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An Automatic and Continuous Recording Balance. (The Odén-Keen Balance.)

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§ (1) *Introduction.*

There are very many experiments in which it is essential to have an accurate record of a change of weight, with time, and the treatment of such experimental data frequently involves a measurement of the *rate* of change of weight with time, or even of the second differential. Until 1915, when one of us (S.O.) devised a suitable apparatus†, the only means whereby an experimenter could follow with any accuracy the course of such a change was to make the weighings himself as frequently and rapidly as possible. This is a very tedious and fatiguing process, especially if the experiment is at all protracted.

In the original form of self-recording balance, control was effected by an automatic discharge of a small steel ball of known weight into one pan at the instant that the increasing weight in the other pan became equal to the total weight of the balls already in the first pan. The time of discharge of each ball was automatically recorded, hence it was possible to obtain a record of weight as a function of time by plotting these values and drawing a smooth curve through the points. An upper limit to the accuracy of such a record is set by the weight of the smallest sphere‡ that can be employed in practice in the ball-discharge mechanism, and it is evident that greater detail and accuracy of the record of increasing (or decreasing) weight can be secured by some form of electro-magnetic control, which will allow the recording of smaller changes of weight than is possible with metal spheres. The present paper consists of an account of an apparatus evolved for this purpose that is reasonably simple, and reliable in its action.

* The successful development of Prof. Odén's suggestion of adding electro-magnetic control to his automatic balance has involved much co-operative work by members of the staff of the Soil Physics Department at Rothamsted, and by mutual agreement the authors' names are given in alphabetical order.—B.A.K.

† Sven Odén, 'Roy. Soc. Proc. (Edin.),' vol. 36 (1916), pp. 219–235, and 'Trans. Faraday Soc.,' vol. 17 (1922), pp. 326–348. Experiments with intermittent electro-magnetic forces were made in conjunction with the late Dr. Nordlund in 1918.

‡ 0·0153 gms.

If a magnet, suspended from one pan of the balance, is attracted by a current in a solenoid surrounding the magnet, then the changing weight on the other pan can be counterpoised by suitable automatic adjustment of the current. A record of current strength as a function of time will provide a measure of the change of weight on the balance. If this record is to be produced as a graph by the instrument it is at once evident that no chart of reasonable dimensions will give a sufficiently open scale for readings of the required accuracy, if both the total change in weight and the sensitivity in the automatic balance are to be of the same order as when the balance is used in the ordinary way.

A fundamental feature in the design is therefore the provision of some mechanism whereby the graph is recorded as a series of successive transits of the same chart. There are two possibilities: (1), to provide for electro-magnetic control over the whole range and to split up the chart by some arrangement of counter (or "setting-up") currents, increased by an appropriate amount after each transit of the chart; or (2), to retain the original method of adding weights, supplementing this by electro-magnetic control between the successive addition of weights. After considerable experimentation it became apparent that method (2) was the more suitable; method (1) demands currents of considerable strength to balance a comparatively small increase in weight, whereas in method (2) the process of ball-dropping can be repeated indefinitely up to the maximum load that an analytical balance is designed to carry. The method also has the advantage that the maximum current required is no greater than that equivalent to the weight of one ball, and further, the sensitivity of the apparatus, besides remaining approximately constant for any one set of balls, is under easy control and may be increased or decreased at will.

§ (2) *The Principle of the Instrument.*

It will save repetition both in the discussion of the theory and the description of the instrument if the principle of the instrument be first described with the aid of a simplified diagram (Fig. 1). Current from the accumulators e flows through a resistance r_1 in series with the slide wire AB, and the current in the solenoids is adjusted to keep the balance in equilibrium by an automatic movement of the sliding contact E along the two wires AB and CD. When, following a slight increase of weight on the pan L, the balance beam is displaced, the insulated platinum prong P_2 forming part of an inverted pointer fixed rigidly to the balance beam, makes contact with a rotating wheel W. This completes a subsidiary relay circuit (not shown in fig. 1) controlling a clockwork mechanism which moves the contact E to the right. Hence, the current through S, and therefore the force on the magnet M, is increased until the balance is restored to the equilibrium position. As the weight on L increases, the contact E moves along the slide wire until it reaches a pre-arranged position X. At this point an insulated projection on E presses into contact two flexible metal tongues and thus closes another relay circuit (also not shown in fig. 1), the function of which is to place on the scale pan R a ball from the ball-dropping mechanism T. The consequent displacement of the balance results in contact of prong P_1 with the wheel W, and a relay circuit and clockwork similar to that connected with prong P_2 operates to bring the slider E back to its initial position Y, when the cycle of operations recommences. The resulting record of solenoid current —which may be obtained by the installation of a recording ammeter in the solenoid circuit—will consist of a series of transits of the type illustrated in fig. 9 (p. 48), and the fundamental feature of the design, mentioned in § (1) is thus satisfied. The current-time record is converted into a weight-time graph by means of a weight-current calibration.

In the earlier work a recording ammeter was used, but in the final form this was abandoned and advantage was taken of the fact that the distance AE in fig. 1 is approximately proportional to the current in the solenoid 1 (§ 3),

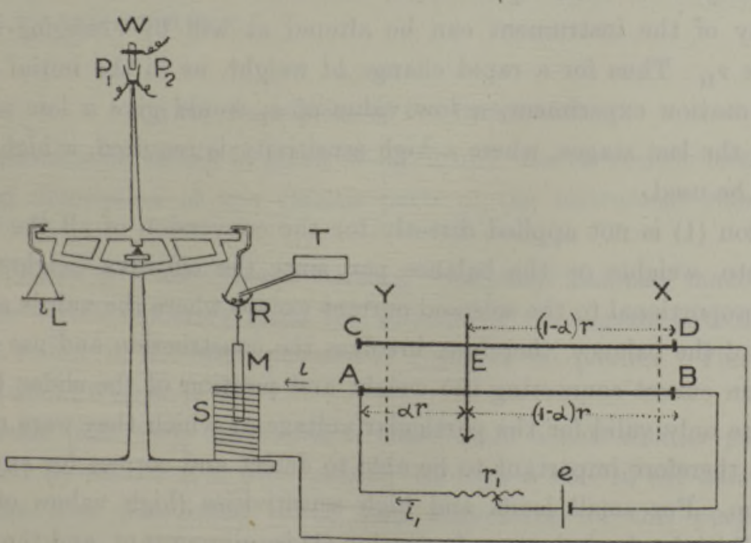

FIG. 1.—Simplified Diagram of Apparatus.

provided the voltage remains constant. Allowance is readily made for small changes in voltage. A mechanism for recording on a rotating drum the position of the slider E is sufficient to provide the necessary data. Dispensing with the ammeter resulted not only in a reduced cost but in an increased sensitivity and accuracy, since the current scale was doubled and the time scale could be changed at will to either one-half or six times that of the recording ammeter, whilst in addition a continuous curve was obtained instead of the series of separate points given by the usual form of recording ammeter.

