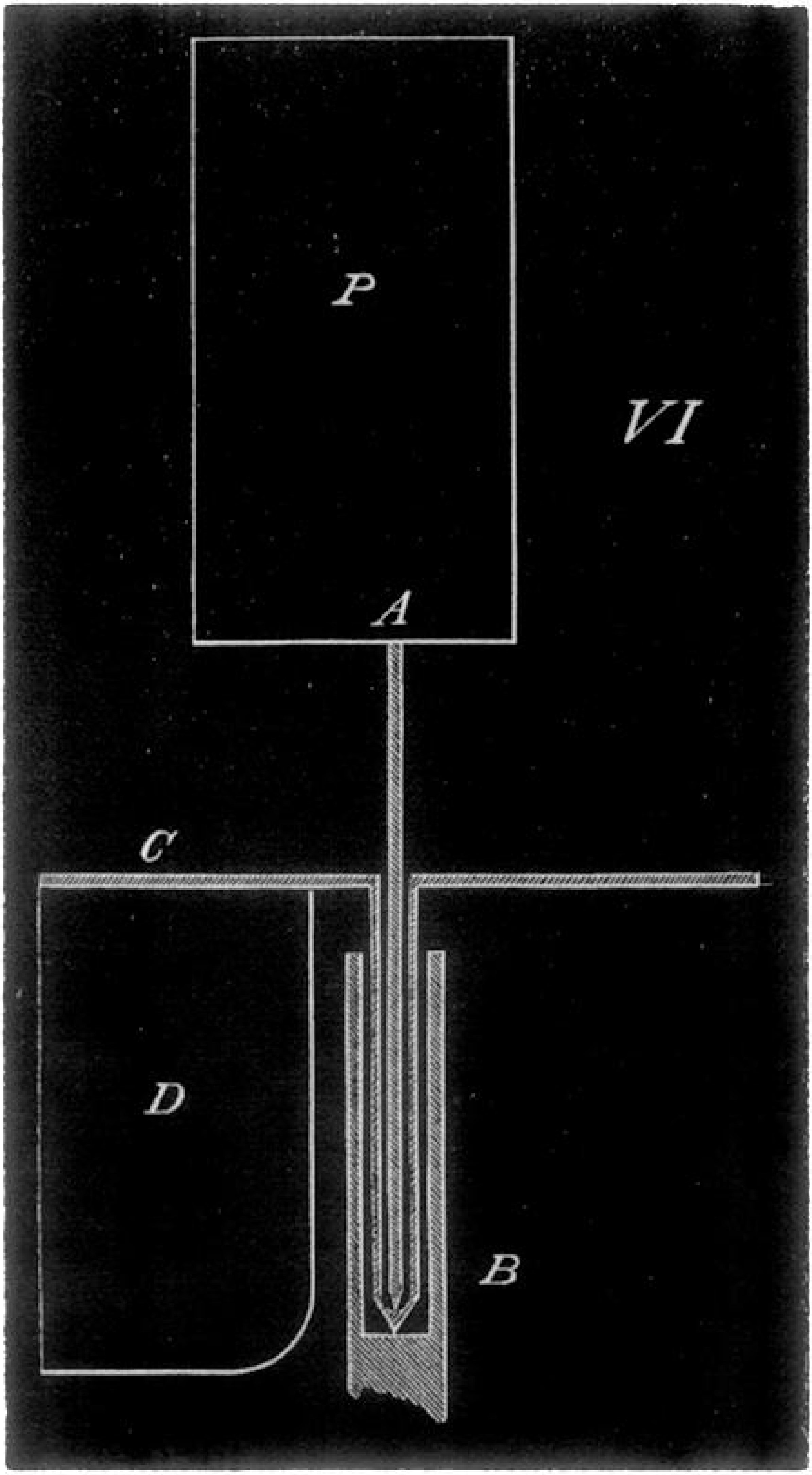
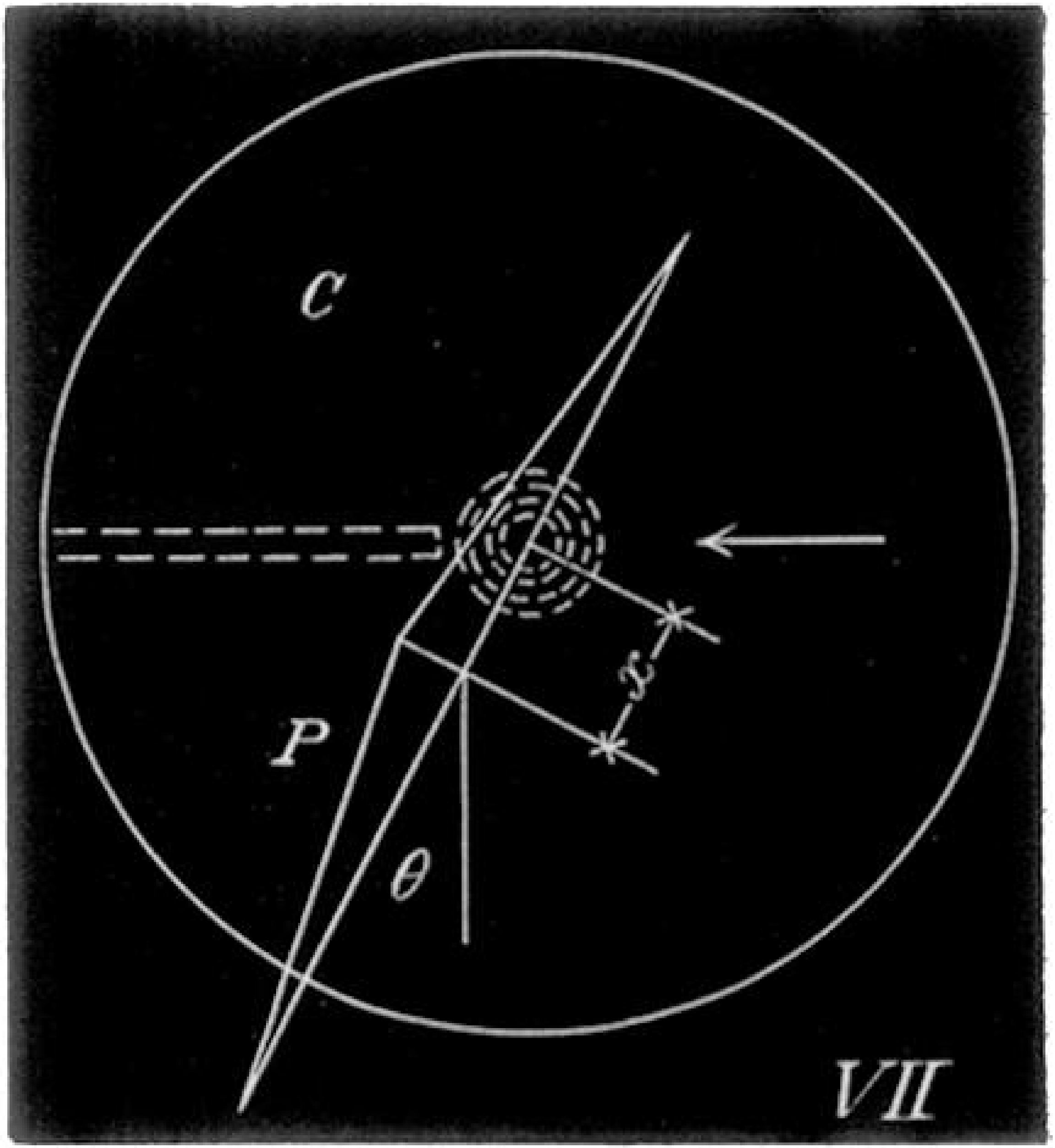


