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Part IV. A Statistical Test for Percussion Sensitiveness of Initiators (Ball and Disk Machine)

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Phil. Trans. R. Soc. Lond. A 1948 **241**, 287-296
doi: 10.1098/rsta.1948.0020

PART IV

A STATISTICAL TEST FOR PERCUSSION SENSITIVENESS OF INITIATORS (BALL AND DISK MACHINE)

By W. J. Powell, H. Skelly and A. R. Ubbelohde

(*Report first issued by the Armament Research Department*, 3 *September* 1942)

[Plates 9 and 10]

Apparatus is described for subjecting various initiators to accurately reproducible blows, in such a way as to permit a large number of impact trials without undue labour, and thereby to determine probability of detonation for blows of graded violence.

Plots of the probability of detonation are given for various initiators, in relation to the velocity, momentum and kinetic energy of the steel drifts used for imparting the blow. It is not yet clear which of these factors is most important in determining sensitiveness to percussion.

Introduction

The impact machine and accessories described have been developed from an earlier Research Department test. By using easily replaced, accurately machined parts such as roller and ball bearings, and using filling plate technique, the test has been developed so as to carry out up to forty-eight impact trials at each impact height, without undue labour.

In order to make accurate comparisons of the sensitiveness of initiators to percussion, it is essential to carry out a large number of trials so as to measure the average probability of detonation at each of the impact heights selected.

Curves relating impact height with probability of detonation show reasonable reproducibility when based on this number of trials, and permit precise comparisons to be made between initiators of similar properties, such as basic and normal lead styphnate or Service and dextrin azides. Such comparisons are of value in orientating research on initiators.

Description of the machine

A general view is given of the machine in figures 46 and 47, plate 9, and of the accessories for preparing samples for trials in figures 48 and 49, plate 10.

The base of the machine is of massive mild steel, weighing about 300 lb. The anvils on which percussion takes place are $\frac{3}{4}$ in. roller bearings, as shown in figures 47, 48 and 49. These rest on a plate of case hardened steel, which forms the base of the horse-shoe shaped explosion chamber (figures 46 and 47 at the front).

The thin sandwich of initiator rests on the centre of this anvil, as can be seen in figure 48. It receives a blow from the hardened steel ball ($\frac{3}{16}$ in. ball bearing) mounted in the drift of toughened steel (Vibrac, hardened and tempered) which can been seen in figure 47 in position. When the $\frac{3}{16}$ in. ball becomes flattened by use, it can readily be replaced. This is of more frequent occurrence with violent initiators such as Service azide.

A momentum is imparted to this drift by allowing steel ball bearings of varying weights to drop on to it from various heights. The height of fall can be measured on the steel pillar seen in figures 46 and 47; this is graduated in inches.

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Accurate centering of the ball over the drift is essential, and is obtained by the screw adjustments which can be seen in figure 46.

The two cylindrical expansion chambers seen at the back of the main explosion chamber, in figures 46 and 47, were introduced in order to take up the shock wave energy when thick sandwiches of explosive are used.

A thick 'Tufnol' sliding door is shown closed and ready for firing in figure 46 and open in figure 47. It serves to prevent fragments of brass disks, and fumes from the explosion from reaching the operator.

The solenoid which holds up the steel balls is shown in figure 46. In order to ensure vertical release of the steel ball, this is separated from the iron core of the solenoid by a ring of rubber.

Immediately after impact, the fumes produced are removed by switching on a powerful suction fan. These fumes are filtered through cotton wool, and to avoid the risk of explosion from accumulated initiator dust, this cotton wool is destroyed at suitable intervals. Suction tubes for removing the fumes can be seen in figures 46 and 47.

Filling and handling of the charges

Six $\frac{3}{4}$ in. roller bearings are if necessary repolished before use, with fine emery, and are placed in position in the Tufnol holding plate in figure 49. A brass disk is then placed at the centre of each of these rollers, using the kit stick with a plasticene tip, as illustrated in figure 49.

The brass disks have diameter approximately $\frac{1}{4}$ in., thickness 0·002 to 0·003 in. Disks which are unduly curved or defective are not used.

The filling plate is positioned over these disks (figure 48) and the composition is gently brushed over the holes in the plate, so as to leave a flat layer of composition on each disk, when the plate with excess composition is lifted away. The holes in the plate are slightly smaller than the disk. After lifting away the plate, a second disk is positioned over the layer of explosive (figure 49). The charges are then ready for transfer to the percussion chamber.

After some practice the weight of composition per disk is constant to about ± 5 %.

Plates of various thickness were conveniently made by impregnating thin paper with bakelite, and pressing a suitable number of layers together in a heated press. Clean holes were punched by mounting these plates between two flat steel plates with holes as required, and using a sharp steel punch.

The usual precautions in working with sensitive compositions are taken during all these filling operations.

Method of firing and recording the results

Each roller with its charge is lifted in turn by tongs with special curved ends and is pushed into the percussion chamber whilst the drift is removed. The horse-shoe guide over the hardened base plate of this chamber automatically centres these rollers under the drift. The Tufnol plate of the percussion chamber is closed at this stage, to prevent damage from any premature explosion which might occur.

A Tufnol tamping drift with end of diameter $\frac{1}{4}$ in. is now placed in the position subsequently occupied by the steel drift, and a weight of 1 kg. is applied on to it, so as to give each charge a standard tamping.

This tamping piece is not shown in the figures; its shape is identical with that of the steel drift which holds the percussion ball, except that the end resting on the charge is flat.

When the charge has been tamped, the small steel ball with its drift is gently lowered on to it, and the blow is delivered by switching off the current through the solenoid, so as to allow the spherical steel ball to fall.

If the charge detonates (recorded as *G*) the suction pump is switched on to remove fumes. If no detonation occurs (recorded as *N*) the Tufnol door of the percussion chamber is opened and the initiator is completely removed by swabbing before inserting a fresh charge.

In carrying out a systematic test on a composition, the steel ball is dropped from various heights. At each height 48 different samples (i.e. 8 fillings of the charge plate) are tested. The sort of errors which would be introduced by making fewer tests may be illustrated from a typical determination with lead styphnate (weight of ball = 254·8 g., 0·016 in. filling plate, height of fall 6 in.).

G	*N*	*N*	*G*	*N*	*N*
N	*N*	*G*	*G*	*G*	*G*
G	*N*	*G*	*N*	*N*	*G*
G	*N*	*N*	*G*	*G*	*N*
G	*N*	*N*	*N*	*N*	*N*
N	*N*	*N*	*N*	*N*	*N*
N	*G*	*G*	*N*	*N*	*N*
G	*N*	*G*	*N*	*G*	*N*

The average probability of detonation is 38 %, and falls on the smooth curve relating probability with height of fall of the ball. The probability which would be calculated from any six determinations shows big fluctuations about this mean; experience has shown that forty-eight determinations give a fair average even when the probability of detonation is around 50 %. Probability theory suggests that fluctuations are at their largest around this value. Heights of fall were selected so as to give a range of detonations from 100 to 0 %.

Experimental results

Tests were carried out with 664, mercury fulminate, L.D.N.R., basic lead styphnate, (commercial) normal lead styphnate, dextrin azide, Service azide, and A.S.A. made from Service azide.

664 and fulminate required the use of the 130 g. ball to give a sufficiently open scale of heights of fall. All the other initiators were tested with a 225 g. ball, and lead styphnate was also tested with ball weighing 535 g.

Effect of velocity of impact, etc.

Inspection of the percussion curve for commercial lead styphnate (figure 50), showed that if the probability of detonation was plotted against the initial velocity of the drift calculated according to standard laws of impact (appendix II), the points fell substantially on the same curve irrespective of the weight of ball (255 or 535 g.) used.

This suggested a plot of the probability of detonation against the initial velocity of the drift as the best means of representing all the sensitiveness data on a single scale. Curves in figures 50 to 53 have been plotted on this scale. In order to obtain a figure to represent the sensitiveness of various initiators on a comparative scale, the areas under the graphs were calculated, taking the area under the fulminate graph as standard (10 units). The slope of the curves around 50 % detonation was also measured.

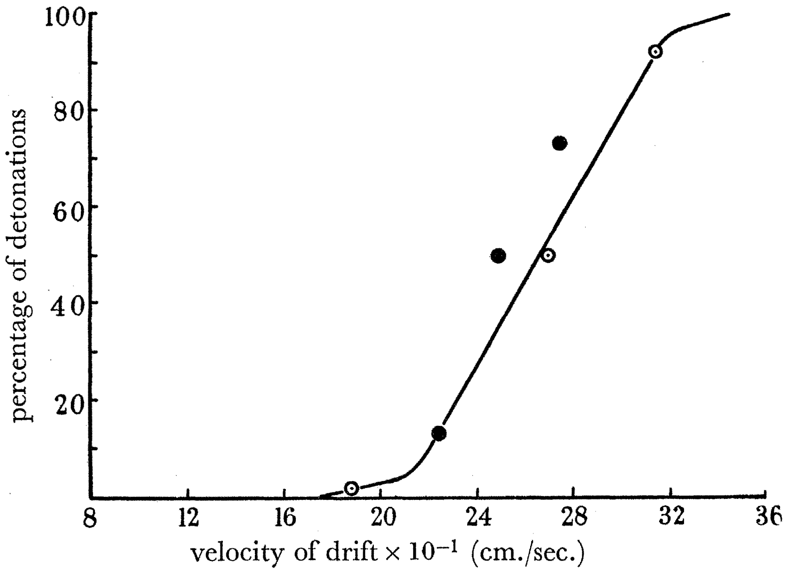

FIGURE 50. Percussion curve for commercial lead styphnate. ⊙ 255 g. ball; ● 535 g. ball.

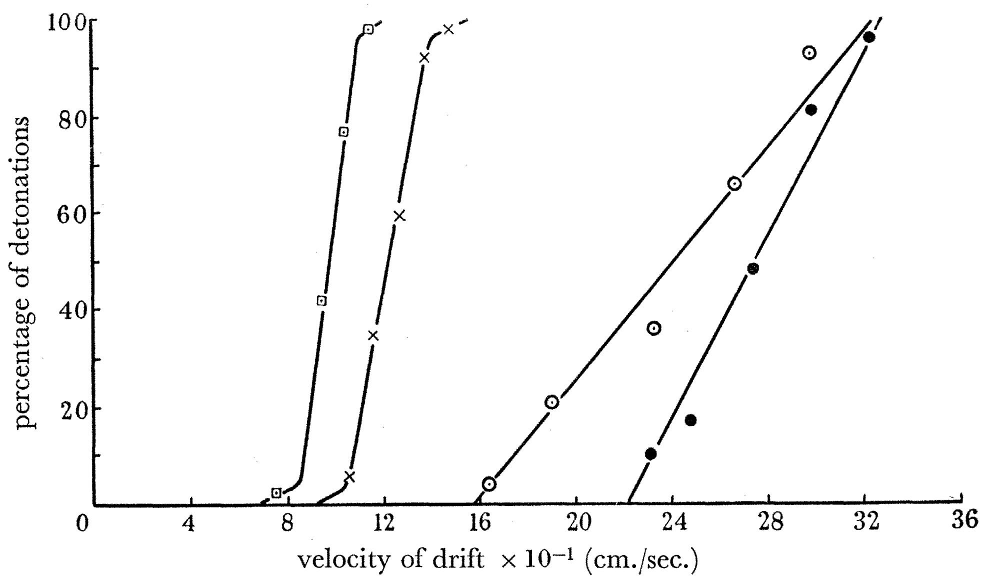

FIGURE 51. Percussion curves of ⊡ 664; × mercury fulminate; ⊙ Service azide; ● dextrinated azide.

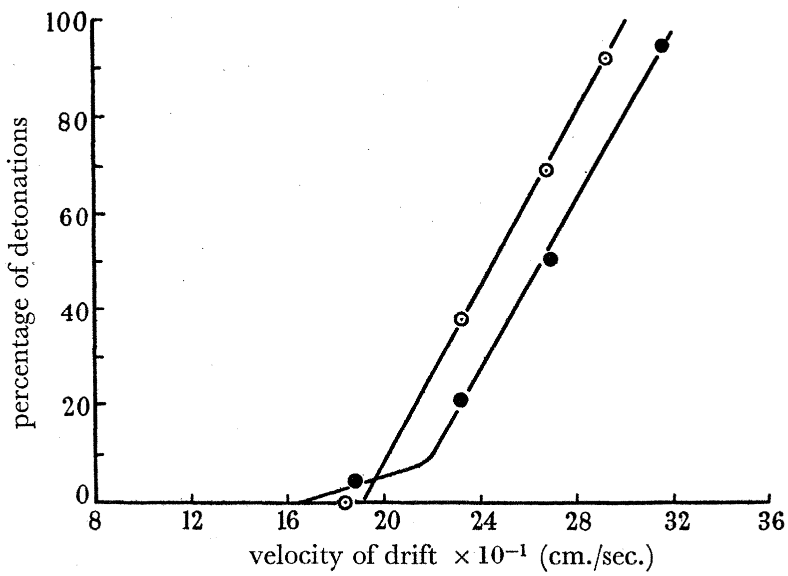

FIGURE 52. Percussion curves of ⊙ coarsely crystalline lead styphnate; ● I.C.I. lead styphnate.

On this scale the least sensitive initiators would have the largest areas. For two initiators with equal areas, the composition with the steepest slope around 50 % would have the smaller marginal sensitiveness for small blows.