§ (3) *The Theory of the Instrument.*

In fig. 1 let the resistance of the slide wire AB be r and let the slider at any given point E divide it so that the resistance of AE is αr. Since the second slide wire CD is uniform with AB, and EB and ED are of equal length, they each have a resistance of $(1-\alpha)\,r$. Let r_1 and i_1 be the external resistance and current in the main circuit, and s and i be the solenoid resistance and current. Then if the voltage of the cells be e, the application of Kirchoff's laws gives for the solenoid current,

$$\frac{i}{e}=\frac{\alpha r}{(r+r_1)\,.\,(r+s)-(\alpha r)^2}, \qquad (1)$$

and for the main current,

$$\frac{i_1}{e}=\frac{r+s}{(r+r_1)\,.\,(r+s)-(\alpha r)^2}. \qquad (2)$$

It is readily seen from equation (1) that since r and s are constants, the sensitivity of the instrument can be altered at will by changing the main resistance r_1. Thus for a rapid change of weight, as in the initial stages of a sedimentation experiment, a low value of r_1 would give a low sensitivity whilst in the last stages, where a high sensitivity is required, a high value of r_1 would be used.

Equation (1) is not applied directly for the conversion of all the observed points into weights on the balance pan since the effective weights are not strictly proportional to the solenoid current except where the values are small. The use of the balance, therefore, involves the construction and use of direct calibration curves connecting the weight and position of the slider E. Such curves are only valid for the particular voltage at which they were obtained, and it is therefore important to be able to detect and correct for any change in voltage. For small loads and high sensitivities (high values of r_1) the term $(\alpha r)^2$ in the denominator of equation (1) is unimportant, and the effective weight on the balance pan is proportional to the solenoid current and is thus proportional to αe. On the addition of a ball of fixed weight, α is changed by an amount which is conveniently referred to as the "return length." Under the conditions just defined the "return length" is obviously inversely proportional to the voltage, and thus its accurate measurement provides a check on the constancy of the voltage. If in any experiment the "return length" differs slightly from that in the corresponding calibration curve, the observed reading can be corrected by multiplying weights read off the calibration curve by the ratio of the calibration return length to that of the actual experiment. By virtue of the limitations imposed this method of treatment is not exact for large voltage changes, especially with heavy loads. It will be shown later that the voltage remains extremely steady, and in practice fresh calibrations are normally determined whenever the "return length" has changed by some 2-3 per cent. for the higher sensitivities and by 1–2 per cent. for the lower sensitivities.

It may be pointed out that the introduction of the resistance ED into the solenoid circuit provides, in addition to certain mechanical advantages, a distinct simplification in the theoretical relationships. If this resistance were omitted by connecting the solenoid directly to the slider E, the solenoid current would be given by

$$\frac{i}{e} = \frac{\alpha r}{(r + r_1) \cdot (s + \alpha r) - (\alpha r)^2}.$$

The denominator of this expression cannot be treated as even approximately constant for variations in α.

§ (4) *Description of the Instrument.*

A diagrammatic sketch is given in fig. 2 and the reference letters in the following description of the various parts of the instrument refer to that figure.

The Balance is a short beam Oertling Analytical Balance, made to carry 100 gms. With moderate loads the addition of 1 milligram causes a movement of 1 mm. in the mean position of swing of the pointer. The period of swing is about 6 seconds.

The scale pans carry hooks below them, from which another pan can be suspended by means of a wire passing through a hole in the balance case. Thin fuse wire was found to be very convenient for this purpose. For increasing loads, as in mechanical analysis, a light silver or gold pan is suspended below the left-hand pan, L; for the case of decreasing loads (*e.g.*, evaporation work) a pan is suspended below the magnet, so that in all cases an increasing solenoid current is to be measured. The right-hand pan is made hemispherical, in order to prevent the balls from falling off when added in the course of an experiment. The prongs P_1 and P_2 are separately connected to terminals P'_1 P'_2 mounted in ebonite on the balance pillar by soldered connections with short lengths of very light silver wire such as is used for

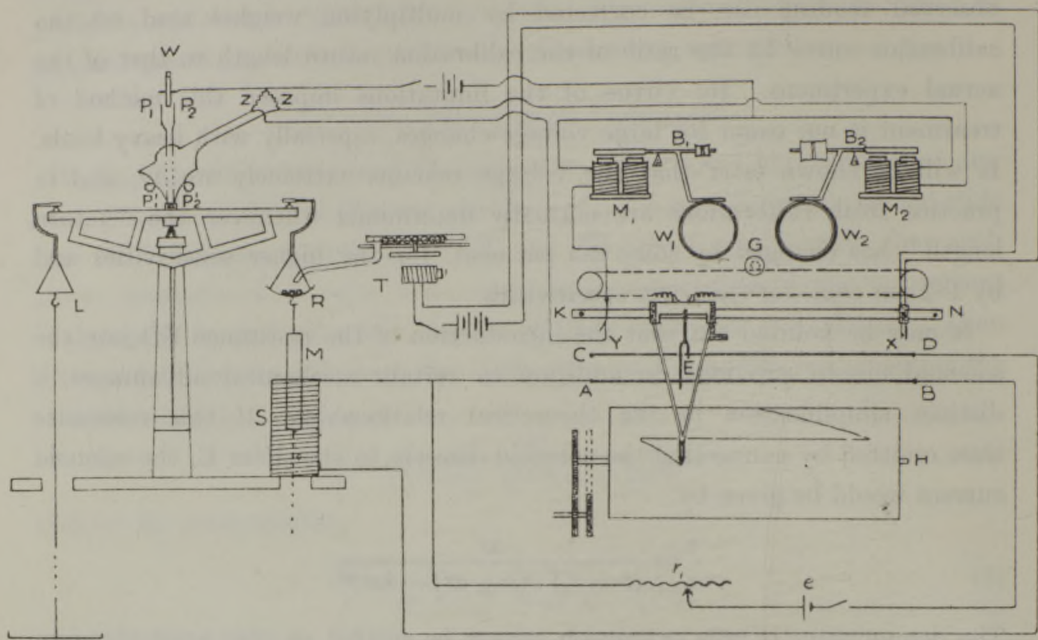

Fig. 2.—Diagram of Complete Apparatus.