FIG. 7.



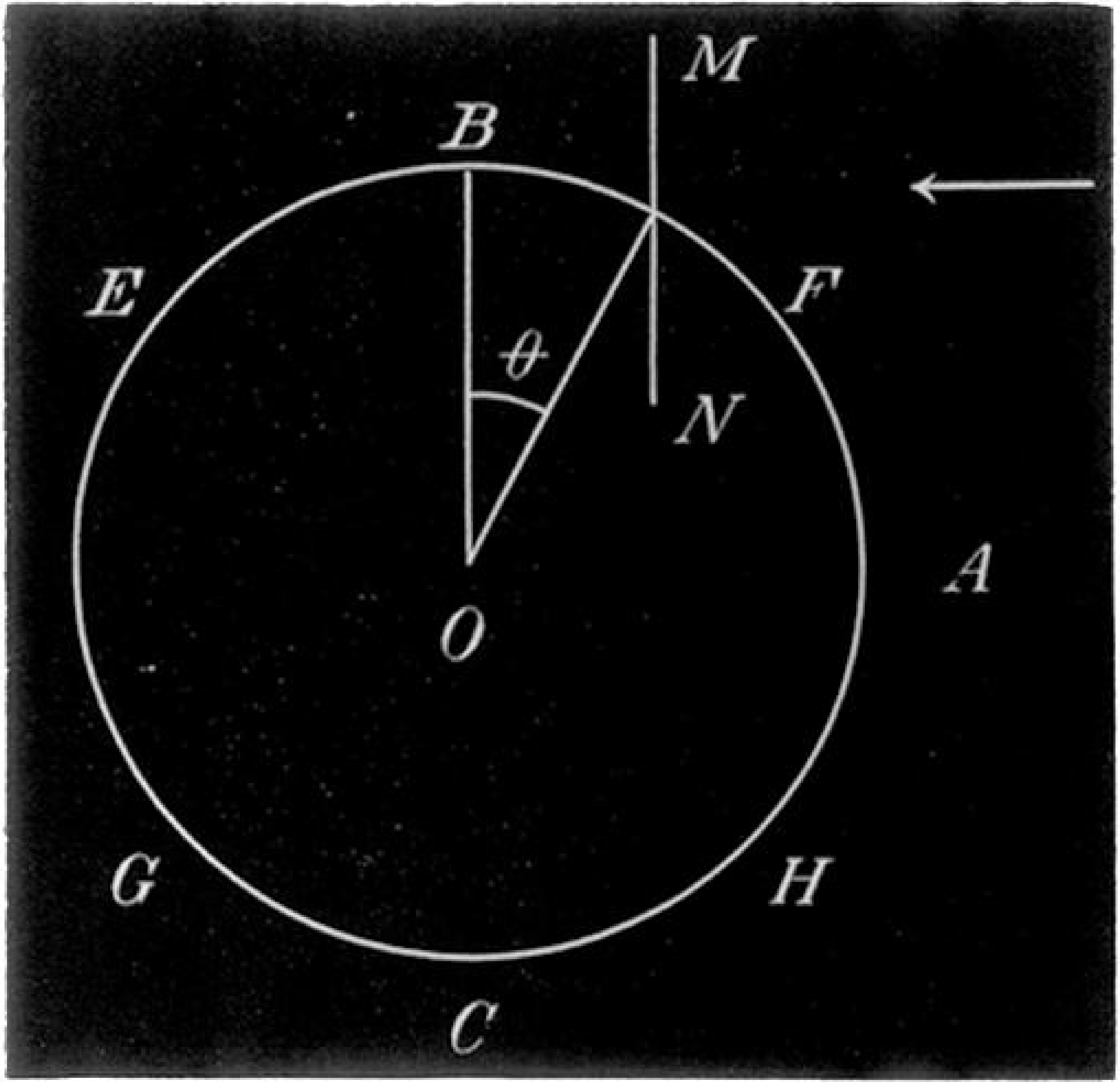

M
B
E
F
θ
N
A
O
G
H
C

FIG. 10.—Diagram of Normal Component.

From Positions II and IV.

