

(*Paper No. 295.*)

“Meters for recording the Consumption of Electrical Energy.”¹

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THE rapid advance that electric lighting from central stations has made during the last few years has brought the question of the construction of instruments for recording the energy used by individual consumers into great prominence. The subject had engaged the attention of inventors for many years previously; but the need was not so pressing, and, numerous as had been the attempts, but few instruments had passed the experimental stage. Hence, the early supply companies were forced to charge their consumers a fixed price per annum based on an average number of hours of burning, such average being of necessity arrived at by guess-work in the absence of any experience. It was found that this system was unsatisfactory to the company and its clients, for in the case of clubs, restaurants and many shops, three hours—the average time assumed—was found to be absurdly small; and, on the other hand, it was too large for many private houses. Endless disputes resulted, and consumers became dissatisfied and ceased to use the light. A large amount of loss was occasioned by persons leaving lamps burning needlessly, because they had not to pay for them; and it is a significant fact that in the case of a large central station in London, the current during the day was sensibly diminished when a large number of consumers were supplied by meter instead of by contract.

The urgency of the demand for meters has brought forth a supply, and there are now in the market several types that are reliable and accurate, and the Author purposes confining his remarks chiefly to these, merely glancing briefly at a few of the best of the early and less successful types.

There are two fundamentally different systems of supply, *i.e.* (i) by continuous, and (ii) by alternating currents; and to each of

¹ This communication was read and discussed at a meeting of the Students on the 11th of December, 1891.

these belong certain classes of meter that will only work with a particular kind of current, while some are common to both systems; these last are usually dependent for their action on the square of the current.

In all cases it is desired to measure the total amount of energy that has been converted into light and heat in the consumers' lamps and wires, and a meter is an instrument that continuously records the power delivered, and integrates it with respect to time.

In the case of continuous currents, if E be the potential difference, or pressure in volts, between the mains at any instant, and C the current in amperes at that instant through the lamps, then $E \times C$ is the power, or rate at which energy is being supplied in watts; and if t is the time in hours during which the rate is kept up, then ECt is the total quantity of energy in watt-hours used by the consumer in the time t . This number divided by one thousand gives the number of commercial or Board of Trade units (B.T.U.) consumed. What the meter has to do, then, is to sum up the successive values of this product.

With alternating currents the measurement of the power is not so simple, for in this case if the mean pressure and the mean current be multiplied together, the product is not necessarily the power absorbed. If the current lags behind the pressure, as it will if the circuit possesses self-induction (and it always does so in practice, though in the case of a bank of incandescent lamps the lag is negligible), the current maximum does not occur at the same instant as the pressure maximum, and the real power is less than that obtained by multiplying together the mean pressure and the mean current. Taking the same units as before, if E be the maximum pressure, C the maximum current, and ϕ the angle of lag of the current behind the pressure,

$$\text{then the true power} = \frac{EC}{2} \cos \phi.$$

Since all distribution is effected at constant pressure, it is sufficient to integrate the current only, and to multiply the result by the pressure in the case of continuous currents, and of alternating currents also, if incandescent lamps only are in circuit; provided in all cases that the standard pressure is closely maintained. This course is adopted in a large number of meters, and is quite satisfactory in practice. If, however, greater accuracy be desired, the principle of the watt-meter must be employed. Here the stress between two coils, one of which carries the main current and the other a shunt current proportional to the pressure, is made

use of. The force in the case of continuous currents is proportional to the product of the pressure and current; but in the case of alternating currents this is only the case if the shunt coil has no self-induction, a condition manifestly impossible to obtain; it can, however, be sufficiently reduced to render the error very small.

It would be entirely out of place in a Paper of this kind, which aims at a description of actual instruments in commercial use, to enter into a mathematical discussion of the measurement of alternating currents, the matter being fully treated in textbooks in language far more able than the Author's, and to which he could add nothing.

Meters fall broadly into four classes:—

1. Those in which the current to be measured, besides controlling the registering gear, supplies the motive power for it.
2. Those in which the current to be measured controls the registering mechanism, while a separate current supplies the motive power.
3. Those in which the current merely controls mechanism which is driven by some force altogether external to the current, such as a spring or weight.
4. Those in which no gearing is driven, but chemical action goes on, involving an alteration in mass of a plate of metal.

CLASS 1.

Numerous forms of motor meter have been designed, and some of the most successful instruments in use at the present time are included in this class. The majority are current-, and not power-integrators, the pressure being assumed constant as already explained.

Ferranti Meter.—This depends for its action on the fact that when a mass of mercury is cut normally by lines of magnetic induction, and an electric current flows radially through it, the mercury tends to rotate. If the same current that flows through the mercury excites the field, the speed of rotation will be proportional to the square of the current; but mercury being a fluid, its motion is opposed by friction against the sides of the containing vessel with a force that varies as the square of the speed, hence the speed of rotation is proportional to the current. This principle is equally adapted to the measurement of continuous and of alternating currents, and it has received very great development at the hands of the inventor. It is the meter that is chiefly used by the London Electric Supply Corporation for

installations exceeding 40 amperes, and as the Author has had a large experience of it, a detailed description may not be out of place.

When the principle is applied to making a practical instrument, an aluminium fan, mounted on a spindle, is immersed in the mercury, and is carried round by it; the spindle carries a pinion gearing into a train of counting wheels. This counting mechanism introduces friction that is practically independent of the speed of rotation, and is greater when the meter is at rest than when it begins to move. The whole friction is thus made up of two parts, one varying as the square of the speed, the other independent of the speed; obviously the relative importance of the latter diminishes as the current, and therefore the speed, increases. In order to compensate for the error that would thus be introduced, a "shunt coil" is provided, *i.e.*, a fine wire winding on the field magnet placed as a shunt across the lamp leads, thus establishing a certain magnetising force independent of the number of lamps alight. The relative importance of this magnetising force manifestly decreases as the main current increases, and this effect is enhanced by a transformer action being set up, whereby the main current generates in the shunt coil an electromotive force oppositely directed to that acting on it, thus further cutting down its magnetising effect. By suitably varying an extra resistance in series with the winding, the compensation can be made practically perfect. In Fig. 1, Plate 11, are plotted three curves that very clearly show the part played by the shunt coil. A constant current was maintained through the main coil, and the current in the shunt coil was varied by altering the extra resistance in series with it, the speed of rotation for successive values of the latter being noted. Another value was then given to the current in the main coil and the same operation repeated. The results are plotted for three main currents, revolutions per unit as ordinates, and extra resistance as abscissae. It will be seen that, except for very large shunt magnetising forces, the effect of the shunt coil at high currents in the main winding is small. The point in which the three curves cut gives the extra resistance required by the particular meter.

One of the latest forms of this meter is shown in Fig. 2, Plate 11. It is intended for a maximum current of 100 amperes, and with this load on for twenty-four hours does not rise to an excessive temperature. This, it may be noted in passing, is a point that should always be tried for each meter containing iron if intended for alternating currents, for it is found that out of a batch of similar

meters several will heat excessively. The cause is somewhat obscure, but is probably due to the laminations of the iron becoming short-circuited. The meter is contained in a well-ventilated brass case, A B C, no wood being used in its construction. The brass cylinder B is slipped on after the leads are fixed, and is secured by a wrought-iron pin D, passing through it and under the base; a small hole, E, is drilled through the end of this pin, and tape is passed through this and sealed. It is thus impossible for the meter to be tampered with, and the whole arrangement is very compact and convenient. The magnetic circuit F F is closed, except for the gap G, which contains the mercury. The current enters by the central portion H, the rest of the top and bottom of the cavity being covered with vulcanised fibre. The circumference of the bath is uninsulated and by it the current leaves, flowing thence through the main coil K, one end of which is attached to the iron of the magnet, and so out of the meter. The shunt coil is shown at L and the extra resistance at M; N is the fan, wholly immersed in the mercury and carried by the spindle O which drives the train P.

The following is a test made of a meter of this type:—

TEST OF 100-AMPERE ALTERNATE-CURRENT FERRANTI METER.

Meter started with 0.92 ampere.

Current in Amperes.	Revolutions per Board of Trade Unit.	Current in Amperes.	Revolutions per Board of Trade Unit.	Current in Amperes.	Revolutions per Board of Trade Unit.	Current in Amperes.	Revolutions per Board of Trade Unit.
1.5	10.4	7.5	17.5	40.0	16.9	80.0	17.3
3.0	15.4	10.0	17.0	50.0	17.0	90.0	17.3
4.0	17.5	20.0	17.0	60.0	17.3	100.0	17.3
5.0	17.3	30.0	17.2	70.0	17.3		

It will be noticed that the uniformity of the constant is most marked, and it has been found, after repeated experiments, that if the meter is adjusted so as to have the same constant at 10 amperes and 100 amperes, the value will be practically the same at all intermediate points.

In the continuous current form, solid cast-iron or steel is substituted for laminated wrought-iron, and the residual magnetism takes the place of the shunt coil.

The following are tests of two of these meters:—

TEST OF 100-AMPERE CONTINUOUS-CURRENT FERRANTI METER. UNSHUNTED.

Meter started with 0.25 ampere.

Current in Amperes.	Revolutions per Board of Trade Unit.	Current in Amperes.	Revolutions per Board of Trade Unit.
1.0	16.6	50.0	16.6
10.0	16.4	100.0	16.5

TEST OF 10-AMPERE CONTINUOUS-CURRENT FERRANTI METER. UNSHUNTED.

Meter started with 0.15 ampere.

Current in Amperes.	Revolutions per Board of Trade Unit.
1.0	110
5.0	112
10.0	110

An important point in connection with the permanent magnetism of these meters, which renders its use unobjectionable, is that the steel giving the initial field is magnetised to saturation by the largest current the meter is intended to carry, so that every time the full load is on the meter the steel is re-magnetised, and any danger of falling off in strength of field is avoided.

