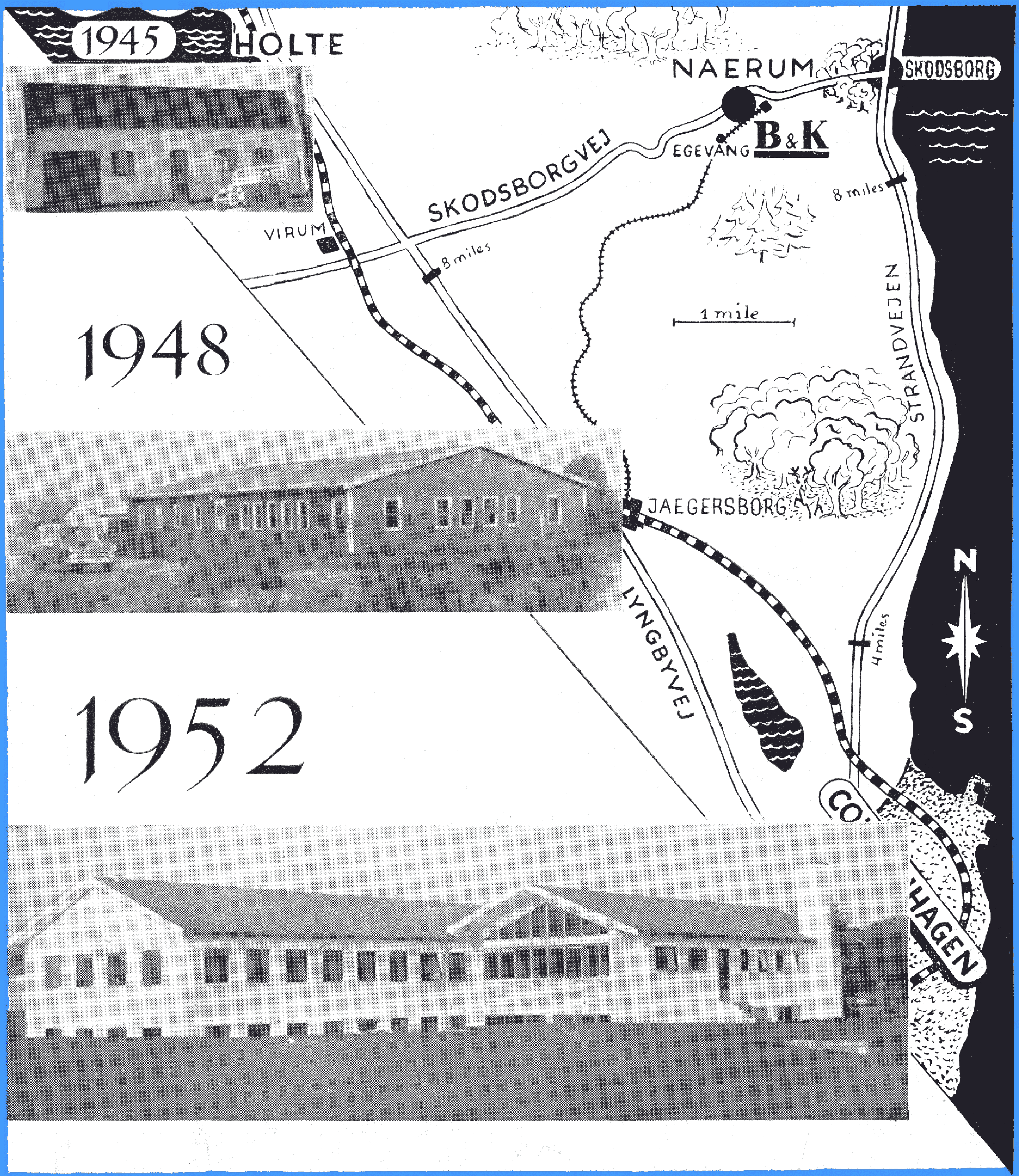
Brüel & Kjær

Technical Review

Teletechnical, Acoustical and Medical Research



No. 1

January 1953

Cover: Development from 1945 to 1952.

The new factory building, designed by Architect Lisbeth Jørgensen and Civil Engineer Ole Remfeldt as the first stage in a larger building scheme, has a ground area of about 11,000 sq. ft. (1000 sq. metres) and contains on the ground floor a machine shop, assembly shop and component stores, while the basement is used as a raw materials store, dressing room, restaurant and central heating plant.

The framework of the building is carried out in reinforced concrete, while the roof, a shell of reinforced concrete, is supported at the ends. It has thus been possible to avoid supporting pillars within the building, making it excellently suited for installation of machines, stock and further partitions.

When the roof was cast, porous plates of wood wool concrete were placed in the base of the casting mould, thus obtaining an effective control over the acoustic qualities of the workshop.

The walls are constructed of porous concrete, this material being chosen on account of its good heat insulating properties, and heat insulating has been carried out throughout the building, with double windows and a 4" (10 cm) rock-wool insulation of the roof. The roof covering is red icopal, and the walls are finished in white and light grey colour, with black plinth. The decoration below the large gable window is carried out by Architect Merete Mattern.

The new factory began production in the Spring of 1952, while our 1948 factory, which is just across the road, is now used as testing room and laboratory.

