Electrical Technology
(EE101F)

Contents

- Measuring Instruments
- Classification of measuring instruments
- Spring control
- Gravity control
- Moving coil instruments
- Test yourself
- NPTEL Link

Measuring Instruments

Classification

1. Absolute instruments:-

   give the magnitude of the quantity in terms of the constants of the instruments

   Example :-

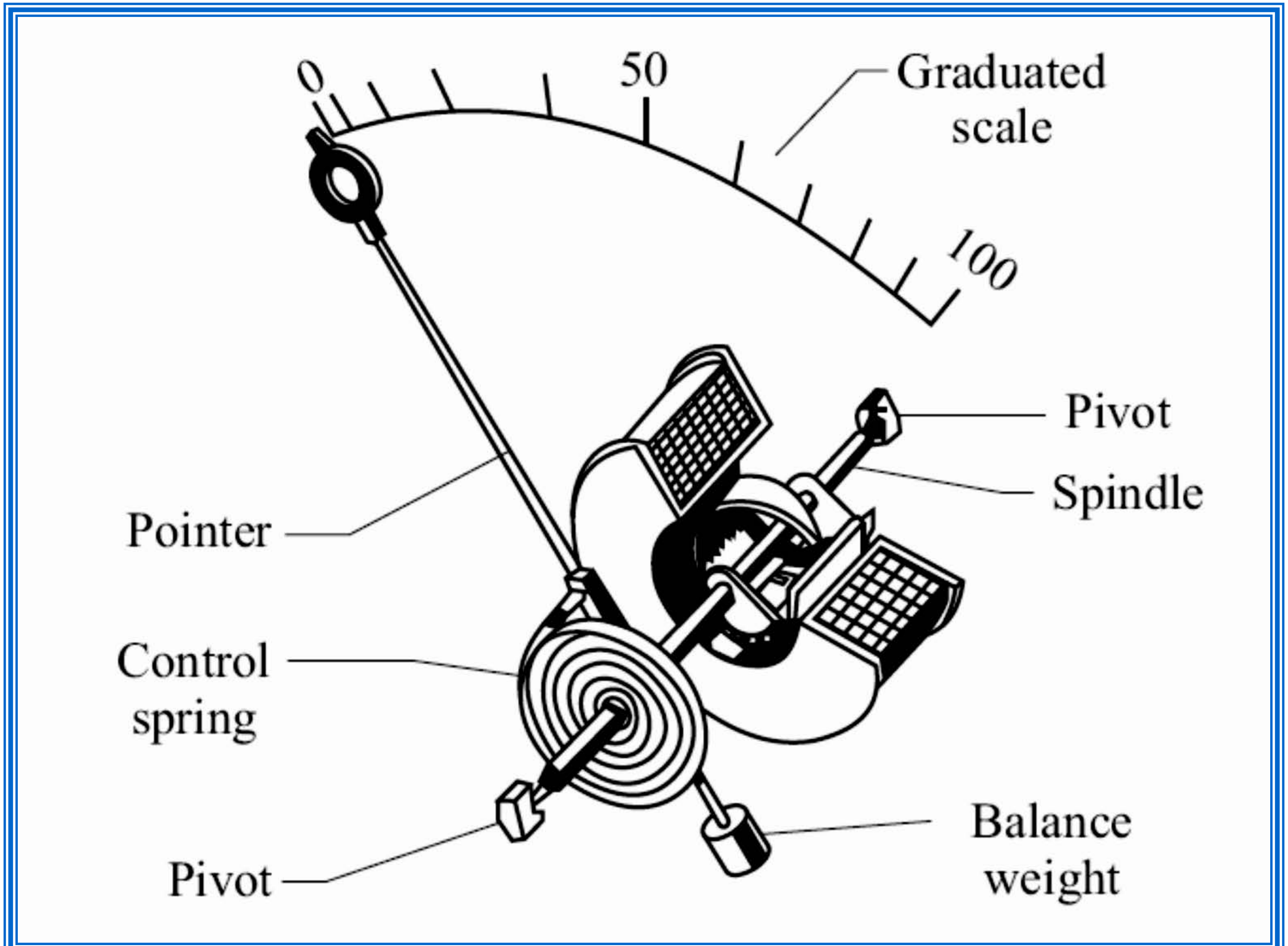
   a tangent galvanometer, used for measuring electric current

2. Secondary instruments:-

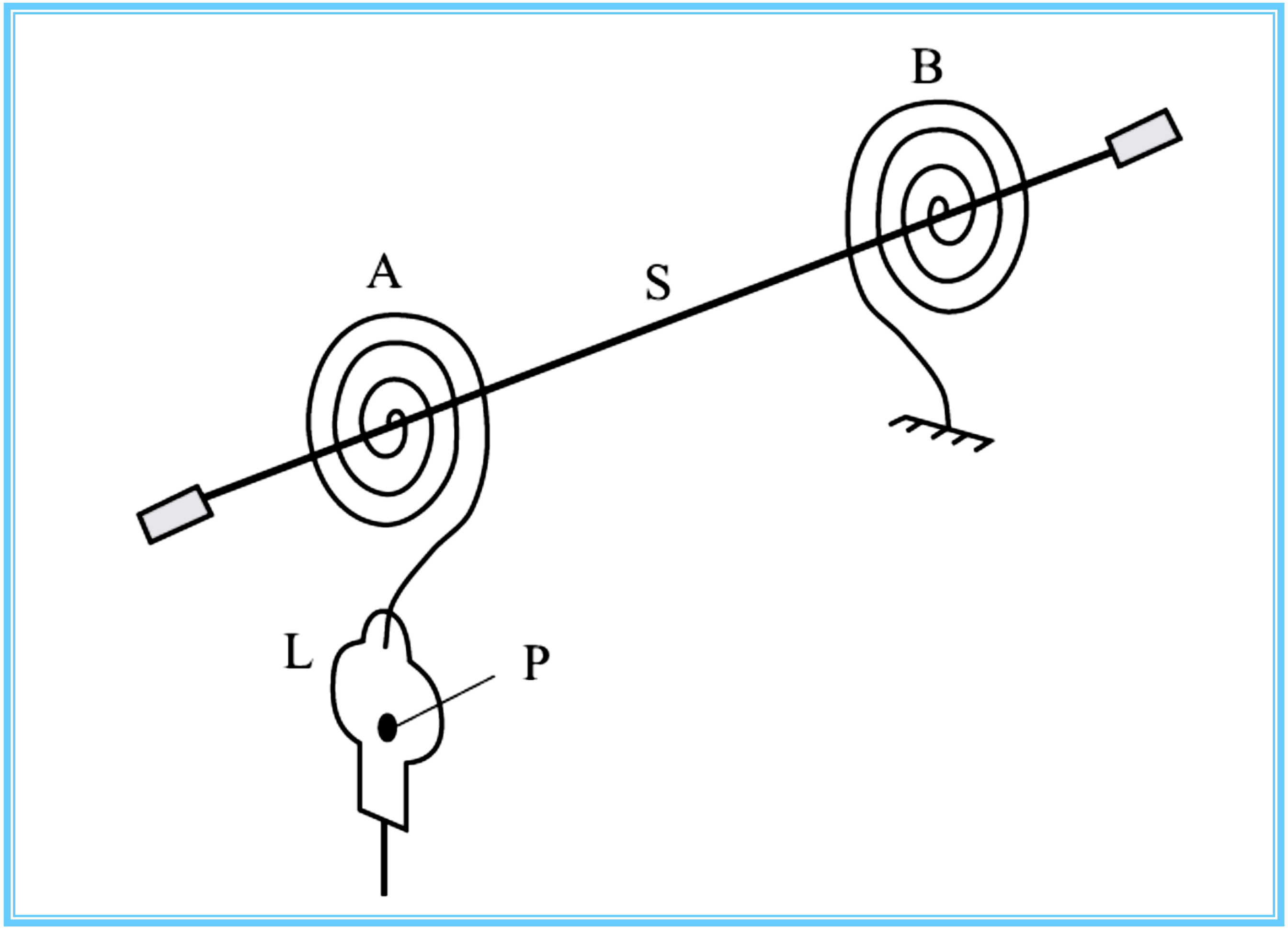
   these have to be calibrated by comparison with an absolute instrument

(*i*) Spring Control

- Most commonly used.
- One or two hairsprings made of phosphor bronze are used.
- The outer end of this spring is fixed and the inner end is attached with the spindle.
- When the pointer is at zero of the scale, the spring is normal.
- As the pointer moves, the spring winds and produces an opposing torque.
- The balance-weight balances the moving system so that its centre of gravity coincides with the axis of rotation, thereby reducing the friction between the pivot and bearings.


0
50
100
Graduated scale
Pivot
Spindle
Pointer
Control spring
Balance weight
Pivot

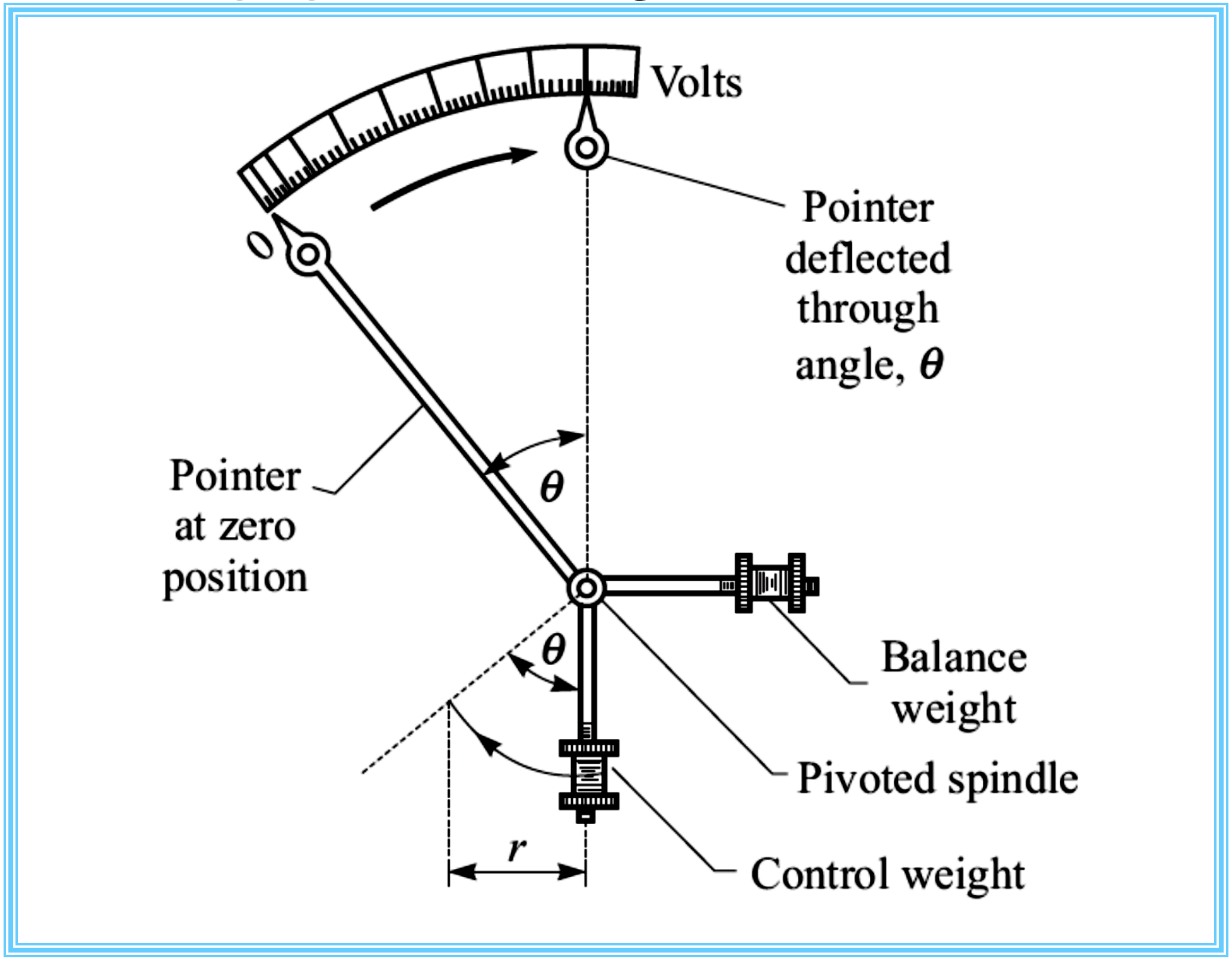
Double Springs



- Two springs A and B are wound in opposite directions.
- On deflection, one spring winds while the other unwinds.
- To make the controlling torque directly proportional to the angle of deflection, the springs should have fairly large number of turns.

- Advantages :
- Since $\tau_c \propto \theta$ and $\tau_d \propto I$; at final position, $\tau_c = \tau_d$
  Hence, $\theta \propto I$
- These instruments have uniform scale.
- Disadvantages :
- The stiffness of the spring is a function of temperature.
- Hence, the readings given by the instruments are temperature dependent.
- Furthermore, with the usage the spring develops an inelastic yield which affects the zero position of the moving system.