In the latest form, meters of the same capacity are made to have the same constant by adjusting the width of a gap in the magnetic circuit, and by the introduction of suitable gearing the constant is dispensed with and the meter is rendered direct-reading. These meters are "double-sealing," i.e. the working parts can be sealed by the local authority against any possible tampering by the supply company, while the latter can independently seal the terminals in order to protect itself from fraud on the consumer's part.

Some of these mercury meters have been at work for two or three years without any attention, though it is desirable to clean the trains and mercury once a year. The following case will give some idea of the constancy that may be attained by this kind of meter. The meter, an alternate-current one, was installed on the 3rd of

December, 1887, and removed on the 25th of February, 1890, during the whole of which time it received absolutely no attention. It was, however, read weekly, so that its performance could be noted, and was constantly at work, except for one week, when it was removed from one consumer's installation—the consumer having ceased to take light from the company—and placed in another's. During the period named the fan made rather more than 9,500,000 revolutions. The tests of the meter before it was put on the circuit and after it was removed are as follows :—

TEST MADE BEFORE METER WAS INSTALLED.

Meter started with 0·8 ampere.

Current in Amperes.	Revolutions per Board of Trade Unit.	Current in Amperes.	Revolutions per Board of Trade Unit.
1·9	17·77	28·75	17·70
4·6	17·77	57·0	17·77
6·4	17·73	95·0	17·73

TEST MADE AFTER OVER TWO YEARS' USE.

Meter just failed to rotate with 2·17 amperes.

Current in Amperes.	Revolutions per Board of Trade Unit.	Current in Amperes.	Revolutions per Board of Trade Unit.
10·2	14·58	70·0	17·83
20·2	16·63	89·6	17·81
50·2	17·93		

The increased current required to start the meter, and the diminished constant at low currents, are obviously due to the train requiring cleaning. The constancy at the high currents is most satisfactory.

Forbes Meter.—Another meter that is adapted equally to alternating and to continuous currents is that invented by Professor G. Forbes. It is based on the heating property of the current, and consists of a horizontal spiral of iron wire, over which is mounted, on a delicate pivoted suspension, a system of mica vanes. Convection currents are set up in the air by the hot wire, and these,

rising against the vanes, urge forward the ring on which they are mounted, its motion being registered by a train of counting wheels.

The standard form at present made has a maximum capacity of 30 amperes, and the heated conductor consists of two concentric wires connected together by a number of fine wires. The current enters at a point in the circumference of one circle, and dividing between its two halves, flows by the fine wires into the other, and leaves by a point in its circumference.

In order to increase the starting power of the meter, a small weight is attached to a cord passing over a pulley and round a drum on the last wheel of the train; this tends to drive the train, and so gives the vanes less work to do.

This meter gave great promise when it first appeared, but it does not seem to have met with much favour, probably because, resembling, as it does, a laboratory instrument in delicacy, it is found unsuitable for practical work. It is liable also to be affected by external changes of temperature and by the temperature of its case not being uniform.

Hookham Meter.—This consists of a motor driven by the current to be measured, the motor being retarded by eddy currents set up in a copper disk. A tungsten-steel permanent magnet with cast-iron pole pieces provides a constant field, and in this is placed the armature, which consists of flat coils laid on a copper disk, the latter serving the double purpose of a support for these coils and of a brake, the latter effect being produced by the eddy currents set up in it. The armature spindle rests on friction-wheels, so that a small force will cause it to move, and with a view to still further diminish friction, mercury contacts are provided, instead of brushes, for the commutator.

The theory of the instrument will be plain from the following considerations. The work done in a given time is proportional to the attraction between the disk and the field, and to the speed. Now in a constant field the electromotive force generated in the disk varies as the speed, and since this acts through a constant resistance, the eddy currents also vary as the speed; hence the work done is proportional to the square of the speed. The work supplied by the armature is proportional to the driving force and to the speed, but the driving force varies as the current; hence the work supplied in a given time varies as the current and the speed; but it has been shown that the work done is proportional to the square of the speed; hence it follows that the speed is proportional to the current.

The principle can be adapted to either alternating or continuous currents, but so far instruments for the latter class of current only have been constructed.

The meter is adjusted so that the dials show Board of Trade units, and it thus possesses the important advantage that its indications have not to be divided by a constant. This is brought about by varying the strength of the field in which the armature revolves, by short-circuiting more or less the magnetic circuit.

Some difficulty was experienced in passing the whole current through the mercury contacts, so that in the latest form all the motors are made to carry 5 amperes, and are shunted with a German silver resistance that allows the requisite proportion of current to pass. This is open to two serious objections, viz. : (i.) any error in the meter is magnified, since a portion only of the current drives the motor ; (ii.) if the resistance of contact of the mercury varies (as it is almost certain to do), the motor does not get its right proportion of current, and its indications are therefore fallacious. The mercury being exposed to the air and being subject to sparking, is rapidly oxidised, and in practice much trouble is experienced on this account, the meter requiring, after a time, a considerable current to start it. The permanent magnet is also an objectionable feature, though it is said that little change is found to occur in the field on account of the care taken in the preparation of the magnets, and because the gap in the magnetic circuit is small.

The Author has not had the opportunity of testing any of these meters, but it is stated that a 20-ampere meter starts with 0.4 ampere ; and that with 0.6 ampere the error is 25 per cent. ; with 1.2 ampere it is 10 per cent. ; while after 2.5 amperes the error is negligible.¹

Elihu Thomson Meter.—Another meter closely resembling this in principle has lately been developed by Professor Elihu

¹ Since this Paper was read, Mr. J. H. Tonge, Stud. Inst. C.E., has favoured the Author with the following test of a 100-ampere Hookham meter for continuous currents. With pure mercury in the contact cups, the meter started with 1 ampere, and with 100 amperes it read 1 per cent. low ; with 50 amperes, 4 per cent. low ; with 20 amperes, 9 per cent. low ; and with 3 amperes, 17 per cent. low. When, however, ordinary commercial mercury which had been in use for a short time was substituted for pure, 3.5 amperes were required to start the meter, and with 100 amperes it read 8 per cent. low. This conclusively proves the statement made as to the error introduced by the variable resistance of the mercury contacts.

Thomson, and appears to be free from some of its defects. A motor is provided, having its armature wound with fine wire and excited with a shunt current, and its fields, without iron, excited by the main current. Since the field is proportional to the current, and the armature current to the pressure, the driving force is proportional to the watts, and hence the instrument is a watt-hour meter. The opposing force, as in the Hookham meter, is due to eddy currents, generated in a copper disk, which is rotated by the armature in a constant field set up by permanent magnets. It is thus open to one of the objections to that meter, but is free from the mercury contacts and variable shunt resistance.

Falling off in strength of the permanent magnets is much to be apprehended, since they are under peculiarly trying conditions: the eddy currents, as in the Hookham meter, tend to demagnetise the magnets; and in the alternating form they are subject to the mechanical vibration which always accompanies this class of current. Another source of error is the friction of the motor brushes, which is likely to alter with wear and dirt.

Time alone can show the importance of these objections; there can be no doubt that when new the meter is capable of giving indications of great accuracy, as the following test proves:—

TEST OF 25-AMPERE ELIHU THOMSON METER.

Meter started with 0.4 ampere.

Current in Amperes.	Pressure in Volts.	Power in Watts.	Revolutions per Board of Trade Unit.	Current in Amperes.	Pressure in Volts.	Power in Watts.	Revolutions per Board of Trade Unit.
24.9	100	2,490	10.14	10.9	100	1,090	9.78
23.9	100	2,390	10.02	9.7	100	970	9.78
22.9	100	2,290	10.02	8.6	100	860	9.84
21.9	100	2,190	10.08	7.8	100	780	9.84
20.9	100	2,090	10.02	6.8	100	680	9.72
19.8	100	1,980	10.02	6.0	100	600	9.72
18.8	100	1,880	9.96	4.8	100	480	9.72
17.9	100	1,790	10.20	4.0	100	400	9.60
17.0	100	1,700	10.20	3.0	100	300	9.42
15.9	100	1,590	10.02	2.0	100	200	8.70
14.9	100	1,490	9.96	0.99	100	99	7.44
13.9	100	1,390	9.96	0.78	100	78	6.66
12.9	100	1,290	9.90	0.58	100	58	4.98
11.9	100	1,190	9.90				

In order to try the effect of varying the pressure as well

as the current, the following tests were made of the same meter:—

Current in Amperes.	Pressure in Volts.	Power in Watts.	Revolutions per Board of Trade Unit.	Current in Amperes.	Pressure in Volts.	Power in Watts.	Revolutions per Board of Trade Unit.
24·8	108	2,678	9·96	24·9	90	2,241	10·14
20·1	108	2,171	9·96	20·1	90	1,809	10·02
15·2	108	1,642	9·72	14·9	90	1,341	9·66
10·0	108	1,080	9·66				

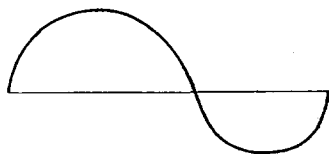
The extremely low speed of the armature, and its property of stopping almost dead immediately the current is switched off, are noticeable points, and the former is an important advantage, as tending to lengthen the life of the meter by diminishing the wear.

In measuring currents supplied on the three-wire system, the neutral wire does not enter the meter, but the others pass each through one of the two field-coils. The armature circuit is connected across the outer conductors, being thus excited with 200 volts.

When it is desired to measure the current conveyed by the high-tension mains from an alternating central station, the high-tension lead is taken through the field-coils, while the armature circuit is excited by the secondary of a special converter, having its primary connected across the high-tension mains.