A NEW MEGOHMMETER FOR 100 MILLION MΩ

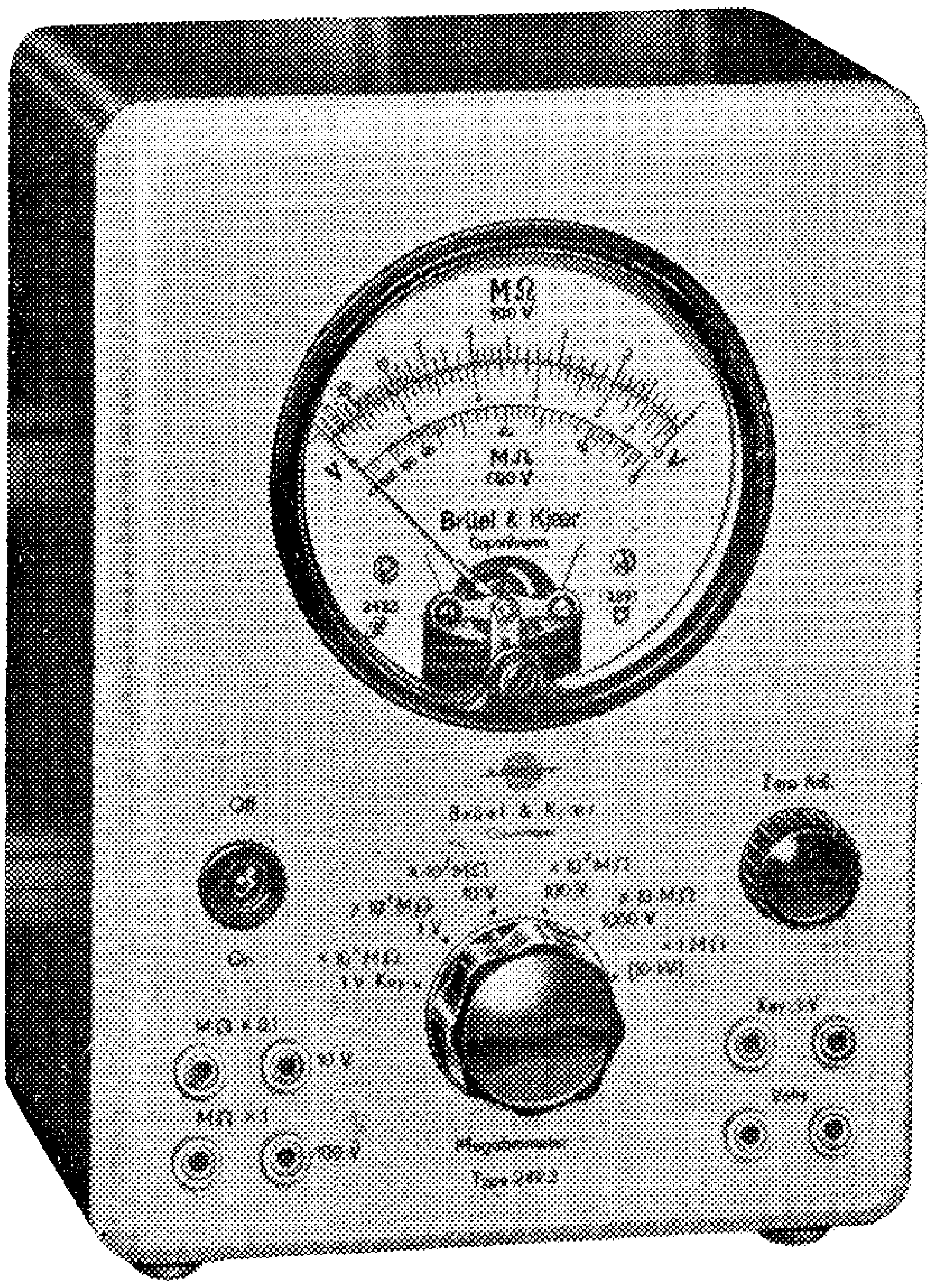


Fig. 1

The instrument (Fig. 1) is intended for the measurement of very high resistance but is also a very useful d.c. voltmeter and sensitive micro-micro-ammeter. The instrument is a stable d.c. tube voltmeter, with the first valve, a balanced double triode, operating as a cathode-follower preamplifier with a low stabilized anode voltage, so that there is a minimum grid-current due to ionization, photo-electric effect and secondary emission. The valve acts as an impedance converter, so that the second valve, another balanced double-triode with the meter between the anodes, is very stable, and not subject to the effect of grid-current fluctuations, as it has a low input impedance.

Thus, the zero position is very stable from one range to the next, as there will be no significant potential developed across the input voltage divider as a result of grid-current. However, the zero point may shift a little when going to the highest range, × 100,000 Megohms. The anode potential of the second valve is also stabilized. Stabilized resistance-measuring voltages of 10 and 100 volts are available.

The meter gives a full deflection for an input voltage of 1 volt, so that, with the 100 volts supply, the following 6 resistance ranges will be obtained:

Max.	Min.
10^8 Ohms	10^6 Ohms
10^9 ”	10^7 ”
10^{10} ”	10^8 ”
10^{11} ”	10^9 ”
10^{12} ”	10^{10} ”
10^{13} ”	10^{11} ”

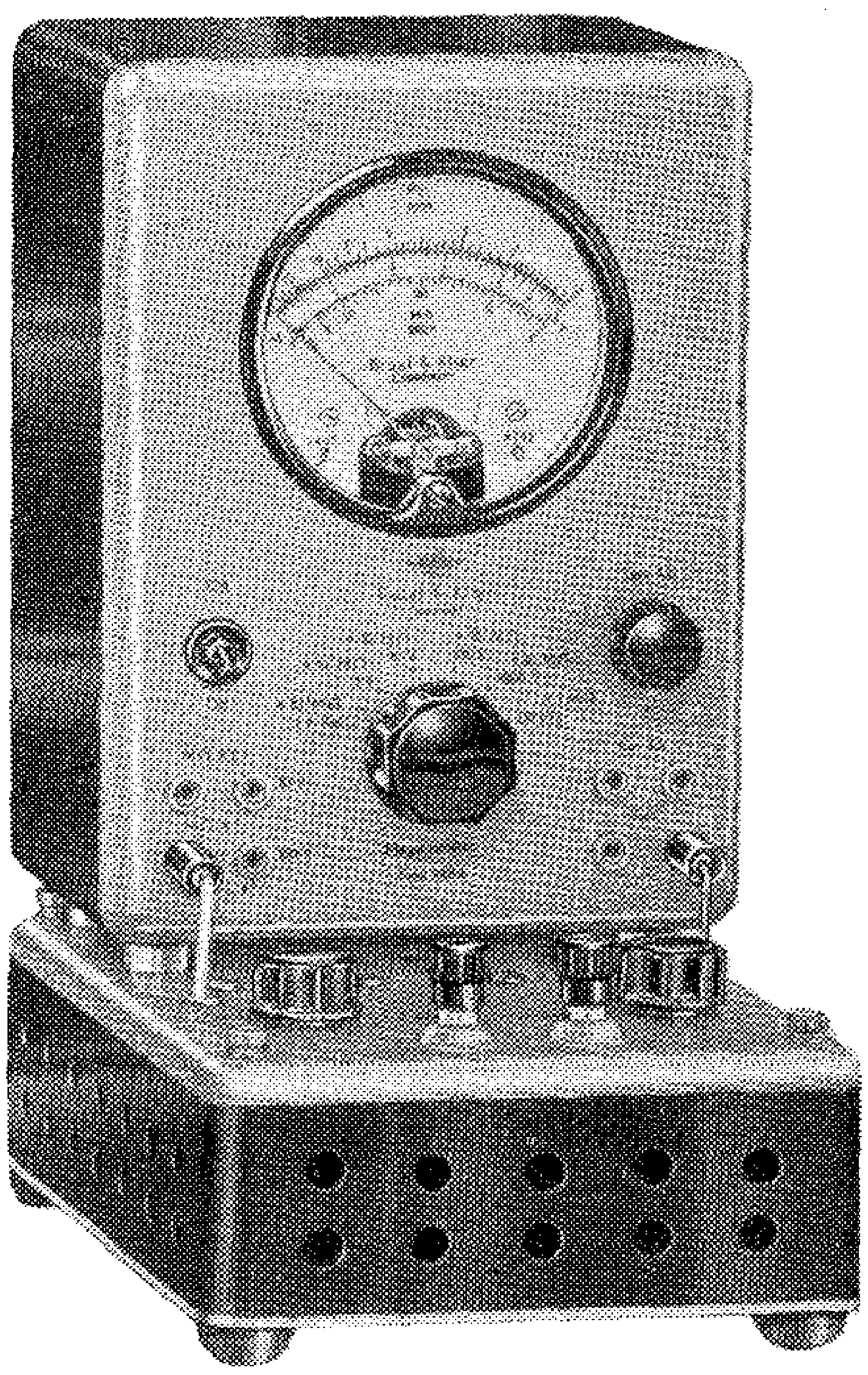


Fig. 2

The first 5 ranges are taken from the voltage divider of 100 Megohms, the last range from the separate 1000 Megohms resistor switched in on position 6.

The scales are semi-logarithmic for inverse Megohms, $\infty - 100$ being 3 % of the total scale length, $\infty - 10$, 25 %, and $10 - 1$ the remaining 75 %. It is thus easy to read 100 × full deflection, i.e., 100 × minimum value, for each range.

If the 10 volts supply is used, all the above values must be divided by 10, as is indicated at the appropriate terminals. Finally, to complete the description of the resistance range measurements, we have the "High Tension Accessory" type 3423, whose details are given later. This has a voltage supply of 1000 volts, built up of hearing-aid batteries (Eveready, Burgess, or Hellesens, 33 volts), so that all the resistance ranges can be multipled × 10 when the accessory is combined with the megohmmeter. We thus have a resistance measuring ranges from 0.1 (10^5 Ohms) to 100,000,000 Megohms (10^{14} Ohms). measuring range from 0.1 Megohm (10^5 Ohms) to 100,000,000 Megohms (10^{11} Ohms). Fig. 2 shows the combined Megohmmeter and High Tension Accessory.

Voltage Measurements.