(*ii*) Gravity Control



- A small control weight is attached to the moving system.
- In addition, an adjustable balance weight is also attached to make the centre of gravity pass through the spindle.
- In zero position of the pointer, this control weight is vertical.

- When deflected by an angle θ, the weight exerts a force,

$$W \sin\theta$$

- The restraining or controlling torque is thus developed is given as

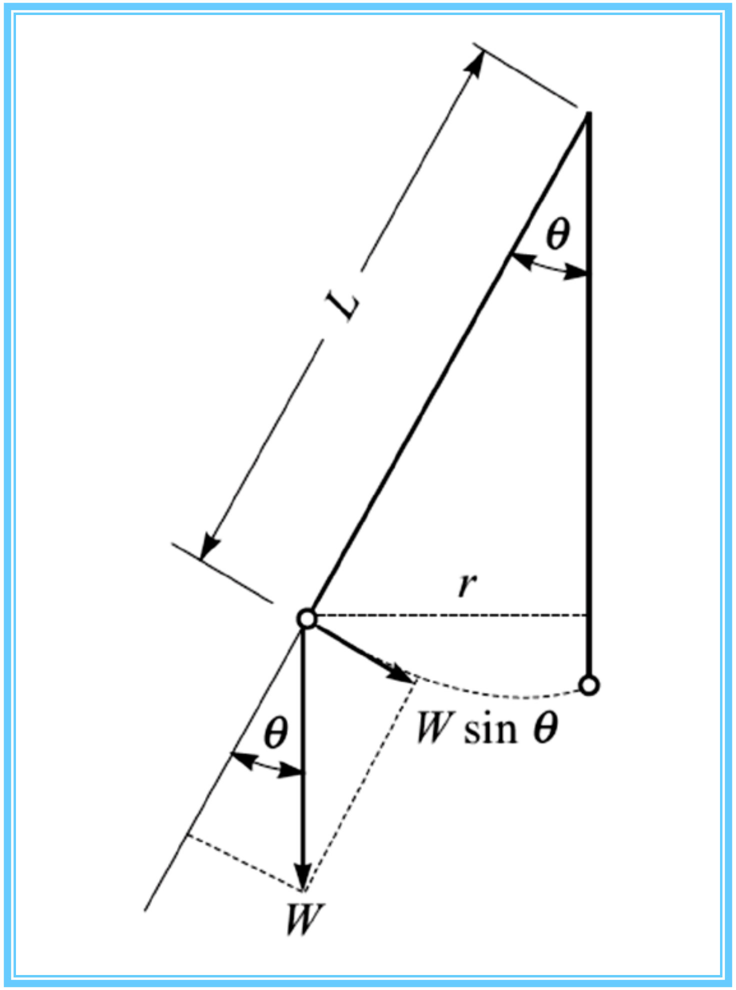
$$\tau_{\text{c}} = (W \sin\theta) \times L = WL \sin\theta$$

Since $\tau_{\text{d}} \propto I$, and $\tau_{\text{c}} = \tau_{\text{d}}$

or $WL \sin\theta = kI$

$$\Rightarrow \quad I = \left(\frac{WL}{k}\right) \sin\theta$$

or $I \propto \sin\theta$



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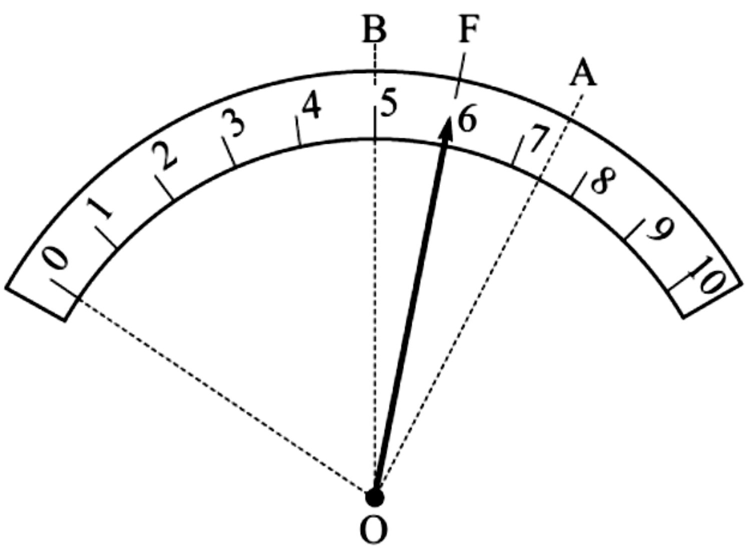
Disadvantage :

1. These do not have uniform scale.
2. These must be used in vertical position so that the control may operate properly.

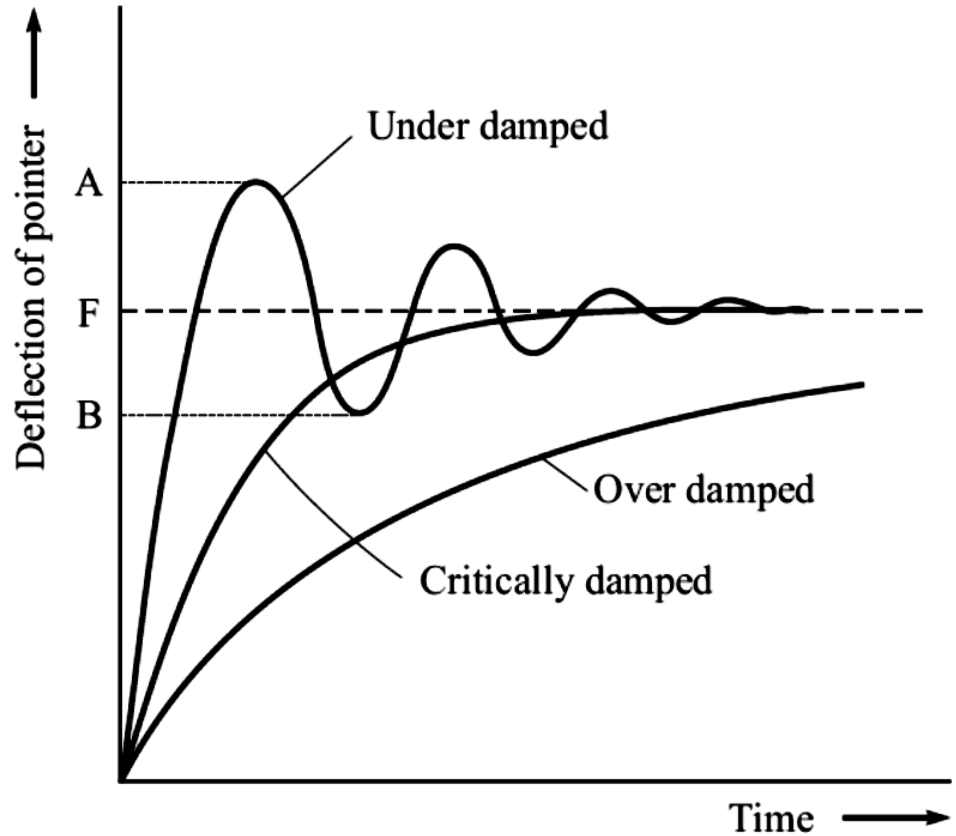
Advantages :

1. Less expensive.
2. Unaffected by changes in temperature.
3. Free from fatigue or deterioration with time.

Damping Torque



(*a*) The deflection of the pointer on the scale.



(*b*) The deflection versus time curves.

- The remedy lies in providing a suitable **damping torque.**
- If **over-damped**, the time-delay in taking the reading becomes unnecessarily long.
- If **under damped**, the oscillations of the pointer would not be killed completely.
- Thus, the damping torque should be just sufficient to kill the oscillation without increasing the delay-time.
- This condition is said to be ***critically damped*** or '***dead beat***'.

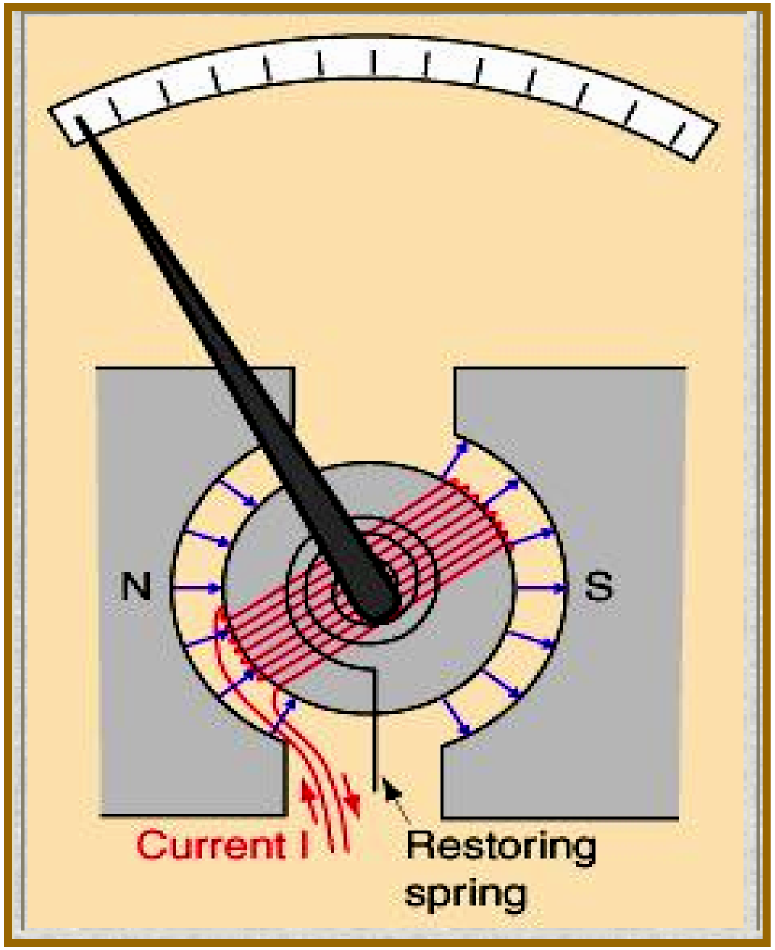
MOVING COIL INSTRUEMNTS

- There are two types :

  (1) ***Permanent Magnet Type*** **:** It is the most accurate and useful for dc measurements.

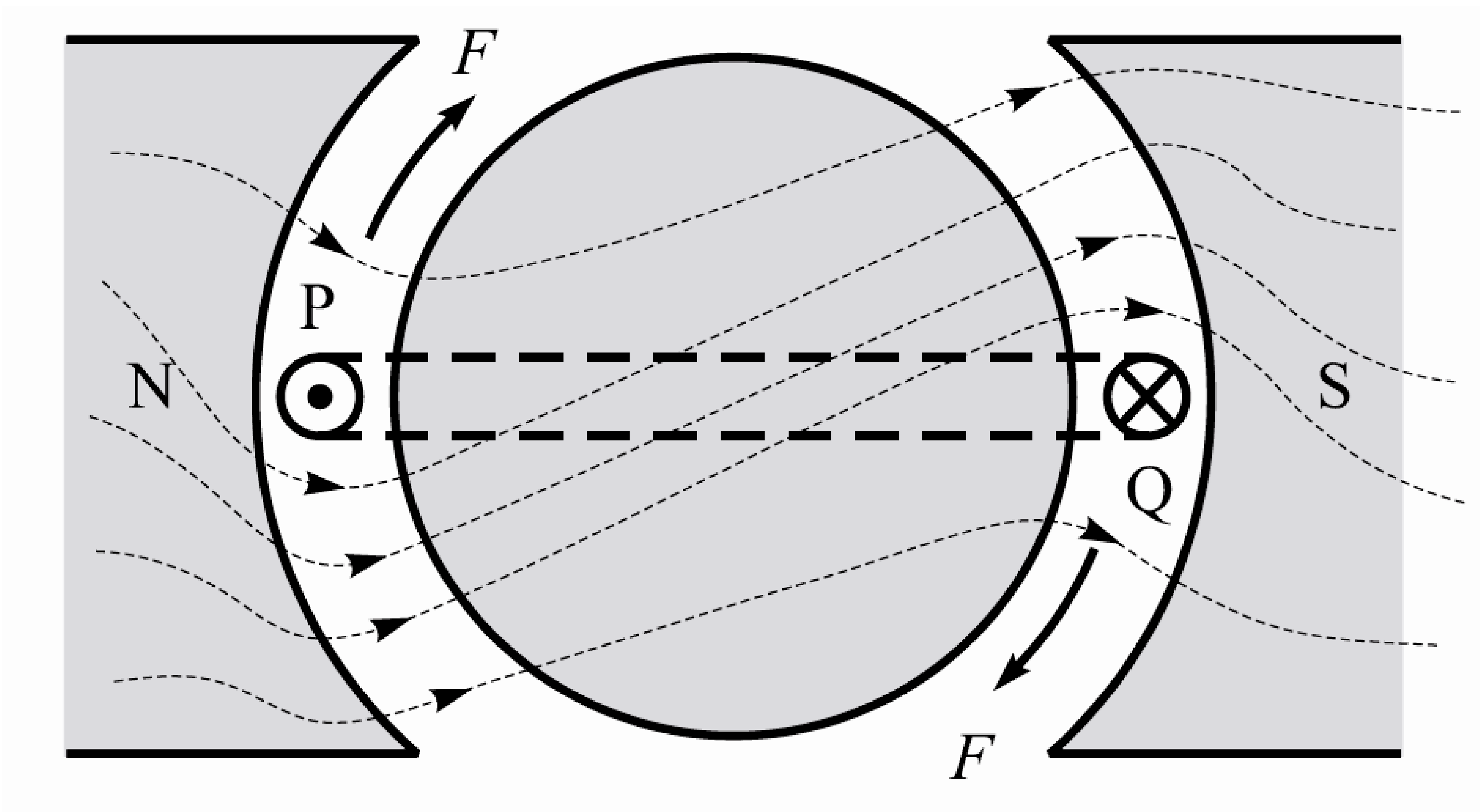
  (2) ***Dynamometer Type*** **:** It can be used for both dc and ac measurements.