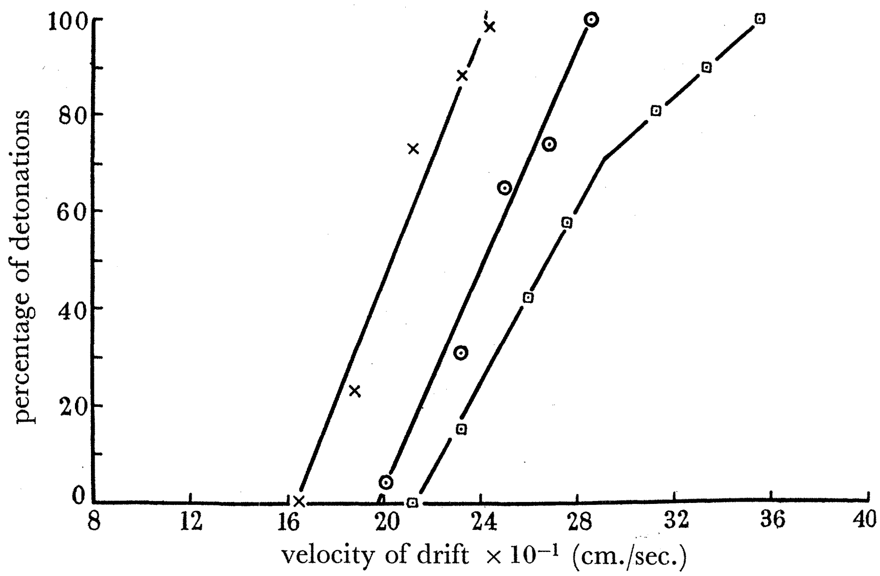

FIGURE 53. Percussion curves of × L.D.N.R.; ⊙ basic lead styphnate; ⊡ A.S.A.

Effect of thickness of layer of explosive

The filling plate was selected according to the properties of the explosive under test. From the experiments described, a 0·012 in. filling plate would appear to be the most serviceable for general use.

In exploratory experiments a 0·024 in. plate was used for 664, mercury fulminate and Service azide, and an 0·008 in. plate was used for basic lead styphnate and A.S.A. It was verified in the case of lead styphnate that 0·008 and 0·024 in. filling plates gave practically the same curve of sensitiveness. Since the probability of detonation did not appear to be sensitive to the thickness of explosive used, the thickness of the plate was selected to give easy filling and a good detonation, with the minimum quantity of explosive.

Checks with an inert material were made to test the weight constancy of the explosive retained by the holes in the filling plates. When no brass disks were used, it was found that the weights delivered on each Hoffman roller were constant to $\pm 1{\cdot}5$ %. With a bottom brass disk, the variation in weight of explosive was somewhat larger ($\pm 4{\cdot}5$ %), owing to small differences in thickness and curvature of the disks. In view of the fact that the probability of detonation does not appear to be sensitive to the thickness of the layer of explosive, within the range investigated, these minor variations in weight may be neglected.

DISCUSSION

The following comments may be made on the results listed in table 50.

(1) It will be noted that with the exception of compositions based on mercury fulminate or L.D.N.R. (lead di-nitro-resorcinate), the percussion sensitiveness of all the other initiators listed in table 50 is of the same order.

Table 50. Comparative sensitiveness to percussion

initiator	figure of sensitiveness	slope around 50 % detonation
664	7·2	82°
mercury fulminate (standard)	10·0 (standard)	78°
4·6 basic L.D.N.R.	15·7	67°
basic lead styphnate	19·0	66°
Service azide	19·2	50°
lead styphnate (free from dust)	20·2	60°
lead styphnate (commercial)	21·5	58°
dextrin azide	21·7	68°
A.S.A. (from Service azide)	22·1	61°/43° (broken curve)

This shows that percussion sensitiveness cannot be directly related to sensitiveness to heat, as measured by the activation energy controlling the induction period before ignition. Detailed illustration of this conclusion may be obtained from a number of comparisons, e.g. between lead styphnate, for which the heat sensitiveness equation is

$$\log \gamma = +\frac{61{,}000}{4{\cdot}57\,T} - 21{\cdot}9$$

and dextrinated lead azide, for which the equation is

$$\log \gamma = \frac{23{,}400}{4{\cdot}57\,T} - 8{\cdot}2.$$

In spite of this difference in heat sensitiveness, the sensitiveness to percussion is much the same.

Furthermore, lead styphnate prepared free from fine dust has practically identical heat sensitiveness with I.C.I. styphnate; it shows a somewhat greater sensitiveness to percussion, probably on account of the more uniform crystal size preventing slipping away of material under the action of a blow (figure 52).

(2) Comparison of measurements of percussion sensitiveness with other sensitiveness tests on initiators suggest a fairly close parallel with the friction sensitiveness figures obtained in the absence of grit, i.e. when the explosive is rubbed between metal surfaces.

This suggests that an analogous mechanical action is involved in both these tests.

The fact that the sensitiveness neither to grit friction nor to heat follows the same sequence as percussion suggests that percussion sensitiveness is a specific measure of the susceptibility to mechanical shock or to a pressure pulse, as distinct from the tendency to detonate due to the formation of local hot spots.

Momentum and energy factors in the sensitiveness to percussion

(a) *Calculation of the velocity of the drift*

If the velocity of the falling ball of mass M is V before impact and V' after impact, and the velocity of the drift of mass m (initially at rest so that $v = 0$) is v before impact and v' after impact and e is the coefficient of restitution, standard theory gives

$$v' = \frac{MV(1+e)}{(M+m)}.$$

For the impact of the hardened ball bearing on the toughened steel of the drift, e may be taken as 0·9 (cf. Chapman 1942). Also $V = \surd(2gh)$, where H is the height of fall of the ball.

In the experiments described, the drift normally weighed 107 g., including the small $\frac{3}{16}$ in. ball which imparts the blow to the explosive. Thus with the various falling balls used,

$$v' = 46{\cdot}15\sqrt{H} \quad \text{for the 130 g. ball,}$$
$$= 59{\cdot}32\sqrt{H} \quad \text{for the 255 g. ball,}$$
$$= 70{\cdot}18\sqrt{H} \quad \text{for the 535 g. ball.}$$

In these equations, v is given in cm./sec. if H is measured in centimetres.

(b) *Momentum and energy factors in the detonation of initiators by percussion*

A special series of tests was carried out in order to determine whether the probability of detonation of an initiator was chiefly determined by the momentum or the kinetic energy of the drift. This information is of theoretical interest in interpreting the process of detonation by impact, and is also of some importance in indicating the kind of impact risks to avoid in practice.

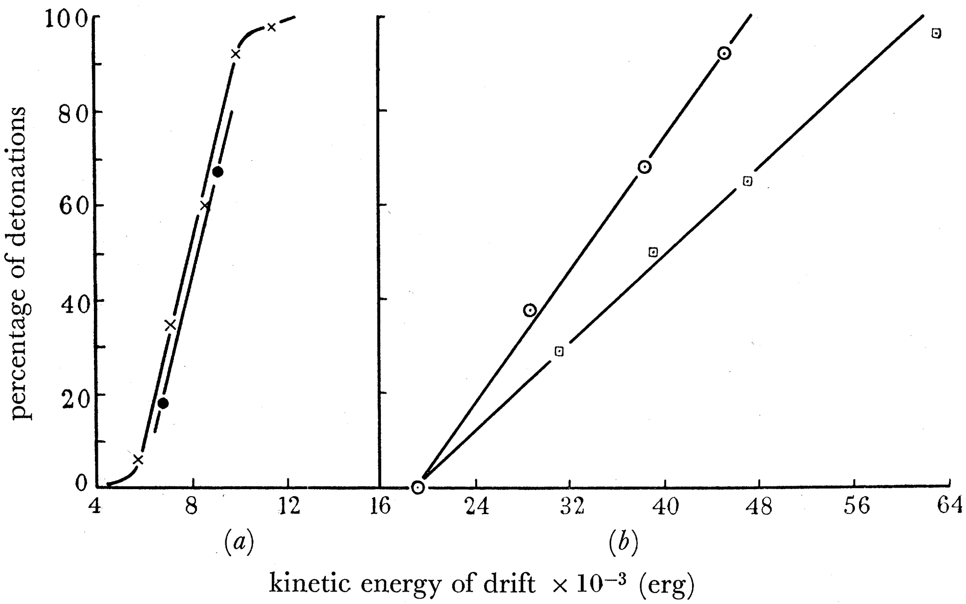

FIGURE 54. (*a*) Mercury fulminate, × heavy drift, ● light drift. (*b*) Coarsely crystalline lead styphnate, ⊙ heavy drift, ⊡ light drift.

For this investigation one of the normal drifts was reduced in weight by about one-third, by machining away metal from two holes at right angles to the axis, and from the top rim. Using this lighter drift, the probability of detonation was determined with lead styphnate and with mercury fulminate, at various impact heights.

The effect of reducing the weight of the drift is to decrease the probability of detonation when other conditions are the same. Since with decreased mass m the velocity of the drift would be greater, this result indicates that a larger mass must compensate for a smaller velocity of drift, in determining the probability of detonation.

Plots of the probability of detonation for mercury fulminate, and for lead styphnate have been tried both as a function of the momentum, and the kinetic energy of the drift (figures 54 and 55).

It will be seen that with different weights of drift, the momentum curves are parallel, whereas the kinetic energy curves show no correspondence in the case of lead styphnate, and practically superpose with mercury fulminate. In the momentum curves, the lighter drift gives a greater probability of detonation with both styphnate and fulminate.

A reasonable interpretation of these results is that the probability of detonation is determined by the momentum of the blow, but that a fraction of the momentum of the drift is lost owing to imperfect rigidity of the supports for the initiator (i.e. the brass disks, the Hoffman roller, etc.). This imperfect rigidity would on dynamic grounds be more important for the heavier drift.

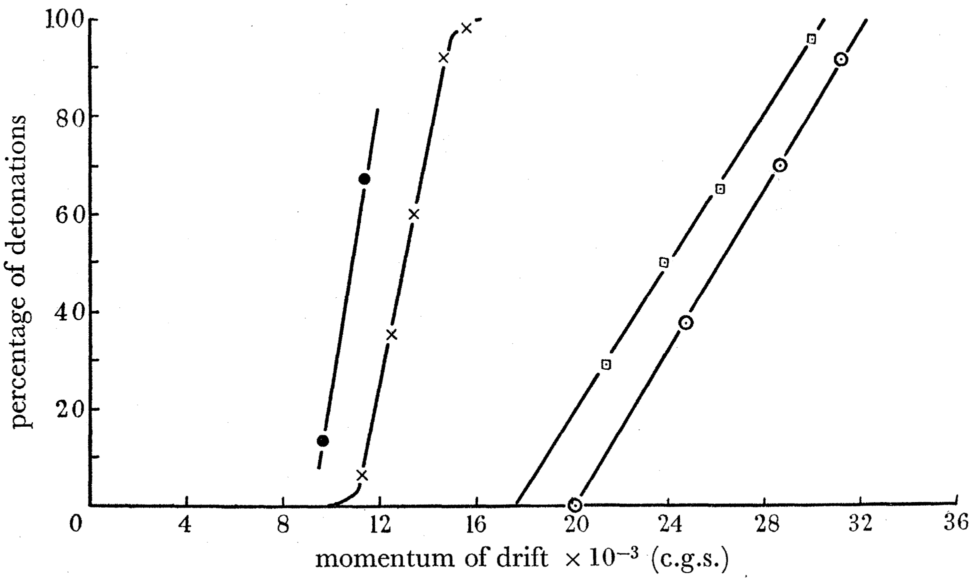

FIGURE 55. Mercury fulminate, × heavy drift, ● light drift. Coarsely crystalline lead styphnate, ⊙ heavy drift, ⊡ light drift.

More specific information on the dynamical variables which determine the probability of detonation could be obtained from measurements of the time intervals involved in the various processes.

It is of interest to note that Taylor & Weale (1932) found that the probability of detonation was determined by the kinetic energy of the blow, less a correction for energy losses. Their apparatus was dynamically not quite the same, since no brass disks were used. This may be preferable on theoretical grounds, though it would lessen the 'squeezing' of composition between brass and steel, which simulates a definite practical risk.

Thanks are due to Sir Robert Robertson, F.R.S., for his continued interest and encouragement in this work and to The Director General of Scientific Research and Development for permission to publish.

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Description of Plates 5 to 10

Plate 5

Figure 10. Photomicrographs of (*a*) Service azide and (*b*) dextrin azide (×66).
Figure 11. X-ray powder photographs of (*a*) Service azide and (*b*) dextrin azide.

Plate 6

Apparatus for measuring relative sensitiveness to grazing friction.

Figure 34. General arrangement of apparatus.
Figure 35. Tilting table showing paper clamps and levelling bolt.
Figure 36. End view of tilting table.

Plate 7

Figure 37. Service lead azide (×100).
Figure 38. Service lead azide after strike with emery surfaces (×100).
Figure 39. Service lead azide after strike with steel surfaces (×100).
Figure 40. Dextrinated lead azide (×100).
Figure 41. Dextrinated lead azide after strike with emery surfaces.
Figure 42. Dextrinated lead azide after strike with steel surfaces.

Plate 8

Figure 43. Glazed paper balance for handling compositions. *A*, stock of lead azide; *B*, scoop for transferring azide to balance. The balance is in the tipped-up position in which the lead azide slides off into the chute.

Plate 9

Figure 46. General view of the percussion apparatus showing the weight ready to drop from the solenoid; the explosion chamber is closed.

Figure 47. Explosion chamber opened to show layer of initiator in position between a steel ball held in the drift, and the steel anvil.

Plate 10

Figure 48. Filling plate for making layers of explosive of uniform thickness and diameter.

Figure 49. Holding plate showing three charges completed for testing by impact, and the positioning of the upper brass disk on a fourth charge.