As the circuit is arranged to give full scale deflection on the meter for a grid voltage of 1 volt on the first valve, we are able to measure d.c. voltages from 1 volt full scale deflection to, theoretically, 10.000 volts full scale deflection. However, the input insulation will not stand more than 2000—3000 volts, so this is the maximum permissible. As we can easily read 1 % of the scale, we can measure down to .01 volt.

Current Measurements.

Very small currents can be measured with the Megohmmeter. On the 1 Megohm switch position a full deflection corresponds to 10^{-4} amps, and 1 % of this,

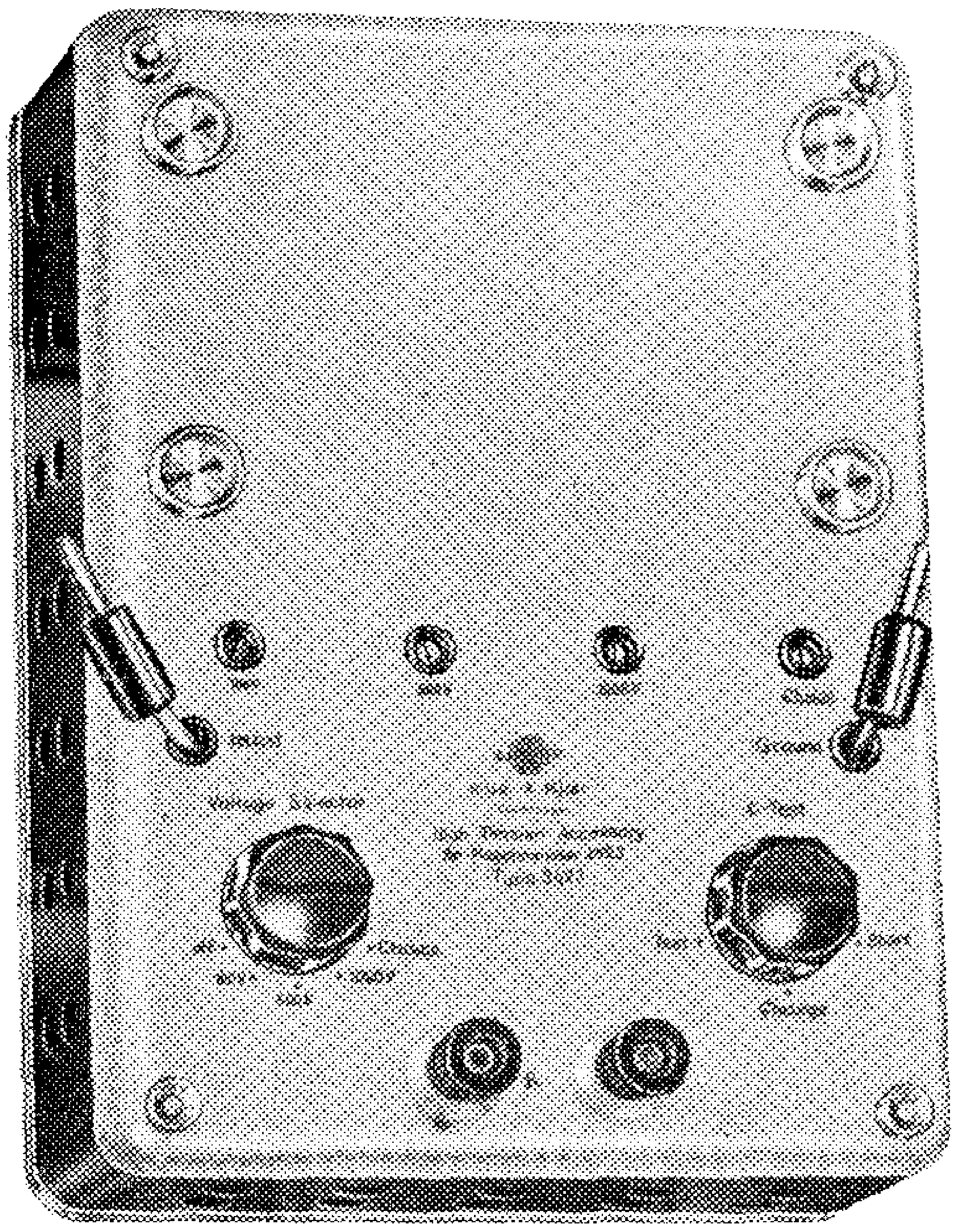


Fig. 3

or 10^{-6} amps, can be read. On the 10^{5} Megohms position, the full deflection corresponds to 10^{-9} amps, so that 10^{-11} amps can be read, that is, 10 micromicroamperes.

High Tension Accessory Type 3423.

This is a battery supply of 1000 volts built up of 33 + 1 hearing aid batteries (Burgess, Eveready, Hellesens or equivalent types). The Megohmmeter rests on four sockets on the accessory, and the two instruments are simply connected by two plug connectors. Fig. 3 shows the High Tension Accessory by itself. A switch on the accessory gives a choice of three fixed measuring voltages of 100, 500, or 1000 volts, with a further position which allows a choice of any other pre-selected voltage between 0 and 1000 volts. These voltage positions have their appropriate potentiometers for calibration, the Megohmmeter voltage ranges being used in combination with the potentiometers to obtain the required adjustment. There is a spare battery position for use when the battery voltage begins to drop. Normally, 33 batteries are in series to give the full 1000 volts.

It should be noted that although a supply of 1000 volts is being used, it is harmless, as the maximum current which can be taken from the supply is less than 1 ma, as there are suitable resistances in series with the battery supply. As the batteries can be purchased everywhere, and have a limited storage life of ½ to 1 year, the instrument is sent out without batteries, as it would not be economical to install them in the factory.

Resistance can be measured either using the stabilized 10 or 100 volts supply in the Megohmmeter, or the battery voltage supply from the High Tension Accessory. If the 500 volts supply is used, the lower scale on the meter is read and multiplied by the appropriate factor on the range switch. If the 1000 volts supply is used, the upper scale is read, and a further multiplication × 10 made. For any other voltage, use the 100 V scale and obtain the resistance value from the formula:

$$R = \frac{\text{Scale value} \times \text{attenuator position} \times \text{measuring voltage}}{100} \text{ Megohms}$$

Applications.

Resistance and insulation measurements (Fig. 4) are straightforward: connect the resistance to be measured to the input of the Megohmmeter at the terminals Megohm × 1 or Megohm × 0.1, depending on whether the 10 V or the 100 V supply is used. For higher voltages, couple the High Tension Accessory to the Megohmmeter and attach the resistance to be measured to the front terminals on the accessory. In all these cases it is advisable to earth the casing of the instruments, so that static voltages on the measuring object do not disturb the measurements by causing the pointer to fluctuate.