fine galvanometer coil suspensions. These terminals in turn are connected to two others mounted in ebonite on the balance case. The prongs are arranged so as to be about 1 mm. from the contact wheel when the balance is in equipoise. Sparking, when the prongs make contact with the wheel, is minimised by placing resistances Z of 500 ohms between the wheel and each of the prongs. For a sedimentation experiment, it is necessary that the movements of the pan in the soil suspension should be as small as possible. To achieve this, the prong P_2 is kept close up to the contact wheel by keeping it bright (so that there is no sticking) and by reducing any overshooting, as described later. During the addition of a weight to the pan R at the end of a transit a displacement of the balance necessarily occurs. The maximum effect on the sedimentation pan is $\frac{\text{(length of arm)}}{\text{(length of pointer)}} \times$ (movement of prong) and cannot, therefore, exceed $0 \cdot 5$ mm.

The prong P_1 is coated with a loose wrapping of tin-foil in order that it may remain in steady contact with the wheel W when the balance is displaced by the added weight, without any bouncing, until the "return" is complete and the balance arm has moved over into the normal position with prong P_2

almost in contact with W. The period of the return is about 15 seconds. In any experiments in which the pan is immersed in a liquid (as in the case of a soil suspension) there is considerable damping of the balance, but this does not seriously affect its sensitivity, since the balance does not swing appreciably during an experiment.

The Contact Wheel, W, is a brass disc about 2 cm. in diameter with a projecting platinum rim and is rotated by clockwork carried on an extension of the balance case. The wheel is rotated about an eccentric axis at a speed of one revolution per minute. The rim, therefore, rubs against the prong, and the point of contact moves slowly up and down the prong so as to keep it clean and prevent sticking due to any irregularity in either surface. The importance of this movement is shown by the unsatisfactory record given if the clock should stop. Considerable experimentation was necessary before this motion could be obtained satisfactorily. In the early experiments the chart consisted of a series of distinct steps occurring once every minute. With small rates of increasing weight the movements of the prongs are extremely slight, and it was found that the prongs remained almost stationary whilst the wheel in its rotation moved slightly towards or away from the prong, thus causing a make and break of contact at one minute intervals. The wheel and axle were made true between centres on a watchmaker's lathe and an additional axle support provided close up to the wheel with a spring for the removal of end-play. Careful adjustment of the prong P_2 then allowed the elimination of the discontinuities in the record. Electrical connection with the wheel is through the supports of its axle to a wire soldered to the clock case.

The Solenoid and Magnet.—The solenoid consists of 2,900 turns of 28 S.W.G. copper wire and has a resistance of 9·46 ohms. It is rigidly supported on a brass plate fitted with levelling screws resting on hole, slot, and plane supports on a brass plate screwed into the balance case.

Tests with a soft iron bar showed that this was not suitable. Such a bar was suspended in a solenoid and a series of increasing and then of decreasing weights added to the balance and the current adjusted to keep the balance in equilibrium. Fig. 3 shows the results. As would be expected the soft iron bar shows considerable hysteresis, and its employment by Svedberg and Rinde,* in their apparatus for the measurement of size distribution in gold sols, is surprising.

No hysteresis was shown in similar experiments with a permanent magnet, and the one finally used was a hollow tube of cobalt magnet steel. The

* T. Svedberg and H. Rinde, 'Journ. Amer. Chem. Soc.,' vol. 45 (1923), pp. 943–954.

magnet and the solenoid were of equal length (3·5 inches) and the magnet was suspended in such a position that the lower end was at the midpoint of the

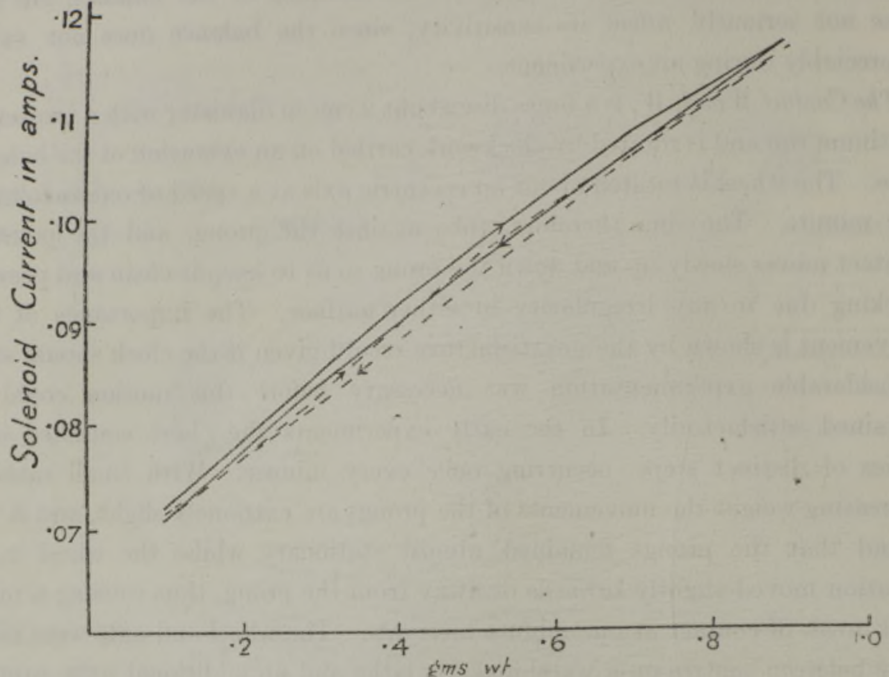

FIG. 3.—Hysteresis Effects given by Soft Iron Bar.

solenoid. Experiments, illustrated in fig. 4, show that this position gives not only the greatest force on the magnet for a given current, but a minimal effect for slight vertical displacements of the magnet due to movements of the balance.