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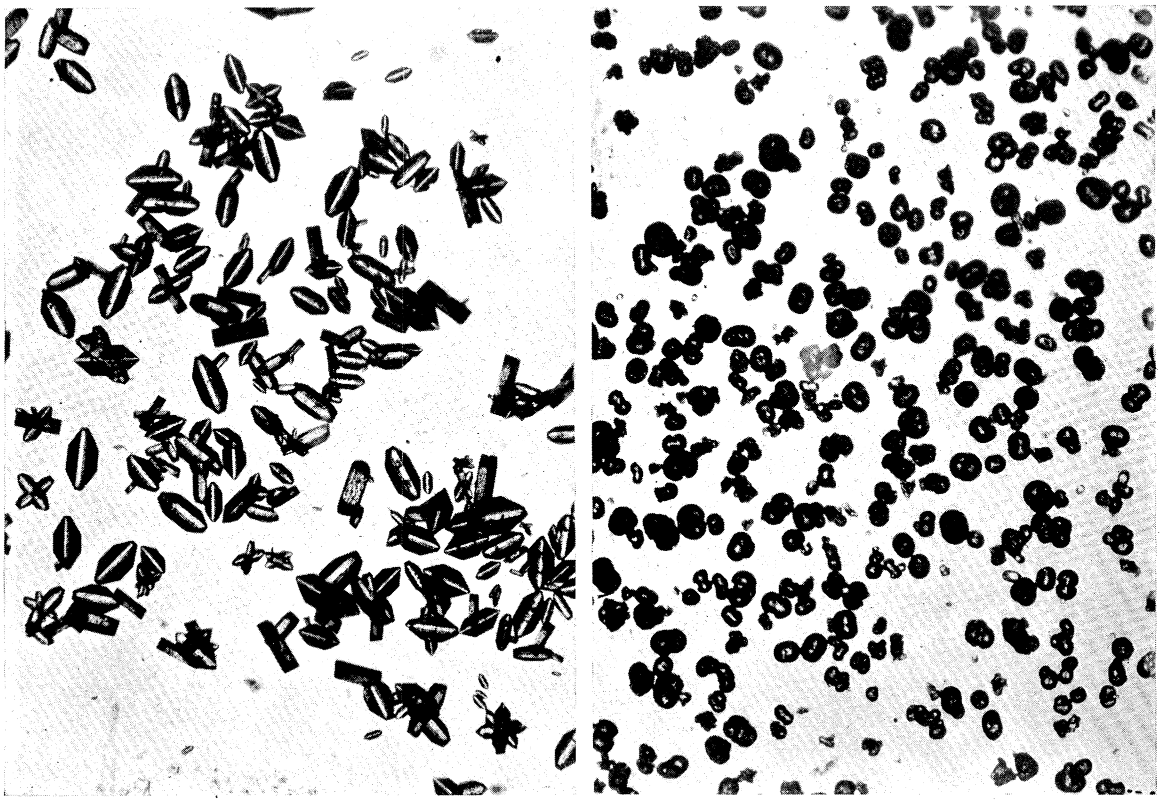
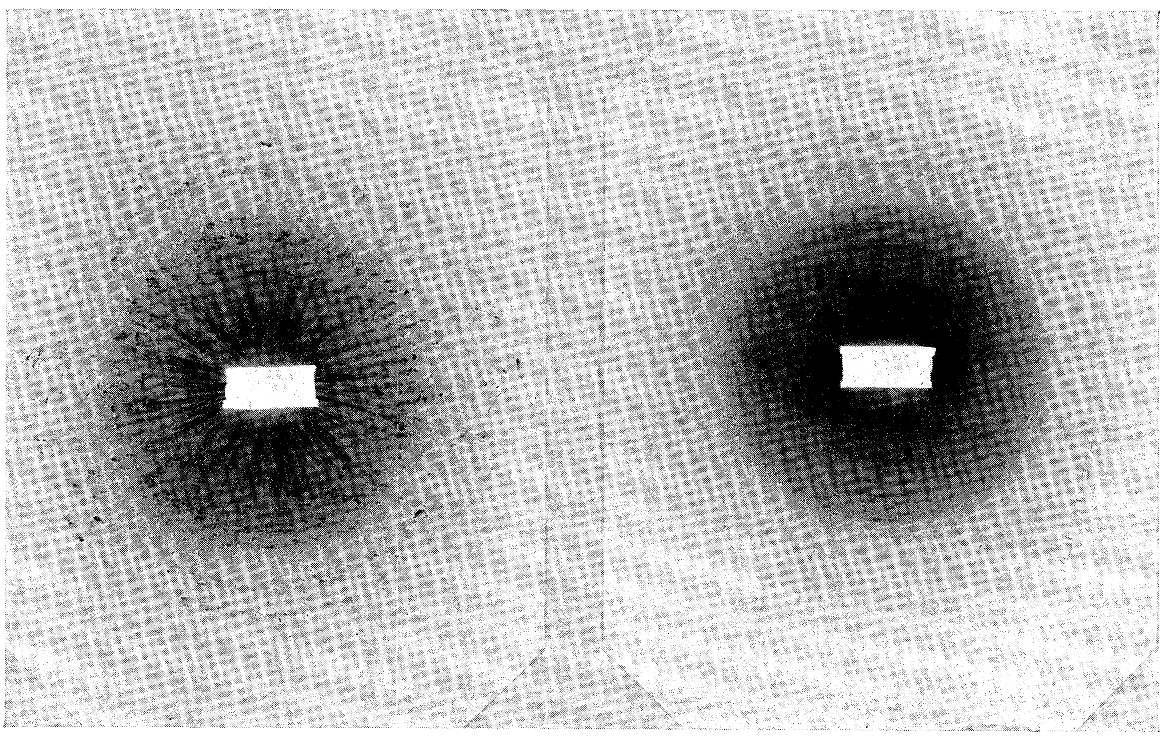


(*a*) (*b*)

Figure 10



(*a*) (*b*)

Figure 11

(*Facing p.* 296)