Ferranti-Wright Meter.—This is, in effect, an alternate-current motor, and depends for its action on one of those peculiar phenomena which take place when a conducting circuit is cut by lines of magnetic induction which are varying rapidly in direction and intensity. The meter is shown in plan diagrammatically in Fig. 3, Plate 11. The four limbs A B, B D, D C, C A, consisting of laminated wrought-iron, are wound so that B and C are opposite poles; each of these is fitted with a pole-piece consisting of an elongated horn, forming part of a circle within which is placed a conducting disk E, usually, but not necessarily, of iron. Each horn is surrounded by a closed conducting circuit of low resistance, consisting of one or more copper bands slipped over them, shown at F F. It is impossible to give a full explanation of this remarkable meter in a few words, but perhaps the following will make its principle fairly

clear. Suppose a current to rise in the magnetising coils from zero to a maximum, then it tends to magnetise the iron, and the induction in the iron follows the successive values of the current in the part enclosed by the coils nearly instantaneously, but in the horns it lags behind the current, partly on account of hysteresis, but chiefly because its change generates in the circuit F F currents that tend to magnetise the iron in the opposite direction. The action of the closed copper circuit is to hinder the rise of magnetism in the iron, giving it a kind of magnetic self-induction, in just the same way as iron gives to an electric circuit ordinary self-induction. Now suppose, for a single rising current, there be substituted a rapidly alternating one, then any point in the horn will experience a series of waves of magnetism following one another, and successive points along the horns will be subject to waves of diminishing amplitude (for the maximum induction falls off towards the tips), differing in phase from one another on account of the lag above mentioned. The state of the induction in either horn at any instant may be represented by a curve such as is shown



in the diagram, the lag being sufficiently great in some cases to cause the induction to be of opposite sign at the tip and at the root. There are thus as it were a series of tufts of lines of force travelling along the horns and brushing past the disk. Now these induce currents in the disk, and, owing to its self-induction, the repulsive effect preponderates over the attractive, and the disk is repelled round. It is found that its speed is proportional to the square of the current, but, by mounting radial mica fans on it, its motion is retarded by the air-resistance with a force that varies nearly as the square of the speed, and hence the disk revolves proportionately to the current. There are two causes operating to disturb this proportion at the two ends of the range : (i.) At starting, the friction of the disk spindle is relatively large, and the speed is lower than it should be; this is overcome by winding the magnets with a shunt coil that is just sufficient not to cause the disk to revolve. (ii.) At high speeds the air-resistance depends on a rather higher power than the square of the velocity, thus making the speed somewhat lower than it should be. This is compensated for by slitting the fans as shown in Fig. 4, Plate 11, so that they yield somewhat, and thus expose a less effective surface. How perfect this compensation is, may be judged from the following tests of a 10-ampere and 20-ampere meter :—

TEST OF 10-AMPERE FERRANTI-WRIGHT METER.

Meter started with 0.25 ampere.

Current in Amperes.	Revolutions per Board of Trade Unit.
1.25	117.0
5.00	116.4
7.50	115.2
10.00	114.0

TEST OF 20-AMPERE FERRANTI-WRIGHT METER.

Meter started with 0.65 ampere.

Current in Amperes.	Revolutions per Board of Trade Unit.	Current in Amperes.	Reformation per Board of Trade Unit.
2.5	117.3	12.5	115.2
5.0	116.1	15.0	116.2
7.5	114.3	17.5	114.5
10.0	114.9	20.0	116.4

The beautiful simplicity of these meters, which have practically nothing to get out of order, has made them a most valuable acquisition, and they are almost exclusively used by the London Electric Supply Corporation for installations up to 40 amperes. They have proved to be reliable, and give practically no trouble as regards repairs; they are moreover light, compact and easy to instal.

In the latest form of these meters it has been found possible by great care in manufacture, to so diminish the friction as to render the shunt winding unnecessary. The field-magnets consist of two vertical limbs with horizontal curved horns embracing the armature; the horns are made movable, so that their distance from the armature can be varied, and the instruments adjusted to have the same constant. They are then rendered direct-reading by proportioning the gearing. The meters are "double-sealing," and the plate protecting the terminals covers also a small screw that admits of the armature and spindle being raised from the jewel during transit, without interfering with the Local Authority's seal. A minor point of difference from the older type is the substitution of aluminium for mica fans.

The following is a test:—

TEST OF 10-AMPERE FERRANTI-WRIGHT METER. UNSHUNTED.

Meter started with 0·4 ampere.

Current in Amperes.	Revolutions per Board of Trade Unit.	Current in Amperes.	Revolutions per Board of Trade Unit.
10·0	240	3·0	240
9·0	238	2·0	238
8·0	242	1·0	224
7·0	247	0·8	209
6·0	240	0·6	193
5·0	238	0·4	198
4·0	243		

The unshunted form of this meter is very suitable for recording the quantity sent out through the high-tension mains of a central station, and it has been applied to this purpose.

Shallenberger Meter.—Like the last, this is an alternate-current motor. It consists of two coils with their axes set at an angle of 45° to one another, both surrounding a horizontal iron disk, free to revolve on a vertical axis; the plane of the disk is at right angles to the planes of the coils. One of these coils carries the current to be measured, the other is simply closed on itself. The current in the former induces in the latter a current which is a quarter of a period behind itself, and the effect of this is that the induced current, reversing as it does with the inducing current, attracts the poles successively set up by the latter, so producing continuous rotation. The motion is retarded by aluminium fans. The following is a test of a 100-ampere meter:—

TEST OF 100-AMPERE SHALLENBERGER METER.

Meter started with 3·5 amperes.

Current in Amperes.	Revolutions per Board of Trade Unit.	Current in Amperes.	Revolutions per Board of Trade Unit.
5	13·0	50	13·3
10	12·8	55	13·1
15	13·1	60	13·4
20	13·3	65	13·3
25	13·3	70	13·3
30	13·0	75	13·3
35	13·3	80	13·1
40	13·3	85	13·1
45	13·3	90	12·5

It will be observed that the constant is remarkably good, but the starting power is distinctly poor.

A test of a smaller size is appended :—

TEST OF 10-AMPERE SHALLENBERGER METER.

Meter started with 0·4 ampere.

Current in Amperes.	Revolutions per Board of Trade Unit.	Current in Amperes.	Revolutions per Board of Trade Unit.
0·6	17·9	5·8	18·1
1·0	17·7	7·0	18·6
1·9	18·5	8·2	17·9
2·9	18·0	9·0	17·5
3·9	18·0	10·0	17·6
4·9	17·9		

Although the above results are given in the form of a constant, the meters are direct reading, the adjustment to identical constants being effected by altering the angle between the planes of the closed and inducing coils. The latest form is arranged to be “double-sealing.”

This meter is very largely used in America by the Westinghouse Company, and in London by the Metropolitan Electric Supply Company. The London Electric Supply Corporation has also a few in use, with satisfactory results.

Slattery Meter.—This depends on the same principle as the Shallenberger, but differs from it in having a light copper cylinder in place of the iron disk, and in the way in which the motion of the revolving cylinder is retarded. Each vane consists of two quadrants of a circle *ABC*, *ADC* (see Fig. 5, Plate 11), the lower being pivoted about the centre *A*; it has attached to it an arm *E* weighted at *F*. When the speed increases, the weight flies out and raises the quadrant *ACD*, which slides behind *ABC*, thus reducing the surface exposed to the air-resistance. This is a different way of accomplishing the result obtained in the Ferranti-Wright meter by slitting the fans.

CLASS 2.

Hopkinson Meter.—One of the earliest practical forms in this class is that invented by Dr. J. Hopkinson, M. Inst. C.E., and, probably, if the present demand had existed at the time at which

it was brought out, it would have received considerable development. This meter is shown diagrammatically in Fig. 6, Plate 11. A high-resistance motor A is placed as a shunt across the lamp leads, and is so arranged that when excited it causes a pair of governor balls B B to rotate; the centrifugal force of these tends to raise an iron core C, which is attracted downwards by the main current passing through the solenoid D. The core carries a contact E, which makes and breaks the motor circuit, and is so adjusted that when no current flows through the solenoid the circuit is broken. Directly a lamp is turned on, the core is attracted downwards and the motor revolves, increasing its speed until the governor balls cause its circuit to be broken. Now the centrifugal force is proportional to the square of the speed, and the attraction of the solenoid for the core is, within certain limits, proportional to the square of the current, hence these two forces will exactly balance, and the motor will revolve with a speed proportional to the current, for, if it rises above the proper speed, its circuit is broken and the speed falls, and if it falls below its right value, its circuit is made and its speed increases. The number of revolutions are recorded by a train of counting wheels driven by a worm from the motor spindle.