The Ball-Dropping Mechanism.—This is carried on the side of the balance and is shown diagrammatically in fig. 5. Phosphor bronze balls were selected as being non-magnetic and readily obtainable at a low cost. For different purposes three weights were found convenient, and balls weighing 0·504 gm., 0·149 gm., and 0·063 gm., graded to an accuracy of $\pm$·0005 gm., were used. The balls are placed in small holes arranged around a horizontal disc rotating on a metal plate. At one point a hole in the plate allows the ball to drop down a tube V on to the balance pan. By means of an electro-magnetic ratchet device the disc is driven forward and a ball dropped down the tube whenever the electro-magnet is actuated.

Slide Wire.—The control of the solenoid current is by means of a modified Callendar Electric Recorder. This consists essentially of a mechanism for moving a sliding carriage E along a bar KN by means of an endless band driven by a worm G. The worm can be rotated in opposite directions by two clockwork

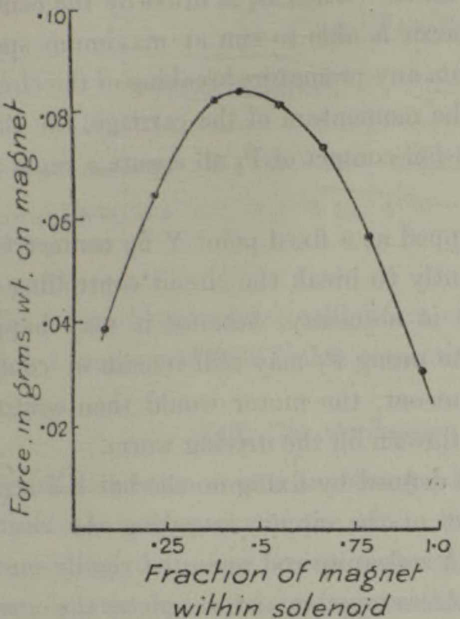

FIG. 4.—Variations of Effective Weight with Relative Positions of Magnet and Solenoid.

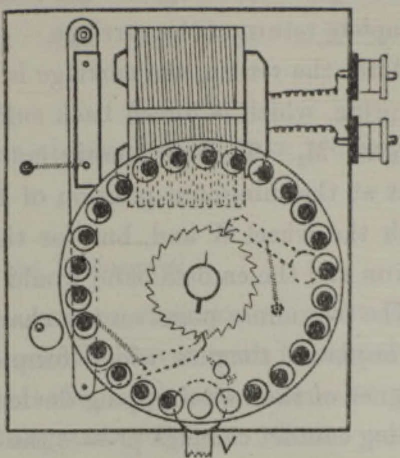

FIG. 5.—Ball Dropping Mechanism.

motors which operate whenever the brakes B_1 B_2 resting on the light fly-wheels W_1 W_2 are lifted by the electro-magnets M_1 M_2 to which they are attached. The sliding carriage E forms a bridge between two slide wires and carries a pen recording its position on a drum H, which is driven forward at the rate of either 0·5 inch or 6·0 inches per hour,* as required by the nature of the experiment. The slide wires AB and CD are 8·75 inches long, with a resistance of 1·79 ohms, and terminate in substantial brass rods passing through ebonite supports. In order to ensure good contact with the slider, the wires are stretched as tightly as possible ; they were selected as possessing the highest resistance consistent with the requisite mechanical strength.

The electro-magnets are operated by a 4-volt battery acting through circuits which include the contact wheel W and one or other of the prongs P_1 and P_2. The brake B_2 is heavily loaded so as to stop the motor immediately the operating circuit is broken. Combined with the clean and hard surface of the prong P_2, this ensures that the forward movement of the carriage shall be

* Lengths have been expressed in inches because it is found most convenient to use charts on the Recorder divided into tenths of an inch.

slight and very frequent, with no risk of appreciable overshooting. The load on the brake B_1 is reduced to the smallest amount that will prevent the rotation of the wheel W_1 when the brake rests on it. When B_1 is lifted by the contact of prong P_1 with the wheel W, the motor is able to run at maximum speed, since the tin-foil wrapping of P_1 prevents any premature breaking of the circuit, and E returns rapidly towards A. The momentum of the carriage, the slight breaking action of B_1, and the soft tin-foil contact of P_1 all ensure a rapid and complete return of the carriage.

After the return, the carriage is stopped at a fixed point Y by contact with a spring, which is forced back sufficiently to break the circuit controlling the magnet M_1. This automatic cut-out is necessary, because it may happen that at the minimum position of E the prong P_1 may still remain in contact with the wheel W and, but for the cut-out, the motor would then continue to run and the endless band would be thrown off the driving worm.

The maximum point on the chart is defined by fixing on the bar KN a pair of insulated tongues which form part of the circuit actuating the electro-magnet of the ball-dropping device. A vulcanite rod mounted rigidly on the sliding contact carriage presses the contacts together and completes the circuit. In determining the position of the tongues it is necessary to pay attention to the behaviour of the balance and contact after the return. If the return length is greater than is needed, the prong P_2 comes suddenly into contact with the wheel W and bounces away again. This, together with the heavy loading of the brake B_2, results in a maximum rate of accommodation and an irregular record on which the precise measurement of the return length is difficult. It is more convenient to make the return length rather shorter than is needed in order that the prong P_2 may remain close to, but not touching, the wheel until the load is increased by a few milligrams. The resulting chart consists of a short interruption followed by a normal record from which an easy extrapolation gives the return length. The tongues are therefore adjusted so that there is such a short stationary period after each return.

Accumulators.—The maximum currents taken from the accumulators, as calculated from equation (2), are 0·38, 0·14, 0·06 amps. for the three sensitivities normally adopted. The lowest sensitivities and highest currents are generally only employed for an hour or two, whilst in prolonged experiments the higher sensitivities and lower currents are needed. To provide these currents with only a very slight voltage change, three 2-volt Fuller block-type accumulators, each of 80 amp. hours capacity, are used in parallel. The cells are usually recharged monthly and show very little reduction in voltage during this interval. The constancy of the return lengths throughout a soil sedimentation experiment lasting two days is shown in Table I.