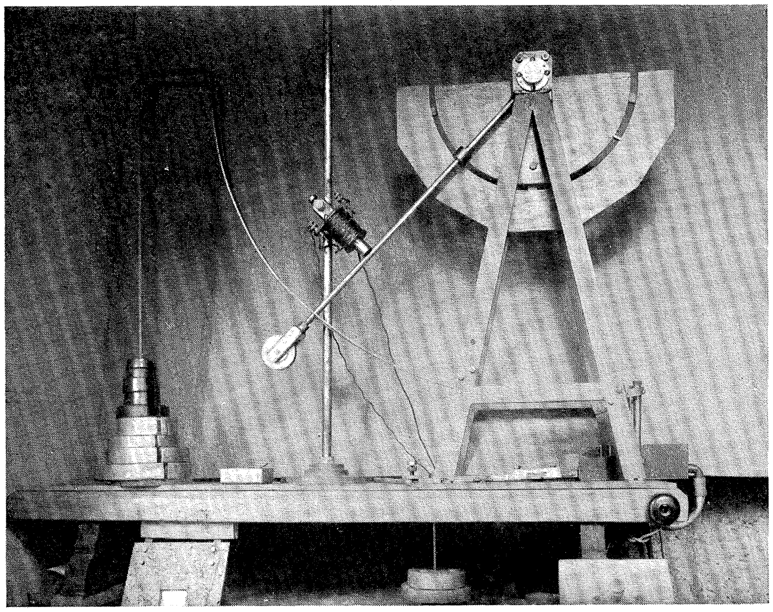


FIGURE 34

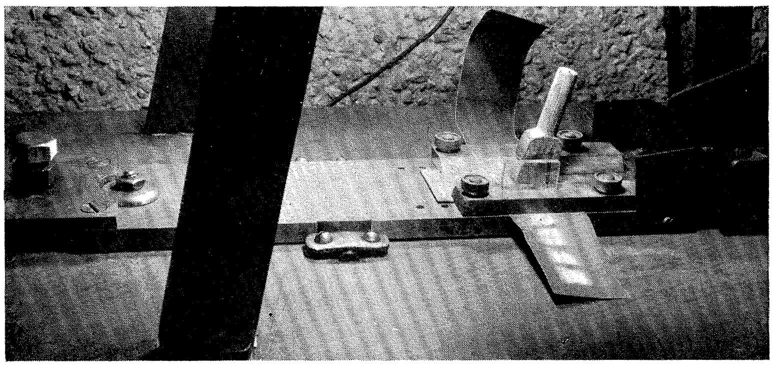


FIGURE 35

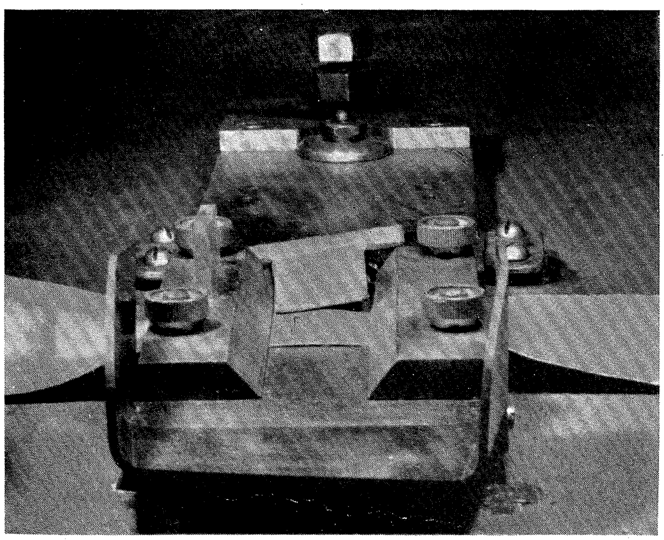


FIGURE 36

FIGURE 37

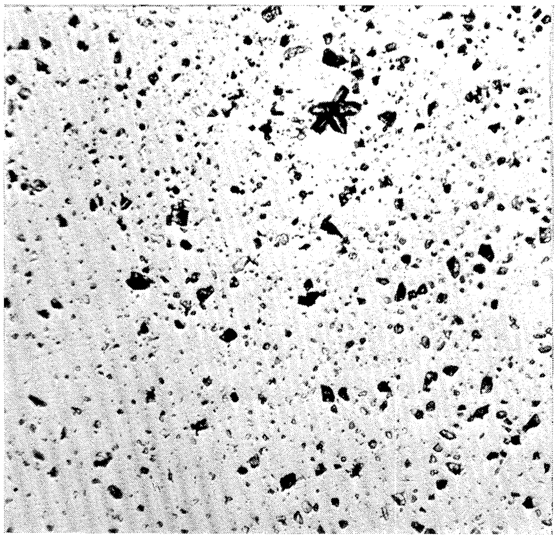


FIGURE 38

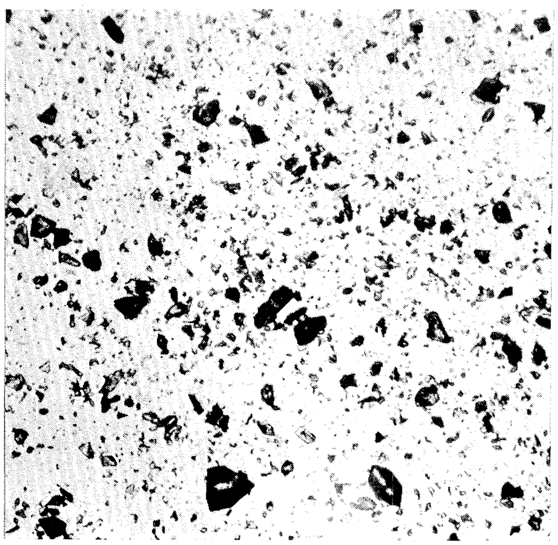


FIGURE 39

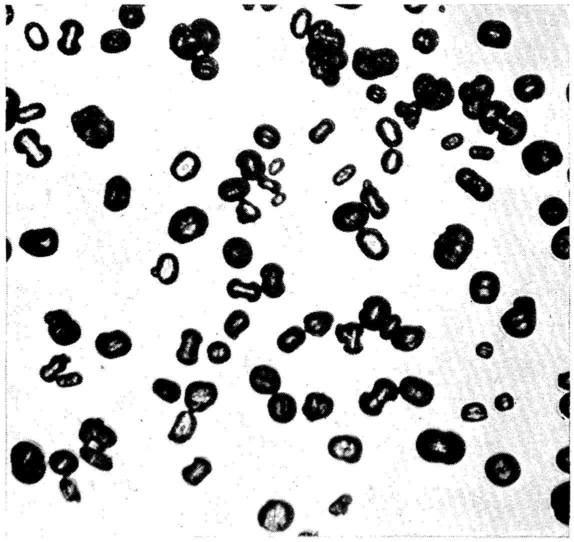


FIGURE 40

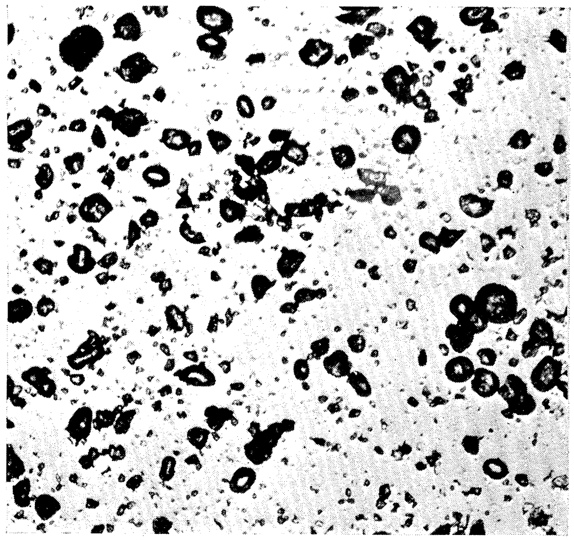


FIGURE 41

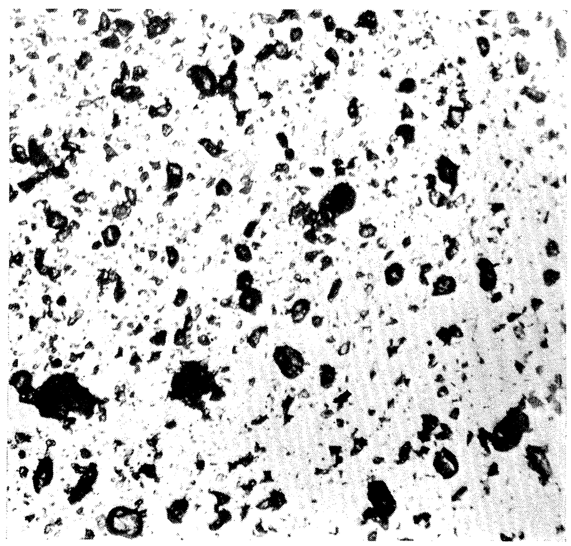


FIGURE 42

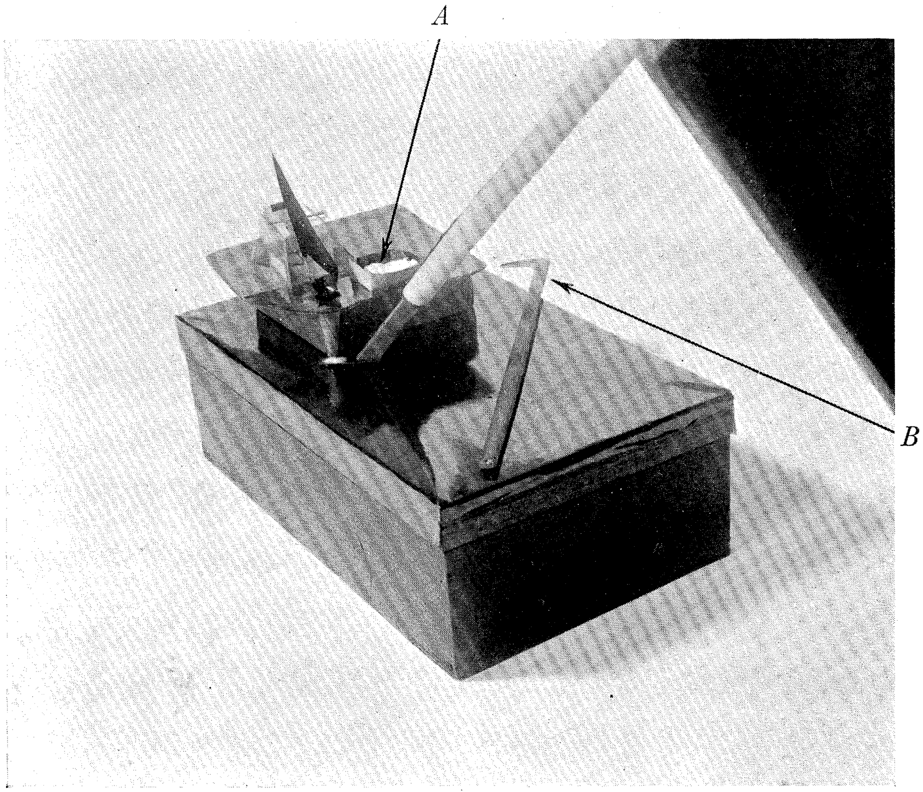


FIGURE 43

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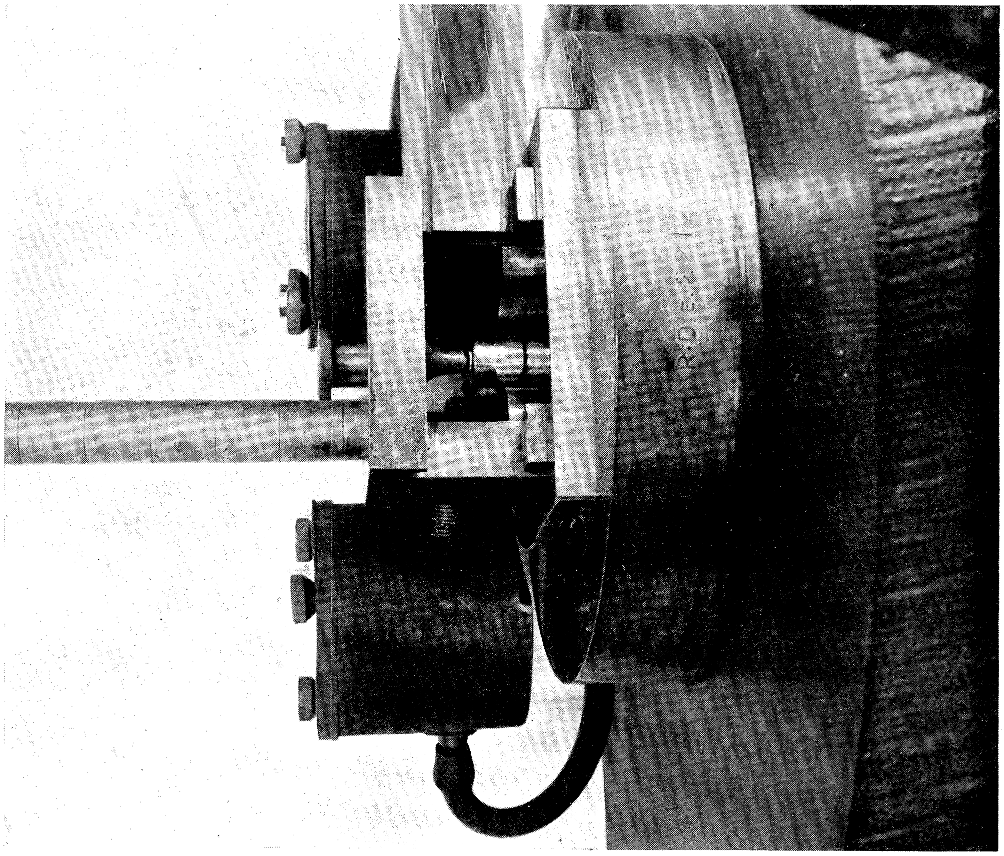

FIGURE 47

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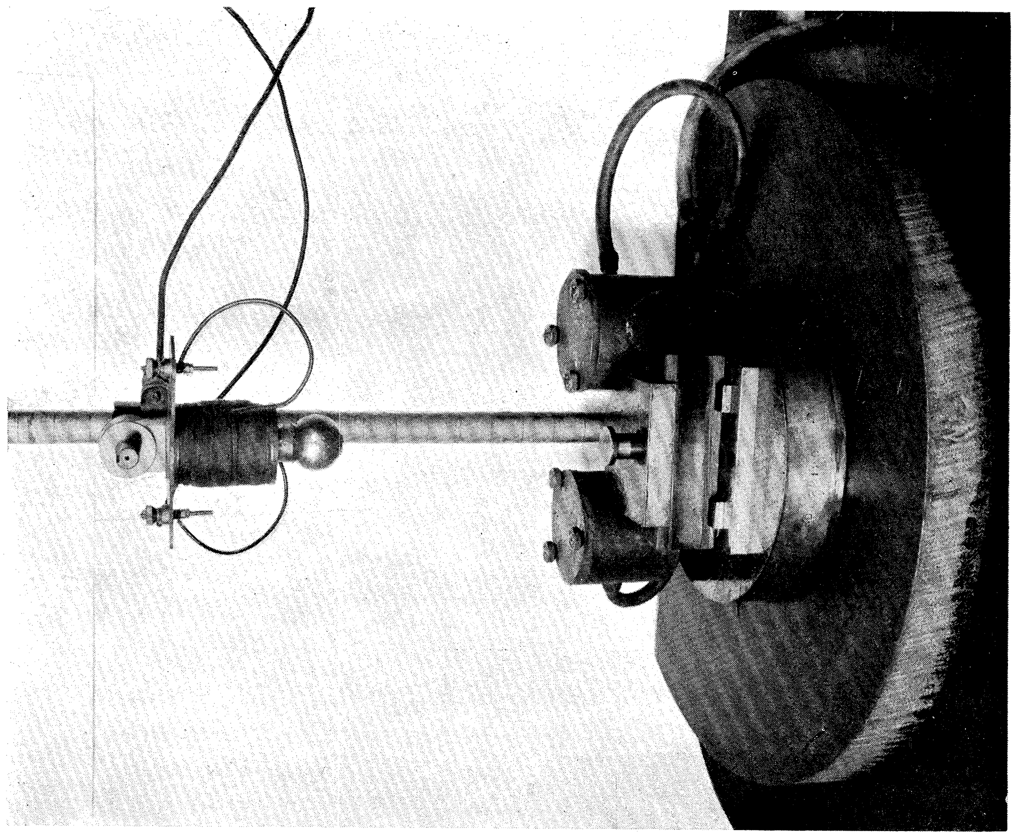