Galvanometers



- When a current is passed through a coil in a magnetic field, the coil experiences a torque proportional to the current.
- A coil spring provides the controlling torque.
- The deflection of a needle attached to the coil is proportional to the current.
- Such "meter movements" are at the heart of the moving coil meters such as voltmeters and ammeters.
- Now they were largely replaced with solid state meters.

How the Deflection Torque is Produced



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- Consider a single turn PQ of the current carrying coil.
- The outward current in P set up a counterclockwise magnetic field.
- Thus, the field on the lower side is strengthened and on upper side weakened.
- The inward current in Q, on the other hand, strengthens the field on the upper side while weakens it on the lower side.
- The coil experience *forces* F-F.
- If d is the width of the coil

$$\tau = F \times (d/2) + F \times (d/2) = Fd$$

Advantages :

(*i*) High sensitivity.
(*ii*) Uniform scale.
(*iii*) Well shielded from any stray magnetic field.
(*iv*) High torque/weight ratio.
(*v*) Effective and reliable eddy-current damping.

Disadvantages :

(*i*) Cannot be used for ac measurement.
(*ii*) More expensive compared to moving-iron type.
(*iii*) Ageing of control springs and of the permanent magnets might cause errors.

- Since the force *F=NIBL* ,
- is directly proportional to the current *I* and to the flux density B in the air gap, the net defecting torque=INAB, Where A = area of the coil=Ld
- $$\tau_d = kI$$
- The controlling torque of the spiral springs

$$\tau_c = c\theta$$

- In the final steady position,

$$\tau_c = \tau_d \qquad \text{or} \qquad c\theta = kI \qquad \Rightarrow \qquad \theta = \frac{k}{c} I$$

- The deflection is proportional to the current and hence the scale is uniformly divided

AMMETERS AND VOLTMETERS

- Consider a d'Arsonval movement having ***current sensitivity*** (CS) of 0.1 mA and internal resistance (R_m) of 500 Ω.
- The ***full-scale deflection current***, I_m, for this instrument is 0.1 mA.
- When full-scale current flows, the voltage across its terminals is given as

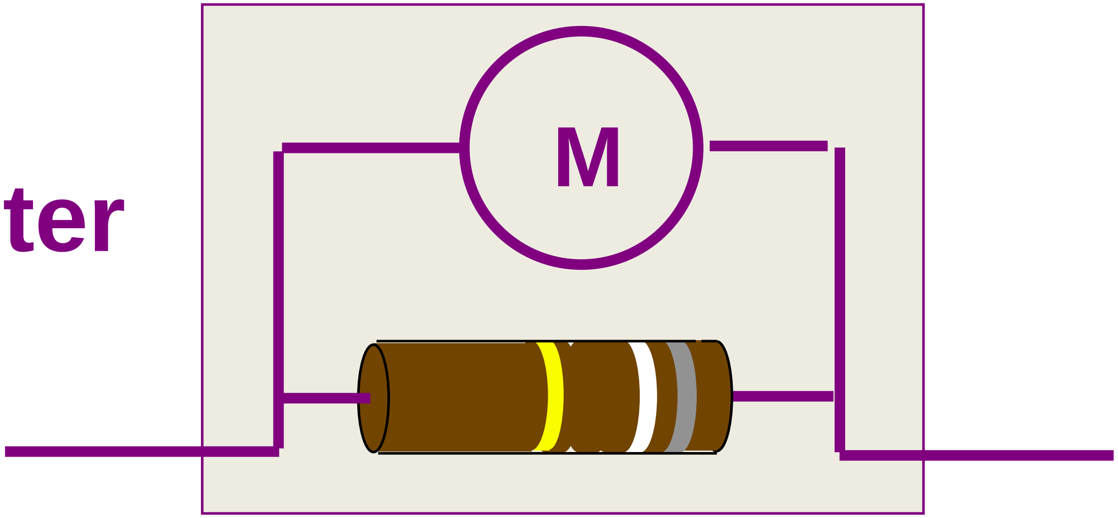
$$V_m = I_m \times R_m = (0.1\text{ mA}) \times (500\,\Omega) = 50\text{ mV}$$

- So, it can serve either as an ammeter of range 0 - 0.1 mA, or as a voltmeter of range 0 - 50 mV.
- We need to extend the range of the meter, by providing a suitable additional circuitry.

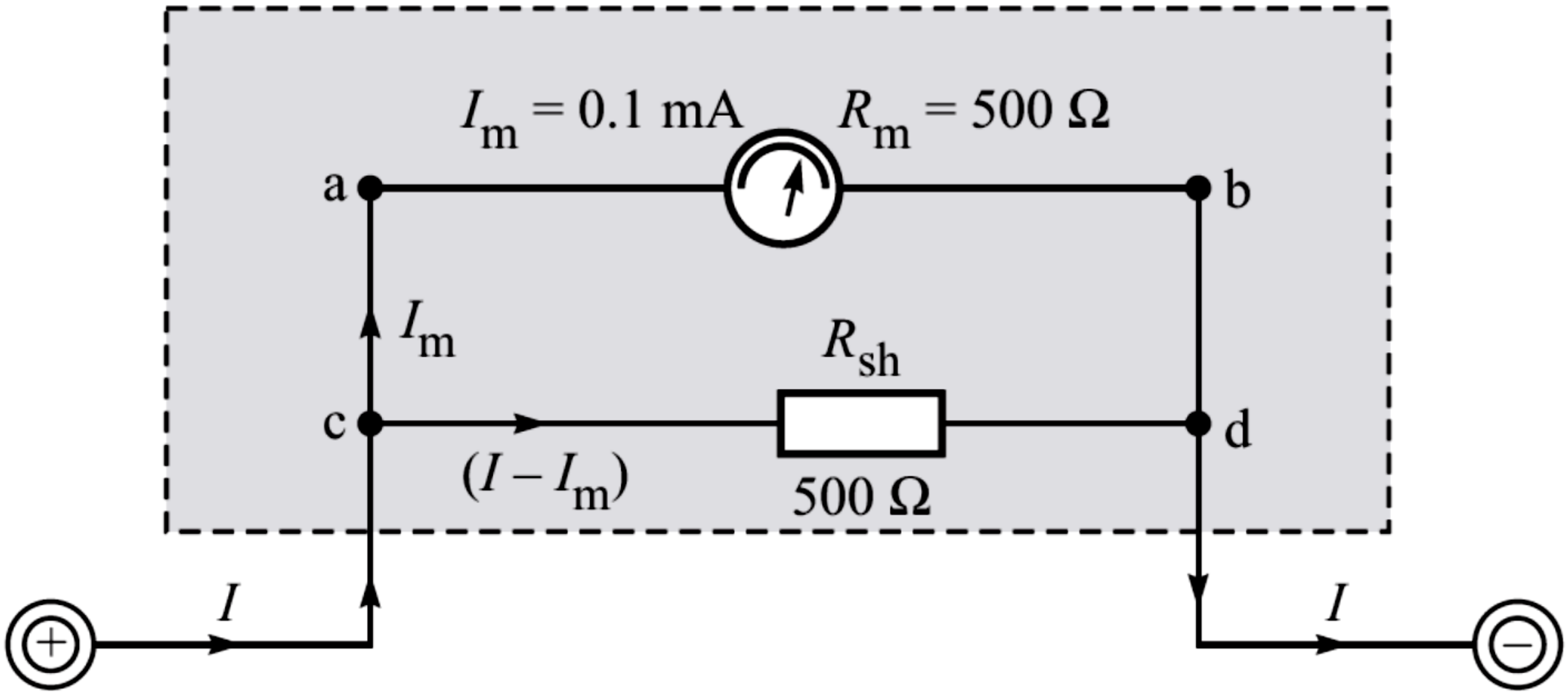
Ammeters

- Connected in series in circuits.
- Low impedance (resistance) so as not to affect the circuit.
- Constructed by adding a **low** resistance (or shunt or bypass resistor) in parallel with the meter.

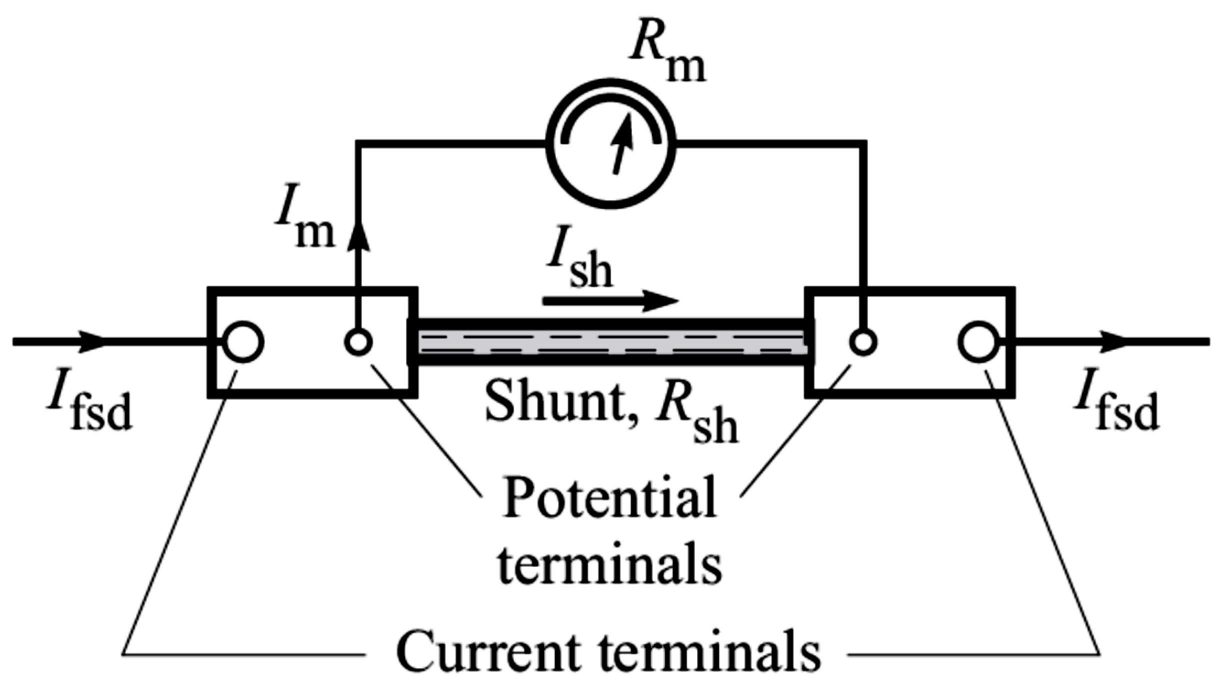
Ammeter



Ammeters



(*a*) Doubling the range.



(*b*) Range extended many times.

The ratio $I_{fsd}/I_m = N$ is called the ***range-multiplier.***

Since the voltage across the parallel elements must be the same,

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$$I_m R_m = (I_{fsd} - I_m) R_{sh}$$

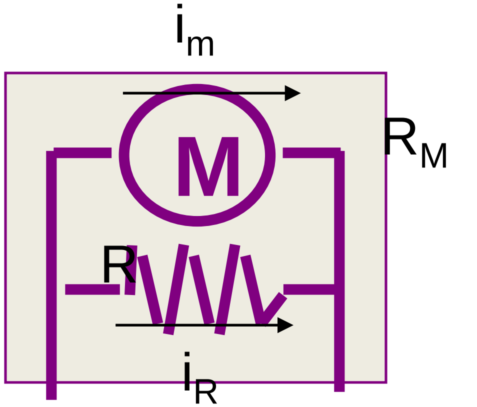
$$\therefore \quad R_{sh} = \frac{I_m R_m}{(I_{fsd} - I_m)}$$

or

$$R_{sh} = \frac{I_m R_m}{(I_{fsd} - I_m)} = \frac{R_m}{(I_{fsd} / I_m - 1)} = \frac{R_m}{(N - 1)}$$

Ammeter Example

An ammeter uses a meter with an internal resistance of 600 Ω and a rating of 1 mA fsd. How can it be used to measure 20 A fs?



Maximum current through meter is 0.001 A.