Frager Meter.—This is, perhaps, the most successful of this class of meter. It is an improvement on an earlier form known as the Caudray, and consists essentially of the combination of an ammeter or wattmeter, a clock and an integrating device connected to a system of counting wheels. The meter is adapted to either alternating or continuous currents—the wattmeter being always used in the former case. Its latest form may be thus described:—The movable coil of the wattmeter is of German silver wire wound on a wooden bobbin, a noticeable point being that, contrary to the practice of most makers, the whole of the shunt circuit is wound inductively and is movable, instead of only a comparatively small portion being so wound and the rest of the circuit formed of a non-inductive extra resistance. The coil is suspended by a wire of phosphor bronze, and carries a long lever, formed of aluminium in the larger sizes and of brass in the smaller, balanced with a brass counterpoise so as to hang horizontally. The end of this lever is furnished on its under side with a wedge-shaped piece of steel, and hangs over a horizontal cam or snail, shown in Fig. 7, Plate 11, which is kept in slow rotation by means of a ratchet-wheel worked by a pawl from a balance wheel, maintained in oscillation by a shunt current. The snail is carried by a cradle, hinged at A B (Fig. 7), and pressed upwards by a spring. Rigidly attached to

the spindle carrying the snail-cradle, and running along the straight edge of the snail and projecting beyond it, is a piece of steel C D, bevelled on its edge, which is circular, having the suspension wire for centre. As the spindle rotates, this bevelled edge comes in contact with the steel wedge on the lever, and causes the latter to rise and to jam against a brass sector placed over it. If no current passes through the main coil of the wattmeter, the lever stands at zero, and, as rotation proceeds, it simply drops off the piece C D. If, however, the lever is deflected when the engagement takes place, the lever drops on to the snail, depresses it, and causes a pawl E which it carries to engage with a ratchet-wheel, which ratchet-wheel drives a counting-train. Rotation goes on, and, as long as the lever remains on the snail, it is locked, and the counting-wheels continue to register. As soon as the lever reaches the round edge of the snail it drops off, the snail rises, and the pawl ceases to drive the counting-train. Now an inspection of the snail will show that its shape is such that the greater the deflection of the lever at the instant of its engagement, the longer it remains on the snail, and that it must drop off once every revolution. The action of the instrument is, therefore, this : at equal intervals of time, this interval being the time taken by one complete revolution of the snail (two hundred, three hundred, or four hundred seconds, according to the size of the meter) the lever is locked in the position which it happens to occupy at the instant, remains on the snail for a time proportional to its deflection, and then quits it, having caused a certain amount to be registered on the dials. Now this amount is that which would have been used in the time occupied by one revolution of the snail, if the current had retained the value it had when the lever engaged. If the current changes, no account is taken of the alteration until the next time the lever engages, when the current is again assumed to remain constant during one revolution. What the instrument does, then, is to take a reading of the wattmeter so many times an hour, to multiply each reading by the time of one revolution, and to add all these successive products together on the dials.

The following are details of the several parts :—

The balance wheel is furnished with a flat chronometer spring, and consists of a nearly complete circle, formed of two pieces of soft iron A A, Fig. 9, Plate 11, united by a brass piece, B. A short solenoid C excited by a shunt current, is so placed that when the wheel is at rest the soft iron cores are unsymmetrically placed. At the top of the spindle carrying this wheel is the contact

making device shown in Fig. 10, Plate 11. Two little steel plates, one above the other, shaped as shown, are mounted loose on the spindle; the top one has a V-shaped slot A, in which works a pin B attached to the spindle C, from which it derives an oscillating motion; the lower plate has a much wider V-shaped groove, shown dotted, and in this works a pin projecting downwards from the upper plate. Each plate has a depression, shown at D, and a knife-edge E fixed to a spring F, one end of which can make contact with a contact-screw G, bears against the plates. When the depressions in the two plates are opposite the knife-edge it drops in, and contact is made at G, completing the circuit through the solenoid. If the amplitude of vibration is small, the depressions in the two plates correspond; but if it becomes large, the lower plate is carried round by the upper one, and left so that it prevents the knife-edge from falling. When the amplitude diminishes, contact is again made and a fresh impulse given.

The counting-gear is connected to the snail-spindle by means of a pair of bevel-wheels, and by adjusting the number of teeth in them the meters are made to indicate Board of Trade units on the dials, however much the constants of the wattmeter may vary.

This meter is certainly ingenious, but evidently highly complicated. When carefully adjusted and protected from vibration, it is capable of giving accurate results with a steady current; but under the conditions of actual practice it labours under disadvantages, among which may be mentioned:—

(i.) The necessity for careful levelling and adjusting *in situ*, thus making it uncertain whether the test made before it is sent out will apply when it is installed in the consumer's house.

(ii.) So many working parts are liable to get out of order.

(iii.) In cases where the amount of light used is constantly varying at short intervals of time, as in a theatre, indications far from the truth may be given. Small variations in current, due to unsteady running, will cause the lever to oscillate, and it may therefore become locked at the wrong point.

Richard Frères Meter.—Like the Frager, this is an intermittent watt-hour meter; but it has this important advantage—its readings are separated by intervals of only fifteen seconds. It comprises a clock, wound electrically four times a minute, a wattmeter, and a train of counting wheels. The following cycle of operations is gone through every fifteen seconds. At a given instant a shunt circuit is made through an electro-magnet, the armature of which is attracted and winds the clock, the circuit being immediately broken again. After ten seconds another shunt

circuit is closed, causing a current to flow through the movable fine wire coil of the wattmeter and through an electro-magnet actuating a friction clutch. This clutch, under normal conditions, mechanically connects the movable coil with the counting train, but when pulled back it allows the coil to move without affecting the train. When the contact is made the clutch moves first, its moment of inertia being much less than that of the wattmeter; the coil then deflects, a dash-pot steadying it quickly; the current flows for five seconds and is then interrupted, the clutch flies back by means of a spring and the wattmeter returns to zero, carrying with it the first wheel of the train through an angle corresponding to its deflection. The clock-winding contact is again made and the same series of operations gone through as before.

This meter is in use in France, but has only recently been introduced into England; it is at present only used for continuous currents, but will doubtless soon be applied to alternating currents also. The Author has had no experience of the meter, but the number of contacts and the complication of its parts will probably be found serious drawbacks.¹

CLASS 3.

The majority of the meters in this class are founded on Professor Ayrton's ergmeter, which consisted of two clocks regulated to keep exactly the same time. One of these had a magnet in place of a bob at the end of the pendulum, and beneath it was placed a coil carrying the current to be measured; the magnet being attracted by the coil when the current flowed through it, the pendulum was accelerated, and the clock gained. The difference in time of the two clocks was thus a measure of the quantity of electricity that had passed. There have been numerous improvements on the original idea, the chief being embodied in the Aron and Oulton-Edmundson meters.

Aron Meter.—In this the two clocks are enclosed in one case, and their wheel-trains are connected to a differential gear, consisting of two bevel wheels, one driven by each clock. Between these, and gearing into both, is a bevel wheel free to revolve at one end of a spindle, the other end of which carries a counterpoise; to the middle point of this spindle, and at right angles to it, is rigidly

¹ This instrument must not be confounded with the Richard Frères recording ammeter, which is a very satisfactory piece of apparatus for a different purpose and hardly comes within the scope of this Paper.

fixed a second spindle connected to a counting train. If the large bevel wheels both revolve at the same speed, the intermediate wheel simply revolves on its axis; but if one goes faster than the other, the intermediate wheel, in addition to revolving, rolls on the large wheels by an amount depending on their difference in speed, and in so doing twists the counting spindle.

This meter is made in two forms, viz., (i.) that just described in which the pendulum carries a magnet; this is adapted to measure continuous currents only, and is a current integrator: (ii.) that in which the magnet is replaced by a fine wire coil oscillating inside a solenoid; this is adapted to either continuous or alternate currents, and is a watt-hour integrator. The former is in very extensive use, and all employing it speak highly of its performance. It is open to the objection already referred to in connection with the Frager meter, that it has to be adjusted *in situ*, for it is a fact well known to clockmakers, that a clock once shifted always requires regulating, no matter how carefully it may have been moved. The permanent magnet is liable to change, and it is found necessary to redetermine the constant of a meter that has been in a house where a short circuit has occurred, the magnet being weakened by the excessive current. The clocks have to be wound up at least once a month, and if one of them by any mishap should stop, the whole record is destroyed. It is the practice in some central stations to synchronise the meters every three months; it is then found that about half are slow and half fast, but the error is not serious. An evidence of accuracy is afforded by a meter at the station agreeing with the sum of the readings of the consumer's meters within, it is stated, a small percentage.¹

The second form is seldom used except for alternating currents, and with these it is extremely difficult to get an accurate test in the lower part of the scale, on account of the great length of time required in order to get a reading and the necessity for having the pressure and current observed during the whole run, since it cannot be relied on to remain steady as in the case of continuous current where cells can be used. The following is a test of the higher part of the scale of this type:—

¹ Since this Paper was read, the Author has been favoured by Mr. J. H. Tonge, Stud. Inst. C.E., with the following test of a 100-ampere continuous current Aron meter. The instrument read $\frac{1}{2}$ per cent. low with 100 amperes, with 50 amperes, and with 20 amperes, and 10 per cent. low with 1 ampere. In forty-eight hours the difference in time between the two pendulums was one complete period.

TEST OF 200-AMPERE ALTERNATE-CURRENT ARON METER.

Current in Amperes.	Pressure in Volts.	Board of Trade Units per Division.	Current in Amperes.	Pressure in Volts.	Board of Trade Units per Division.
200·1	100	1·071	120·0	100	1·070
190·2	100	1·081	110·3	100	1·055
180·0	100	1·075	100·0	100	1·057
171·0	100	1·101	90·3	100	1·056
159·7	100	1·063	80·0	100	1·102
150·0	100	1·068	70·0	100	1·083
140·3	100	1·065	60·0	100	1·068
130·0	100	1·066			

The meters are now made direct-reading, and are provided with an attachment for keeping the clocks in synchronism when no current is on, the difficulty in ensuring this being the chief objection to the meter. It is extremely simple, consisting merely of a light, very slack thread joining the two pendulums and having a small weight hung at its middle point. It effects its object perfectly, but it would appear probable that the constant at low readings would be altered. The Author has not yet tried whether this is the case or not.

A most ingenious modification has been introduced into this meter by Mr. Miller of the Kensington and Knightsbridge Electric Light Company. He employs only one clock which drives a soft iron disk through the differential gear already described. The disk revolves in front of a coil carrying the current to be measured and is retarded by it. This admirable device does away with the whole trouble of synchronising, as there is only one clock, and prevents the danger of the record being destroyed by one clock stopping. There should be an excellent future for this meter.

An adaptation of the Aron meter, made by the same inventor, supplies a great want felt by users of secondary batteries, viz., an indicator of the amount of charge in the battery. Now it is obvious that if the main current be reversed in the watt-meter form, repulsion will ensue and the pendulum will be retarded, the meter, in consequence, registering backwards. Mr. Miller found that, with the ordinary form of coils, if the current was reversed, the indications were not accurate, owing partly to the slow speed. He accordingly altered the form of the coils and shortened the pendulums, and in this way he succeeded in producing a meter that would register accurately whichever way the current flowed. In order to ascertain the condition as to charge of a secondary battery, he charges it fully through this meter, and

notes the quantity registered; the battery is then allowed to discharge through the meter, and the instrument goes back. When the time for recharging arrives, all the attendant has to do is to keep on the charging current until the meter shows its original reading. In this way the exact state of the battery is shown by an inspection of the meter.