FIGURE 46

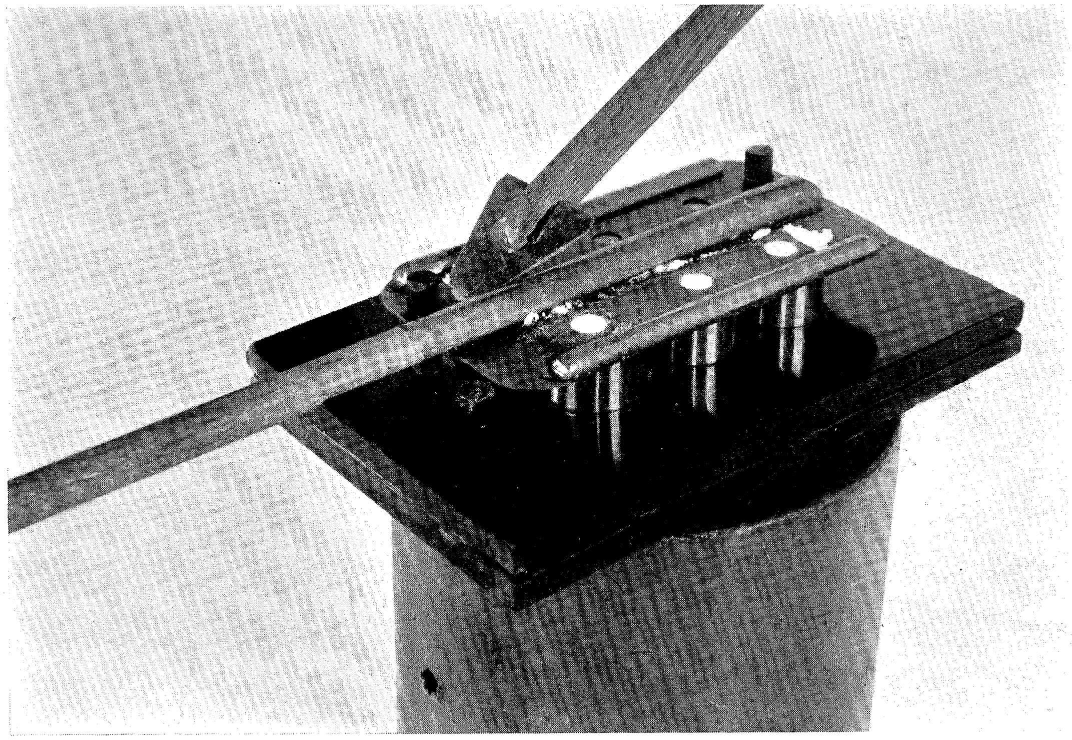


FIGURE 48

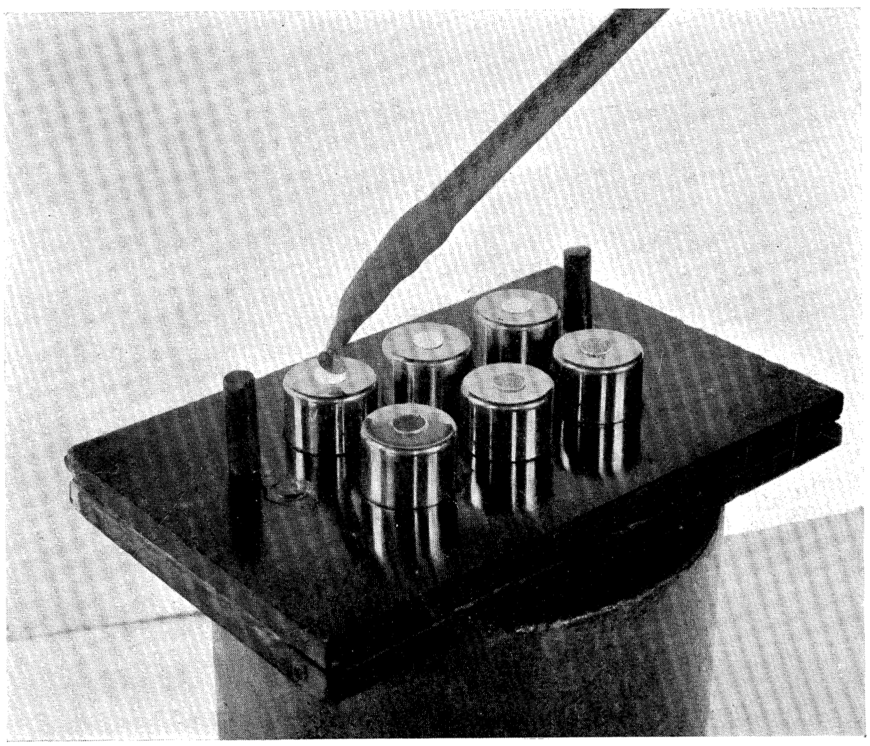
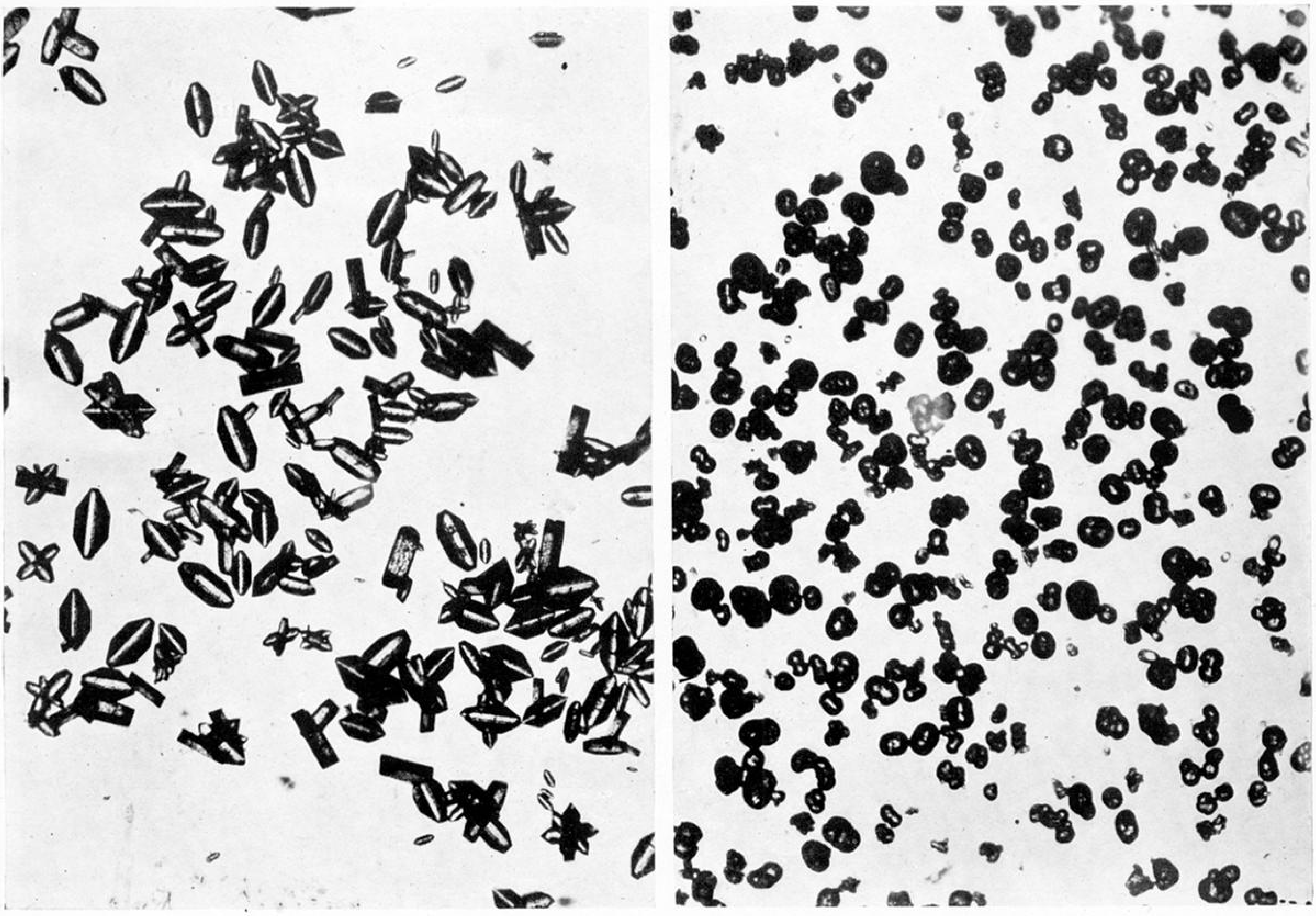
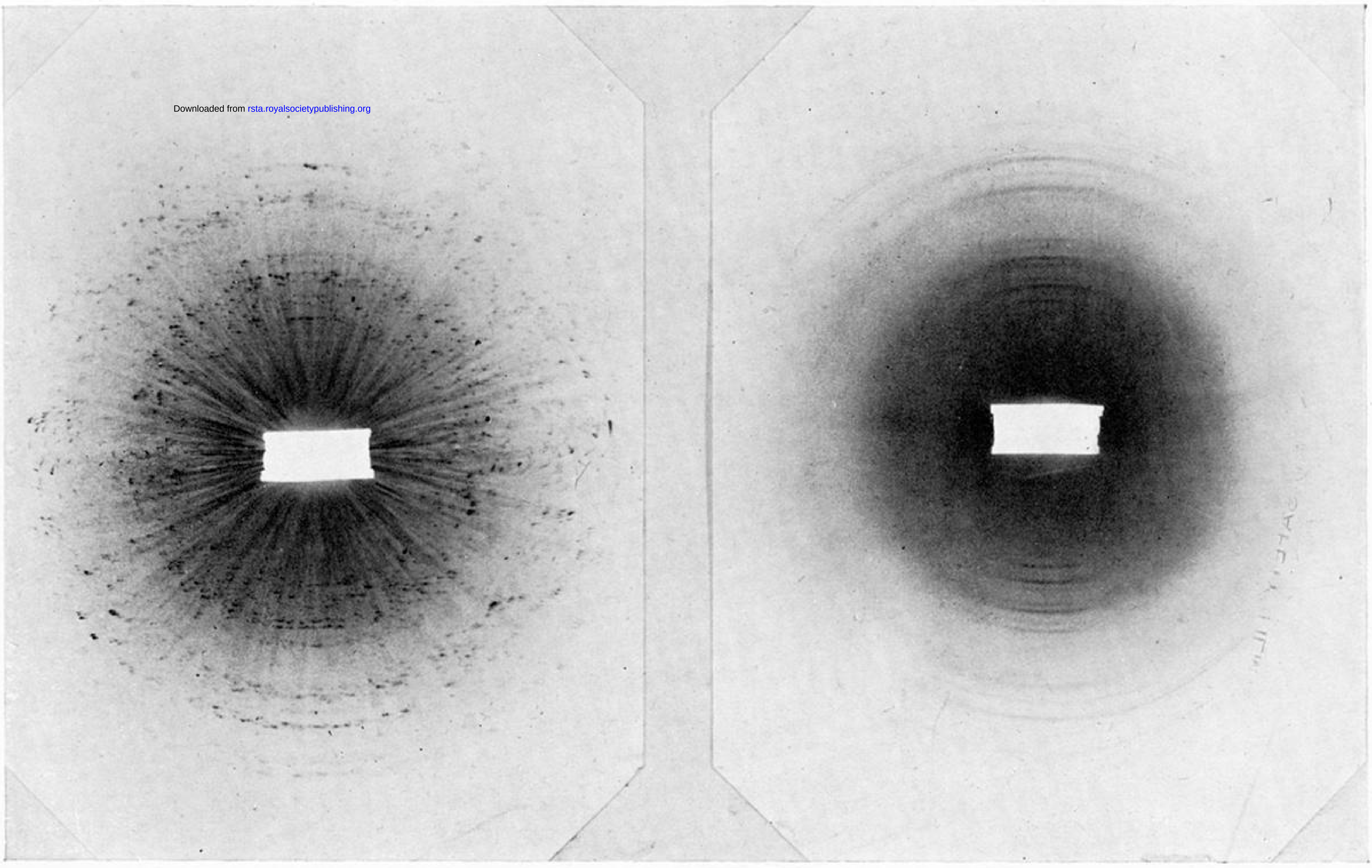


FIGURE 49



(a) (b)

FIGURE 10



(a) (b)

FIGURE 11

(Facing p. 296)