Therefore, the shunt resistor must take

19.999 A

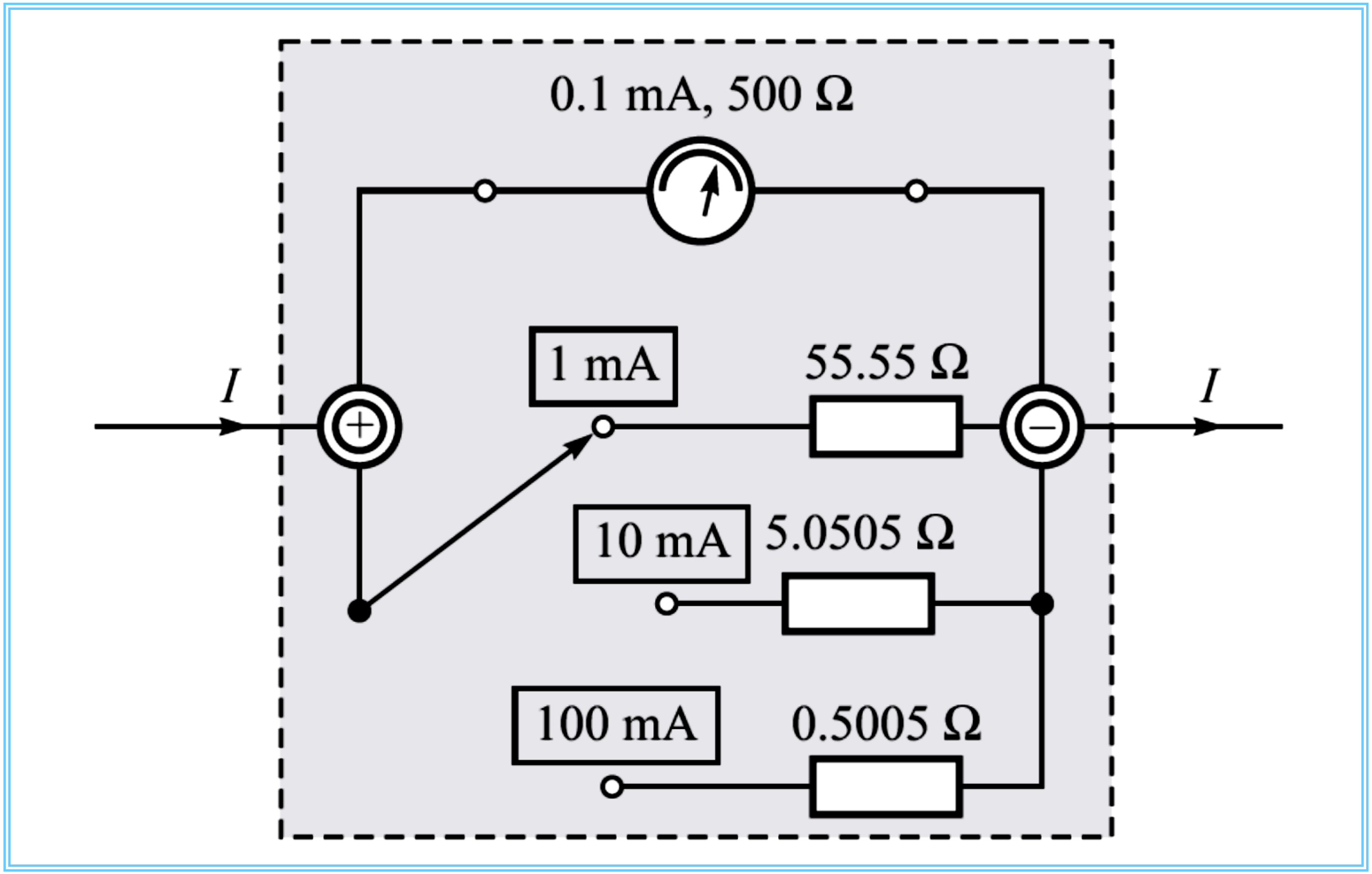
Because both *M* and *R* are in parallel, the same *V* must be dropped across both

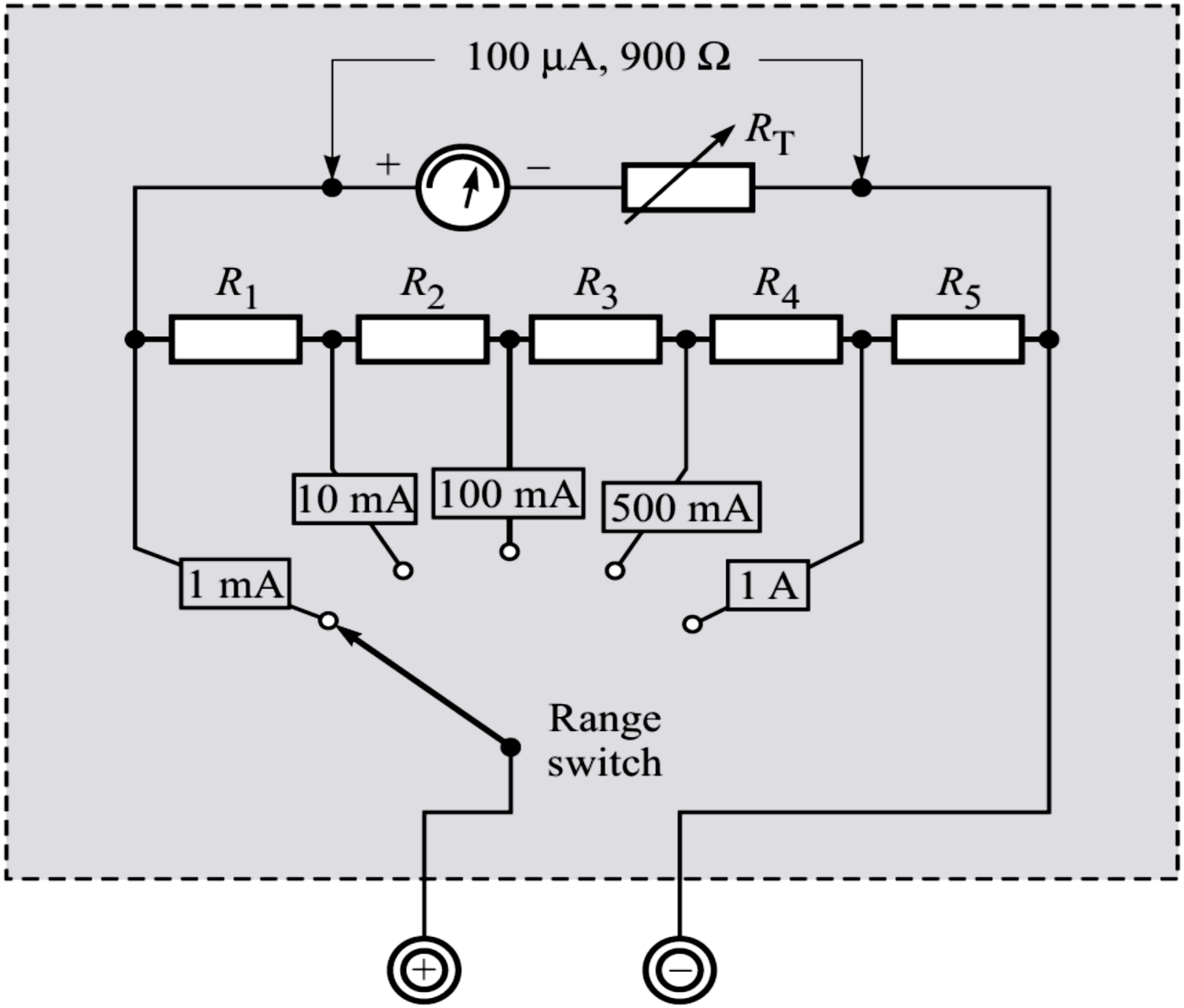
$$V = I_m R_m = 0.001 \text{ A} \times 600\ \Omega = 0.6 \text{ V}$$

Thus *R* must be V / I_R = 0.6 V / 19.99 A

= 0.03 Ω (in parallel.)

A multi-range ammeter.



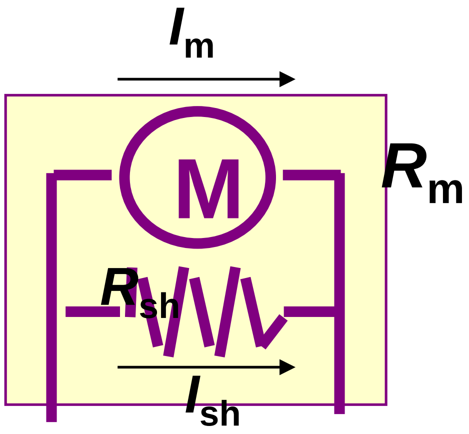


Universal shunt for multi-range milliammeter

Example 3

An ammeter uses a meter with an internal resistance of 600 Ω and a rating of 1 mA fsd. How can it be used to measure 20 A fs?

Solution : Maximum current through meter is $I_m = 0.001$ A.



Therefore, the shunt resistor must take $I_{sh} = 19.999$ A

Because both M and R_{sh} are in parallel, the same V must be dropped across both

$V = I_m R_m = 0.001 \text{ A} \times 600 \ \Omega = 0.6 \text{ V}$

Click

Thus, R_{sh} must be $V / I_R = 0.6 \text{ V} / 19.999 \text{ A}$

$= 0.0300015..\ \Omega$

Ammeter Sensitivity

- Measured in ohms/amp; should be as low Ω/A (small *V* drop) as possible.
- Sensitive ammeters need large indicator changes for small current.
- Example : (1) A 0.01 Ω/A meter with 5 A fsd,

  R_m = Ω/A x A = 0.01 x 5 = 0.05 Ω

  V_{max} across the Meter will be
  5 A x 0.05 Ω = 0.25 V for fs.

  (2) A 0.1 Ω/A meter with 5 A fsd,
  will drop 2.5 V (i.e., it is 10 times less sensitive), which may bias the results.

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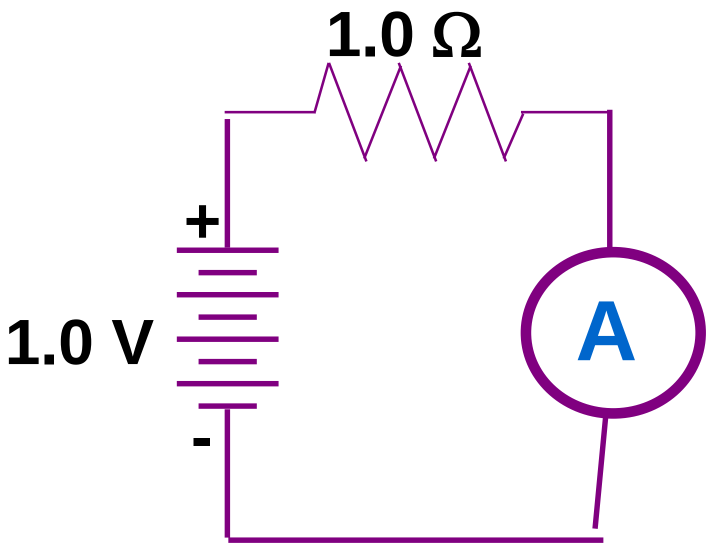
Ammeter loading

- **Significant where ammeters are used in circuits with components of resistance comparable to that of the meter.**



What is the *current* in the circuit ?

Is it **i = 1 V / 1 Ω = 1 A ?**

Next

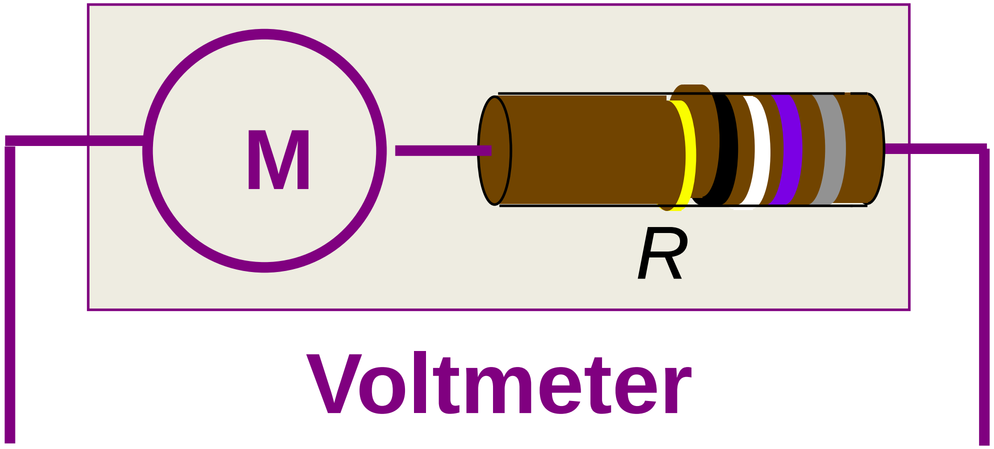
- **Now, suppose that the meter has a resistance of 1 Ω.**
- **How much will be current in the circuit ?**
- **Obviously, the current in the circuit will be halved !**