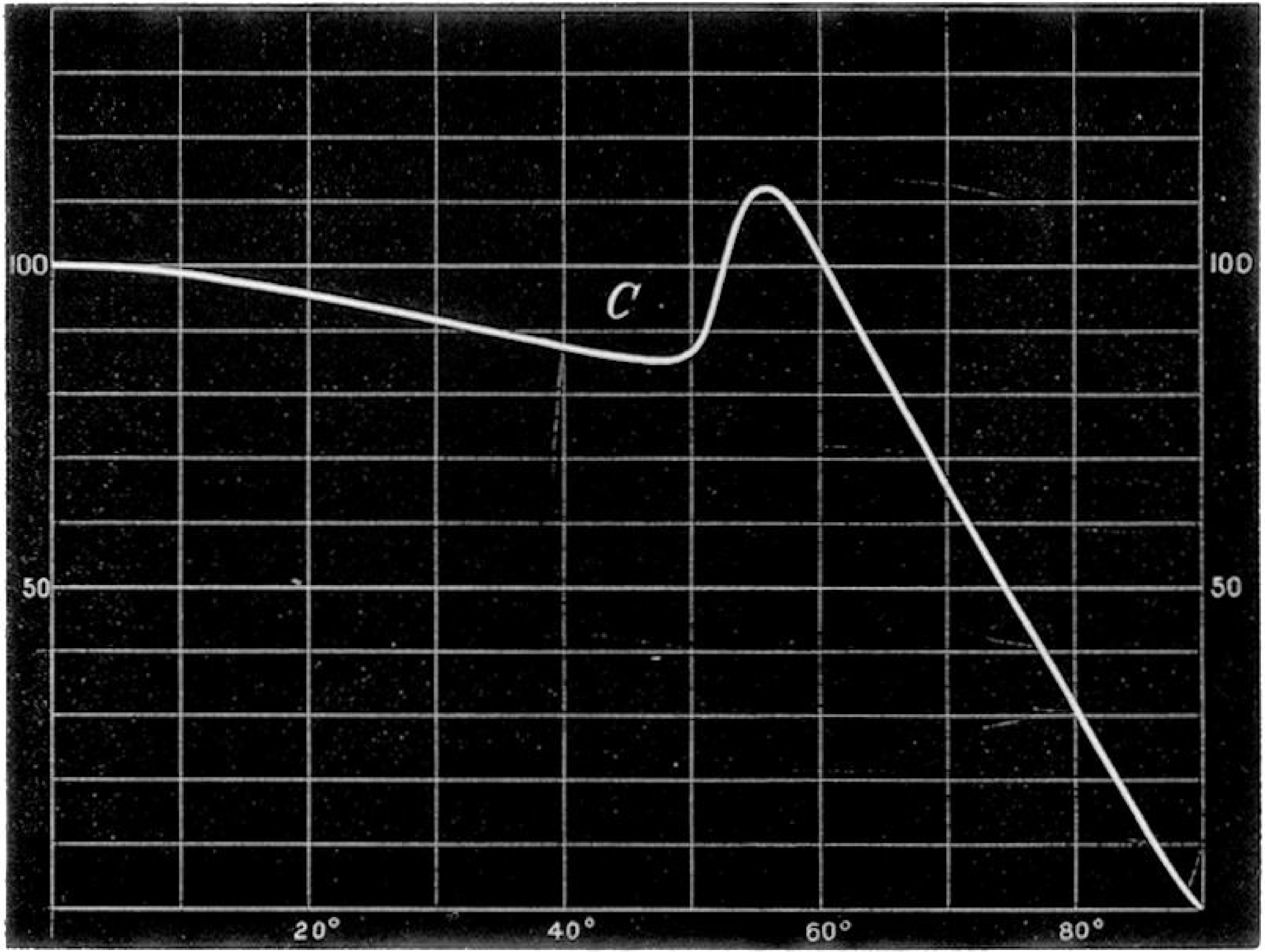
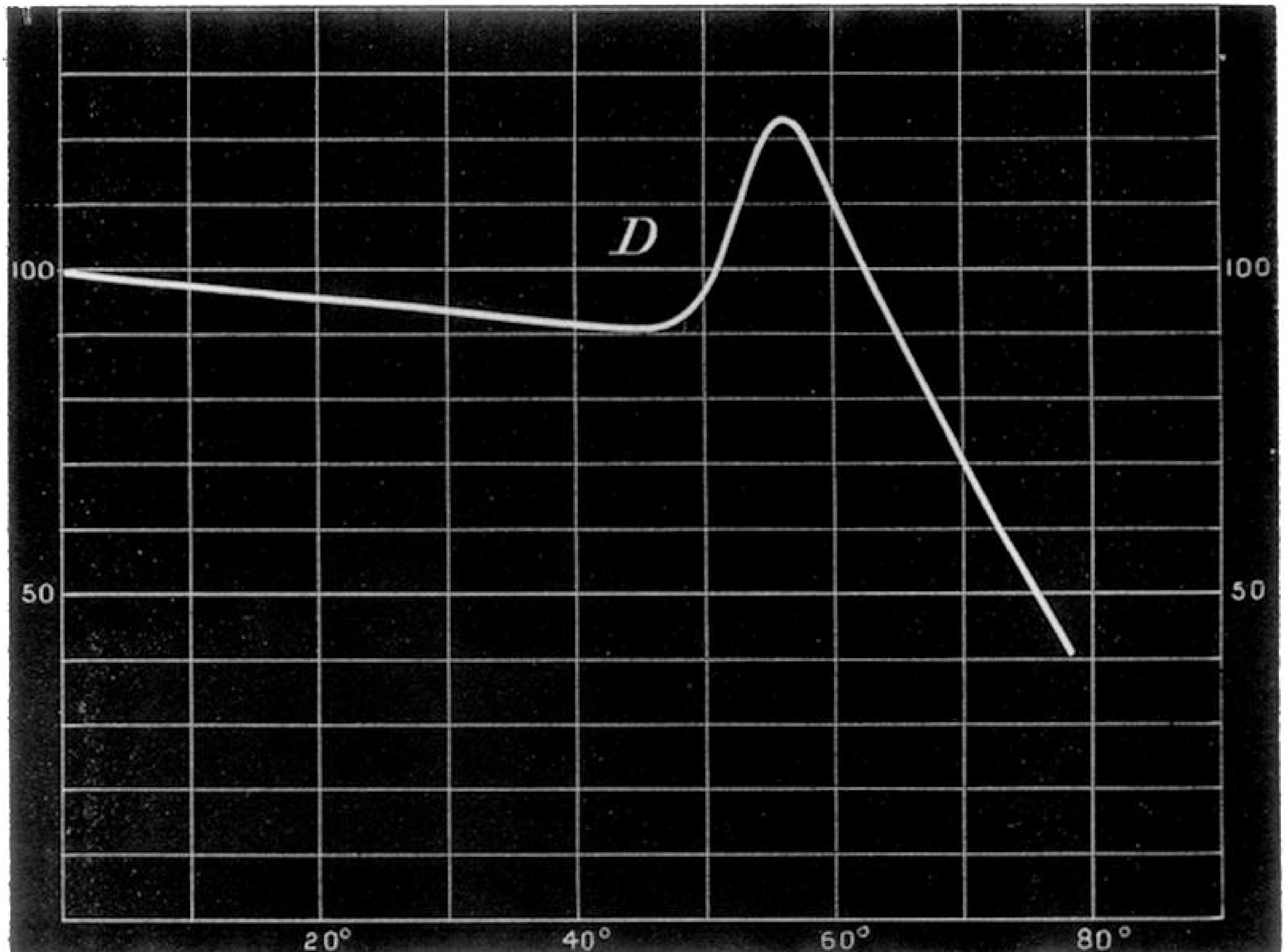