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

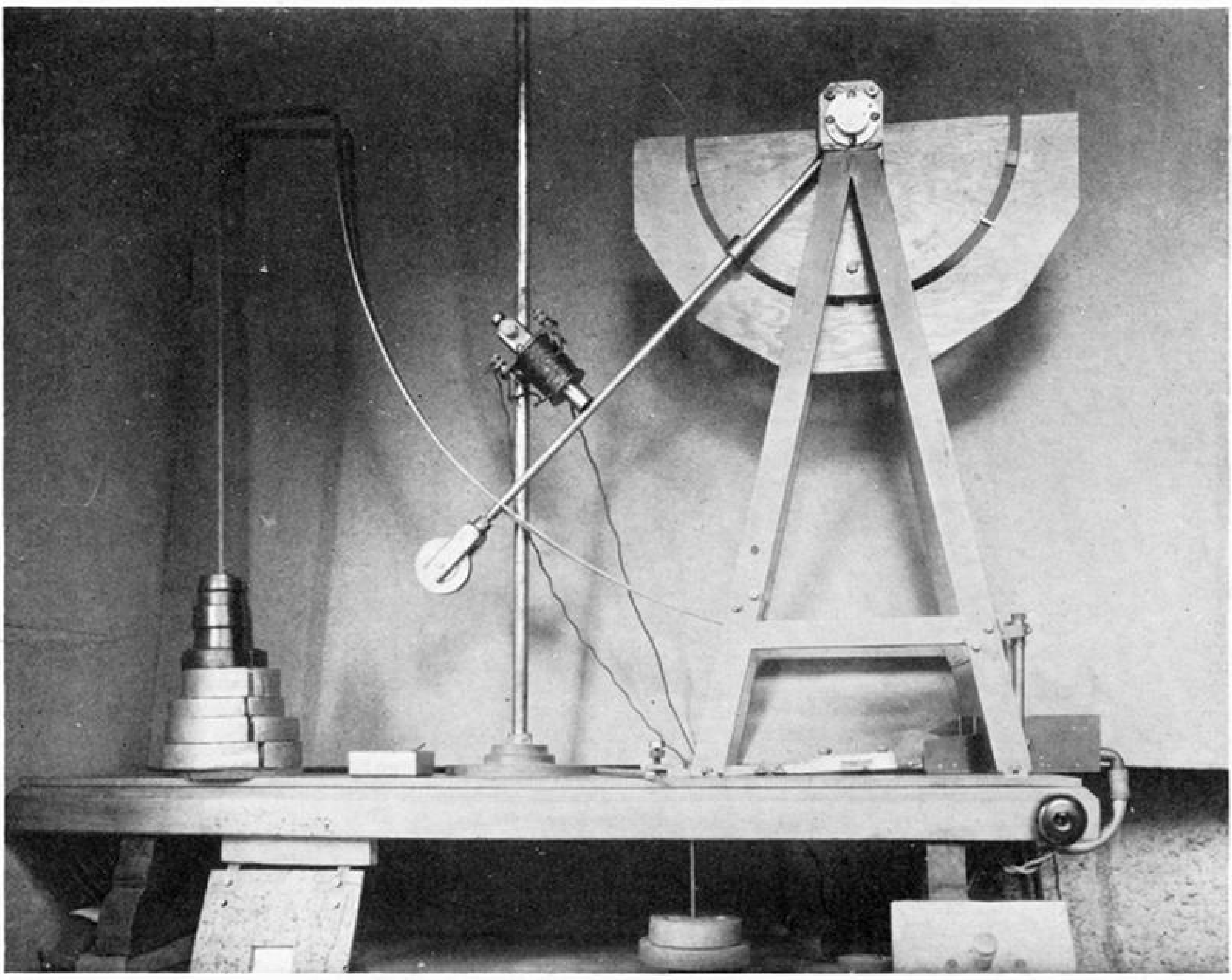


FIGURE 34

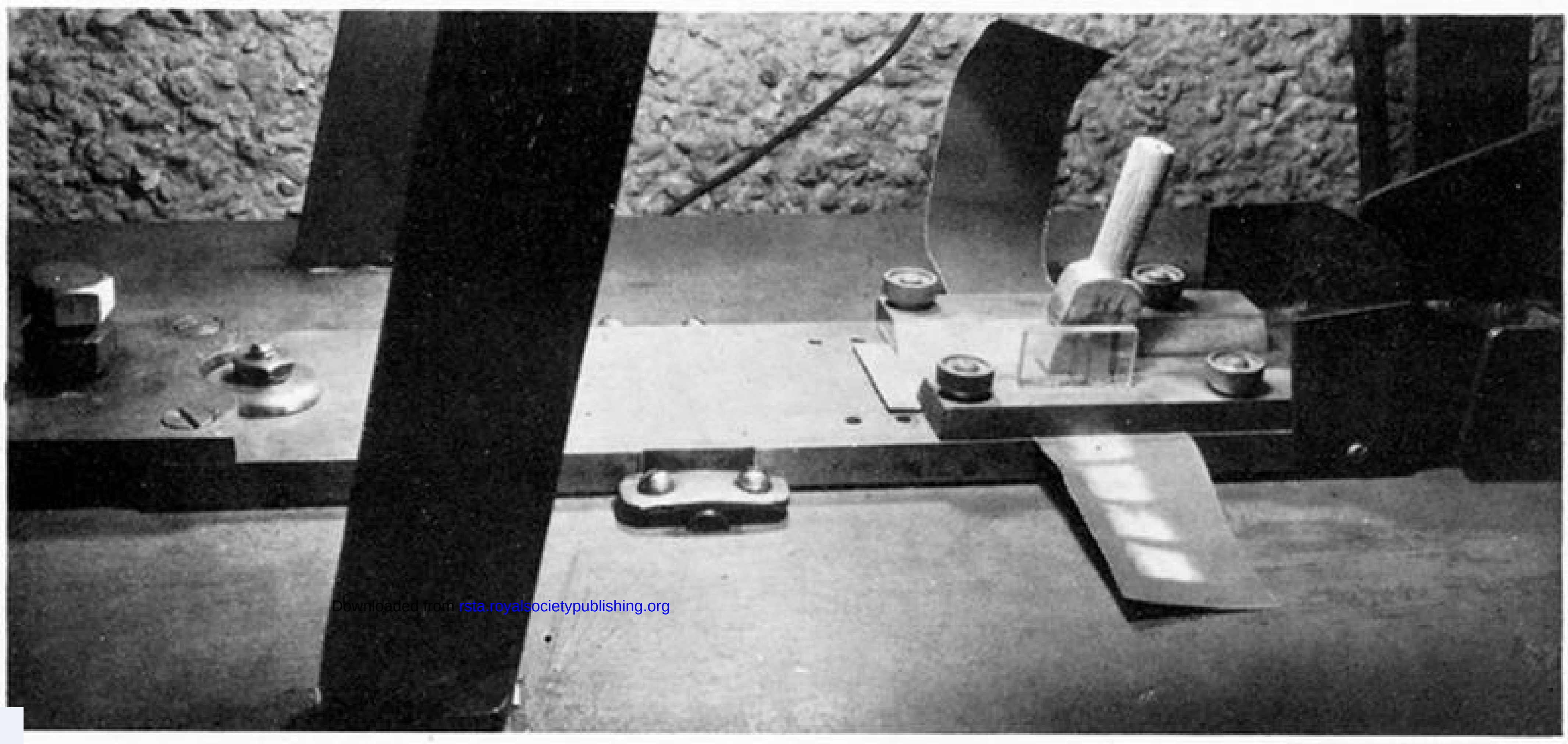


FIGURE 35

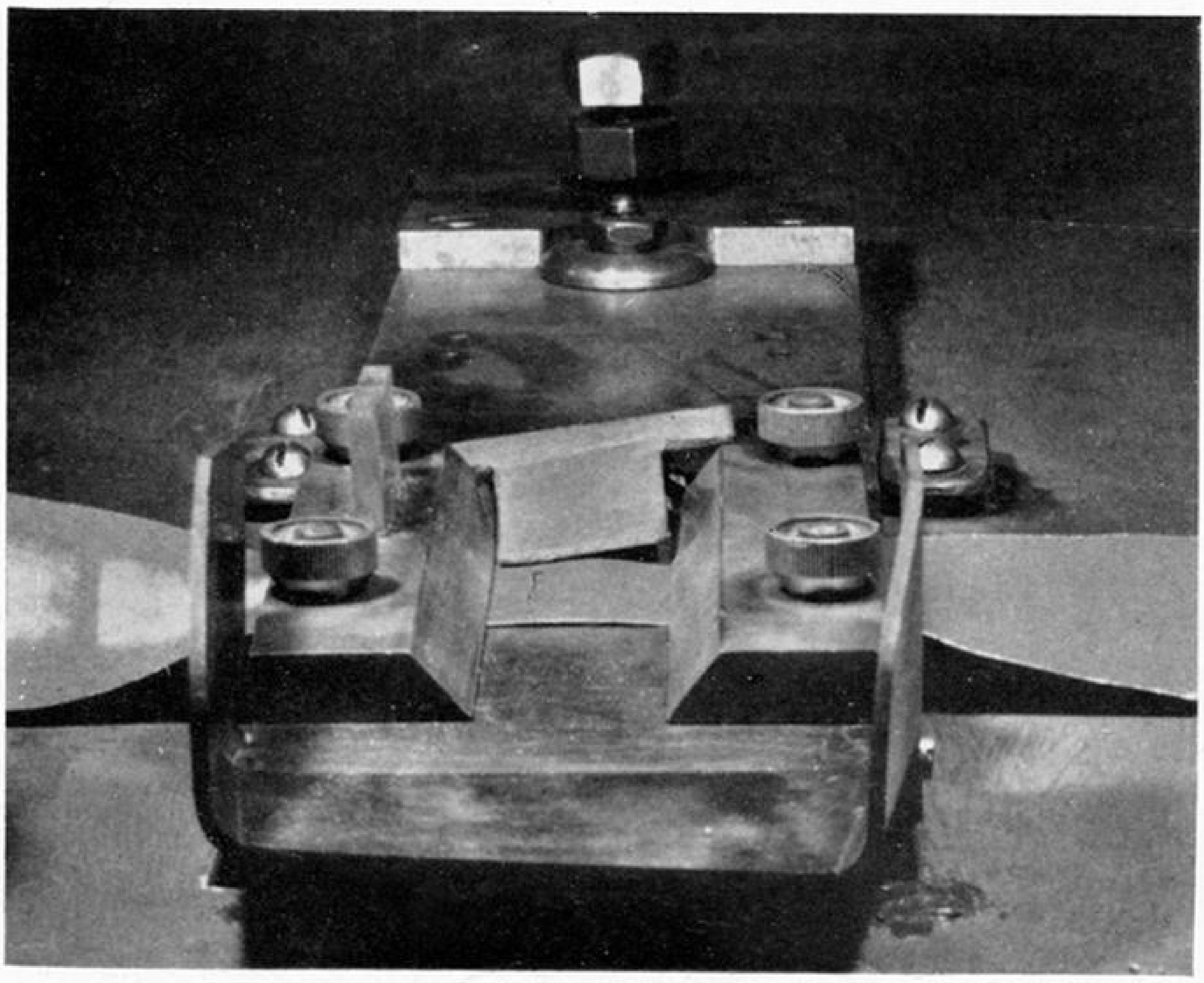


FIGURE 36

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

FIGURE 37