Click

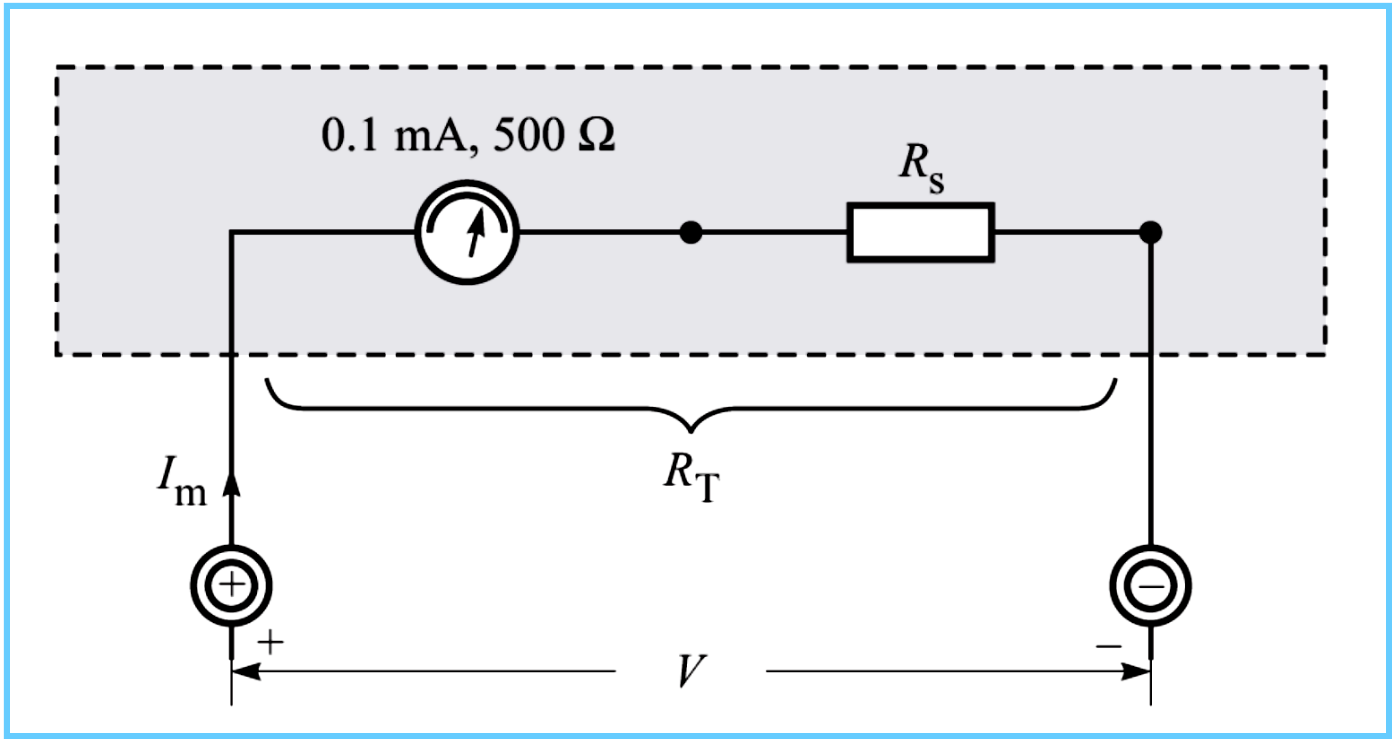
When working with low value resistors, be sure to use very low impedance ammeters.

Voltmeters

- Connections to circuits and components in parallel.
- High impedance (resistance) so as not to affect circuit.
- Constructed by adding a high resistance (*R*) in series with an electrically sensitive meter (M).



Extending the Range of Voltmeters



Suppose that we want to extend the voltage range of this basic meter to 0-10 V.

Next

The total resistance R_T must be such that

$$V = I_m R_T \qquad \text{or} \qquad R_T = \frac{V}{I_m} = \frac{10\ \text{V}}{0.1\ \text{mA}} = 100\ \text{k}\Omega$$

$$\therefore \quad R_s = R_T - R_m = 100\ \text{k}\Omega - 0.5\ \text{k}\Omega = \mathbf{99.5\ k\Omega}$$

Now, suppose that the range of a basic meter is to be extended to V_{fsd} volts. Then, we should have

$$V_{fsd} = I_m (R_m + R_s) \qquad \text{or} \qquad R_s = \frac{V_{fsd}}{I_m} - R_m$$

The series resistor R_s is also called a ***range-multiplier***, as it multiplies the voltage range.

Example 4

A meter is rated at 1 mA fsd and has an internal resistance of 2000 Ω. How can it be used to measure 100 V fsd ?

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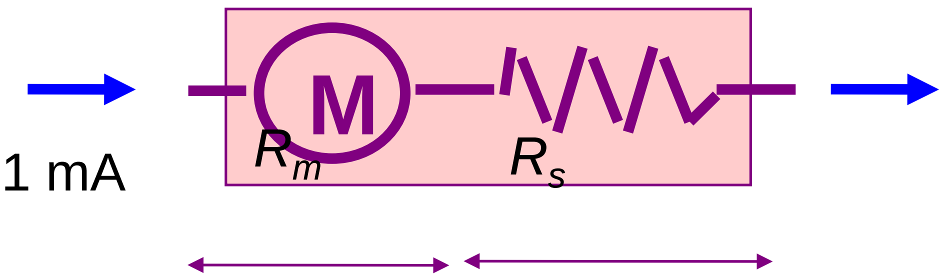
Solution :



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$V_m = 2$ V $\quad V_s = 98$ V $\quad R_T = R_s + R_m$

Click

Maximum voltage that can be put across galvanometer is

$$V_m = I\,R_m = 0.001 \text{ x } 2000 = 2.0 \text{ V}$$

Thus, $V_s = V_T - V_m = 100 \text{ V} - 2 \text{ V} = 98 \text{ V}$

This voltage must be dropped across R_s. Therefore,

$$R_s = V_s/I = 98 \text{ V} / 0.001 \text{ A} = \mathbf{98\ k\Omega}$$

Next

Voltage Scaling or Multiplying Factor

It is defined as the number of times the voltage range is increased. Thus,

$$n = \frac{V_{\mathrm{fsd}}}{V_{\mathrm{m}}} = \frac{V_{\mathrm{fsd}}}{I_{\mathrm{m}} R_{\mathrm{m}}}$$

Example 5

- A 50-μA meter movement with an internal resistance of 1 kΩ is to be used as a dc voltmeter of range 50 V. Calculate

  (*a*) the multiplier resistance needed, and

  (*b*) the voltage multiplying factor.

Solution : Here, $I_m = 50\ \mu A$, and $R_m = 1\ k\Omega$.

Click

(*a*) The series resistance needed is given as

$$R_s = \frac{V_{fsd}}{I_m} - R_m = \frac{50\ V}{50\ \mu A} - 1000 = \mathbf{999\ k\Omega}$$

Click

(*b*) $$n = \frac{V_{fsd}}{V_m} = \frac{V_{fsd}}{I_m R_m} = \frac{50}{50 \times 10^{-6} \times 1 \times 10^{3}} = \mathbf{1000}$$

Next

Meter Sensitivity
(Ohms-per-Volt Rating)

- Measured in Ω/V.
- Higher the sensitivity, more accurate is the measurement.
- If current sensitivity (*CS*) of a meter is known, its Ω/V rating can easily be determined.
- Consider a basic meter with *CS* of 100 μA.
- If used as a voltmeter of range 1 V,

$$R_T = 1\text{ V} / 100\ \mu\text{A} = 10\text{ k}\Omega$$

- Thus, the meter sensitivity is simply 10 kΩ/V.

In general,

$$\text{ohms-per-volt rating} = \frac{1}{\text{current sensitivity}}$$

- Note that if the same meter was used for 2 V range, the required R_T would be 20 kΩ.
- Its ohms/volt rating is 20 kΩ / 2 V = 10 kΩ/V.
- The *ohms-per-volt rating does not depend on the range of the voltmeter*.

- Also, note that the range of a voltmeter (or an ammeter) is changed by switching in another resistor in the circuit.
- Therefore, for a given range the internal resistance of the voltmeter remains the same irrespective of the deflection of the pointer.

Voltmeter Loading

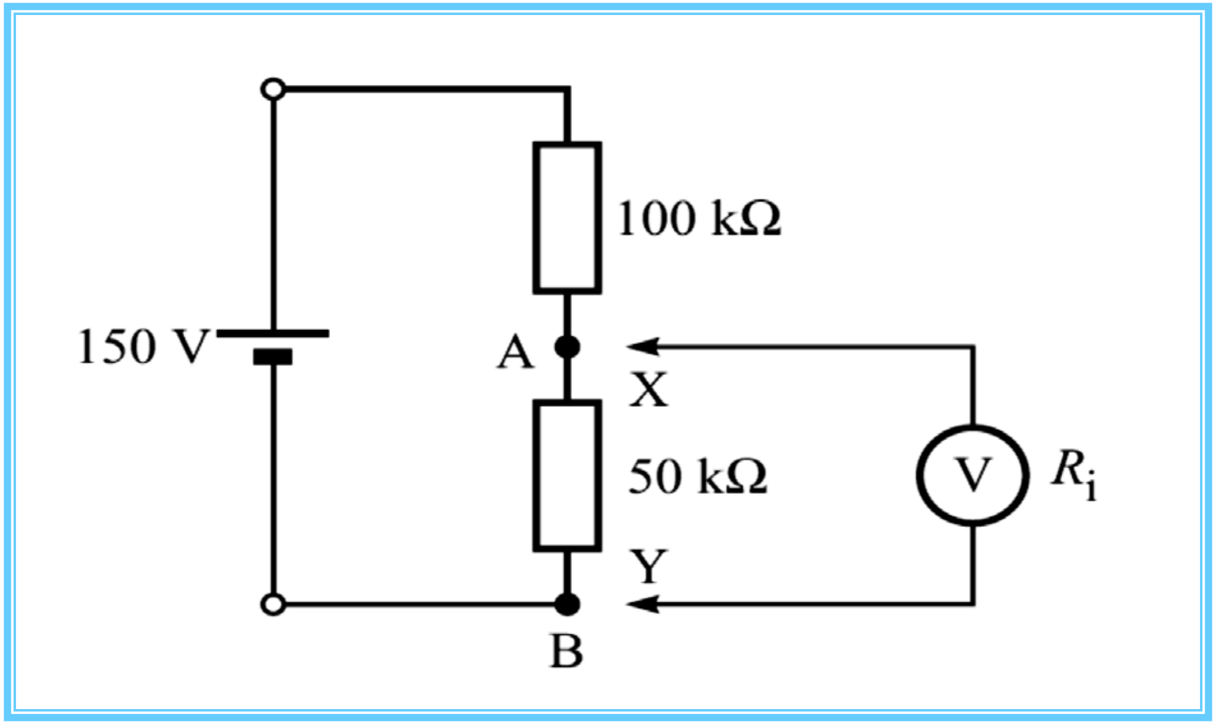
- A voltmeter, when connected, acts as a shunt for that portion of the circuit.
- This reduces the resistance of that portion.
- Hence, the meter gives a lower reading.
- This effect is called the ***loading effect*** of the meter.

Example 6

- It is desired to measure the voltage across the 50-kΩ resistor in the circuit.
- Two voltmeters are available for this measurement. Voltmeter-A has a sensitivity of 1000 Ω/V and voltmeter-B has a sensitivity of 20 000 Ω/V.
- Both meters are used on their 50-V range.
- Calculate

  (*a*) the reading of each meter, and

  (*b*) the error in each reading, expressed as a percentage of the true value.