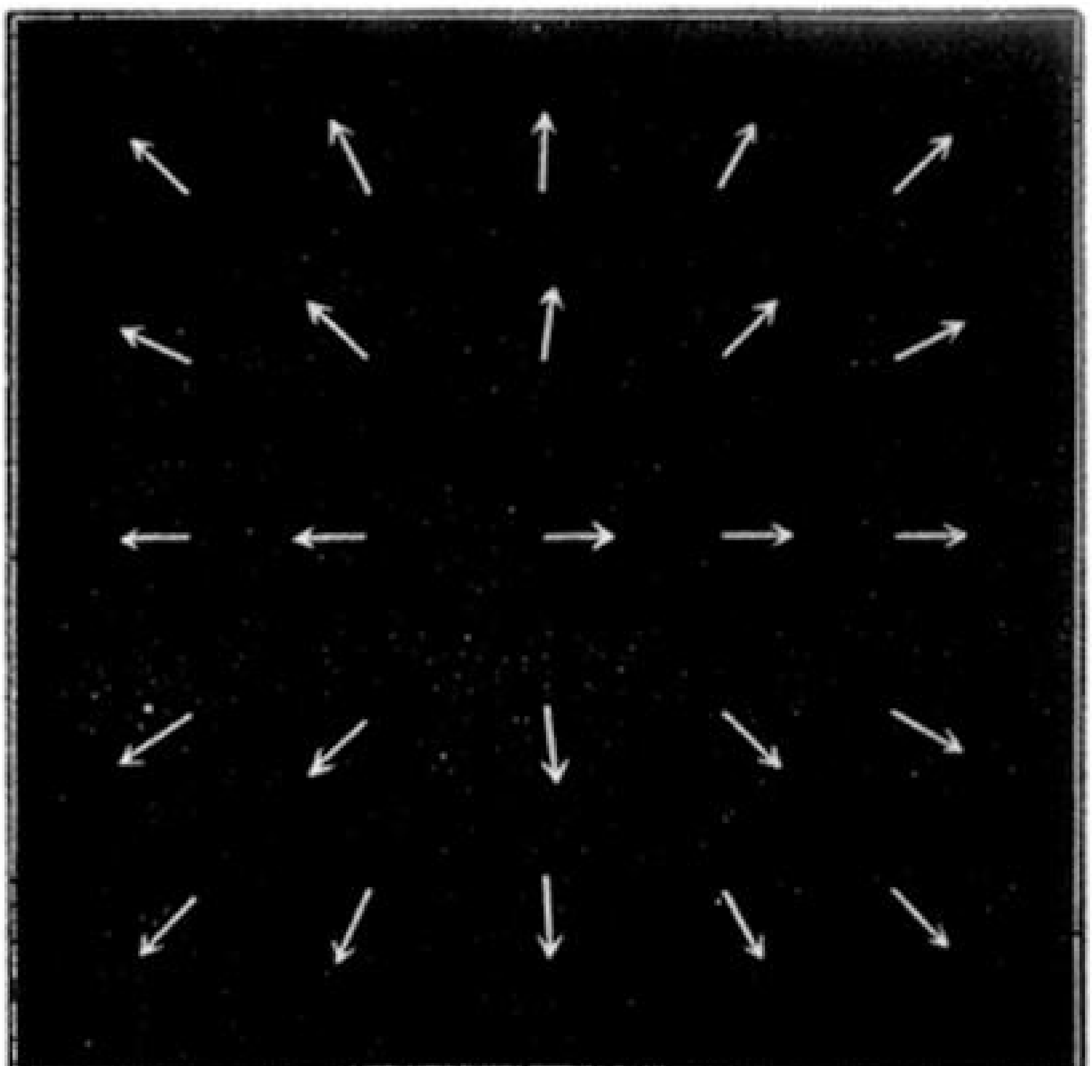
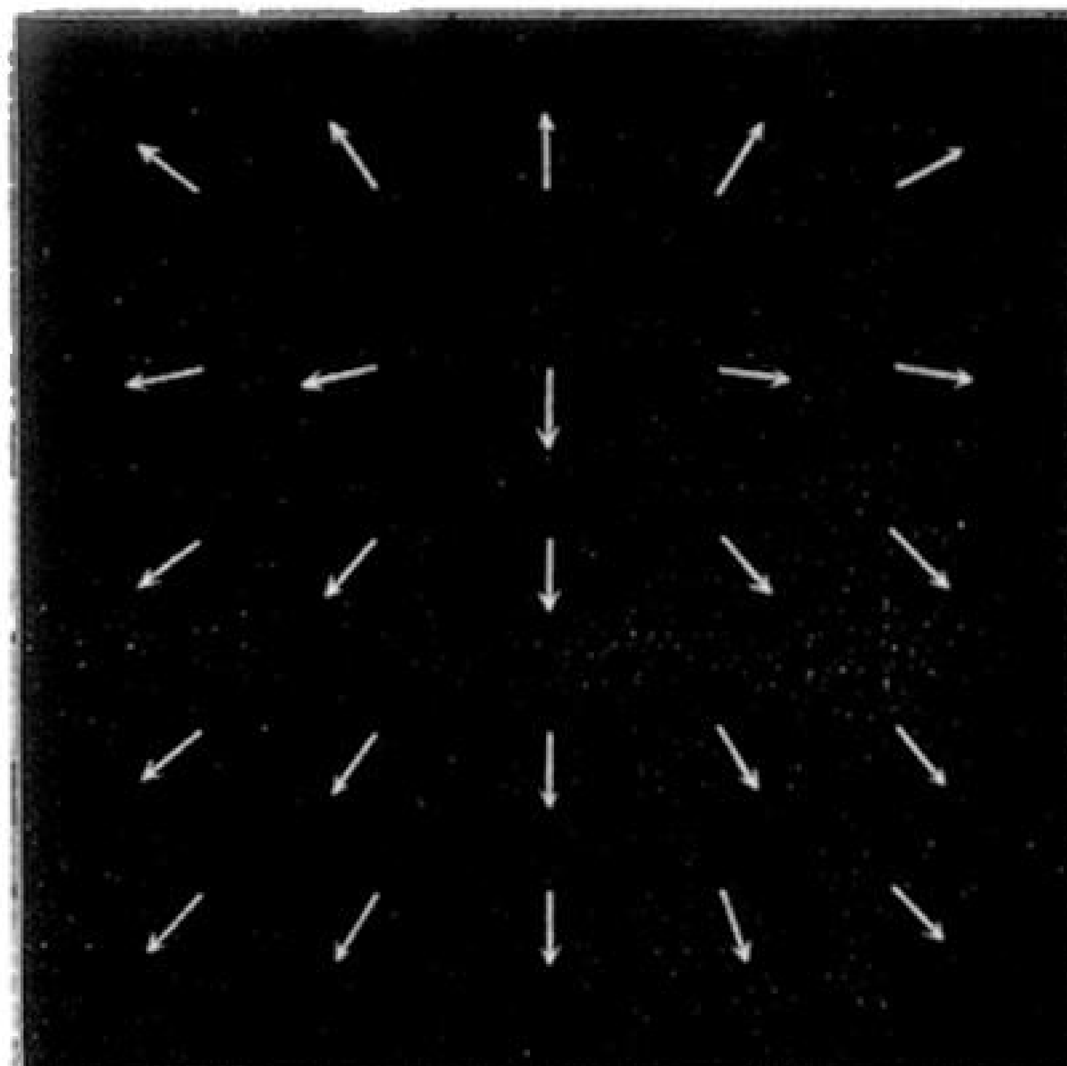