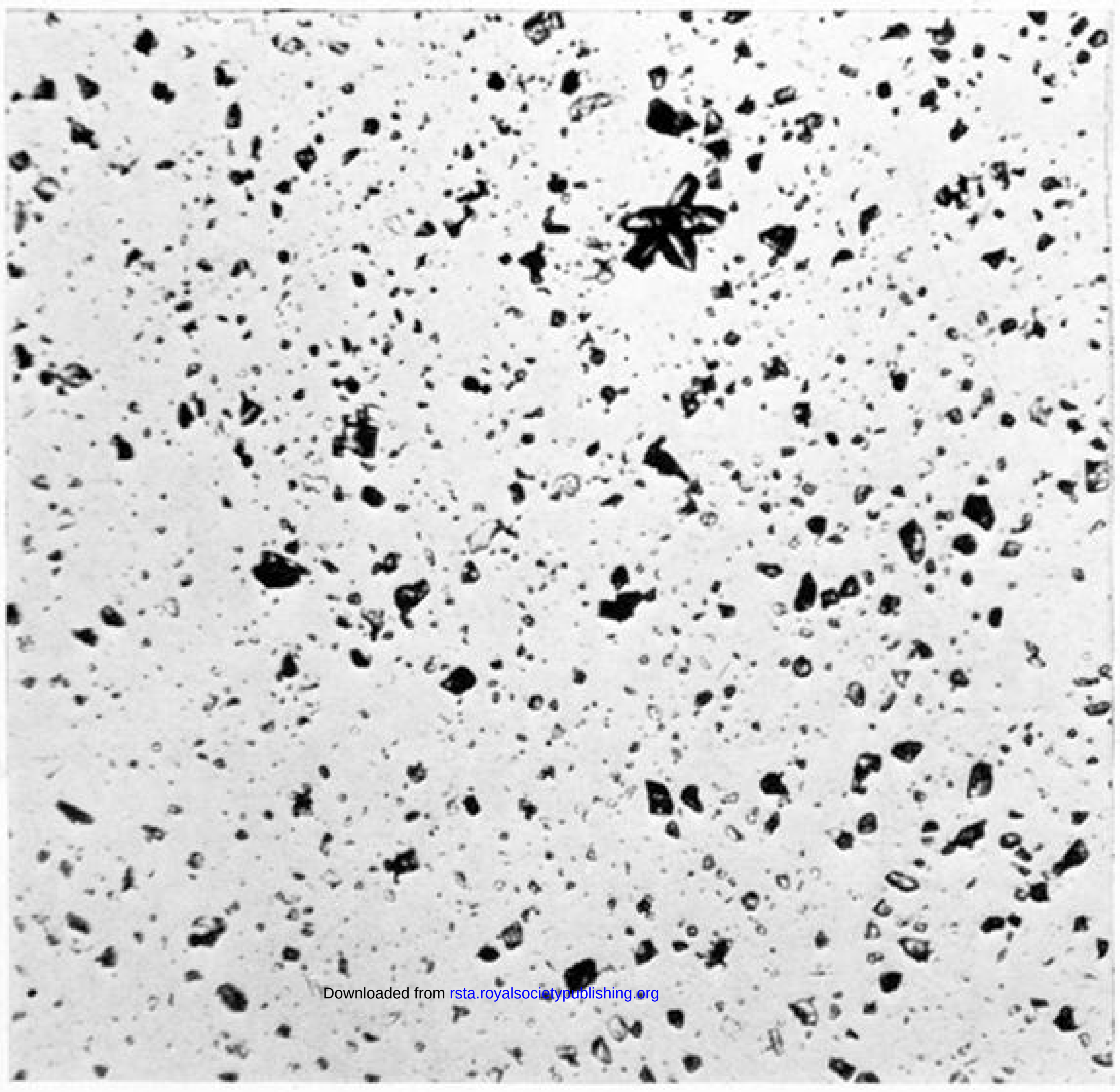


FIGURE 38

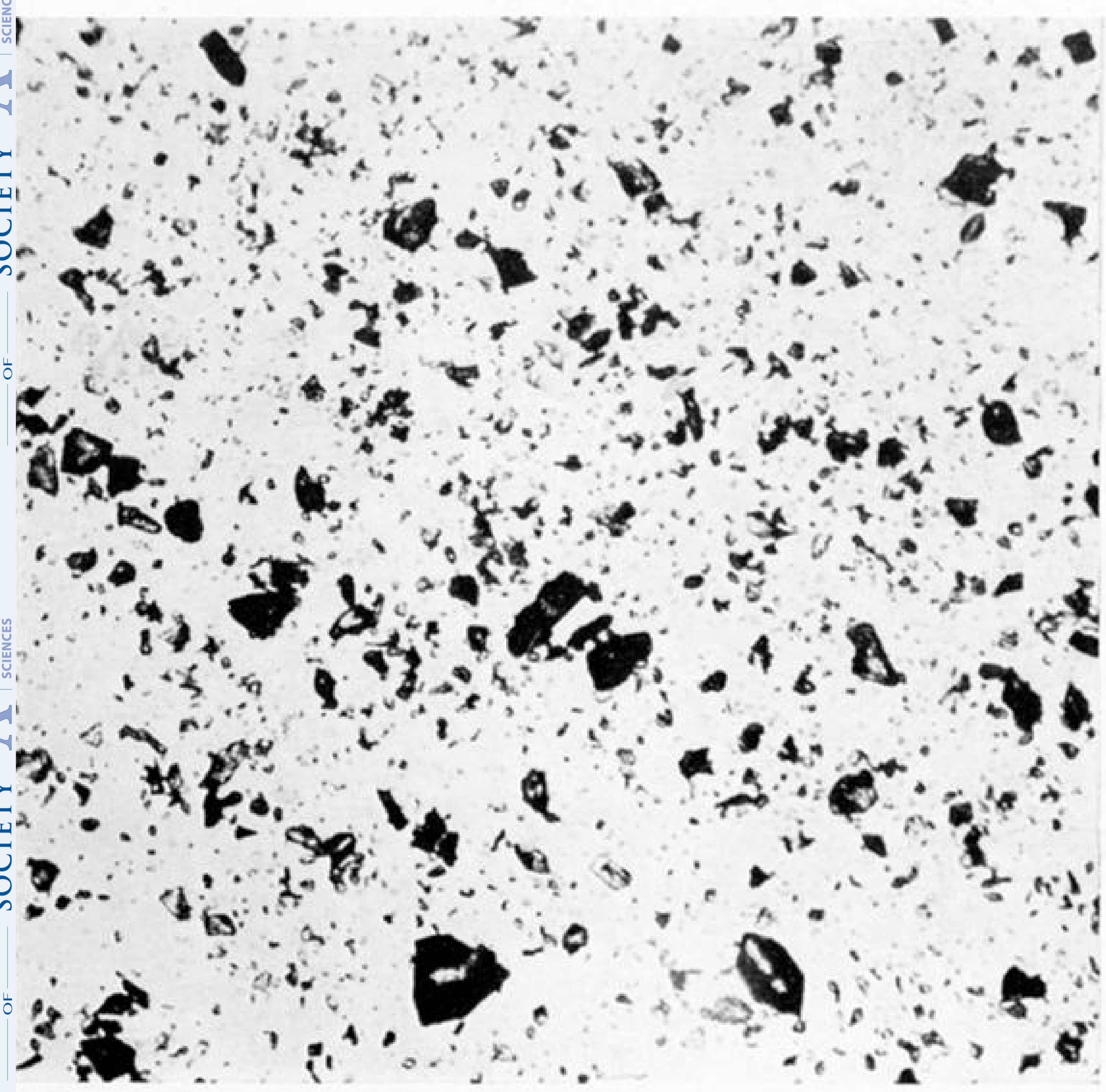


FIGURE 39

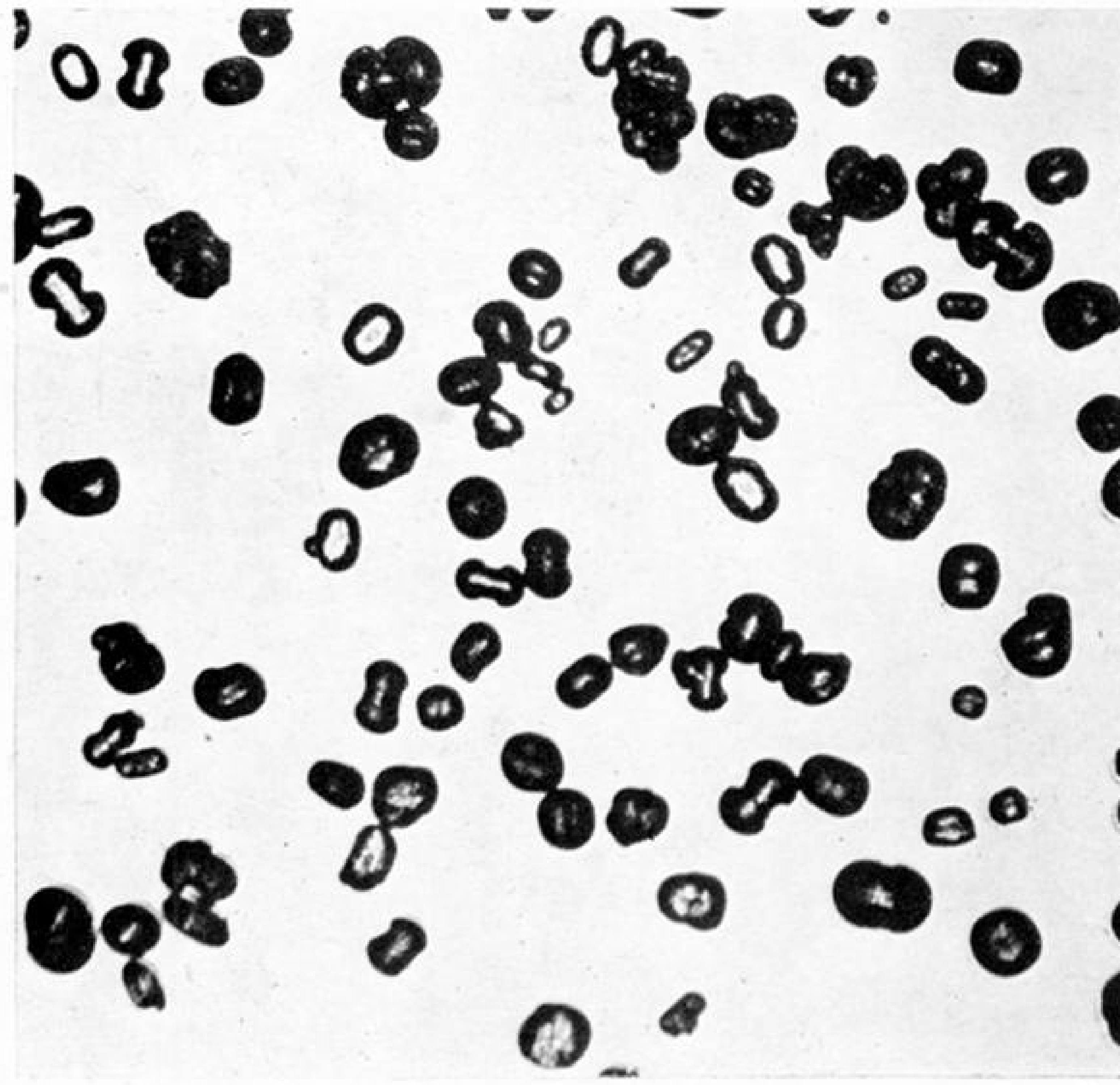


FIGURE 40

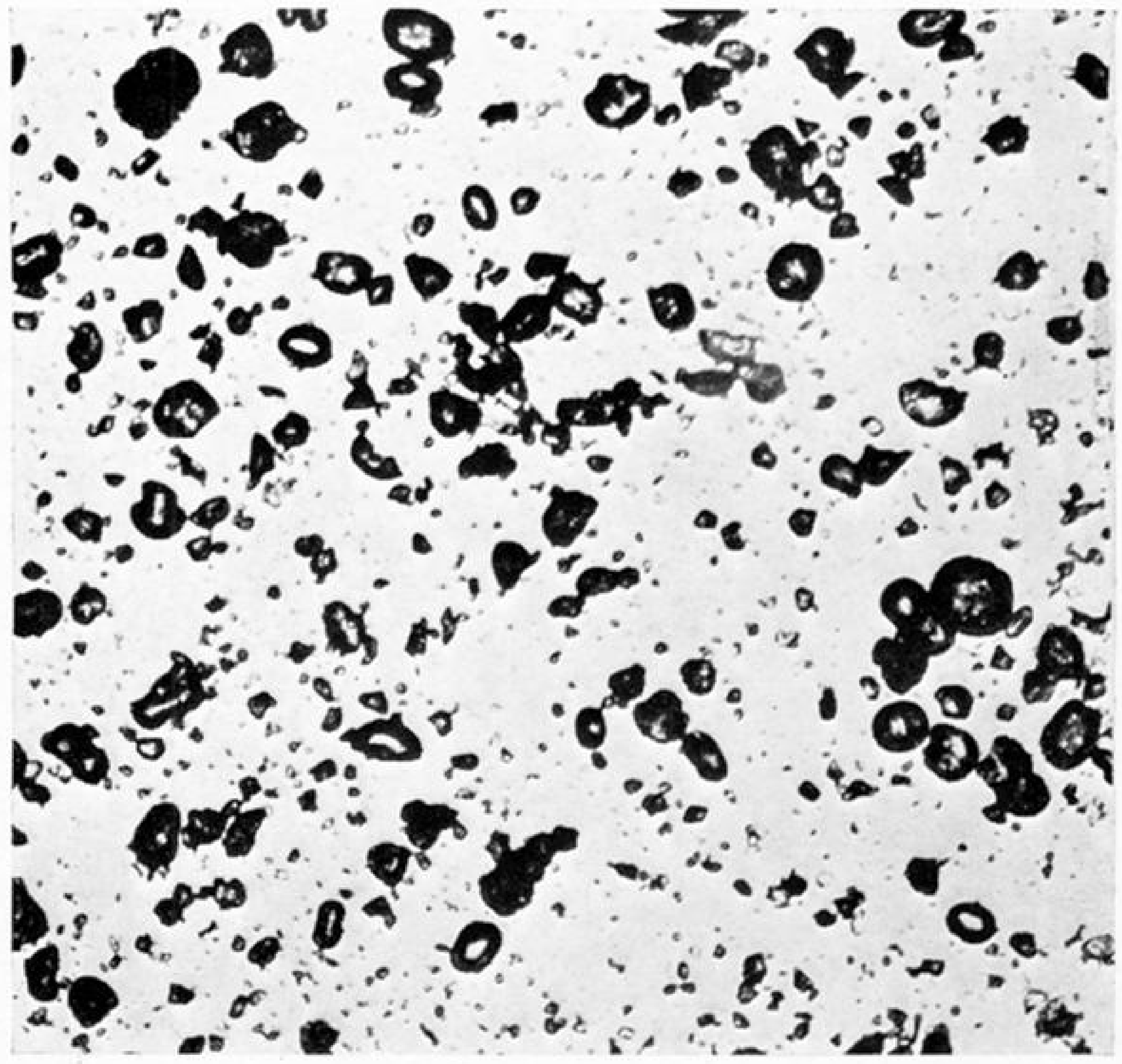


FIGURE 41

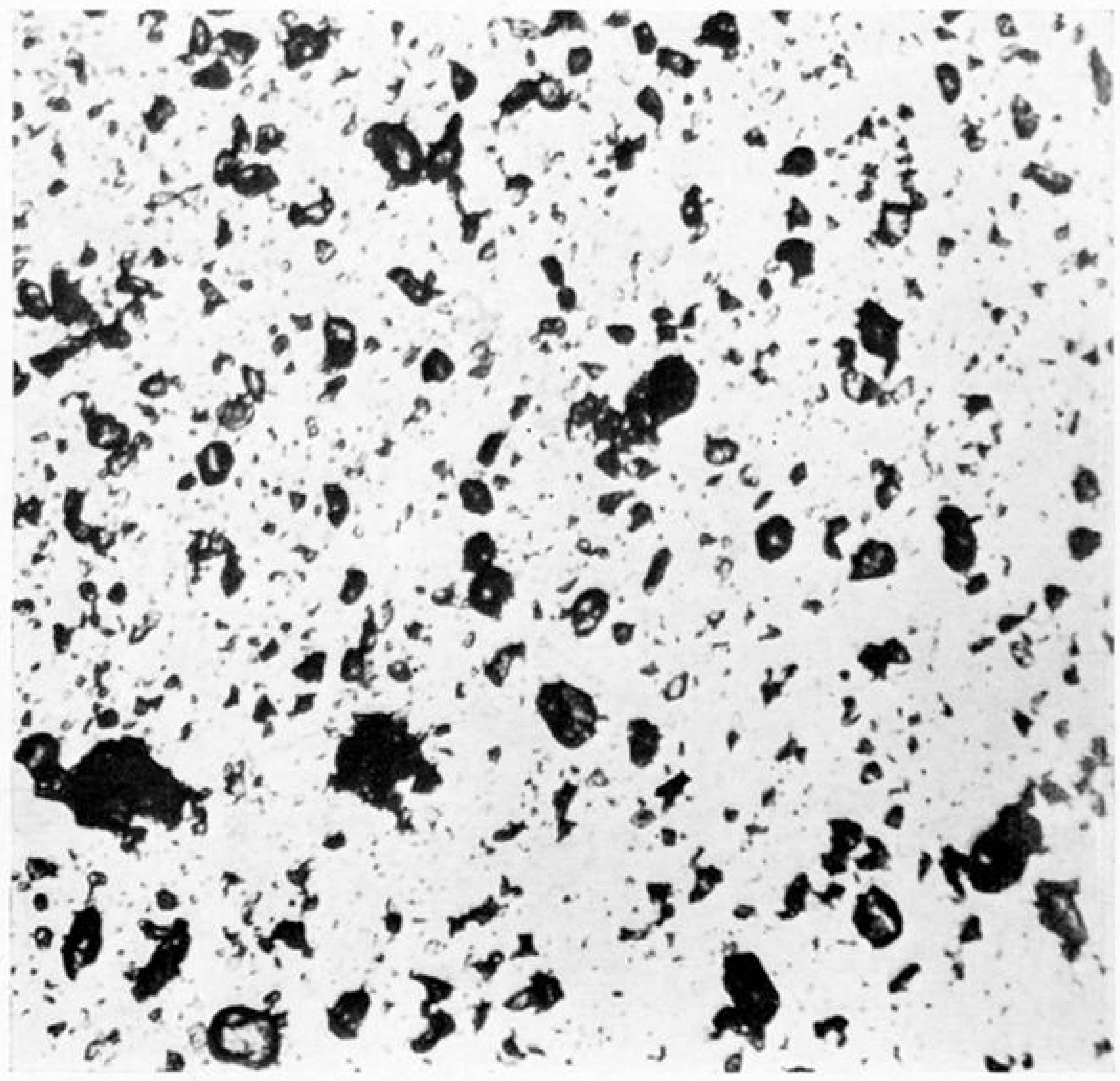


FIGURE 42

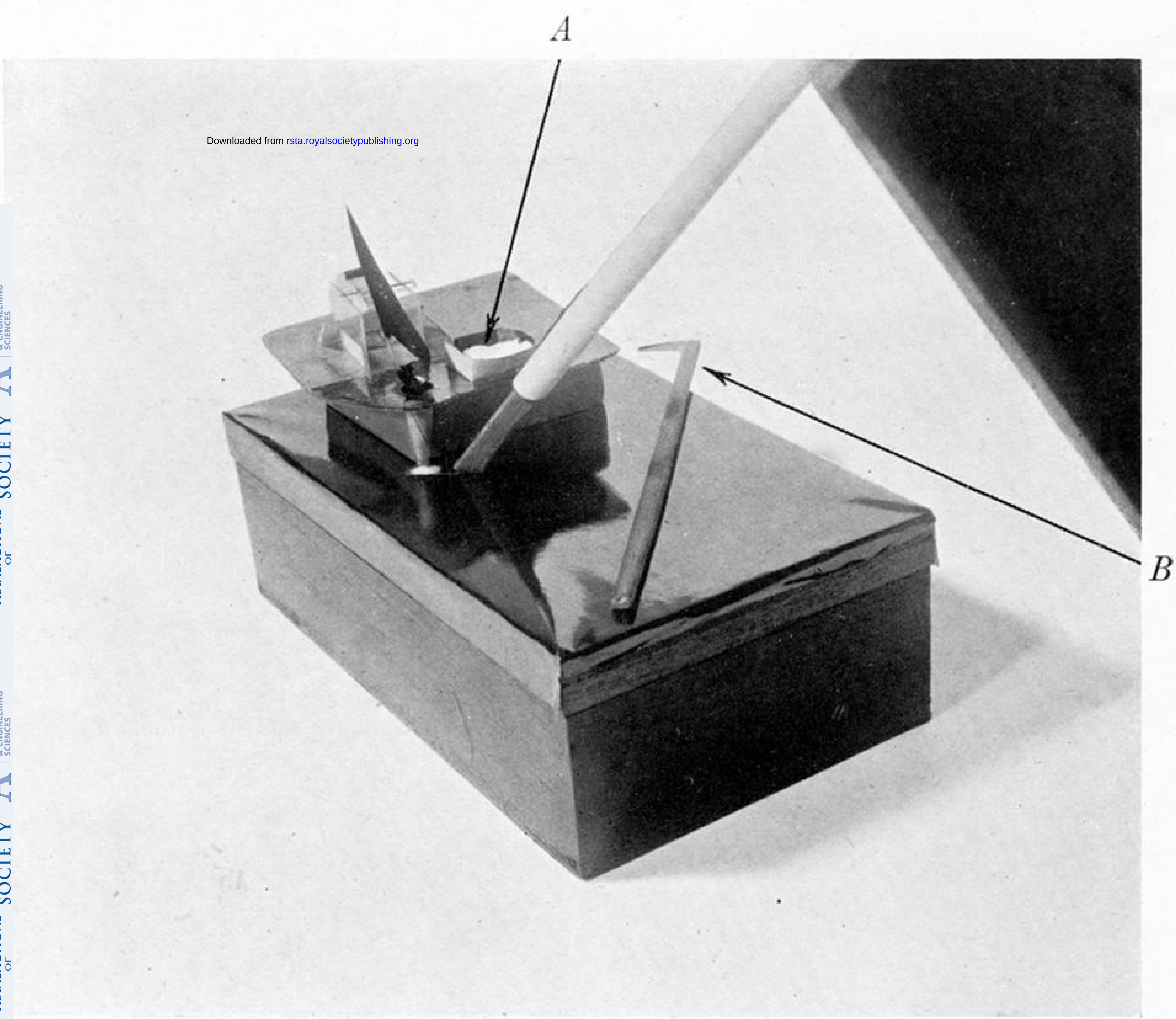