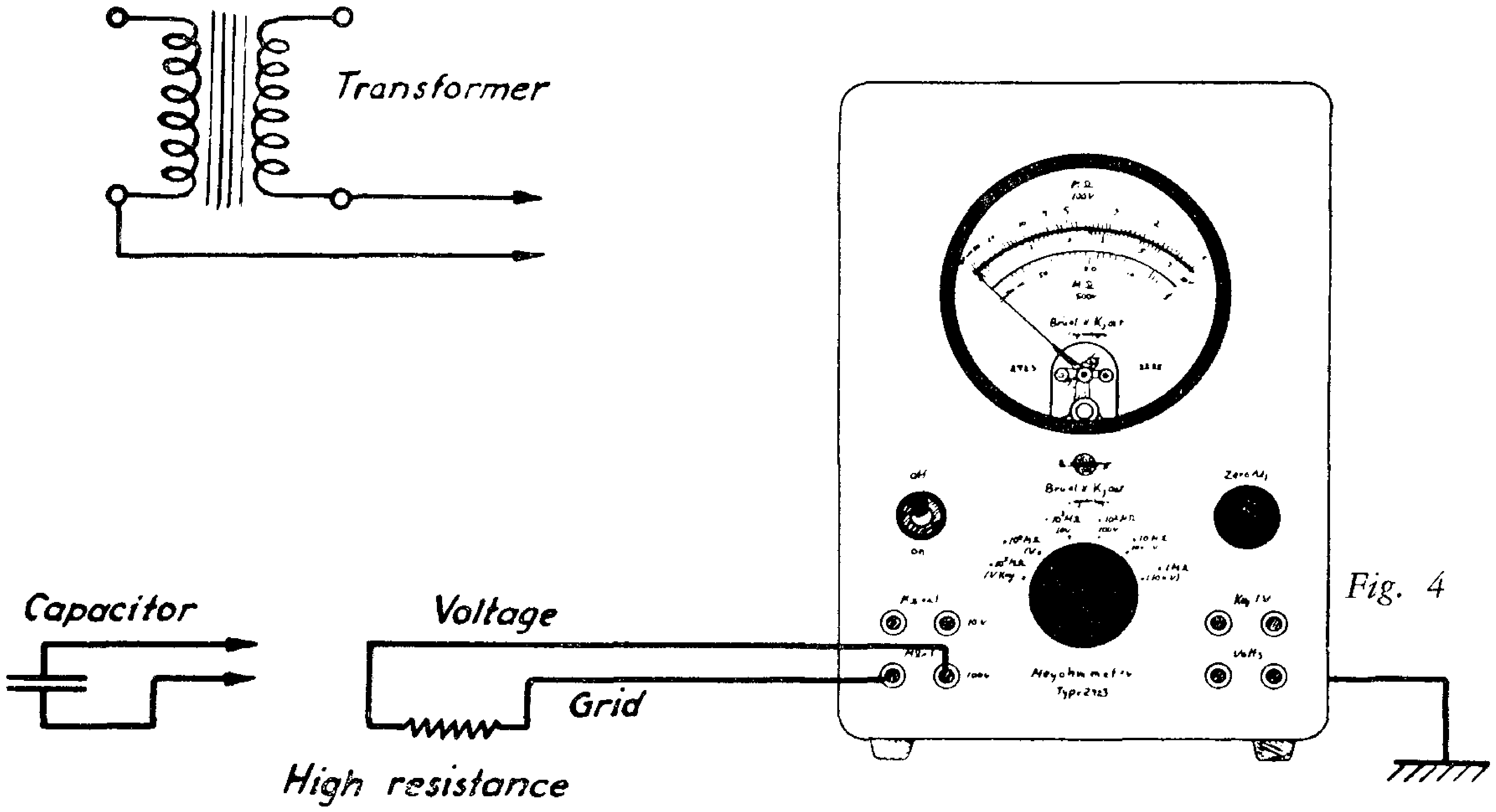


Fig. 4

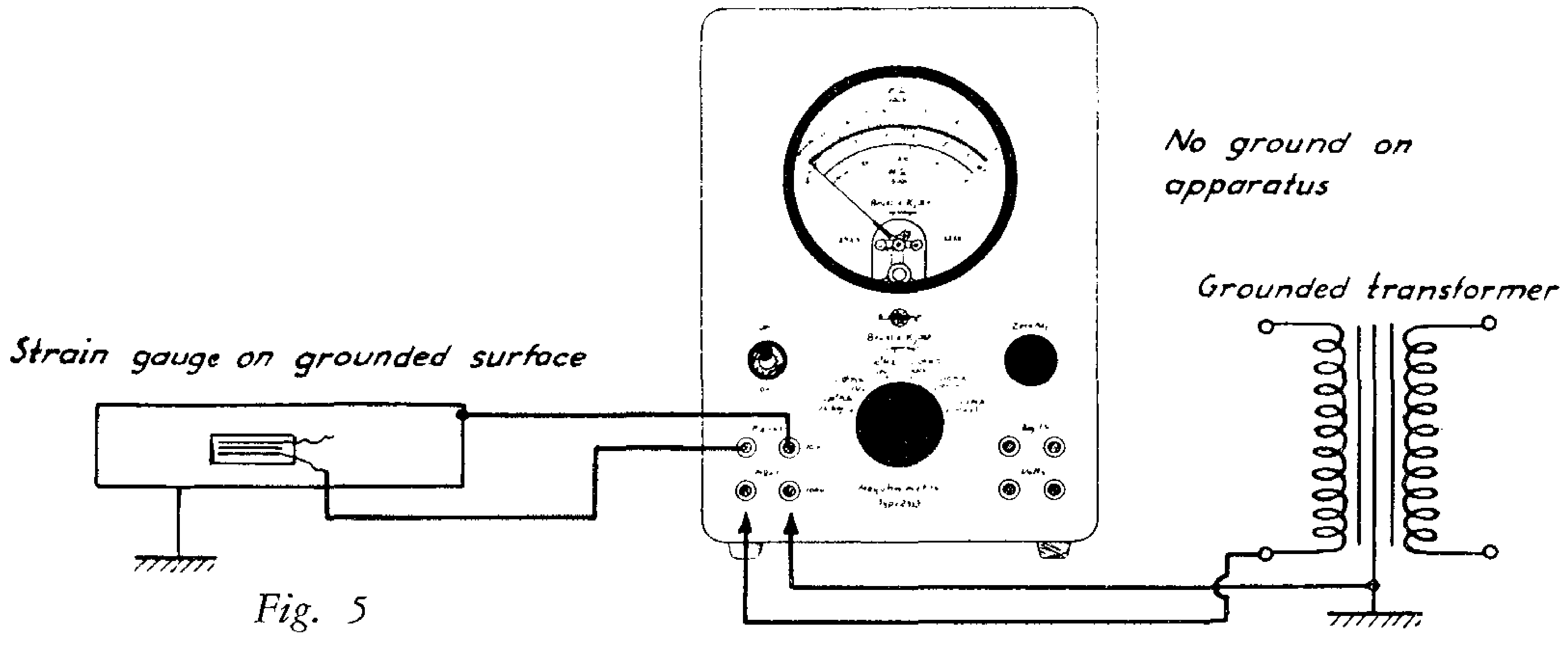


Fig. 5

With insulation measurements, the voltage used will depend on circumstances. If, for example, it is wished to measure the insulation resistance of strain gauges (fig. 5), it is advisable to use the 10 volts supply, as most strain gauges will break down if subjected to 100 volts, the distance between the gauge wire and the metal surface to which it is attached often being only some few hundredths of a millimeter. Furthermore, as the gauge is fastened to a grounded object, the Megohmmeter must not be grounded, as this would produce a short-circuit either across the voltage supply or across the voltage divider, depending on which way round the connections from the gauge and its ground were made. These remarks also apply to insulation measurements on cables with respect to ground, the insulation between the windings of a transformer and its iron core, which is ground connected, generator and motor windings, and so on.

Standards of Insulation Testing.

As insulating materials usually show a marked voltage coefficient of resistance, it is advisable for purposes of standardization to make measurements at an accepted level. 500 volts appears to be a common standard widely agreed on in U.S.A. (A.S.T.M. Standards on Electrical Insulating Materials, D. 257—49 T), while in Great Britain, the standard appears to be 100 volts (C.C.I. and I.R.E. standards). We must distinguish, however, between the standardized voltage for measuring insulation resistance and the high voltages applied in breakdown tests, usually several Kvolts. For the routine testing of components such as resistances and capacitors, the standards chosen will be determined essentially by the purposes to which the components will be put and the potentials to which they are liable to be subjected.

Testing capacitors.

When testing capacitors, or cables which have appreciable capacitance, it can be an advantage to use a key to allow quick charging (fig. 6). This can be a simple telegraph key, whose insulation resistance should be great in relation to 1000 Megohms. It is connected across the points marked "Key". It is arranged so that when depressed the key circuit is broken, and when released the input circuit of the Megohmmeter is short-circuited, so that the capacitor or cable under test is charged up at once. When depressed once more, the capacitor or cable's insulation resistance is measured.