TABLE I.

	Coarse Sensitivity.				Fine Sensitivity.						
Time in minutes	20	35	63	130	253	330	433	746	975	1657	2808
Return length in inches.	6·1	6.1	6·2	6·13	5·40	5·40	5·43	5·34	5·33	5·36	5·33

The return lengths from calibration curves obtained some days previously were 6·1 inches and 5·38 inches respectively.

§ (5) *The Calibration of the Instrument.*

Direct calibration curves involving a large number of points were obtained to check the uniformity of the wire. Subsequently curves with fewer points were constructed after every recharging of the cells and whenever the return lengths indicated an appreciable change of voltage. These points were quickly obtained by adding a series of weights to the pan and operating

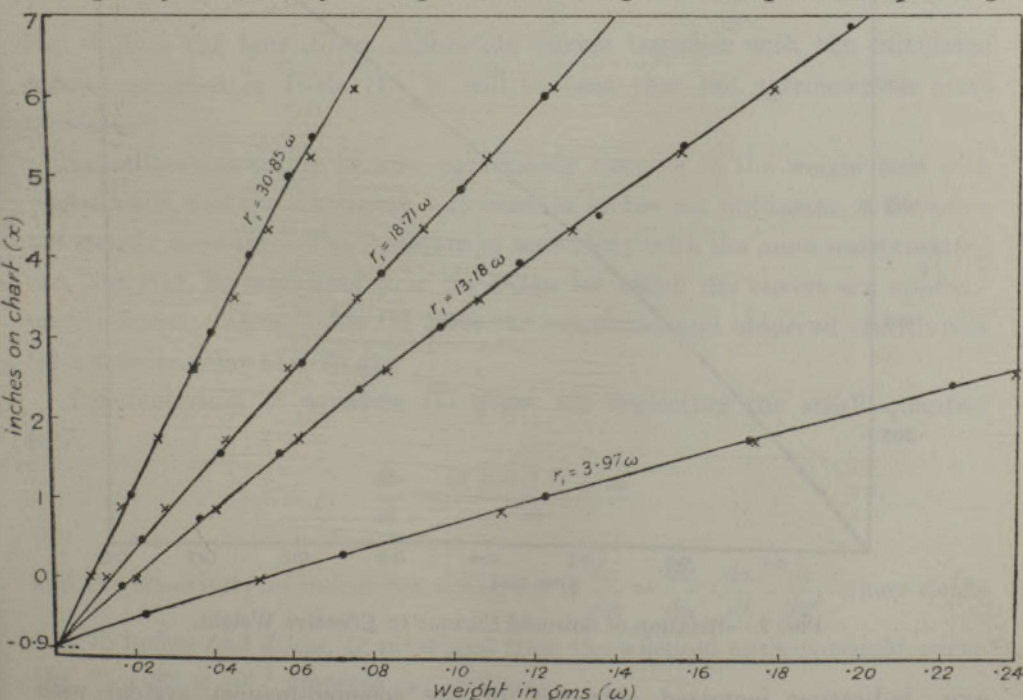

FIG. 6.—Typical Calibration Curves. • determined by experiment; × calculated in Table II.

the relays by hand until the prongs moved symmetrically about the contact wheel. The curves are most conveniently constructed on squared paper identical with that used on the drum.

Typical curves are given in fig. 6, and a useful check on the behaviour of the apparatus is provided by comparing the direct calibration curves with those deduced from equation (1). Careful measurements were made of the resistances of the various parts of the circuit, including those of the leads and switches, which were made as low as possible. The values of i/e from equation (1) were converted into weights by a special solenoid current-weight curve. This was obtained by passing a current from the cells through a standard resistance box in series with the solenoid and adjusting the resistance to give equipoise. The direct calibrations with four sensitivities were then made and potentiometer measurements showed that the voltage had not changed throughout both series of experiments. It may be observed that the solenoid current-weight curve in fig. 7 shows an unexpected concavity to the weight

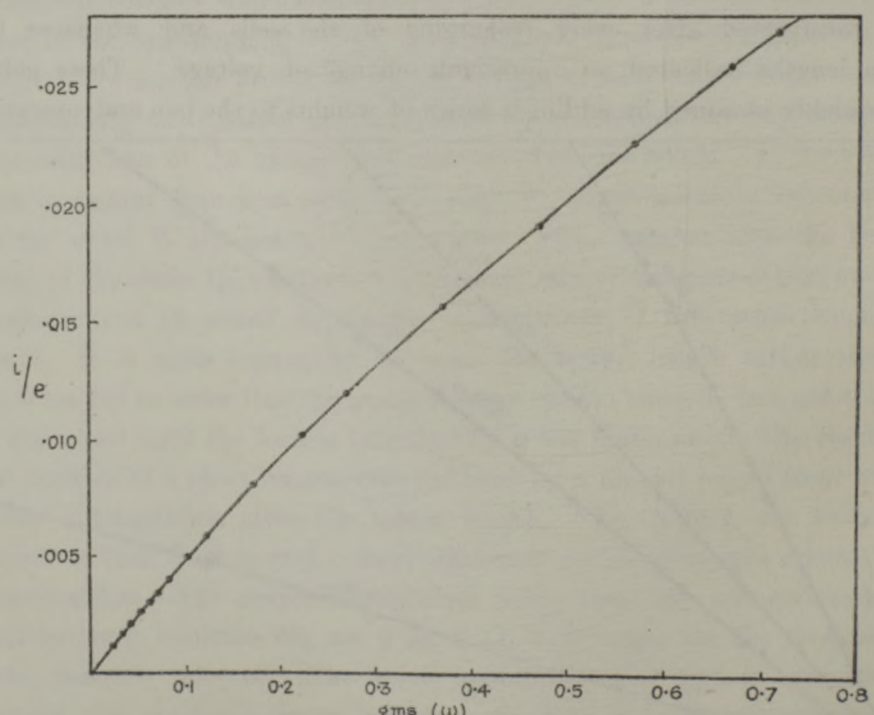

Fig. 7.—Relation of Solenoid Current to Effective Weight.

axis, indicating increased efficiency of the solenoid-magnet system with increased loads.