FIG. 11.—Diagram of Normal Component.
From Position II and Natural Wind Experiments.

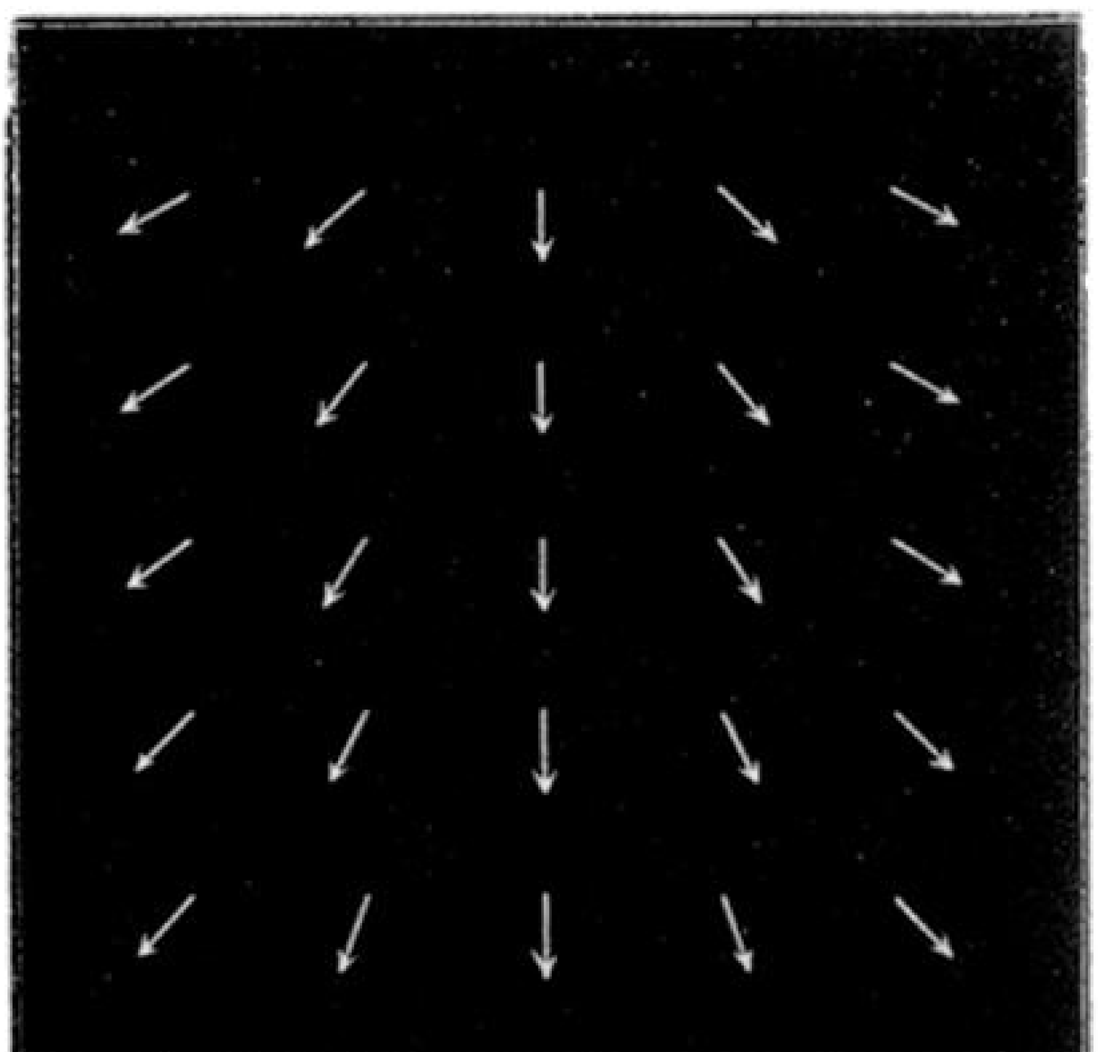