The Richard Frères meter has been adapted to the same purpose by so mounting the fine wire coil that it can deflect on either side of its position of rest, thus driving the counting train either way according to the direction of the current. It has also been arranged that if a fixed loss in the battery be assumed, it can be allowed for by inserting a resistance in series with the fine wire coil when charging, thus making the meter register only the percentage of the charging current that will be returned.

Oulton-Edmundson Meter.—In this the ordinary pendulums are replaced by horizontal balances oscillating at about one-quarter the speed, the torsion being supplied by a straight flat spring which also serves as a suspension. The two clocks are driven by one mainspring. The controlled pendulum carries two fine wire coils, one swinging within the main coil, and the other above it. Each of the movable coils consists of two circuits, one placed across the lamp leads in the ordinary way, the other forming a shunt across the main coil; the small current passing through this second circuit is stated to be required in order to raise the constant at the higher readings. This meter in its present form has only recently been introduced.

Kelvin Meter.—One of the latest additions to this class of meter comes from the hands of Lord Kelvin, the inventor who has produced so many electrical measuring instruments of unsurpassed accuracy. As a laboratory instrument, no doubt the meter about to be described is extremely accurate, but it may be doubted whether it is suitable for practical use. In the first place, it is somewhat unreasonable to expect a consumer to descend every day to his coal-cellar, it may be, in order to wind up an instrument of which he is, in all probability, afraid and looks upon as some infernal machine. Next, it has working parts of extreme delicacy and is unsuitable to put into the hands of an ordinary linesman. Lastly, it is preferable to have a continuous, rather than an intermittent, integrator.

The instrument is a combination of a weight-driven clock which automatically breaks the circuit when it requires winding, an ampere balance and an integrating cam. A fixed coil carries the main current, and in front of it is placed a fine wire coil

carried at the end of a vertical aluminium lever free to turn on knife-edges about a horizontal axis. The lower end of this lever has attached to it a train of counting wheels, the first one of which can roll on a cylindrical cam which is kept revolving at a constant speed by means of the clock. When a current passes through the main coil the other is repelled, and the rolling wheel, which originally stood clear of the cam, moves over it, is raised by it, and rolls on its surface, thus actuating the counting wheels. Now the cylindrical surface of the cam is cut away screw fashion, so that, when at one end of it, the wheel only rolls for a small portion of its revolution, and at the other, remains on it for the greater part of a revolution, the time it remains on being proportional to the current corresponding to the position of the lever. A series of grooves are cut on the surface of the cam so that, once engaged, the wheel cannot shift sideways. A scale is provided over which the lever moves, enabling the instrument to be employed as an ampere gauge and its indications to be checked. The constant of the instrument can be altered so as to adapt it to various currents, by altering the weight on a horizontal rod projecting from the movable arm, and by altering the height of a nut on a vertical screw.

CLASS 4.

Edison Meter.—This is a meter adapted to continuous currents only, and depends for its operation on the electrolytic action of the current. A definite portion of the current to be measured is shunted through a bath containing a solution of zinc sulphate, the electrodes being of amalgamated zinc. The meter in its latest form contains three essential parts:—(i.) the electrolytic cell and compensating coil, (ii.) the shunt resistance, and (iii.) a device for keeping the electrolyte from freezing. The case of the meter is of well-seasoned hard wood, specially prepared to exclude air and to secure good insulation, and its front is closed by a substantial sheet-iron door.

(i.) The cell. This is of bottle form, and is covered to avoid evaporation. It is partially filled with a 10 per cent. zinc sulphate solution in which are suspended zinc plates supported by screws and nuts on ebonite distance pieces, connection being made to them by copper rods held by spring clips. The plates are prepared by being first thoroughly cleaned, then covered on the top and for a short distance up the rod with asphalt varnish and, lastly, amalgamated and dried. The positive plate is weighed before being immersed. The size of the plates is regulated by the

maximum current the meter is intended to carry, the quantity of zinc allowed for being at the rate of 150 milligrams per month for every ampere of nominal capacity. If the meter is likely to run at its full load for a large number of hours during the day, a larger cell is required than the above amount would give. In calculating the quantity that has passed through the meter, one ampere flowing for one hour is taken as depositing 1,224 milligrams of zinc. The counter-electromotive force of the cell decreases as the temperature rises, and its resistance also falls; in order to compensate for the error thus introduced, a copper coil, the resistance of which of course increases with the temperature, is placed in series with the cell, and is so adjusted that the effective resistance of the combination is identical at 50° Fahrenheit and at 86° Fahrenheit, varying about 1 per cent. between these two points. As regards the change of effective resistance with change of current, it is found that the increase in counter-electromotive force is about compensated for by the fall in resistance of the cell.

(ii.) The shunt resistance is of German silver, and has such a value that $\frac{1}{9\frac{1}{3}}$ th part of the whole current flows through the cell. The resistance of this material varies 1 per cent. for every 45° Fahrenheit change in temperature, and the maximum temperature attained by the meter is about 120° Fahrenheit; hence the error from this source does not exceed 2 per cent.

(iii.) The cell is kept from freezing by means of an incandescent lamp placed in the case of the meter and automatically lighted by means of a thermostat when the temperature falls below a certain value. This portion of the apparatus consists of a compound metallic strip which alters its curvature when the temperature falls, completing the circuit through the lamp. The contact point is carried by a screw having a pitch of $\frac{1}{48}$ -inch, with a hexagon head, the faces of which are numbered. In this way the temperature of contact can be adjusted to within 2° Fahrenheit.

A curve given by Mr. W. J. Jenks, in a Paper on this meter, read before the American Institute of Electrical Engineers, shows that after 3 amperes the rate of deposit is absolutely constant up to 20 amperes; the meter having, therefore, a sevenfold range, and registering with the smallest current, the error is in favour of the consumer.

The chief objections to this meter are :—the remarkably small fraction of the current that is measured—any error, either in deposit or in weighing the plates, being multiplied nearly a thousandfold; the necessity for the consumer relying entirely upon the good faith of the supply company for the accuracy of his

account—it being absolutely impossible for him to check his consumption from day to day, or to ascertain for himself the amount registered by his meter; and the constant attention required—the plates having to be removed every month, weighed and replaced.

This meter is in extensive use in America, and was used with satisfactory results at Eastbourne before the system was changed to an alternating current one; it has not, however, met with much favour in this country.

Lowrie-Hall-Kolle Meter.—This meter attempts to apply the electrolytic method to the measurement of alternating currents, and was worked out by the three inventors whose names it bears when they altered the system at Eastbourne from continuous to alternating, the Edison meter having given, as already stated, satisfaction in the former case. In series with the converter is placed a secondary cell, giving a pressure of 2 volts, and an electrolytic bath; the effect of this is to raise the positive wave bodily by 2 volts, and to diminish the negative wave by the same amount, the effect being the equivalent of 2 volts always acting in one direction through the circuit—the current flowing being proportional to the number of lamps turned on. The whole current thus passed through the secondary cell, but, so far from it having any ill effect, it seemed to prevent sulphating. It was found that in a suitable electrolytic solution, any metal can be by this method deposited by an alternating current, and the quantity so thrown down used as an indication of its amount.

Improvements in other types of meter prevented this being brought to a state of perfection in spite of its being fairly promising. It was, however, open to at least one serious drawback, namely, if the alternating current was switched off, and any lamps left turned on, the cell discharged through them and caused a registration to be effected in the electrolytic bath; moreover, the secondary cell had to be recharged every three months, and there can be little doubt that the inventors would have had trouble with the direct electrolytic action of the alternating current, for it has been shown that without any secondary battery being in circuit, such a current will cause deposition of an uncertain amount, depending on the size of the electrodes.

TESTING OF METERS.

In the commercial employment of meters, an important matter is their efficient and rapid testing; and it may be of some interest if the Author describe the arrangements designed and used by him

for testing the meters employed by the London Electric Supply Corporation. Their system being an alternating one, only meters adapted to this class of current are provided for. The kinds used are Ferranti mercury, Ferranti-Wright and Frager.

The method adopted in testing the mercury meters is to string a number together with their main coils in series with one another, and with an adjustable non-inductive resistance the shunt coils being connected in parallel across the converter terminals.

It may be well here to call attention to a source of error that is likely to be overlooked in testing any kind of shunted meter. When in use, the shunt coil has one end attached to the shunt terminal and the other to the converter end of the series coil. If the meters be connected in series, each being allowed to feed its shunt in the ordinary way, two errors will be introduced, as an inspection of Fig. 11, Plate 11, will show—(i.) With large currents in the series coils, the shunt of the meter nearest the converter is the only one receiving its full pressure (100 volts); the second has a pressure that is less than the 100 volts by an amount equal to the drop of pressure in the first; the third is deficient by the drop in two meters, and so on, the last of a long series receiving much less than 100 volts. (ii.) The last meter is the only one that has flowing through its series coil the current that is measured; the last but one receiving in addition to this the shunt current of the last; the third from the end those of the last two; and so on to the one nearest the converter, which receives in addition to the measured current, the sum of all the shunt currents of the other meters. These two errors are easily and completely disposed of by running a separate lead from the converter to excite them, as shown in Fig. 12, Plate 11.

To resume, the reading of the dials having been noted, the desired current is thrown on, and kept on for a time sufficient to obtain a reading of such a magnitude that an error of ± 0.1 would not affect the constant more than 1 per cent. It is then thrown off, and the reading is taken when the meters have come to rest. The number of revolutions per hour shown by the dials having been calculated from the difference of the readings, it is divided by the product of the current and the pressure; this gives the number of revolutions per watt-hour, and, when multiplied by one thousand, the "constant"—*i.e.*, the number of revolutions—per Board of Trade unit. The pressure, and therefore the current, is maintained constant within one-half per cent., by the means described below.