Table II gives, for four values of the resistance (r_1) the values of i/e from equation (1) and the corresponding weights (w) in gms. from fig. 7. The resistance of solenoid, leads, and slider (s) was 9·66 ohms and the resistance of the slide wire AB was 1·79 ohms. The slide wire was 8·75 inches long and extended 0·90 inch beyond the arbitrary zero of the chart; the chart reading (x) is thus equal to ($8·75\ \alpha - 0·9$) inches.

TABLE II.

a	x.	$r_1 = 30·85\ \omega$.		$r_1 = 18·71\ \omega$.		$r_1 = 13·18\ \omega$.		$r_1 = 3·97\ \omega$.	
		$i/e . 10^3$.	w.	$i/e . 10^3$.	w.	$i/e . 10^3$.	w.	$i/e . 10^3$.	w.
0·1	−0·02	0·48	0·0096	0·76	0·0138	1·05	0·0202	2·72	0·051
0·2	0·85	0·96	0·0178	1·52	0·0282	2·09	0.0406	5·44	0·111
0·3	1·72	1·44	0·0272	2·28	0·0436	3·14	0·0614	8·21	0·174
0·4	2·60	1·92	0·0354	3·05	0·0596	4·19	0·0838	10·95	0·238
0·5	3·48	2·40	0·0460	3·83	0·0762	5·26	0·1062	15·00	0·353
0·6	4·35	2·88	0·0556	4·61	0·0936	6·32	0·1292	19·80	0·490
0·7	5·23	3·35	0·0658·	5·38	0·1094	7·41	0·1560	24·98	0·643
0·8	6·10	3·85	0.0766	6·16	0·1256	8·47	0·1796	31·62	—
0·9	6·98	4·35	0·0874	6·94	0·1438	9·58	0·2038	40·40	—

Fig. 6 gives the four direct calibration curves together with the calculated points contained in Table II. It will be seen that the agreement is quite satisfactory.

The calibration curves become appreciably concave to the weight axis with higher loads, and the sensitivity, expressed in inches per milligram, is therefore not strictly constant. The variation of sensitivity with the main resistance (r_1) can, however, be calculated over the range for which the curves are approximately linear. Thus, Table III gives the calculated and observed sensitivities for a definite value of 0·05 gm.

Differentiation of equation (1) gives, on neglecting the small quantity $(\alpha r)^2$,

$$\frac{d\alpha}{di} = \frac{(r + r_1)\,(r + s)}{er}.$$

and the sensitivity in inches per milligram is $\frac{dx}{dw} = \frac{dx}{d\alpha} \cdot \frac{d\alpha}{di} \cdot \frac{di}{dw}$, where $dx/d\alpha$ is 8·75 inches and di/dw, as measured from the solenoid current-weight curve (fig. 7) $4·98 \times 10^{-5}$ amperes per milligram.

Table III.

r_1 ohms.	Sensitivity (dx/dw) inches per milligram.	
	Calc.	Found.
30·85	0·092	0·094
18·71	0·056	0·056
13·18	0·042	0·042
3·97	0·016	0·016

§ (6) *Typical Applications.*

The apparatus may be adapted for use in a variety of problems involving either increases or decreases of weight. At Rothamsted the problems at present under investigation include mechanical analysis or the determination of size distribution in soils and other suspensions, the flocculation of colloids such as clay, and the evaporation of water from various materials. Detailed reports of these investigations will be given later ; those given below are intended merely to illustrate the behaviour of the balance.

(*a*) *The Size Distribution in Suspensions.*—One of us* has shown that the size distribution in suspensions can be obtained from an analysis of the " accumulation curve," *i.e.*, the weight of sediment expressed as a function of the duration of the sedimentation process. The results are conveniently represented by plotting against the logarithm of the " equivalent radius " of the particles or of the velocity of sedimentation, ordinates such that the area cut off between two ordinates represents the fraction by weight of the total material with " equivalent radii " between the corresponding values of the abscissæ. The evaluation of this function involves the second differential of the accumulation curve. It is obvious that this curve must be obtained with considerable accuracy. Hitherto a graphical treatment of a limited number of observations has been necessary, but the new balance allows a purely numerical treatment of any desired number of points.

Fig. 8 gives the size distribution of four soil fractions prepared by repeated sedimentation. A portion of one of the actual records for fraction C of fig. 8 is reproduced directly in fig. 9. This chart illustrates the smoothness of the record both for fairly rapid and very slow weight changes. The last portions of the record (which are not reproduced) gave a very smooth curve for a weight change of about 1 milligram in six hours.

* Sven Odén, *loc. cit.* *See also* Fisher and Odén, 'Roy. Soc. Proc. (Edin.),' vol. 44 (1924), pp. 98–115, for a theoretical treatment of the conditions in a sedimenting column.

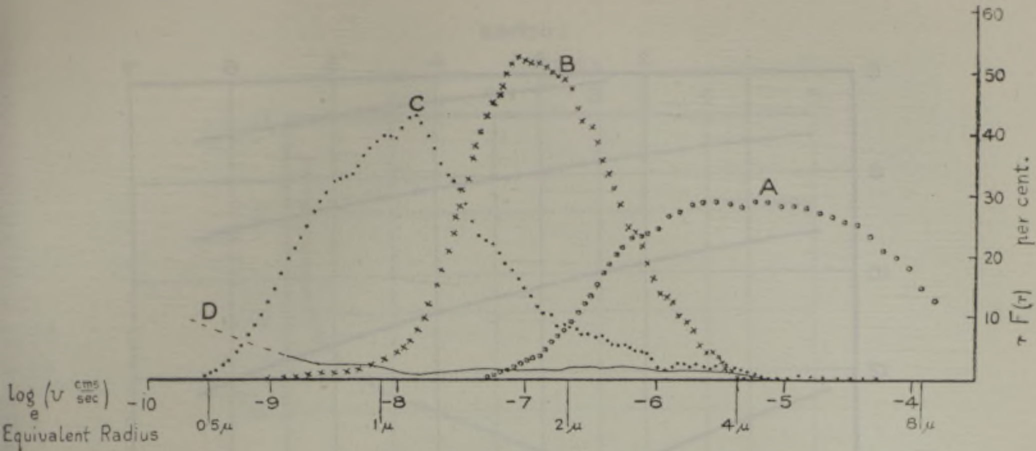

FIG. 8.—Size-distribution Curves for Four Soil Fractions.