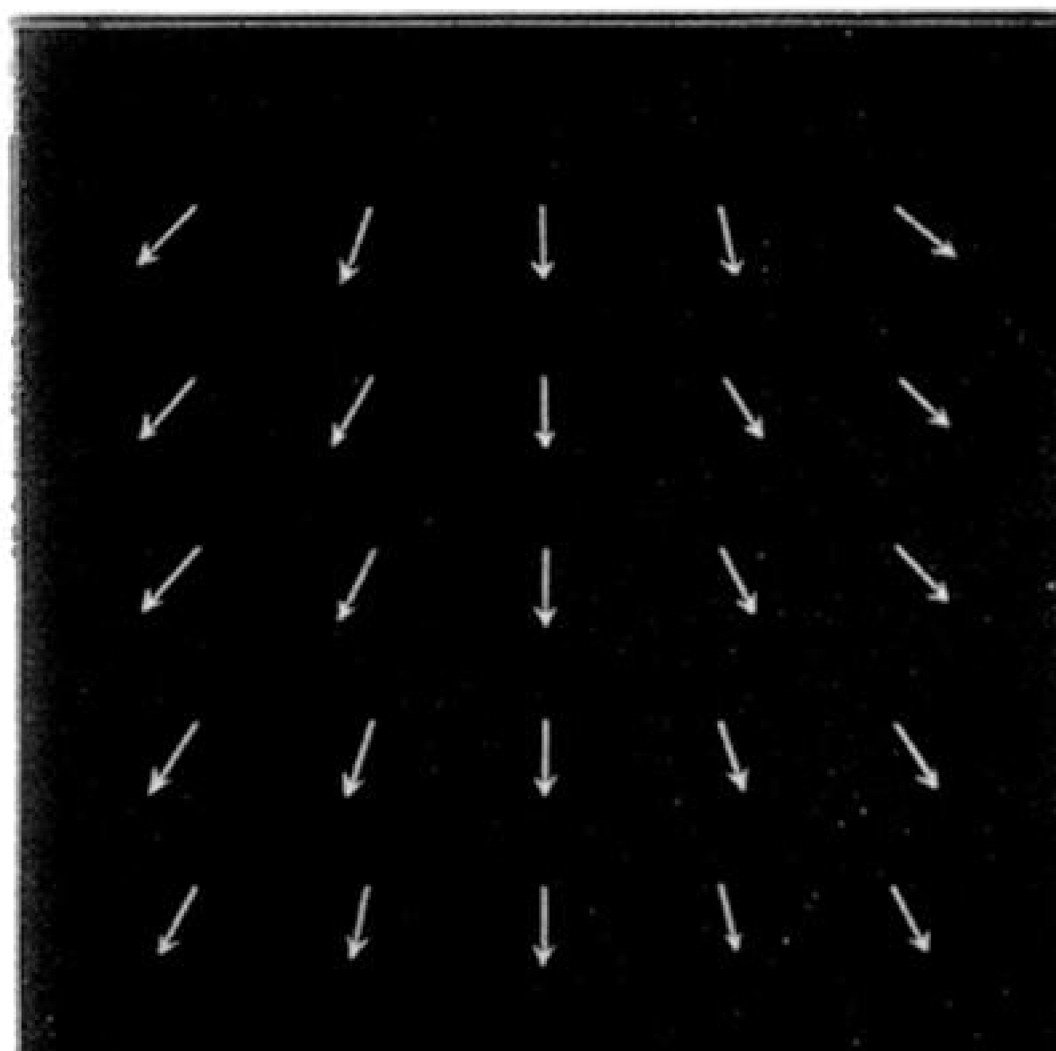
Front. 0°.



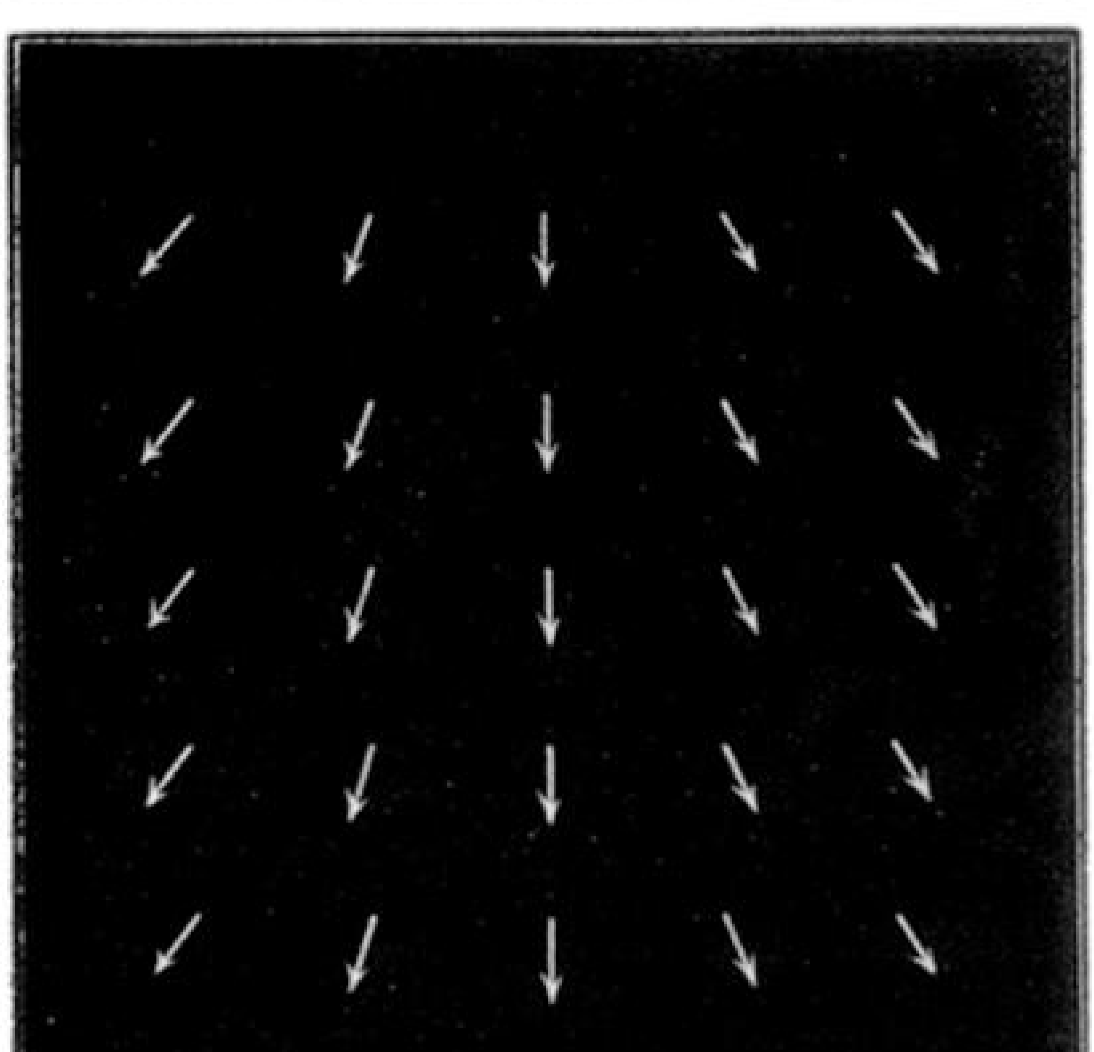
Front. 15°.