Solution : The *true* value of the voltage across A-B,

$$V_t = (150\ \text{V}) \times \frac{50\ \text{k}\Omega}{100\ \text{k}\Omega + 50\ \text{k}\Omega} = 50\ \text{V}$$

Next

(a) Voltmeter-A

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The internal resistance,

$$R_{i1} = \text{Sensitivity} \times \text{Range} = (1000\,\Omega/\text{V}) \times (50\,\text{V}) = 50\,\text{k}\Omega$$

When connected, the equivalent parallel resistance across A-B is 50 kΩ || 50 kΩ = 25 kΩ. Hence, reading of voltmeter,

Click

$$V_1 = (150\ \text{V}) \times \frac{25\ \text{k}\Omega}{100\ \text{k}\Omega + 25\ \text{k}\Omega} = \mathbf{30\ V}$$

Voltmeter-B

$$R_{i2} = \text{Sensitivity} \times \text{Range} = (20\,000\,\Omega/\text{V}) \times (50\,\text{V}) = 1000\,\text{k}\Omega$$

$$R_{\text{A-B Eq}} = (50\,\text{k}\Omega) \,||\, (1000\,\text{k}\Omega) = 47.6\ \text{k}\Omega$$

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$$\therefore \quad V_2 = (150\ \text{V}) \times \frac{47.6\ \text{k}\Omega}{100\ \text{k}\Omega + 47.6\ \text{k}\Omega} = \mathbf{48.36\ V}$$

(*b*) **Error** in reading of Voltmeter-A,

$$\%\,\text{Error} = \frac{V_t - V_1}{V_t} \times 100\ \% = \frac{50 - 30}{50} \times 100\ \% = \mathbf{40\ \%}$$

Error in reading of Voltmeter-B,

Click

$$\%\,\text{Error} = \frac{V_t - V_2}{V_t} \times 100\ \% = \frac{50 - 48.36}{50} \times 100\ \% = \mathbf{3.28\ \%}$$

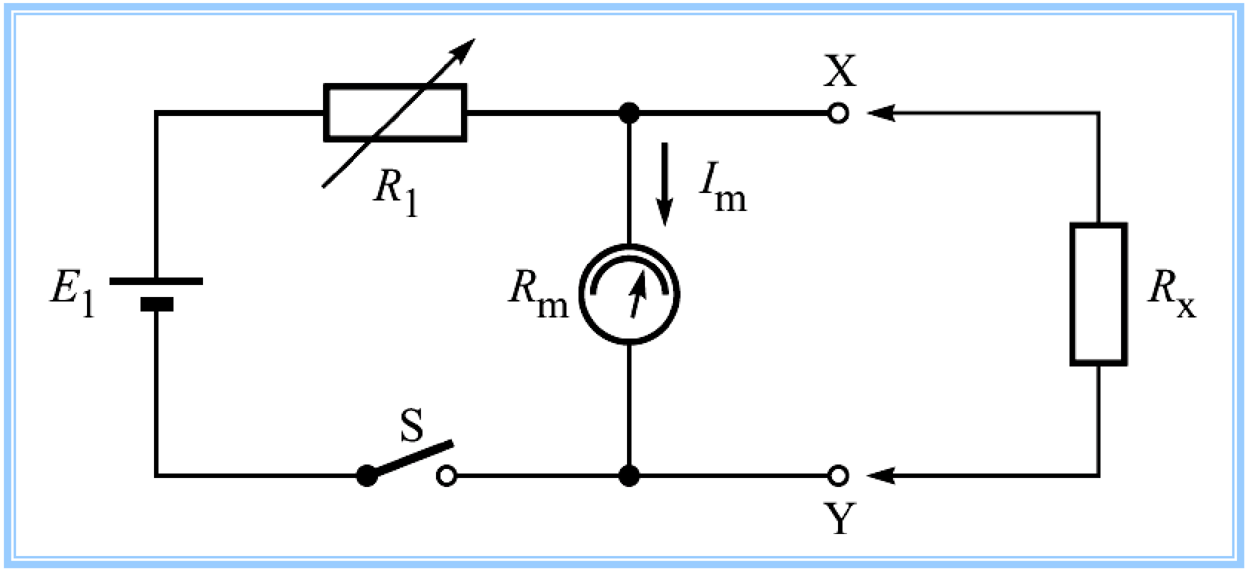
Note the voltmeter with higher sensitivity gives more accurate results, since it produces less loading effect on the circuit.

RESISTANCE MEASUREMENT

- The instrument is called ohmmeter.
- Three types :

1. **Shunt-Type Ohmmeter :** For *low value* resistors.
2. **Series-Type Ohmmeter :** For *medium-value* resistors.
3. **Meggar-Type Ohmmeter :** For *high-value* resistances, such as the insulation of a cable.

Shunt-Type Ohmmeter

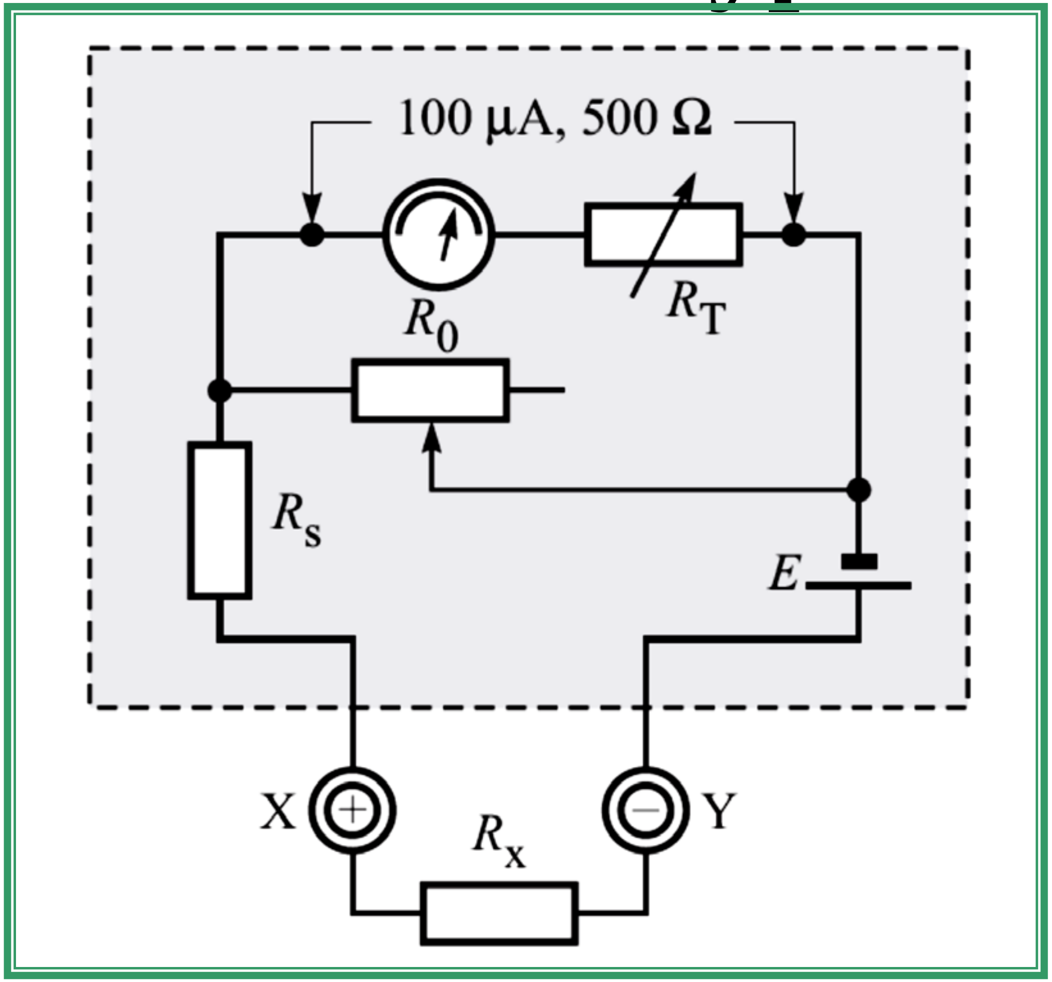


When $R_x = 0$, no current in meter.

When $R_x = \infty$, entire current flows through the meter.

Proper selection of R_1 gives full-scale deflection on open circuit.

Series-Type Ohmmeter



R_T is pre-set resistor.

R_0 is zero-adjust resistor. It compensate for the decrease in battery voltage E with ageing.

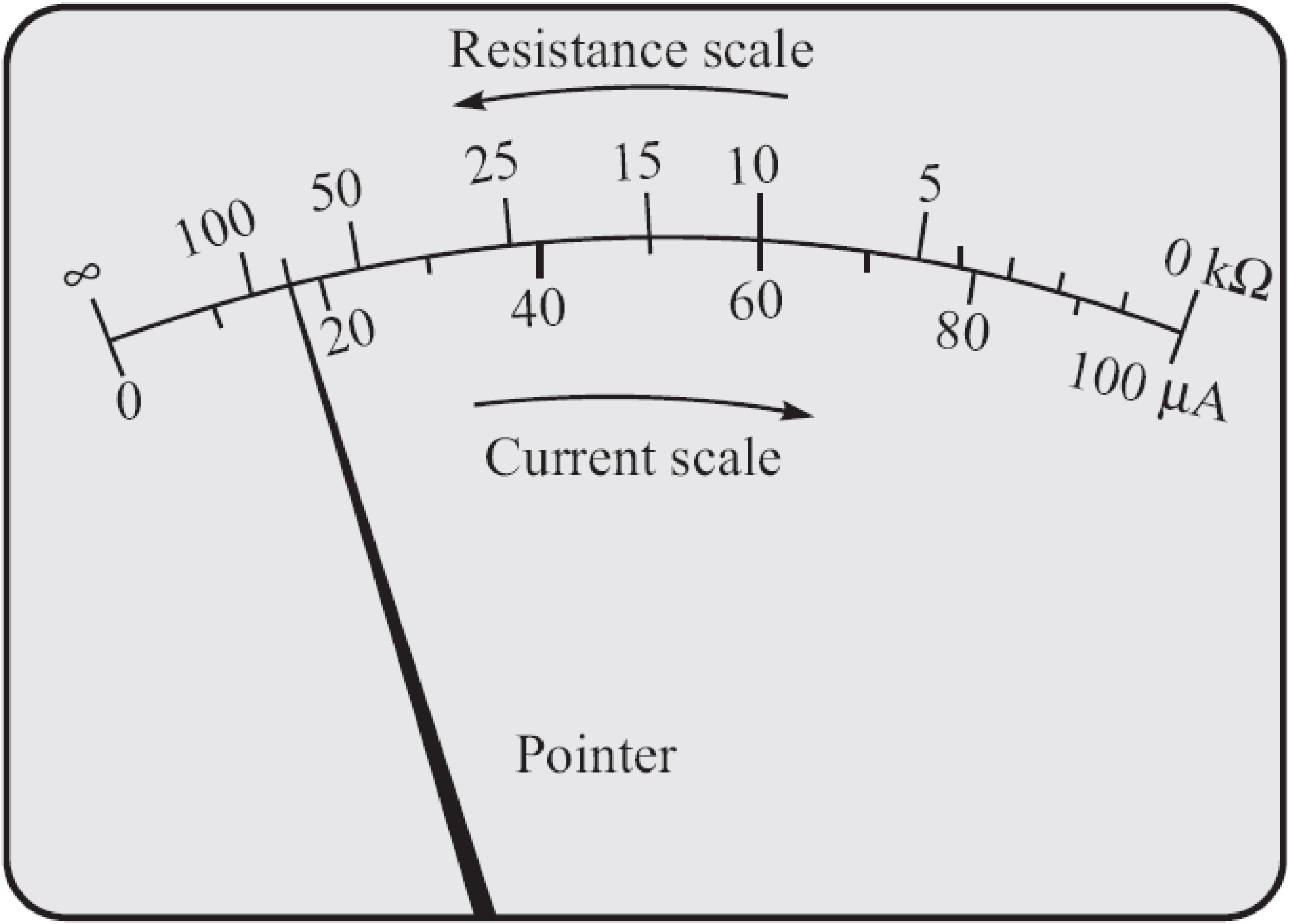
R_s limits the current to fsd.

Next

- When X-Y shorted, the current is maximum (fsd).
- When X-Y open, the current is zero.
- Thus the scale is inverted.
- Different ranges are obtained by switching in different R_s

Caution

- Never connect to an energized circuit.
- Make sure that there is no parallel branch across the resistance you are measuring.



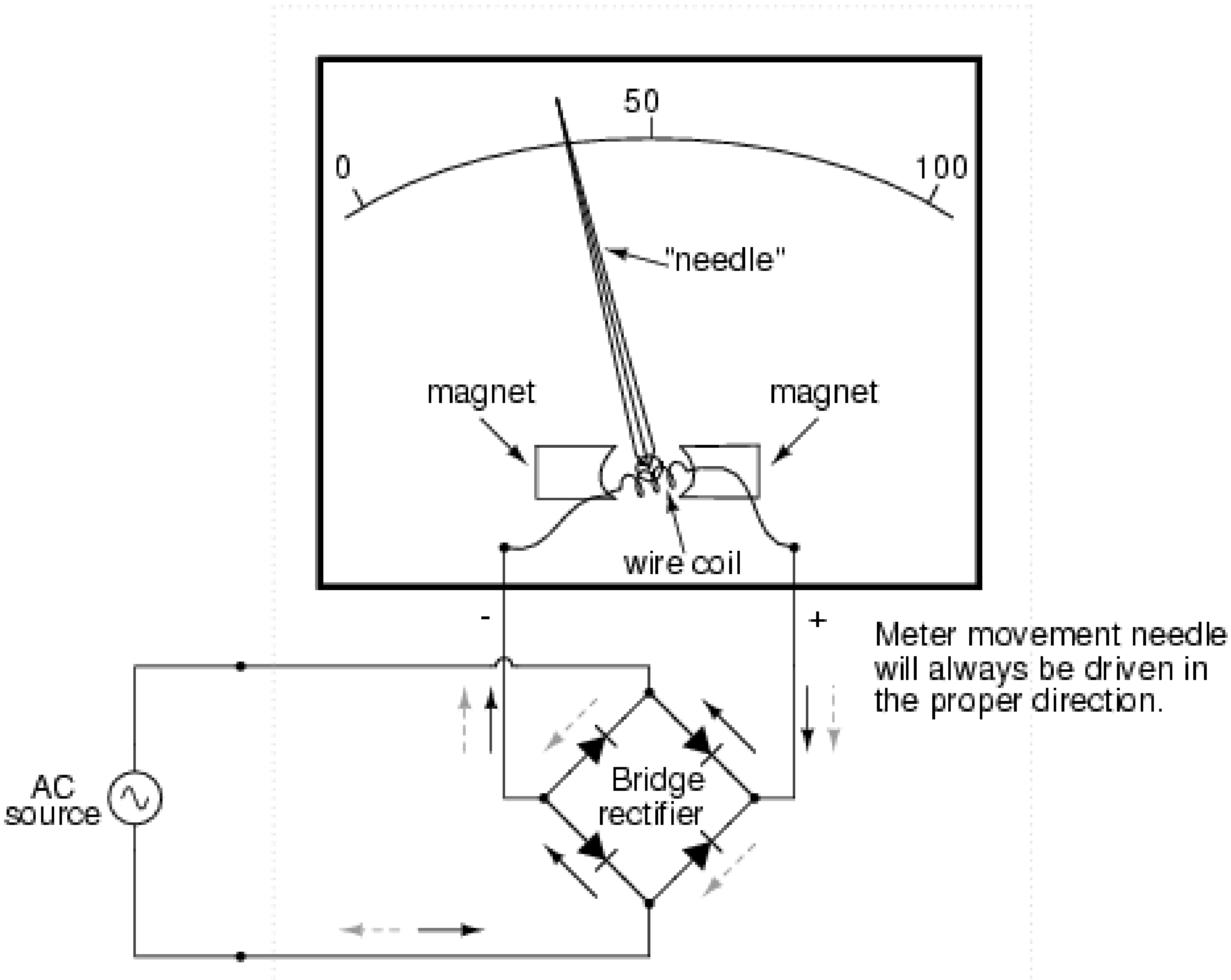
The current and resistance scales.