(*b*) *Flocculation of a Clay Suspension.*—Fig. 10 is a direct reproduction of an actual chart in an experiment in which the balance-pan was placed near the bottom of a cylinder containing a dilute clay suspension with a small amount of acid. The chart brings out clearly the various stages in the course of the flocculation and sedimentation,* viz., (1) an initial period with no sedimentation; (2) a period of rapid sedimentation at a uniform rate, corresponding to aggregates of equal size; and finally, (3) the slow sedimentation of the incompletely flocculated material.

(*c*) *Evaporation of Water from Cotton-wool.*—A piece of commercial absorbent cotton-wool, containing about 0·25 gm. of dry matter, was thoroughly soaked under water and freed from air by the suction of a filter pump for 24 hours. After removing surplus water by light pressure, the cotton-wool was placed in a weighing bottle suspended in a chamber exposing a large surface of strong sulphuric acid ; the suspending wire, attached below the magnet, passed through a very small hole in a glass plate, such that there could be only very slight diffusion of air into the drying chamber. The temperature of the chamber fell steadily from 10·5° C. to 10·2° C. in 60 hours. The records for the first 50–60 hours showed such a close approximation to straight lines that nothing is gained by plotting weights against time. As the simplest method of bringing out any irregularities, the method of representation was to read off the weights at hourly intervals and obtain the hourly change in weight. Fig. 11 gives the values of two point means of the rate, expressed in milligrams per hour against the time in hours. The points do not deviate

* Sven Odén, 'Kolloid Zeitschrift,' vol. 26 (1920), pp. 100–121.

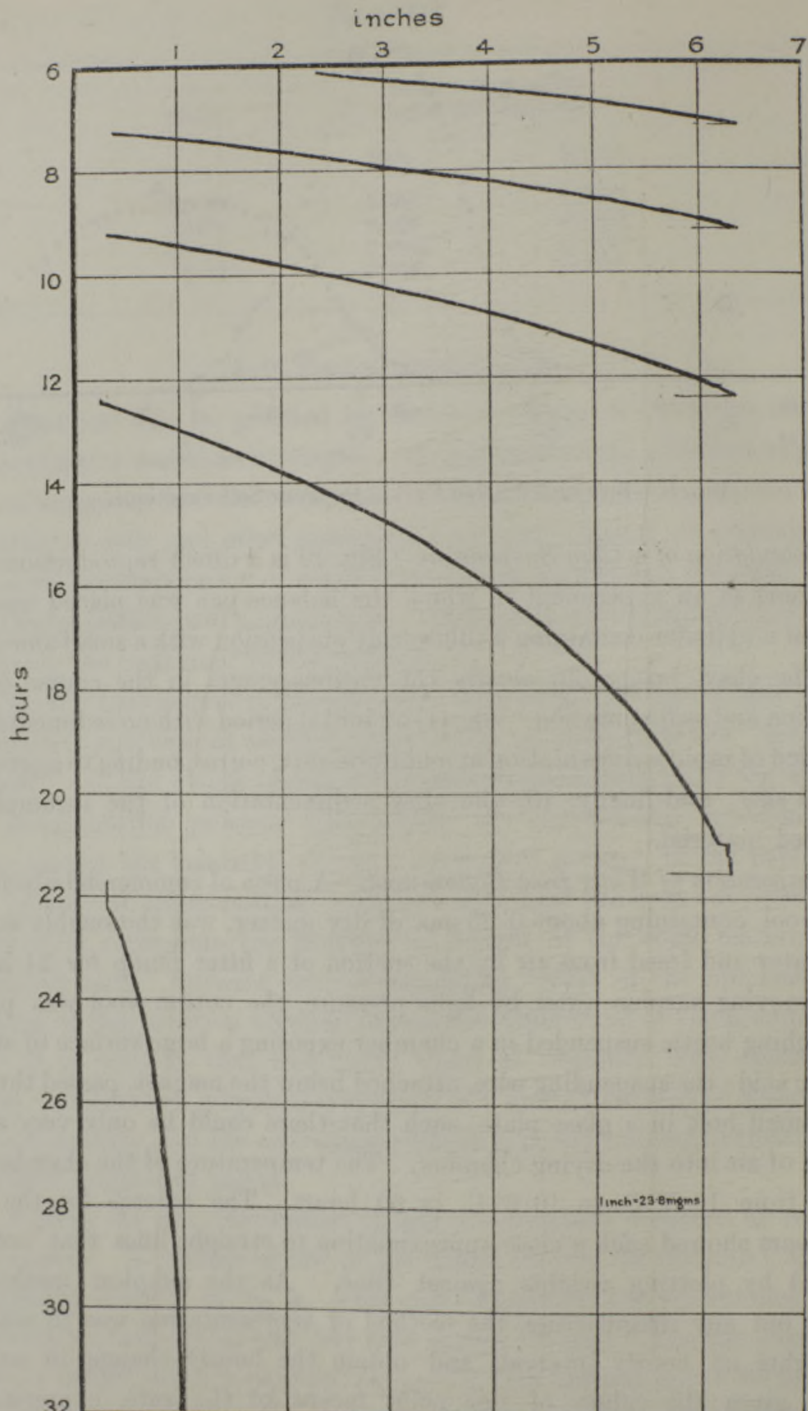

Fig. 9.—Typical Balance Chart from a Soil Sedimentation.