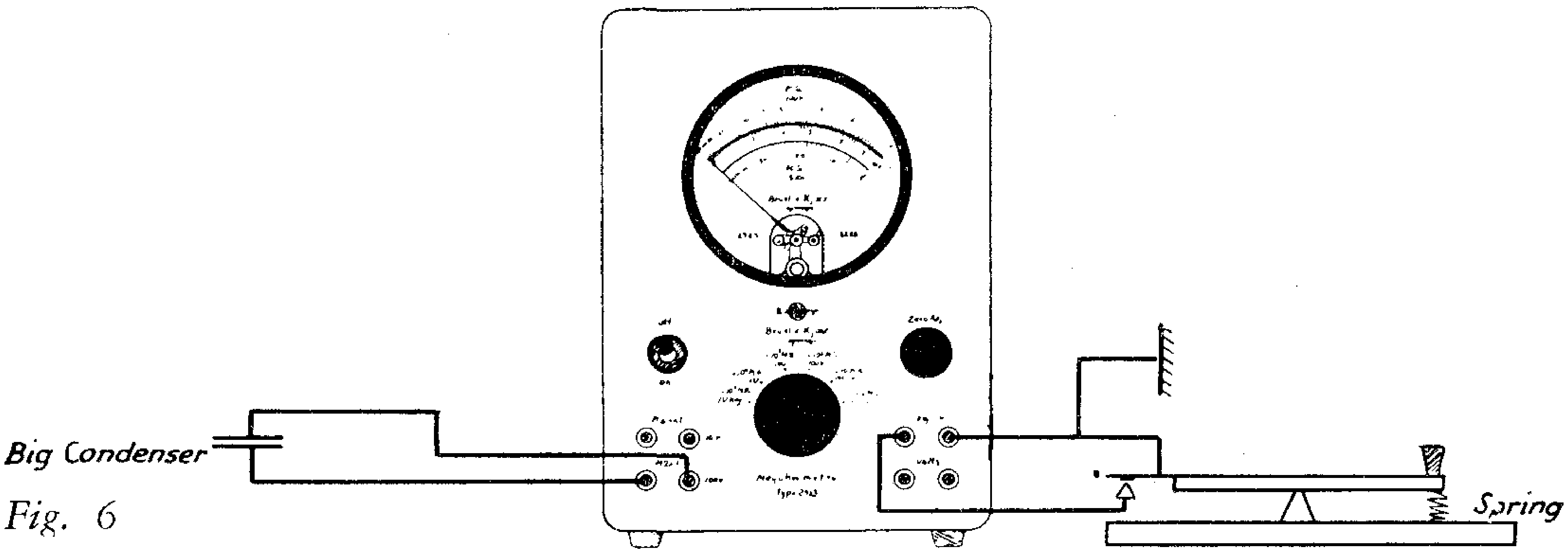


Fig. 6

If working with no more than 100 volts, there is little risk in having the capacitor or cable charged, but with higher voltages it is advisable to have some means of easily discharging the component, and for this purpose a 3-position double-pole switch can be used (fig. 7). In the middle position the component is immediately charged up, cutting out the input resistance, in the left hand position it is on test, and in the right hand position it is discharged through a resistance.

It is necessary that the insulation resistance of the switch be great by comparison with the 1000 Megohms which is the greatest resistance in the Megohm-

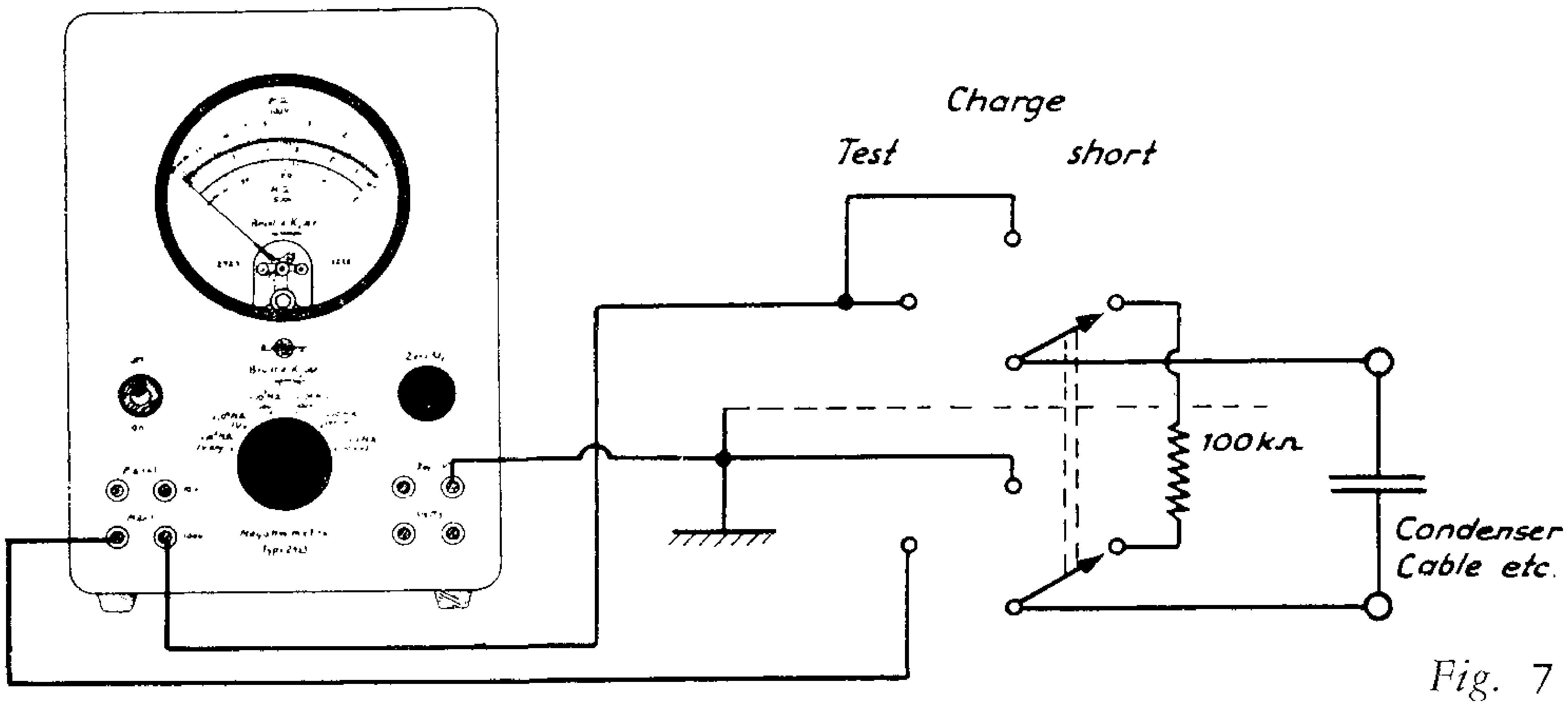


Fig. 7

meter input. Possible leakage currents from one side of the switch to the other are lead to earth, as the switch is constructed in two sections, so that we have a guard-ring.

If one wishes to make resistance measurements with an external voltage source other than the High Tension Accessory, for example a battery, this can be done as shown (fig. 8). The resistance can then be calculated from the following formula, when the deflection is read on the Megohm scale for 100 V:

$$R = \frac{\text{Scale deflection} \times \text{multiplication factor} \times \text{battery voltage}}{100}$$

It is generally advisable to ground the Megohmmeter.