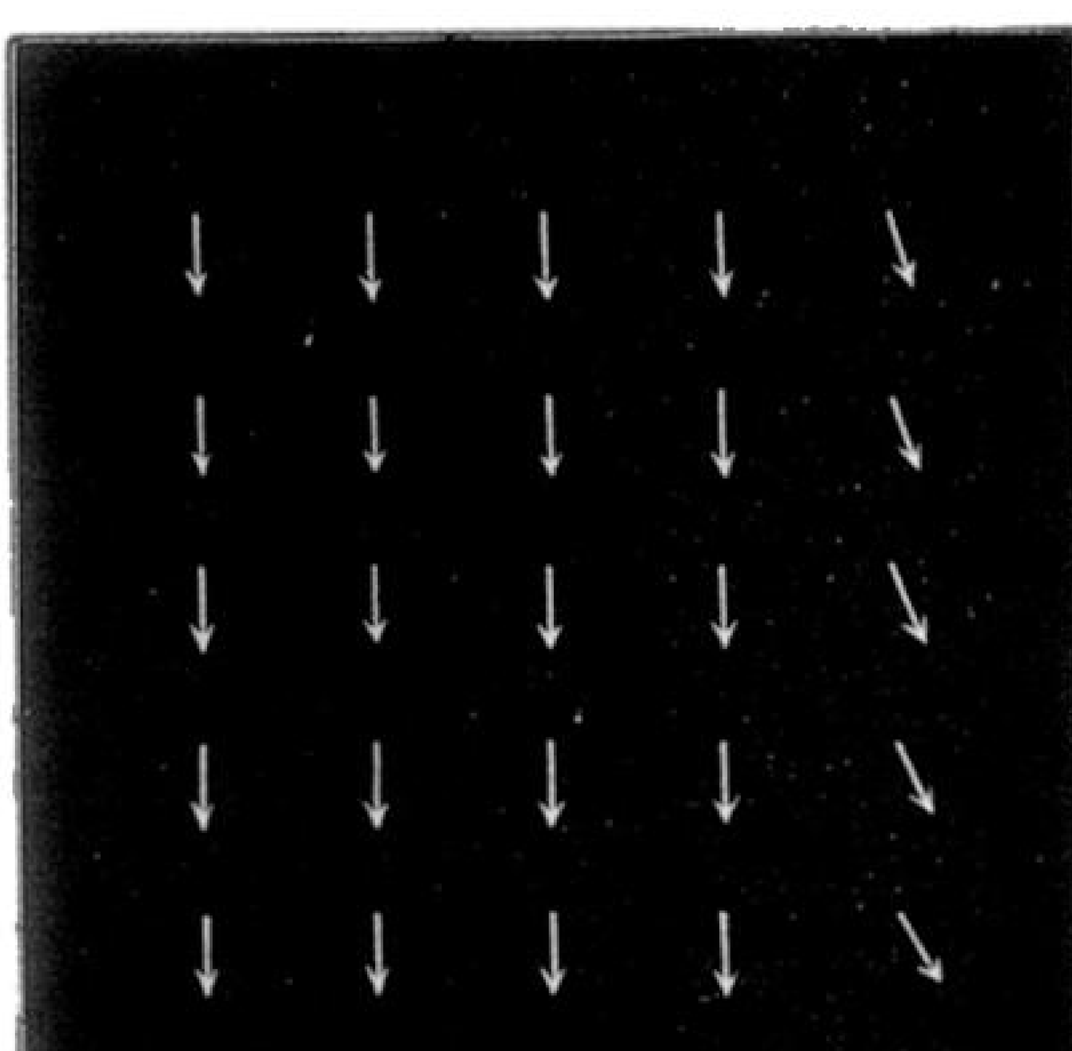
Front. 30°.



Front. 45°.



Front. 60°.



Front. 75°.