FIGURE 43

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

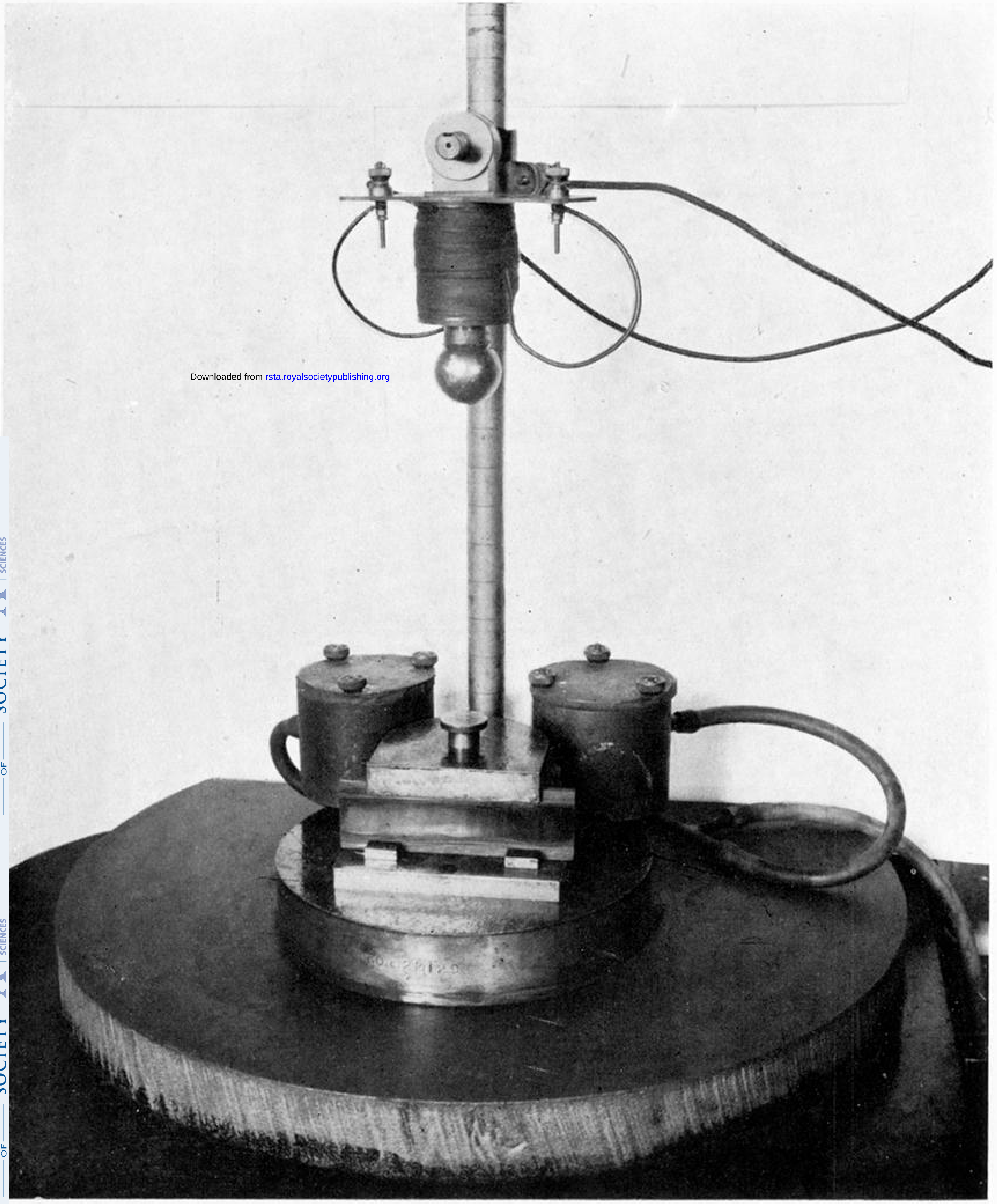


FIGURE 46

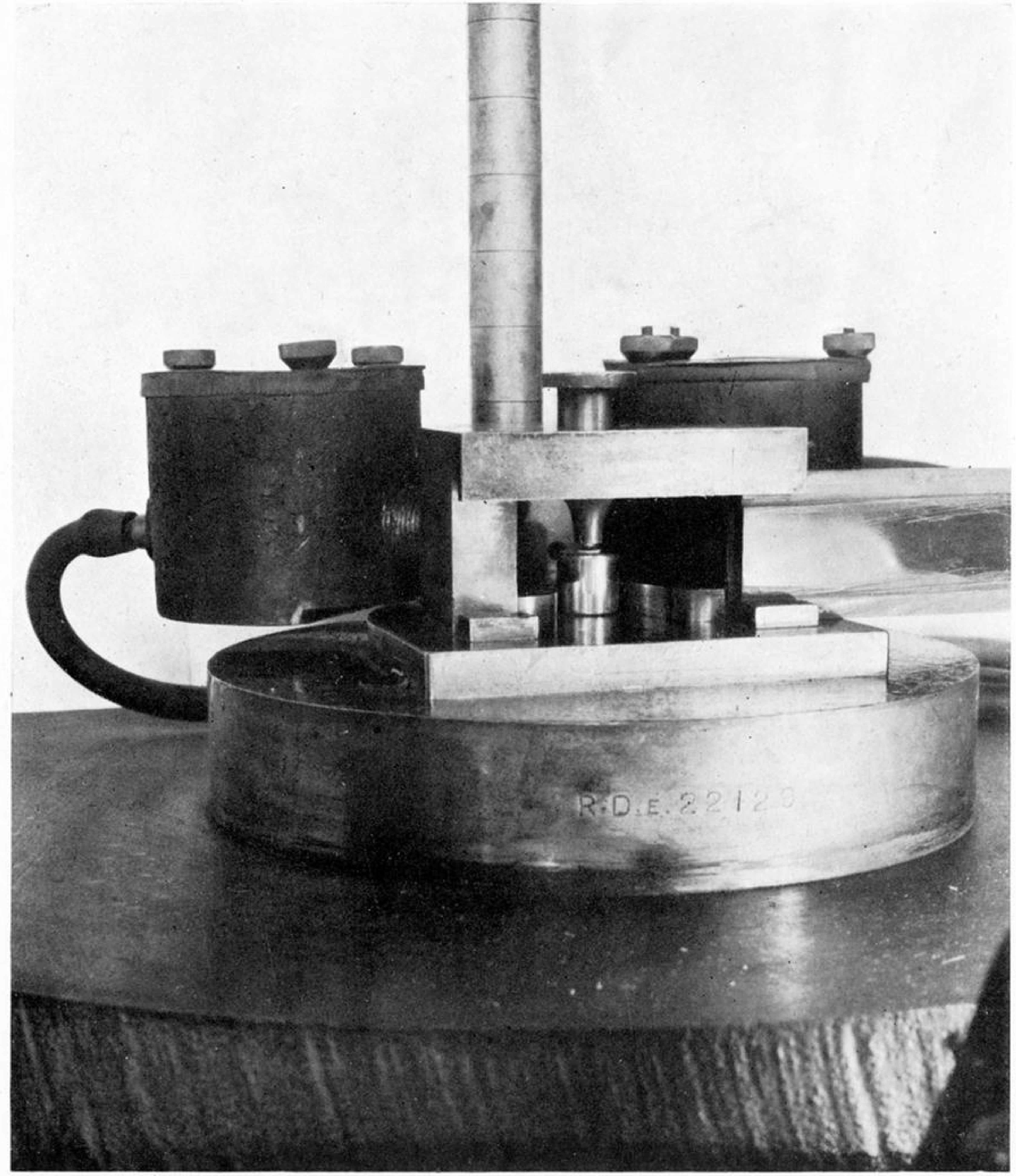


FIGURE 47

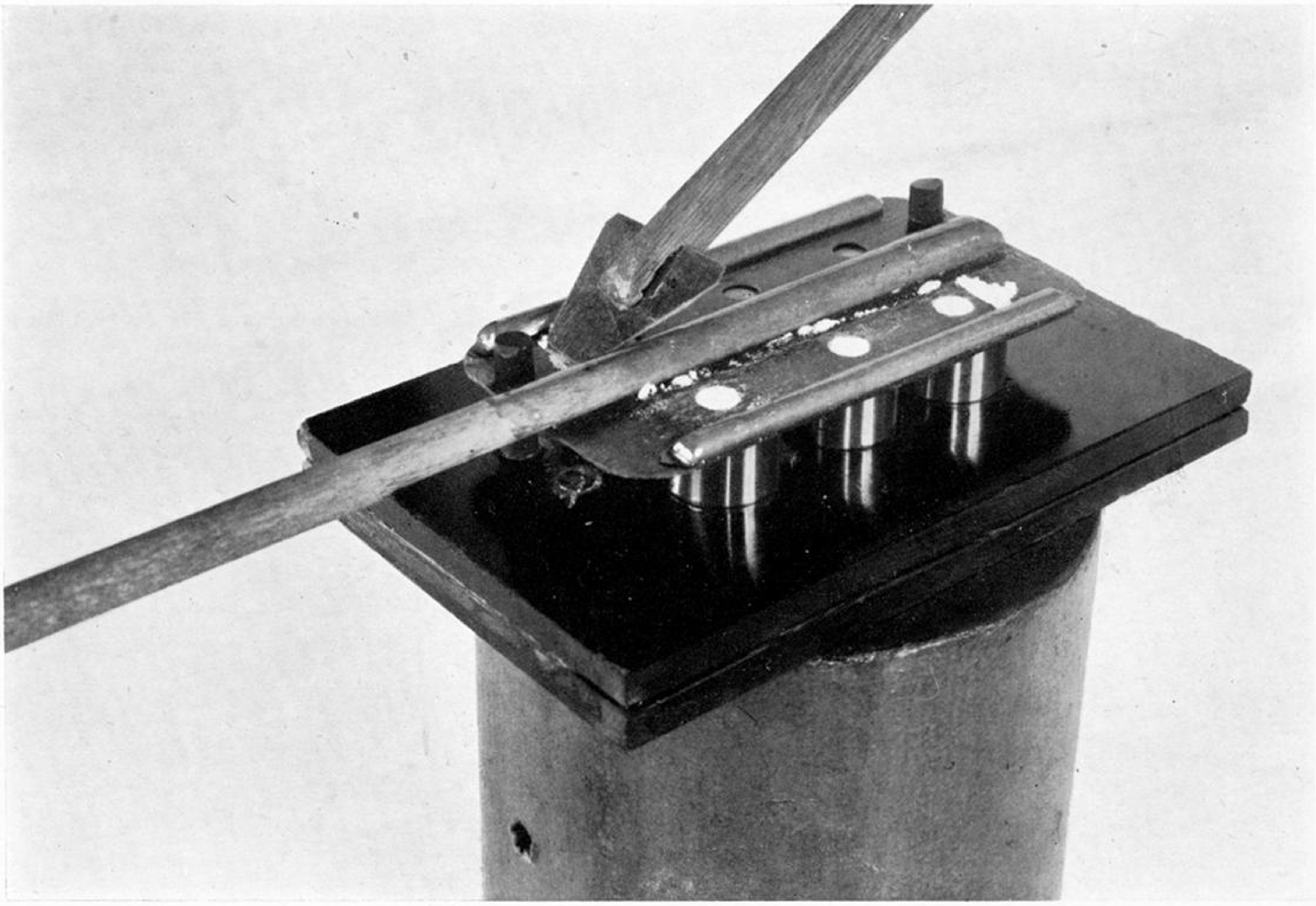


FIGURE 48

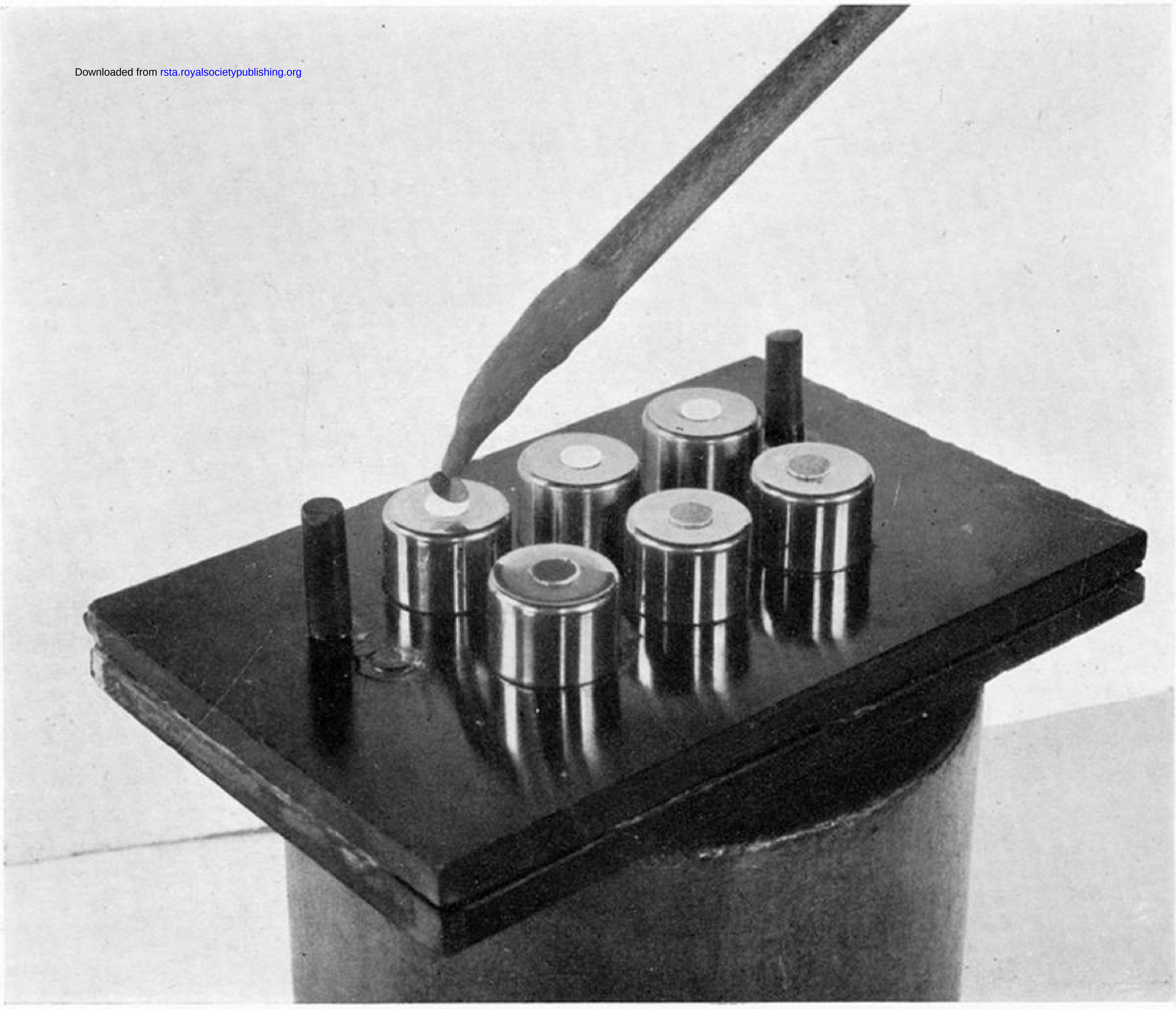


FIGURE 49