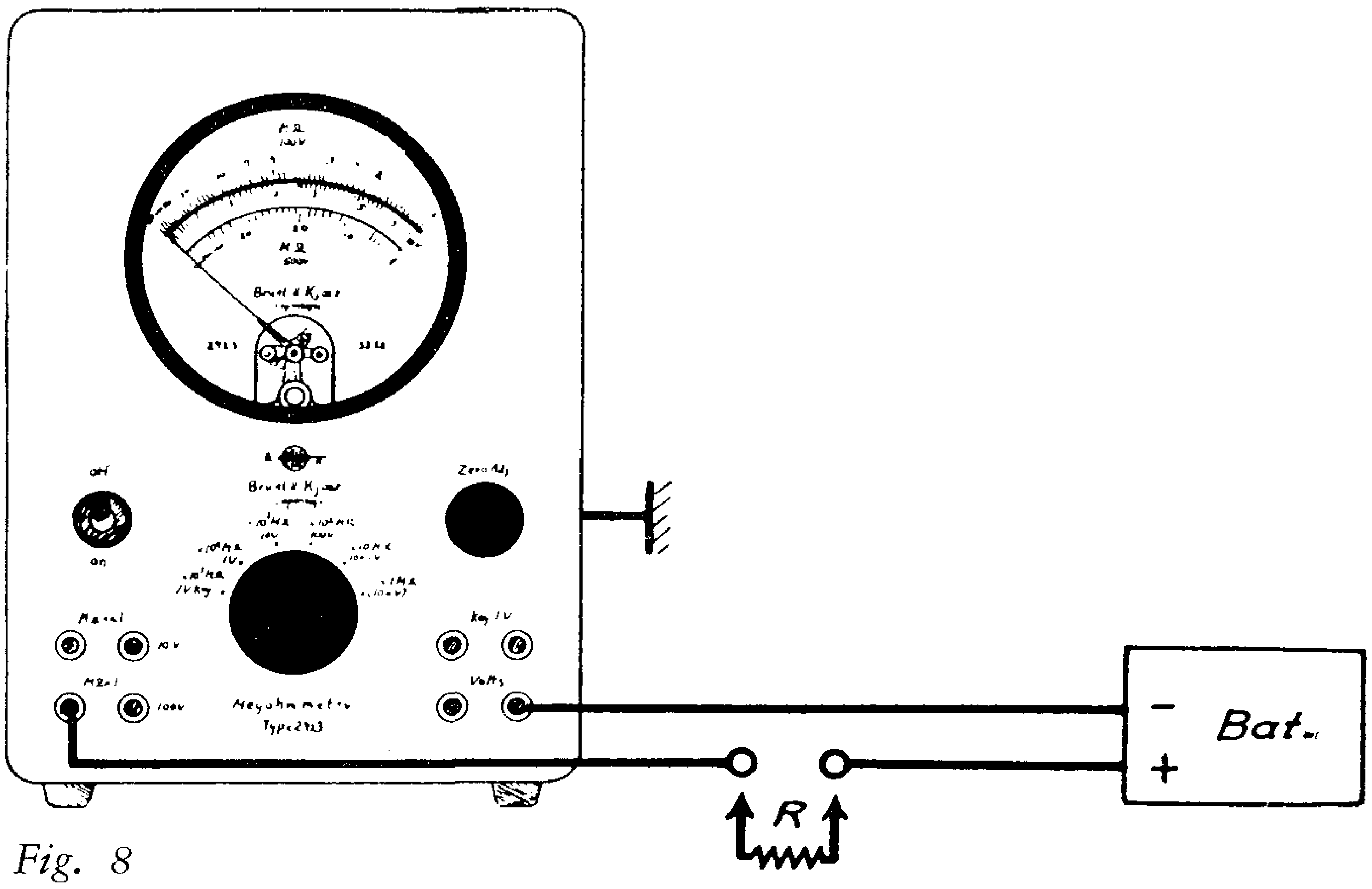


Fig. 8

Insulation Characteristics of Transformer Oil.

The oil's insulating characteristics can be measured as shown (fig. 9). The electrodes should be of considerable size, and the distance between them and the container great in relation to the distance between them. The specific resistance of the oil can be determined from the formula:

$$\text{Specific Resistance} = \frac{\text{Measured resistance} \times \text{electrode area}}{\text{electrode distance}} \text{ ohm cm}$$

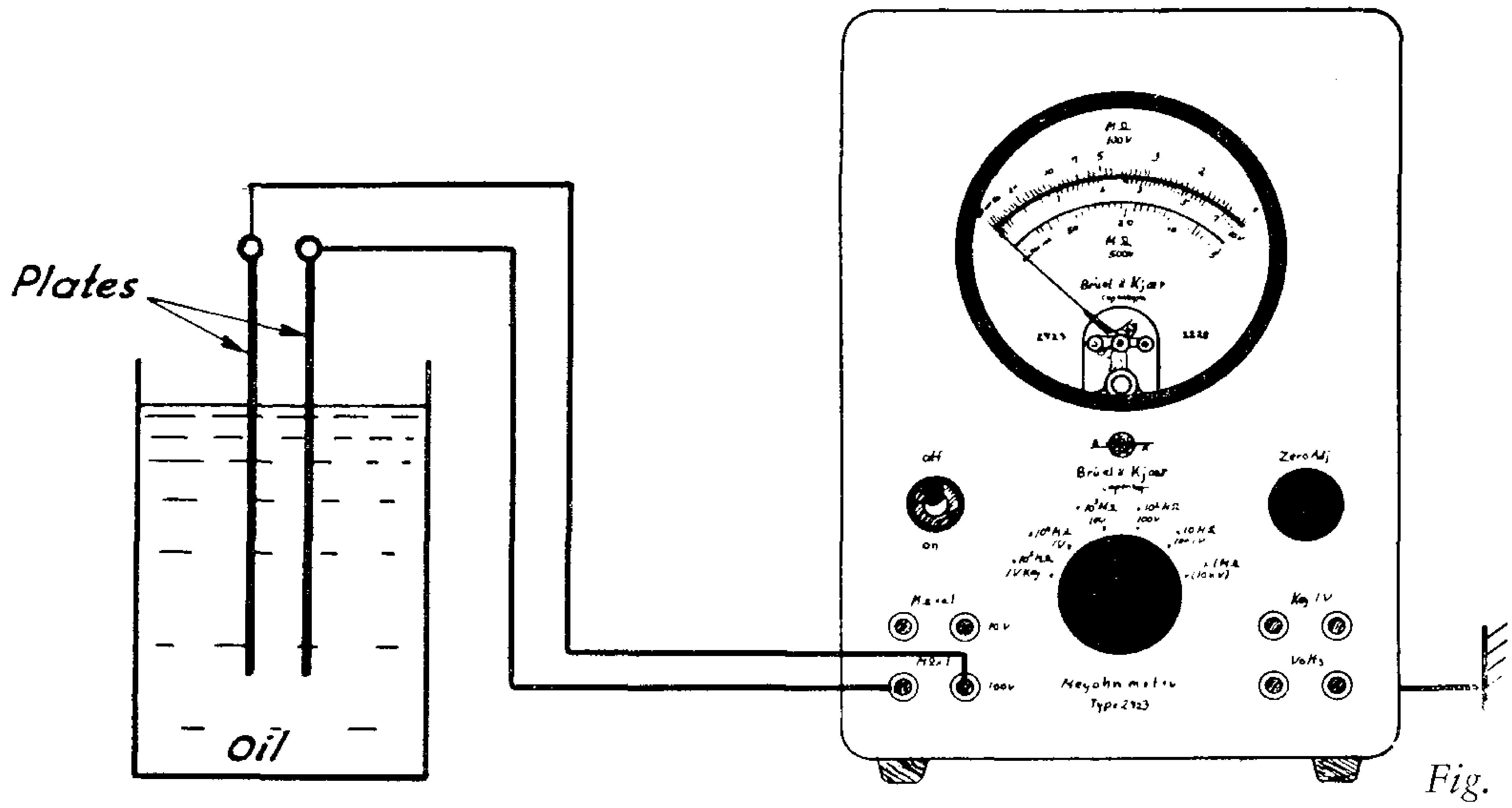


Fig. 9

If the oil has a very high insulation resistance, a small electrode distance and large electrode area should be chosen. The Megohmmeter should be grounded. The specific resistance for pure oil is approx. 10^6 Megohms cm at 20°C, falling considerably with temperature, and is furthermore highly dependent on its purity, the most important impurity being water, only slight amounts of which can reduce the insulation characteristics, and therefore the break-down strength, very considerably.