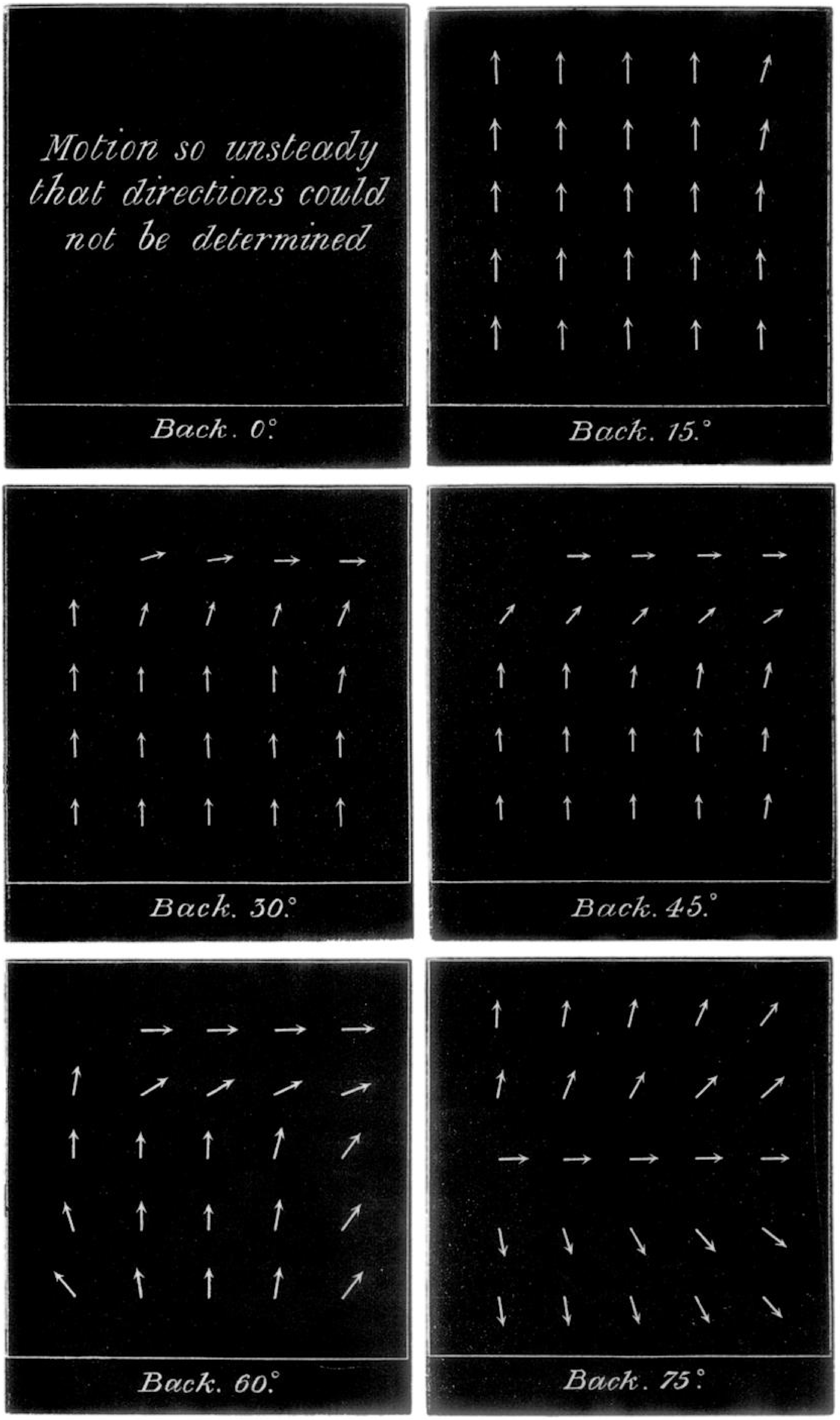

Motion so unsteady that directions could not be determined
Back. 0°.
Back. 15.°
Back. 30°.
Back. 45.°
Back. 60°.
Back. 75.°

Fig. 12.—Long Strip. Diagram of Moments.
Shorter Axis inclined to the Wind.

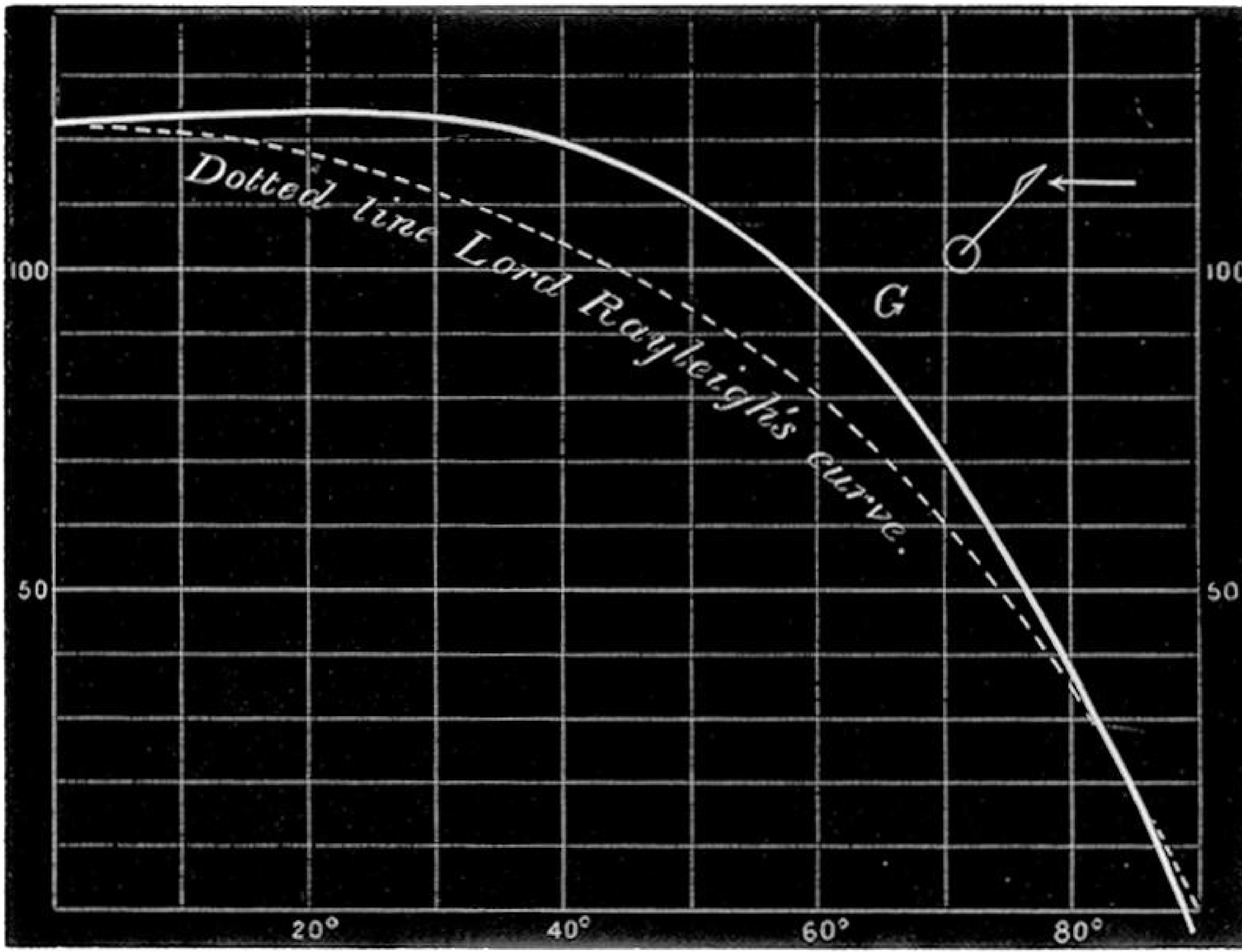


FIG. 13.—Long Strip. Diagram of Normal Component.
Longer Axis inclined to the Wind.