Obviously there is a slight error in this method owing to the

meters requiring time to get up speed, but this is compensated for in practice by their taking approximately the same time to slow down after the current is removed. When the current is so small that the time required for a run is inconveniently long, the meters are allowed to attain their full speed with that current and the centre hands are counted, the number of revolutions at the end of 1, 2, 3 . . . minutes being noted. With practice, it is easy to estimate to the tenth of a revolution, and these meters revolve with such remarkable regularity that repeated experiments have shown it to be quite safe to infer the constant from a two-minutes count. The rate per hour of the dials having been calculated, the constant is found as before. This meter, as has been shown, has so smooth a curve that it is sufficient to adjust it at two points, one being that of maximum current and the other one-tenth maximum.

The Ferranti-Wright meters are tested in exactly the same way as the last, except that the first method is always used, the centre needle never being counted. Three points are usually determined in the curve, one being the maximum current, one about one-seventh maximum, and one midway between the two.

The Frager meters also are strung in series, and the same precautions observed as regards exciting their shunts, but their different nature requires a different method of testing. There are two stages:—(i.) In the first the clock motor is timed and adjusted until it beats seconds within 2 or 3 per cent. (ii.) The meter as a whole is tested. The dials being set to zero, and the snails being in such a position that the levers have just left them (this is to allow them to become steady before engaging with the snails), the desired current is thrown on and the pressure, and therefore the current, kept constant within $\frac{1}{2}$ per cent. until the snails have made six complete revolutions. When the lever of the slowest meter has left the snail, the current is taken off and the readings are noted. The known percentage errors of the clocks having been allowed for, the number of Board of Trade units that would have been registered by each in an hour is calculated, and this is compared with the actual amount that would have passed in an hour. The percentage error is then corrected by altering the ratio of the wheels between the snail spindle and the train as already described.

Passing on to the arrangements for performing the above tests, it may be well to remark that the space at the Author's disposal was extremely limited; two rooms, one above the other, each 28 feet long, 12 feet wide at one end tapering away to 3 feet at the

other, having to suffice for testing-room, stores, Frager meter repairing shop and for containing the converters. The upper room was taken for testing, the lower for workshop, converter room and stores; a handlift in one corner formed a convenient means of communication. The testing-room is all that need be described; the narrow end is partitioned off, and a reflecting galvanometer and Wheatstone bridge placed in the chamber so formed; the galvanometer rests on a shelf supported on **H** iron cantilevers let into the wall, thus avoiding vibration. A space about 6 feet wide on the wall opposite the windows is faced with solid teak thoroughly coated with shellac, and to this are attached all switches; 5 feet 2 inches from the floor a shelf, supported like the one for the reflecting galvanometer, serves as a steady base for the ampere balances. Above this are fixed the primary fuses and switches from which vulcanised india-rubber covered cables, carried in iron pipes chased into the wall, lead to the converters in the room below.

A standard horizontal, tube-pattern, Cardew voltmeter, made by Messrs. Goolden and Co., is fixed below the switches, and shows the pressure on the shunt coils. Beneath the shelf are placed all the secondary switches. With a few trifling exceptions, the secondary connections for large currents are made of bare copper strip 1 inch by $\frac{1}{16}$ inch supported on teak cleats, coated with shellac, the number of strips being proportioned to the current to be conveyed. This is a very convenient and cheap method, and, when neatly done, looks well.

The mercury and Ferranti-Wright meters stand on narrow teak shelves one above the other, fixed on light T-iron cantilevers projecting from the wall.

It seemed desirable to be able to carry on tests of all three kinds of meter simultaneously, and so three separate testing circuits, each with its adjustable resistances and switches, were provided. A fourth circuit was added, for running meters from eighteen to twenty-four hours continuously on full load, to determine whether they would rise to an unsafe temperature.

An obvious way of reducing the cost of testing is to feed the main coils with current at a low pressure, say 10 volts, and to excite the shunts only with 100 volts. After careful consideration, the Author decided not to adopt this plan, partly because he was not absolutely satisfied that it gave results identical with those obtained when both were excited from the same source, and partly because with many meters in series the pressure would have to be raised with large currents, and the additional complication entailed

seemed hardly compensated for by the saving in expense. This objection clearly does not apply to the heating test, in which the shunts are not excited and no measurements are made; and accordingly a converter giving current at 10, 20, or 30 volts pressure at will in its secondary is employed, the lowest pressure that will give the desired current through the circuit being used, this pressure varying with the number of meters in series.

The mercury meter testing circuit is provided with resistances having a conductivity of 1.11 mho, divided into three sets, one of 1 mho, having ten steps of 0.1 mho each; one of 0.1 mho, divided into ten steps of 0.01 mho each; and one of 0.01 mho, divided into five steps of 0.002 mho each. Each set has its members brought to a switch which, by the rotation of a handwheel, joins the desired number of coils in parallel one after the other. In this manner any current up to 111 amperes can be obtained by steps of 0.2 ampere.

It may be well to give a few details respecting these coils and switches.

Coils.—All the wires are of platinoid, and the diameter in no case exceeds $1\frac{1}{2}$ millimetre, the object being to allow them to attain their final temperature rapidly. The coils that have to carry 10 amperes are of No. 17 B. W. G. bare platinoid wire, and are wound in two parallel oppositely directed spirals carried on circular brown porcelain insulators, through which are passed bolts fixed to a light wrought-iron frame. The spirals are steadied by passing over two intermediate sets of insulators. Fig. 13, Plate 11, shows the arrangement. The other two sets of coils are wound on zinc cylinders about $3\frac{1}{2}$ inches in diameter, split parallel to their axes to eliminate eddy currents, and each spiral is wound half in one direction and half in the other.

Switches.—Those for the 100-ampere and the 10-ampere coils have each eleven ring contacts, projecting inwards radially round a semi-circle. The first contact is of sufficient size to carry the whole current of the set of coils to which it belongs, while the other ten are in each case adapted to the current that flows through each member of the set. A brass sector, worked by a handwheel insulated from it, subtending the same angle at the centre of the switch as the eleven contacts, is so placed that when the handwheel is moved continuously in one direction, it is forced successively through all the ring contacts, thus connecting the ten one after the other with the first. The position of the handwheel thus determines the number of coils in parallel, and there is none of the annoyance experienced when a number of separate switches are

used and an effort of memory has to be made to remember which switches allow the desired current to pass; moreover, at full load there is no idle wire. The switch for the 1 ampere set is similar, but, of course, has only six contacts. The three sizes of switch are shown in Figs. 14, 15, and 16, Plate 11. It will be seen that the details vary slightly, but all are provided with brass eyes into which the leads are sweated.

Ferranti-Wright meters are provided with an identical set of resistances and switches.

The Frager meter testing circuit has resistances having a conductivity of 22.2 mhos, the finest adjustment being 0.004 mho instead of 0.002. Only the third set is wound on zinc cylinders, the other two being of bare wire on wrought-iron frames, and the 2-mho set is on two separate frames, having 1 mho conductivity each.

For the circuit for running the meters on full load, the pressure being only 10 volts, coils having a conductivity of 22.2 mhos are used, the adjustment being by steps of 0.04 mho. These coils are, of course, much shorter than those used with 100 volts pressure, but are mounted in the same general way.

With the exception of the last-named circuit, all are fed from an ordinary Ferranti 40-HP. converter, transforming from 2,400 volts to 100 volts, and therefore giving about 300 amperes in its secondary. This current is sufficient, since it is easy to so arrange the runs that it is not exceeded. There is a certain amount of drop of pressure at full load, even in this type of converter, which is exceptionally good in this respect, and the ordinary high-tension service mains being used, the pressure cannot always be relied upon to be exactly 100 volts. In order to obtain a constant pressure, the Author employs a subsidiary regulating converter, having its secondary in series with the main converter; it transforms down from 2,400 volts to $9\frac{1}{2}$ volts, and will yield 300 amperes in its secondary. Connection can be made at ten points of its secondary, so as to obtain the current at a pressure of $\frac{1}{2}$, $1\frac{1}{2}$, $2\frac{1}{2}$, to $9\frac{1}{2}$ volts. By means of one two-way and one ten-way switch, the pressure can be varied $9\frac{1}{2}$ volts (see Fig. 18, Plate 11). In the primary is a reversing switch, so that this converter can either help or oppose the main. In this way a regulation of $9\frac{1}{2}$ volts either way, or range of 19, is obtained. This, of course, is unnecessarily large, but it was designed for use when the Deptford works were still in a more or less experimental stage and the large margin was very useful.

The current is measured by Lord Kelvin's standard balances,

of which there are three, one reading nominally to 10 amperes but actually to 6 amperes (getting very hot even with this if the current is on for any length of time), one reading to 100 amperes and the third to 600 amperes. All these are required on each testing circuit though only one at a time; in order, therefore, to render any one available for all circuits a switch is employed, consisting of two sets of bars running at right angles to one another, on opposite sides of a slab of slate. At alternate points of crossing, holes are drilled through bars and slate, being tapped in those at the back, and allowing brass bolts provided with insulating handles to pass through the front bars and the slate. These bolts have each a collar which takes a bearing on the front bar when the bolt is screwed into the back, thus connecting the bars. By means of two such bolts any two vertical bars, to which are connected the balances, can be joined to any two horizontal bars to which are brought the circuits. Two spare vertical bars or "bridges" with holes drilled at every point of intersection, take the place of the balance in the circuit without one (usually the heating circuit), and admit of changing from one balance to another without stopping the run. This switch is shown in Fig 17, Plate 11.