D.C. Voltages.

As previously mentioned, d.c. voltages from 0.01 V to 2000/3000 V can be measured. In the first four positions of the range switch the input impedance is 100 Megohms, and in the last position, 1000 Megohms. One has thus a measuring range of 1 volt f.s.d. with an input impedance of 100 Megohms or 1000 Megohms. Because of this, it is possible to measure small potentials of sources with very high internal resistance, where no appreciable power can be taken from the circuit, for example, voltages in tubes and oscillographs, electrochemical equipment with glass measuring electrodes, Hydrogen ion concentration electrodes, and so on.

If the positive pole of the voltage source being measured is earthed, it is still possible to take measurements of d.c.—ve voltages, by shifting the zero point of the scale to a middle position and reading the deflection backwards when the negative voltage is applied.

Measurements of Small Currents.

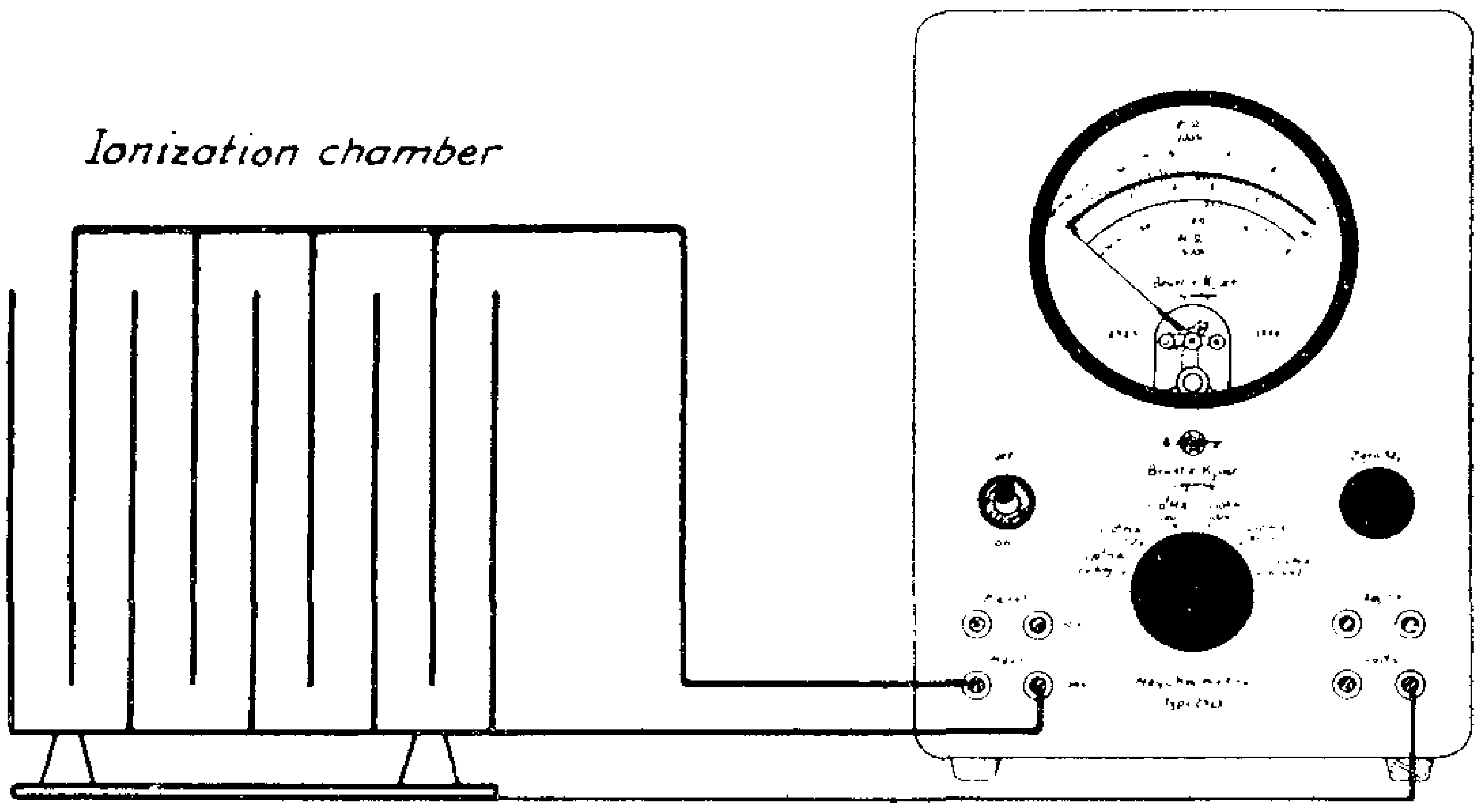
As mentioned, currents down to 10^{-11} amps can be read off the scale, this being 1 % of the full deflection in the 10^5 Megohm range. Although 1 % of the full scale deflection, this minimum value nevertheless covers about 3 % of the scale, as the latter is logarithmic. The current to be measured is connected to the sockets marked "Key". The right socket is grounded, and should be the negative pole.

Compensation Measurements.

The Megohmmeter, because of its low current consumption, is well suited as indicator in compensation measurements. A voltage from a calibrated attenuator and the unknown voltage are connected in series, and the attenuator adjusted so that no current passes through the Megohmmeter. The unknown voltage is then read off on the attenuator. Because of the very low current consumption of the meter, the unknown voltage source can have a very high internal resistance, and a precise balance point can still be found on the meter.

Radioactivity Measurements.

The great current sensitivity of the Megohmmeter makes it suitable for measuring currents from ionization chambers, using its internal voltage of 100 V, or, if heavier radiation intensities have to be measured, the 1000 V supply from the High Tension Accessory, to collect the saturation current from the heavier ionization. If the chamber is constructed from a series of parallel coupled plates, as shown (fig. 10), it is possible to obtain a field strength of at least 100 volts/cm between the plates, allowing the measurement of up to 1000 Röntgen/hr. With an effective chamber volume of 1000 cm^3, and the definition of 1 r/hr as = 1 e.s.u./cm^3/hr, the values in r/hr for full deflection on the various ranges will be obtained as shown in the table. If the effective volume of the chamber is reduced to 926 cm^3, full deflection will be obtained for the radiation intensity in powers of 10.



Full deflection reading

Switch position	$\times 10^5$ MΩ	$\times 10^4$ MΩ	$\times 10^3$ MΩ	$\times 10^2$ MΩ	× 10 MΩ	× 1 MΩ
1000 cm^3 chamber volume	10,8 r/h	108 r/h	1080 r/h			
926 cm^3 " "	10 r/h	100 r/h	1000 r/h			

Fig. 10

Measurements on Capacitors with very High Insulation.

To measure the insulation resistance of small capacitors, they should first be charged up with exactly 10 or 100 volts from the megohmmeter's voltage output, using the R.H. Megohm × 1 or Megohm × 0.1 terminal and the R.H. volts terminal, then left charged for a long enough period, if necessary weeks or months, and then the residual voltage measured. If the capacitors are small, they will naturally discharge very quickly across the megohmmeter's input resistance, and the instrument will then be unable to show the proper voltage. In such a case, the maximum deflection is read, and the capacitor then charged up with different known voltages and discharged again, until the same deflection is obtained. One has then a measure of what the capacitor voltage was when it was connected to the voltage terminals. The insulation resistance can then be calculated from the formula $V_t = V_0 e^{-\frac{t}{cr}}$

Measurements on Insulating Materials.