Wheatstone Bridge

- A clever method to accurately measure a resistance
- R_1 and R_3 are known
- R_2 is a variable resistor

- R_x is an unknown resistor
- R_2 is varied until no current flows through the galvanometer G
- Let I_1, I_2, I_3 and I_x be the currents through the four resistors.
- $I_1 = I_2$ and $I_3 = I_x$
- No current through G: no voltage difference across it
- $I_1R_1 = I_3R_3$ and $I_2R_2 = I_xR_x$ → $R_x = R_3R_2/R_1$

"Rectified" AC meter movement



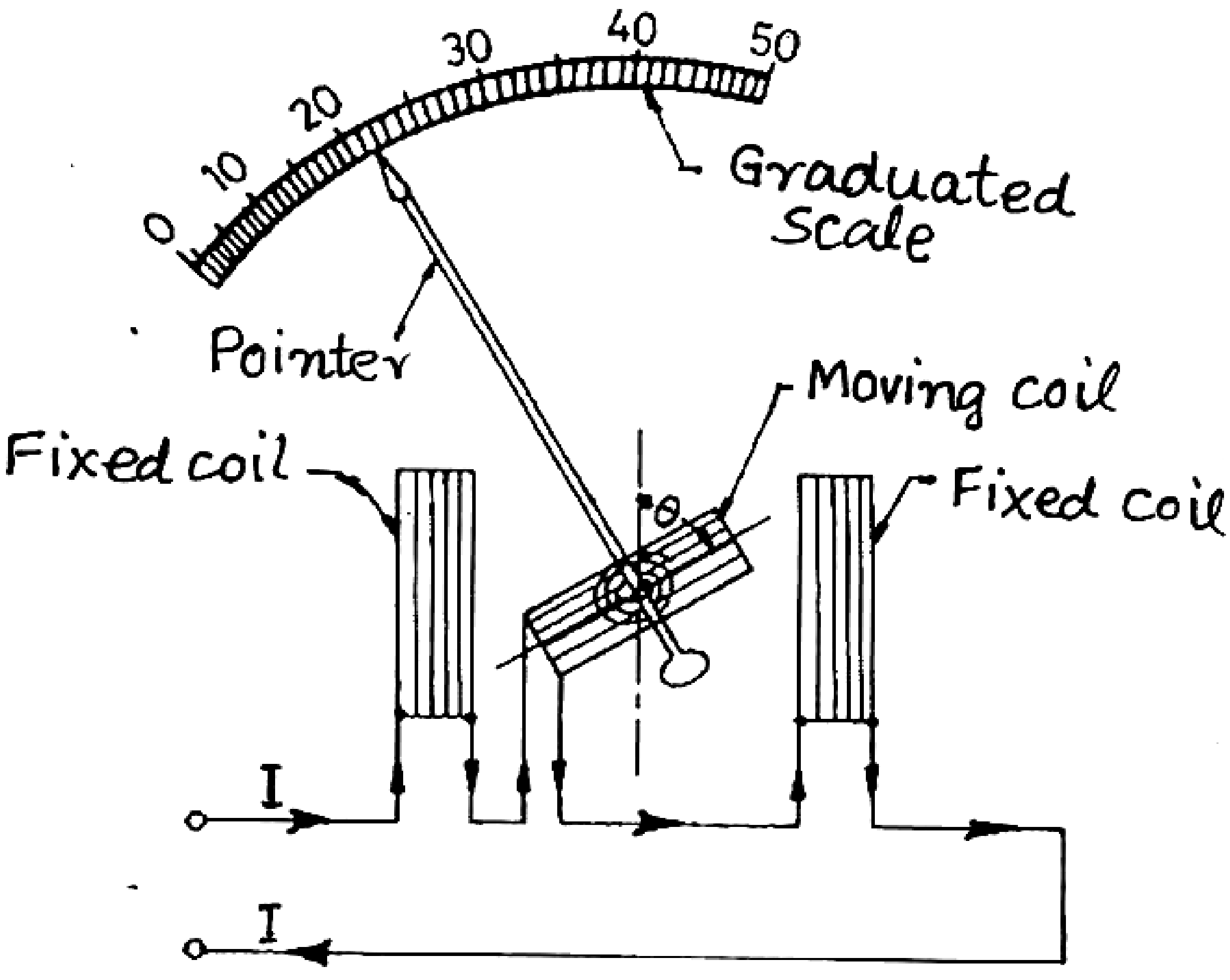
DYNAMOMETER TYPE INSTRUMENTS
For both ac & dc measurements

- These instruments are similar to the permanent magnet type instruments, except that the permanent magnet is replaced by a fixed coil.

- The coil is divided into two halves, connected in series with the moving coil.

- The two halves of the coil are placed close together and parallel to each other to provide uniform field within the range of the movement of moving coil.

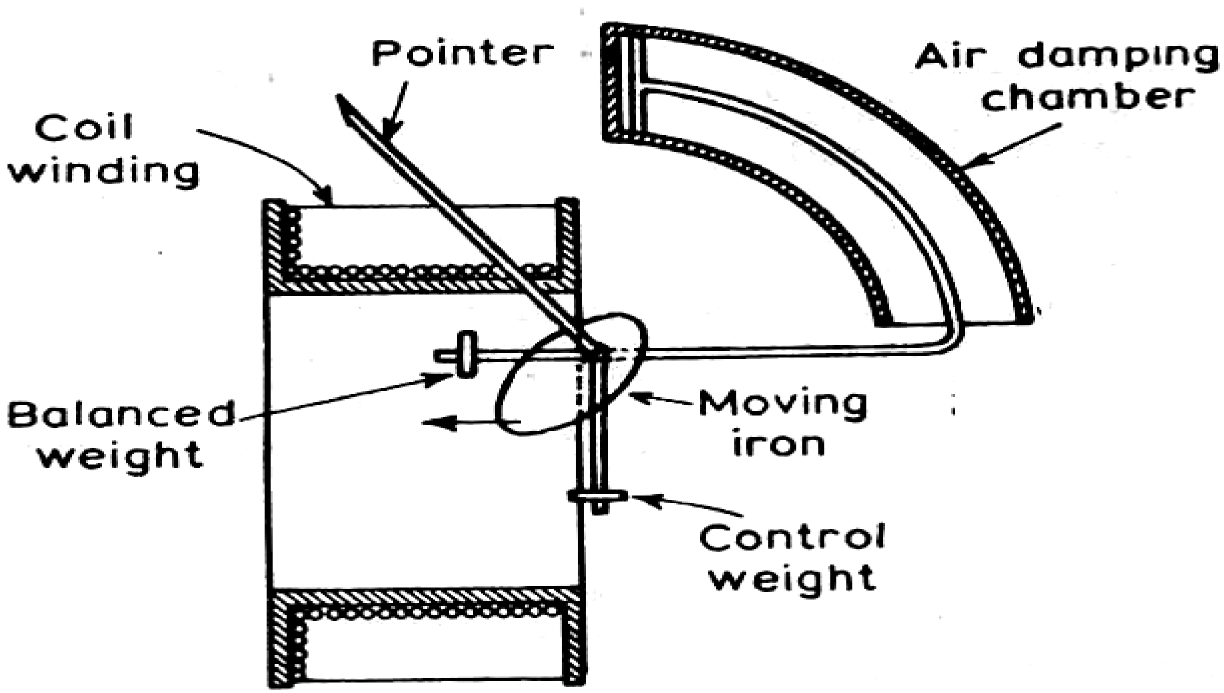
DYNAMOMETER TYPE INSTRUMENTS



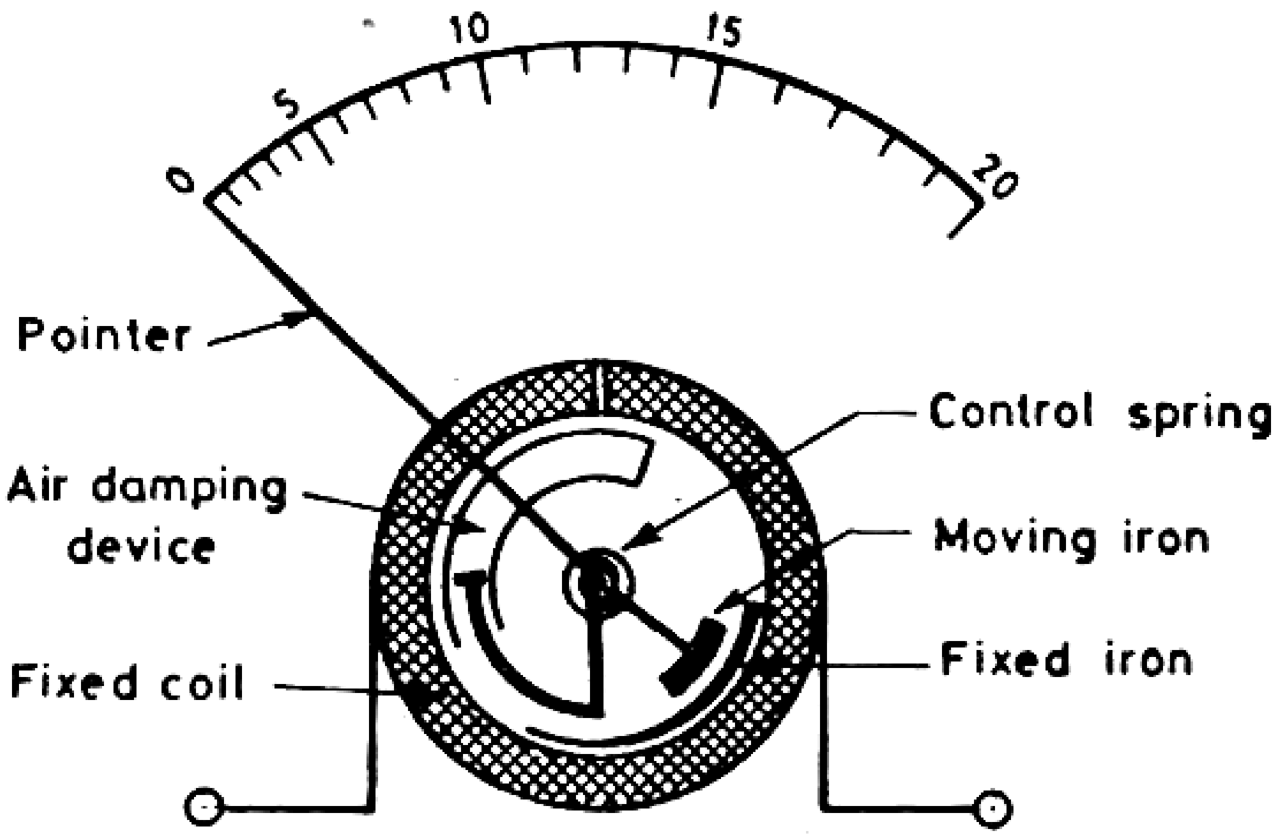
MOVING-IRON INSTRUMENTS

For both ac & dc measurements

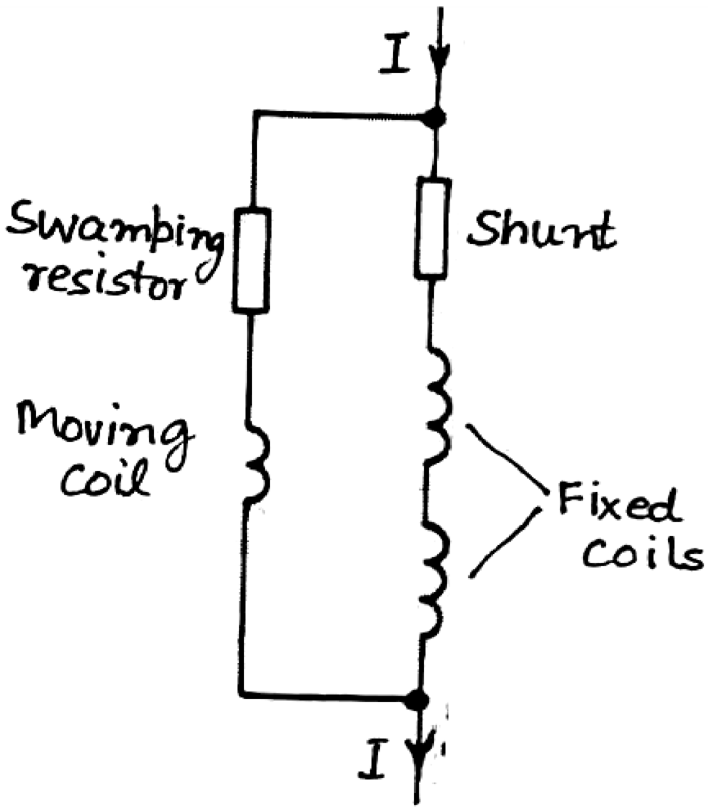
- **Attraction (or Single-iron) Type Moving-Iron Instrument**