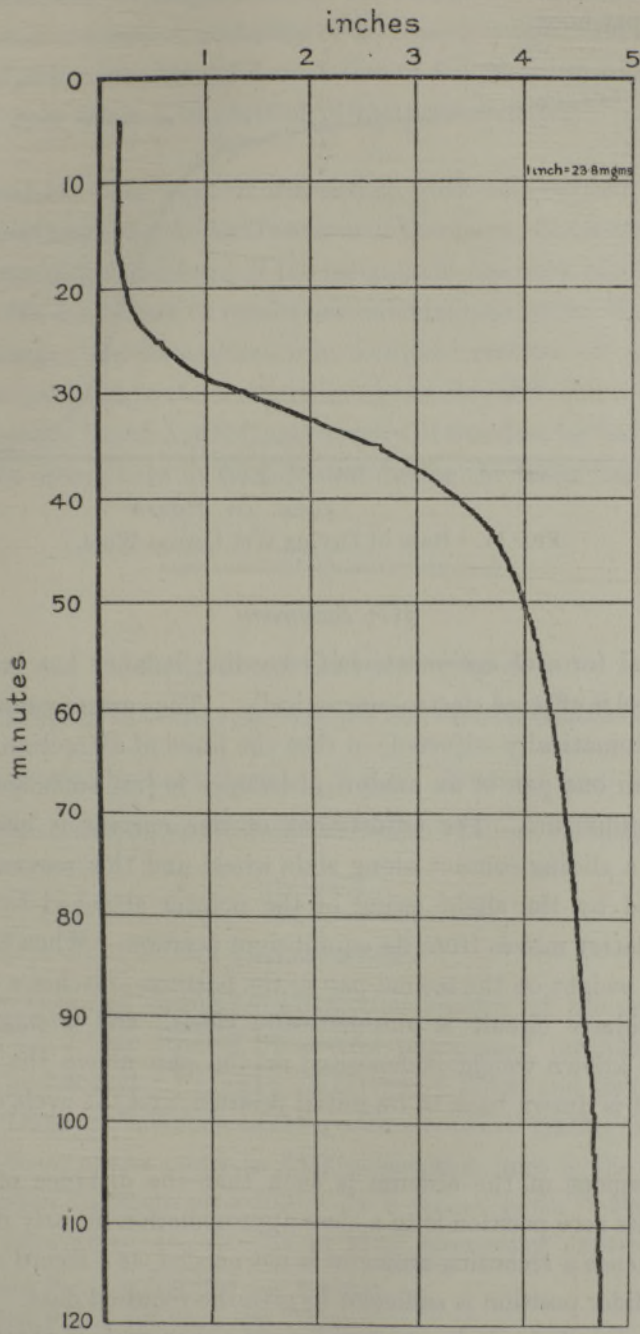

FIG. 10.—Typical Balance Chart from a Clay Flocculation.

considerably from a smooth curve although the maximum rate was less than 8 milligrams per hour.

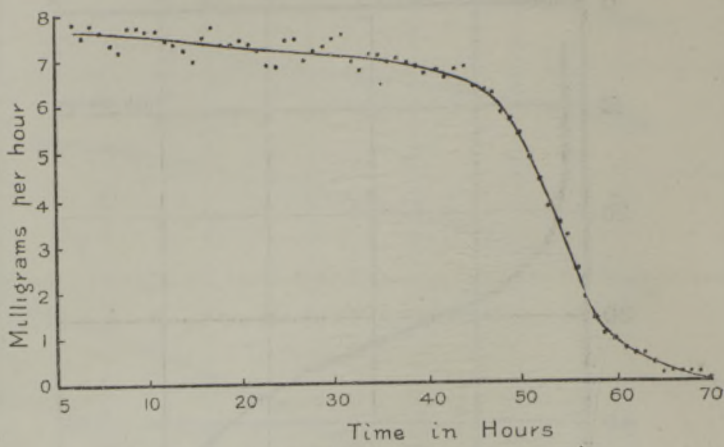

Fig. 11.—Rate of Drying Wet Cotton Wool.

§(7) *Summary.*

An improved form of automatic self-recording balance has been described, in which control is effected electro-magnetically. The current passing through a solenoid is automatically adjusted, so that the force of attraction on a magnet suspended from one pan of an analytical balance is just sufficient to keep the balance in equilibrium. The adjustment of this current is effected by the movement of a sliding contact along slide wires, and this movement is in its turn controlled by the slight swing of the pointer attached to the balance beam, as the latter moves from its equilibrium position. When the current—and hence the weight on the second pan of the balance—reaches a pre-arranged value, a subsidiary circuit is automatically closed, and a small phosphor-bronze ball of known weight is deposited on the pan above the magnet, the sliding contact is drawn back to its initial position, and the cycle of operations recommences.

The arrangement of the circuits is such that the distance of the sliding contact from its zero position is to a close approximation linearly related to the current, and hence a recording-ammeter is not needed, as a record on a rotating drum of the slider position is sufficient to give the required data. The records consist of a series of stepped curves and a very open scale is obtained.

The apparatus can be used with no loss of sensitivity up to the maximum load the balance is designed to carry. Further, the sensitivity can be very simply adjusted, so that both rapid and slow changes of weight can be recorded.

The apparatus can be employed with advantage in experiments involving a continuous measurement of increasing or decreasing weight, and its application to the study of sedimentation and flocculation of soil particles, and the evaporation of water from fibres is illustrated in the present paper.

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We are also indebted to the authorities of the Royal Technical High School, Stockholm, and the Royal Agricultural Society of Sweden, for having facilitated the visit of one of us (S.O.) to Rothamsted during the latter half of 1923.

Absorption of Lithium Vapour.

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(Plate 2.)

Introduction.

The fluorescence and channelled absorption spectra of the vapours of the alkali metals have been studied by several physicists,* notable among them being Roscoe and Schuster,† Liveing and Dewar,‡ Wood and his collaborators,§ Bevan,‖ and Dunoyer,¶ Wood, working with a concave grating of large radius showed that there are as many as 8,000 absorption lines in the visible region of the absorption spectrum of sodium. In a recent paper** Prof. McLennan and Ainslie have given an account of some interesting experiments on this

* 'Roy. Soc. Proc.,' A, vol. 103, pp. 304–306.

† 'Roy. Soc. Proc.,' vol. 22, p. 362 (1874).

‡ 'Roy. Soc. Proc.,' vol. 27, p. 132, and vol. 28, p. 352.

§ 'Astrophys. Journ.,' vol. 18 (1903) and vol. 30 (1909).

‖ 'Roy. Soc. Proc.,' A, vol. 84, p. 213 (1910), and vol. 85, p. 61 (1911).

¶ 'Le Radium,' pp. 177, 209, and 218 (1912).

** 'Roy. Soc. Proc.,' A, vol. 103, pp. 306–315.