The circuit is never broken with the plugs; a single-break "pointsmen" switch is placed in each circuit, and admits of runs being started and stopped in any one circuit independently of the others.

The number of meters of any kind required to be tested at once is constantly varying, and if two fixed terminals only are provided between which to join them, a number of different lengths of cable for connecting them thereto are required; these are clumsy and unsightly, and the following has been found to be a convenient device. A series of brass bars, about 2 feet 6 inches long, having bolts and nuts projecting at intervals of 8 or 9 inches, are fixed on teak against the wall above the shelf on which the meters stand; bridging pieces serve to bridge across the gaps when required. Short pieces of very flexible cable, terminating in brass eyes, are used to join the ends of a set of meters to the nearest bolts of separate bars. On removing the bridging-piece connecting the bars, the meters are looped in. Another advantage of this is that a second batch of meters can be got ready at another part of the shelf while the first are running.

Fig. 18, Plate 11, shows diagrammatically the arrangement of the whole testing plant described above.

COMPARISON OF SUPPLY OF ELECTRICAL ENERGY BY METER
AND BY CONTRACT.

Having reviewed most of the practical types of meter and the means adopted for testing them, it may be of interest to examine what is the result of supplying consumers by meter instead of at a fixed contract price. The Author has not as much material at his hand as he would wish, but the following examples may throw some light on a subject which is one of great practical importance to supply companies.

In order to have a common basis on which to compare all consumers, irrespective of the number of their lamps, the percentage that the quantity used bears to the maximum quantity that could be used if each lamp burnt for twenty-four hours per day, has been taken; for each consumer a curve has been plotted, having this percentage as ordinates, and weeks as abscissae. A whole year is given in each case, but unfortunately it is not possible to give the same year for each. Now when lamps are paid for by contract, it is assumed that each 33-watt lamp is alight for three hours each day throughout the year; taking the percentage that this quantity bears to the maximum possible, *i.e.*, $12\frac{1}{2}$ per cent., and setting this up as ordinate for each week in the year, a rectangle is formed. In order to find whether it is profitable to supply by meter, it is only necessary to compare the area of the curve with that of the rectangle; if this is greater than unity it is profitable, if less, the contract method is preferable.

The following are the cases selected :—

Theatre.—An inspection of Fig. 19, Plate 12, shows that, with few exceptions, this keeps well above the contract line, and the ratio of the areas is 1·4, thus showing a large gain from supply by meter.

Restaurant.—Here again (see Fig. 20, Plate 12) the consumption is heavy throughout the year, and the meter brings a large return, the ratio of the areas being 1·3.

Club.—The only club available for this comparison is a rather unfortunate example; it is shown in Fig. 21, Plate 12, and it comes out 0·98, which is much below what the Author believes from experience to be the average of this class of consumer. In support of this, a portion of a curve for another club is given in Fig. 22, Plate 12, where the consumption is much heavier; the ratio cannot here be given as there is not a complete year, but the curve is up to the contract line even in the summer months, and it is clear it must be much heavier in the winter.

Shop.—Two examples differing widely are given :—

(i.) West End jeweller, Fig. 23, Plate 12. The demand is kept up well throughout the year, the ratio being 1·02.