Figure 11 shows the principle of the guard-ring, for the elimination of leakage currents across the connections to the material being measured. The guard-ring, filled with mercury, is earthed, so that any currents leaking over the surface of the material from the test area to the outer connection are earthed. The current measured will be only that which goes through the body of the material itself. The Specific Resistance is then defined as

$$\text{Specific Resistance} = \frac{\text{Measured Resistance} \times \text{Test Area}}{\text{Disk Thickness}} \quad \text{Ohm cm}$$

If one wished to measure surface insulation of the insulating material, instead of volume insulation as has been done in the example discussed, the set-up would be the same, but the connections to the guard-ring mercury and surrounding mercury would simply be reversed. The appropriate formula would then have to be used.

In the above set-up, the High Tension Accessory has been used to give a high voltage, but there is no reason why the measurement could not be carried out with the megohmmeter alone, particularly if the insulating material had a poor figure, or one wished to work with lower voltages.

Guard Rings.

The purpose of a guard ring or screen is to divert leakage currents so that

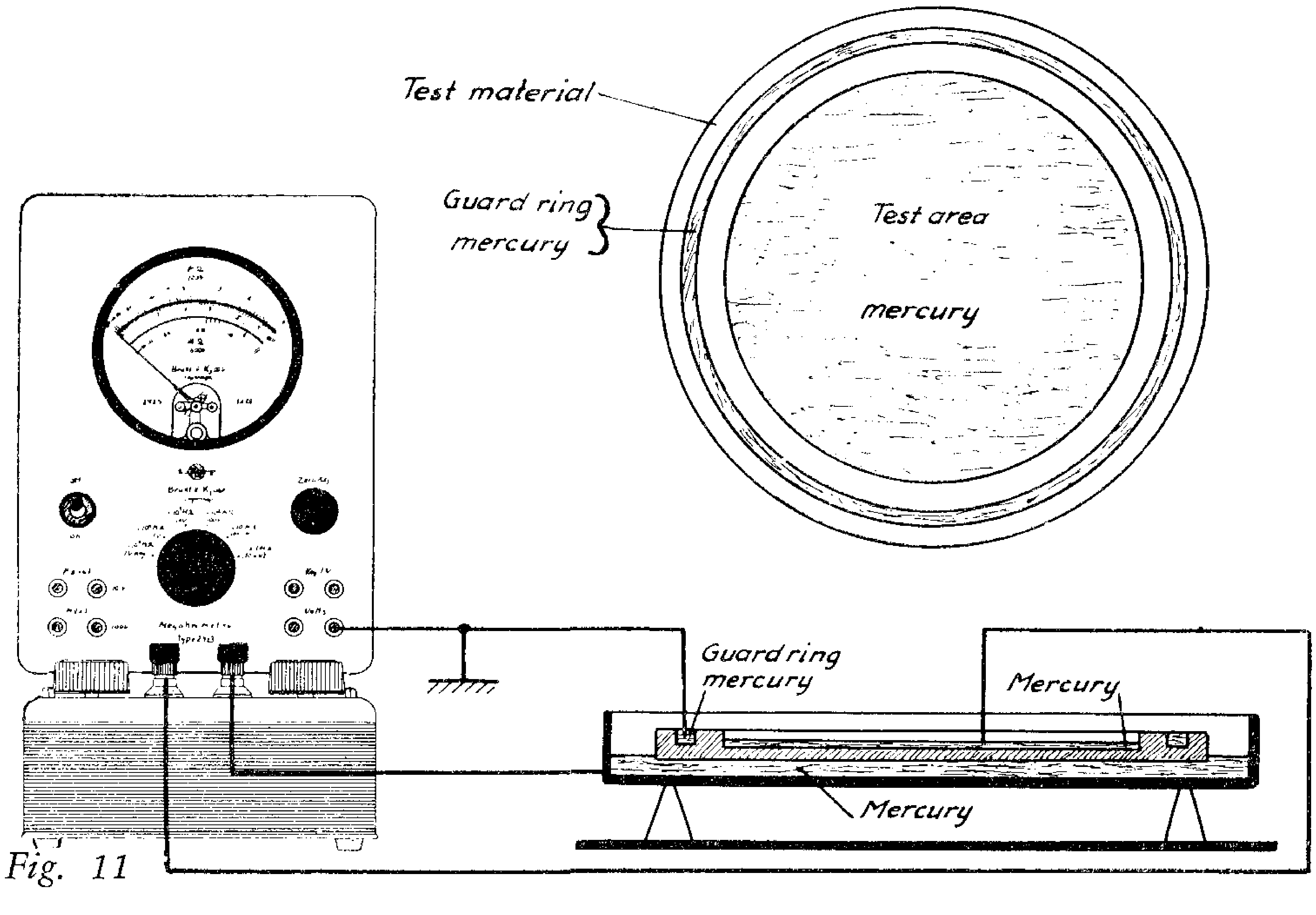


Fig. 11

they do not flow through the measuring instrument. Whether or not they should be employed depends on the impedance in the circuit. When measuring a resistance of 10,000 Megohms, leakage resistance may be the determining factor, but across a much smaller resistance it would be insignificant.

To illustrate the method, consider the simple case of measurement of a resistance R by a galvanometer G in conjunction with a battery b (fig. 12)

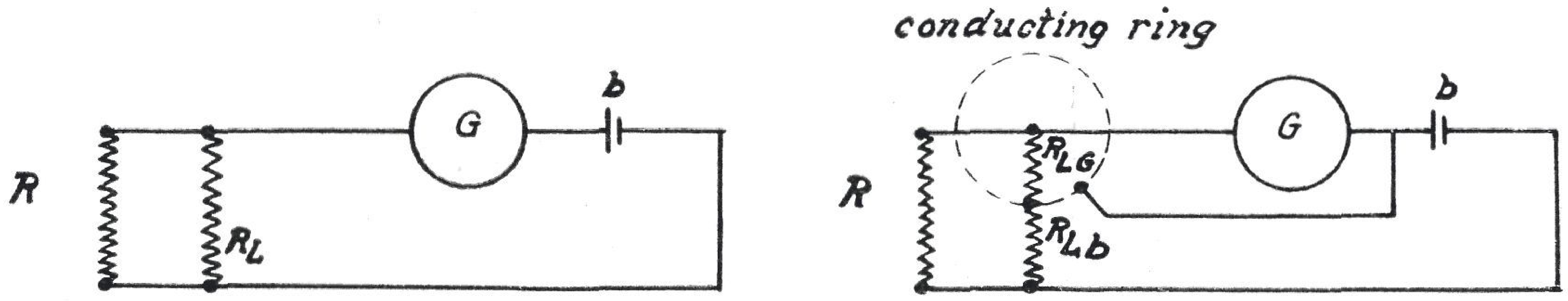


Fig. 12

R is the resistance being measured, while R_L is the surface leakage, which will therefore affect the measurement. If R_L is split by a conducting ring, as shown, R_L will be replaced by two resistances, R_{Lb} and R_{LG}, the first of which will be placed across the battery, while the other will be placed across the galvanometer. These resistances will both be too large to have any shunting effects. The conducting ring or "Guard-Ring", which effectively eliminates the leakage path across the measuring points, may have all the other possible leakage points connected to it. In practice, the guard-ring is earthed, as shown in the fig. No. 11.

All points of a circuit from which current is liable to leak, for example batteries and components at high potential, should be screened or placed on screens, and the screens connected to the guard-ring, which should enclose the + input terminal. For example, if measuring the leakage between 2 cables in a multi-core conductor, all the other cables should be connected to the guard ring terminal.

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