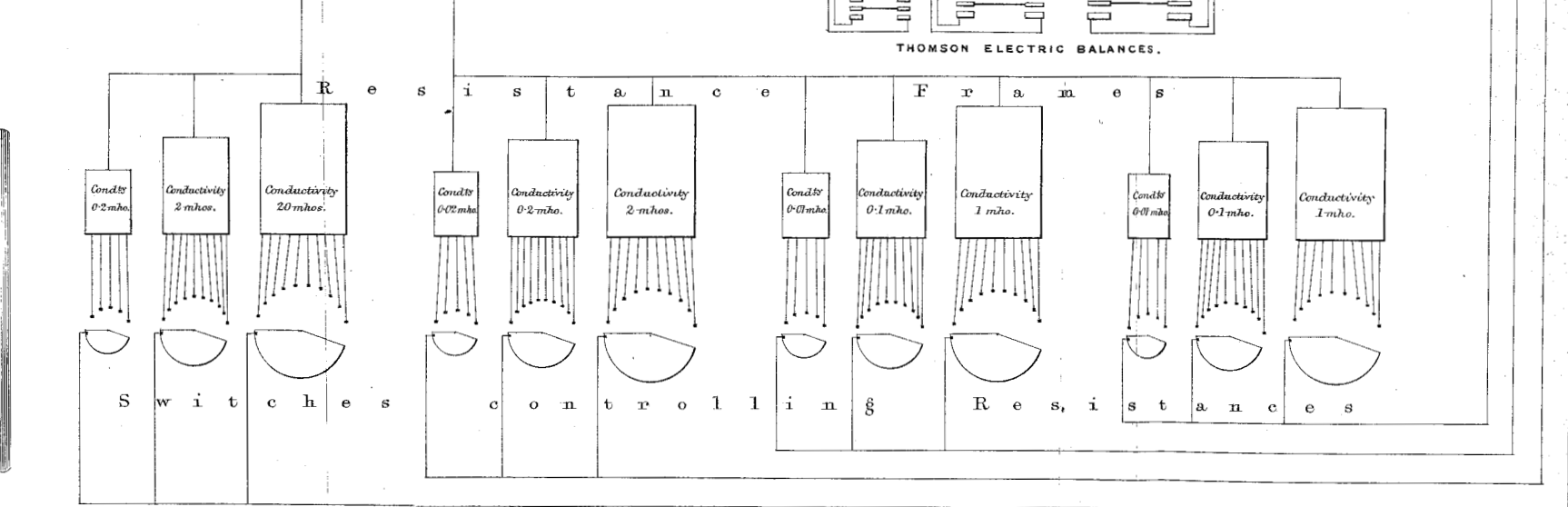
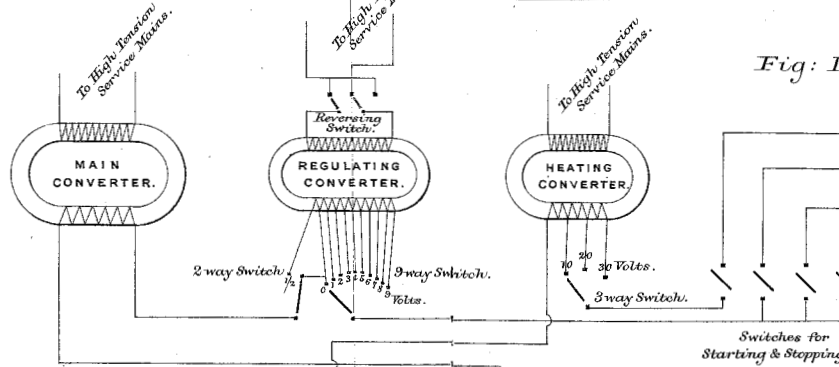
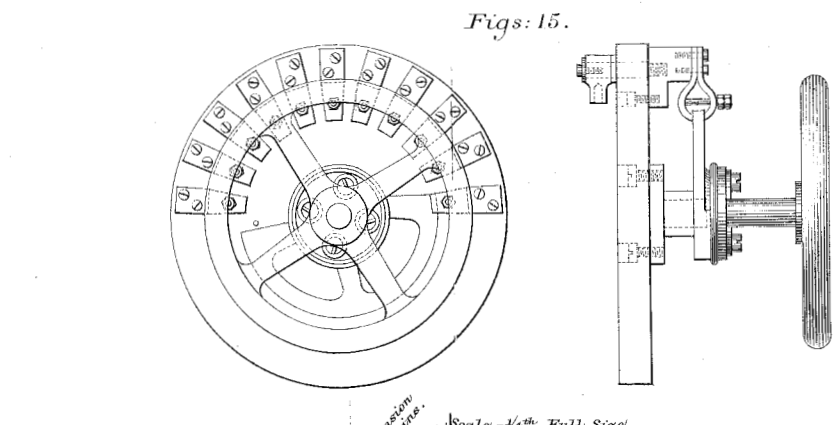
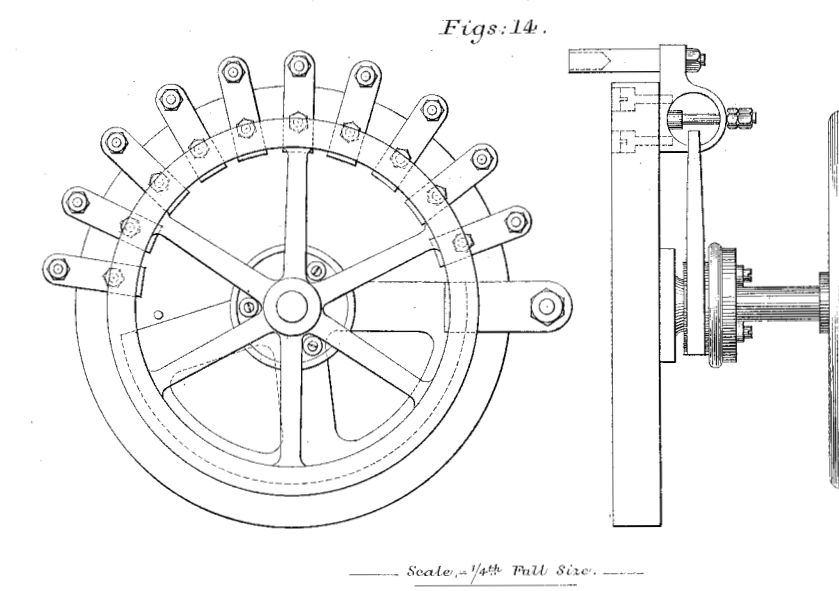
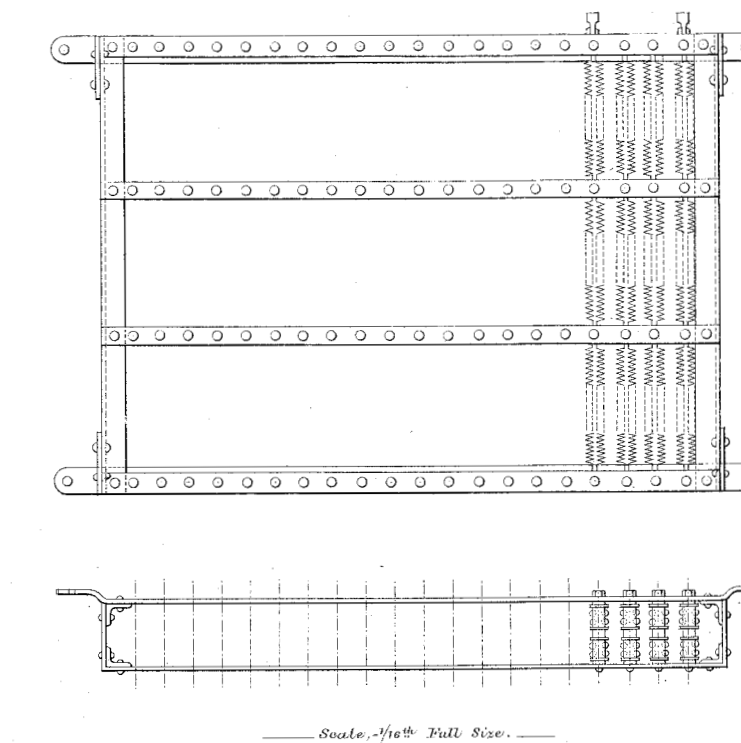
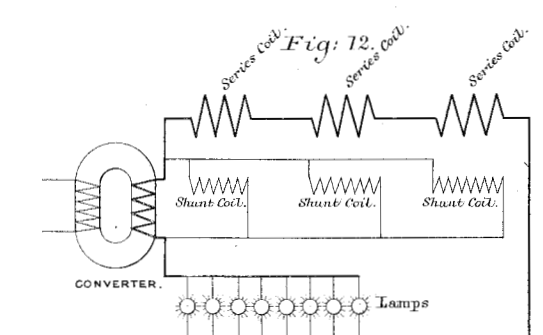
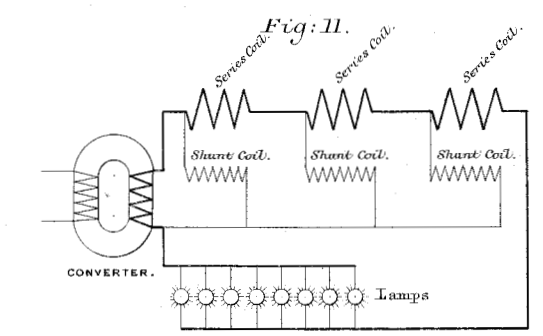
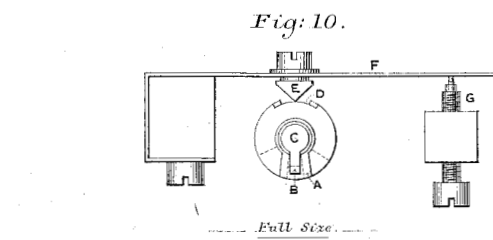
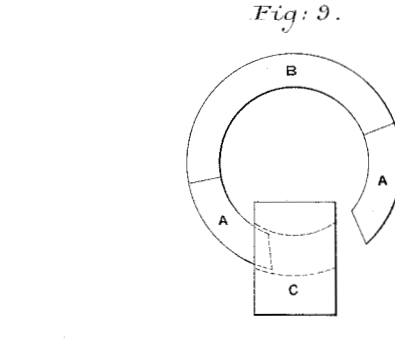
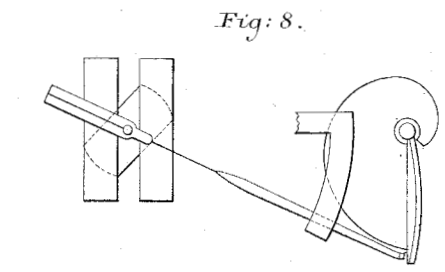
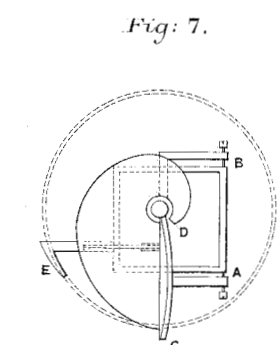
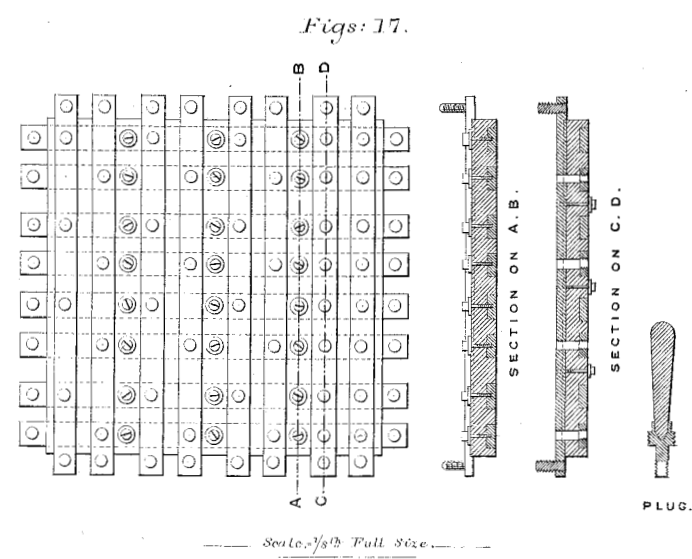
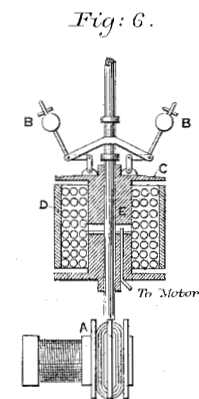
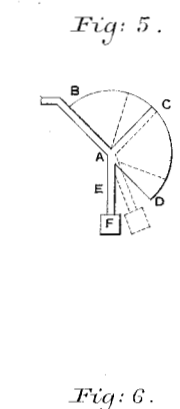
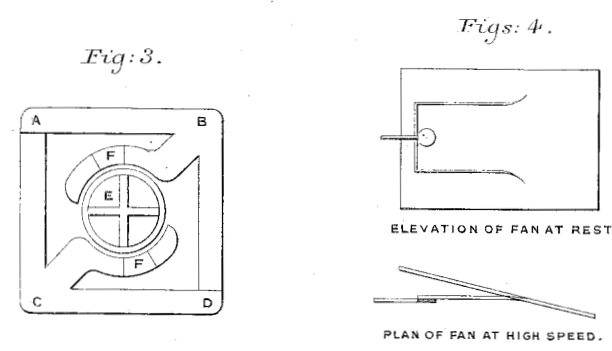
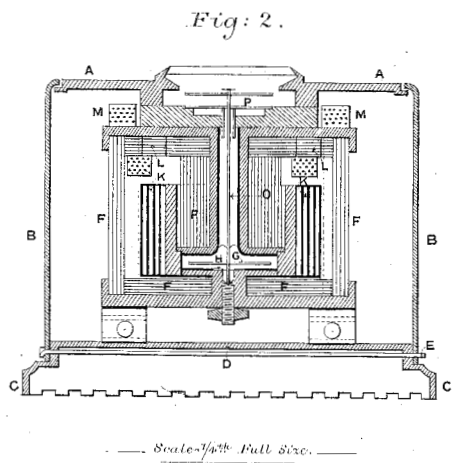
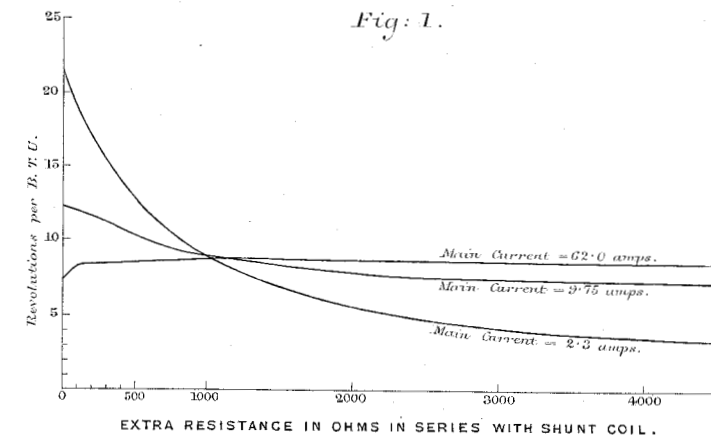
(ii.) West End china merchant, Fig. 24, Plate 12. Here is an example of the gross injustice of the contract system to some consumers. The consumption during the months from June to September is practically nil, and the ratio of the areas shows that in this case only one third (ratio = 0·3) of the amount charged for by contract is used.

Library.—This (see Fig. 25, Plate 12) is very similar to the last case, the ratio being 0·5.

In order to obtain any safe deductions as to the relative value of different consumers, the mean of many curves for each class must be taken, but the above examples serve as an indication. The consumption of a theatre, for instance, is seen to be uniformly high, with occasional extra loads owing probably to morning performances or extra rehearsals. Restaurants being open late, always take a large proportion of their full load, while shops vary much according to their character, those closing early consuming practically nothing during the summer months and being therefore unproductive.

The curves just given afford conclusive evidence on one point at least, namely, that the only equitable method of supply is by means of meters, and the Author trusts that he has made it clear that if there is not yet a perfect meter, there are nevertheless within the reach of companies employing either alternating or continuous currents, several instruments sufficiently reliable under working conditions, which have stood the test of time and practical work.

The Paper is accompanied by three sheets of tracings from which Plates 11 and 12 have been prepared.



METERS FOR ELECTRICAL ENERGY.

PLATE 12