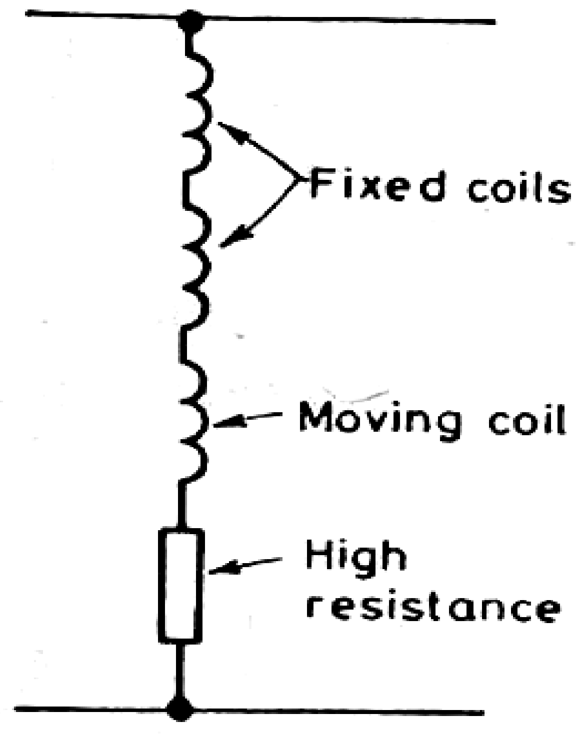


Repulsion (or Double-Iron) Type Moving-Iron Instrument

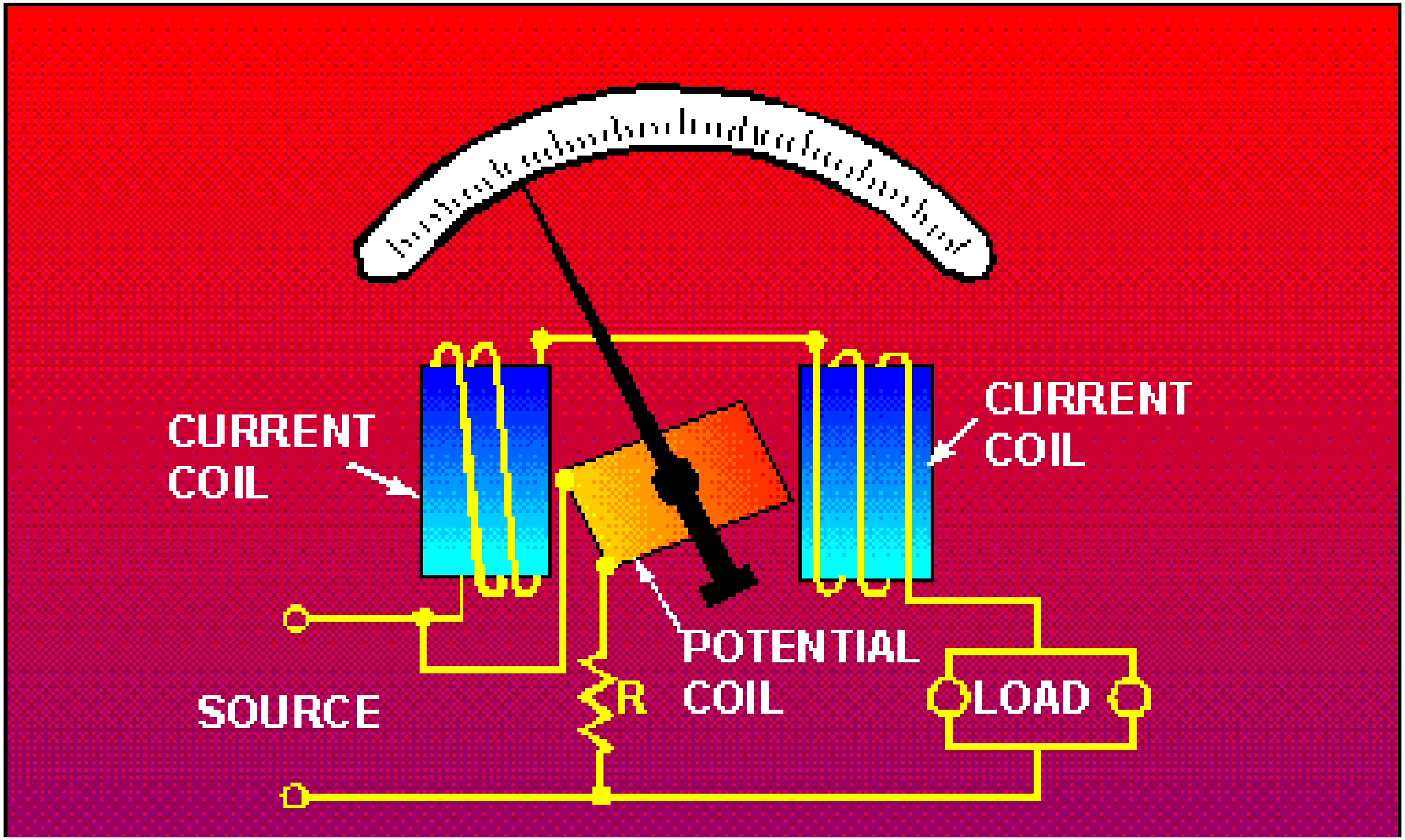


DYNAMOMETER TYPE-Ammeter & Voltmeter

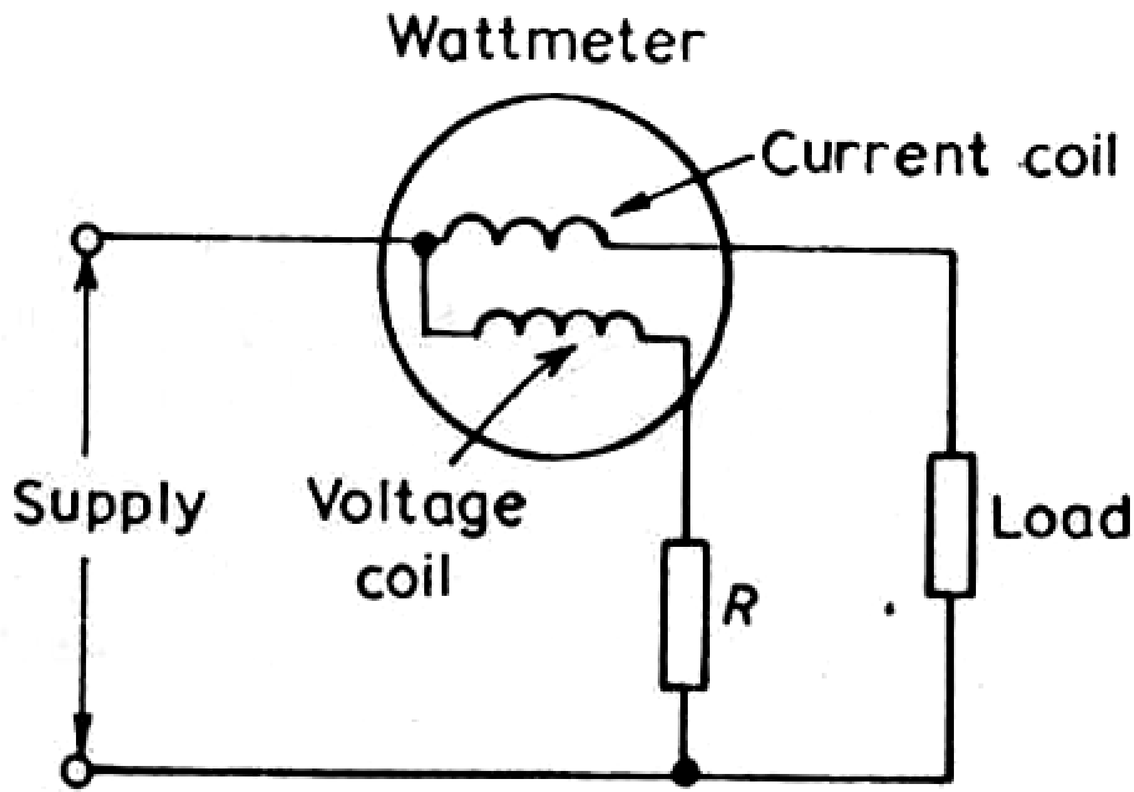




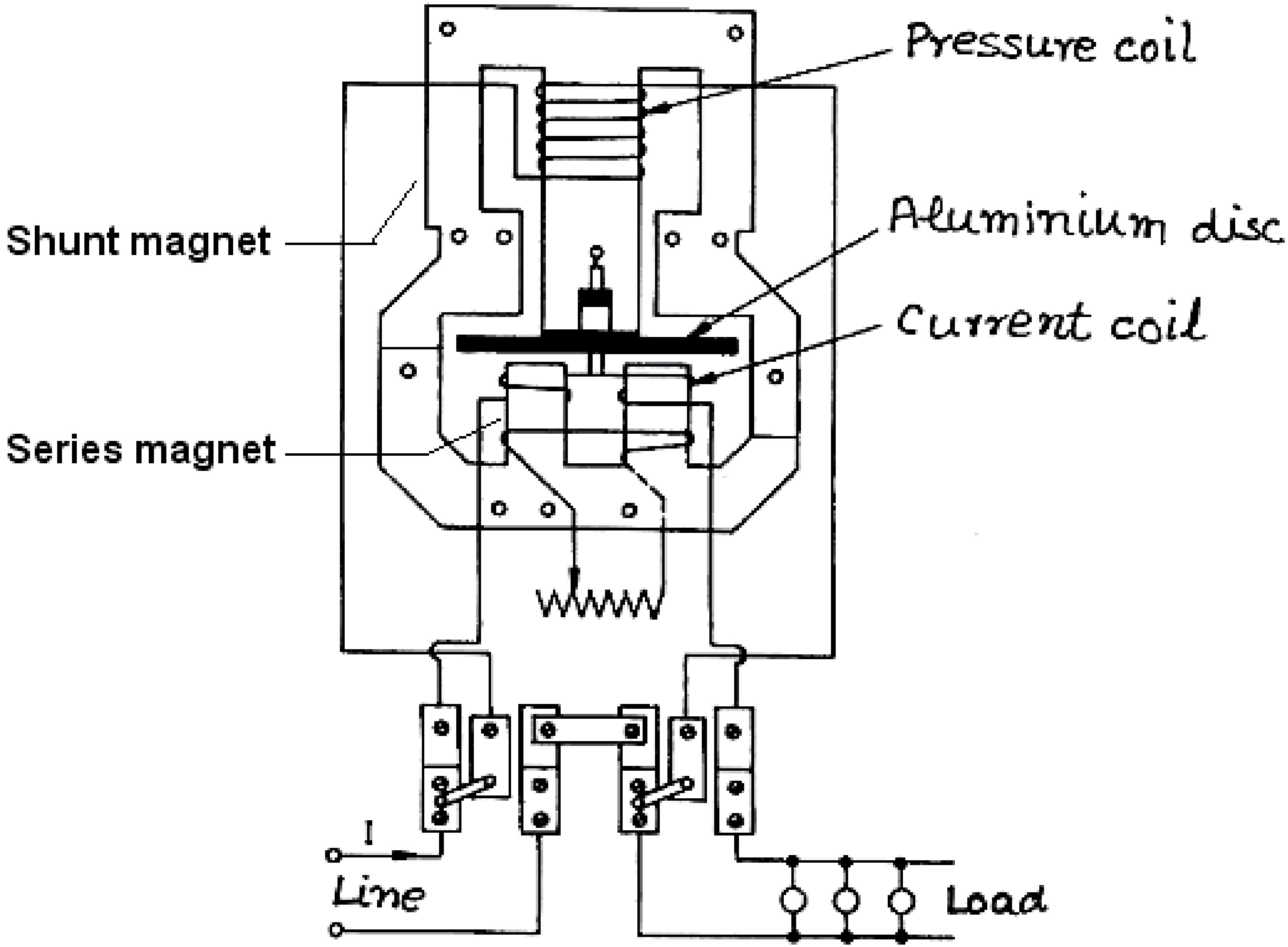
Dynamometer Type WATTMETER



Dynamometer Type Wattmeter



Single-Phase Induction Type Wattmeter/Energy Meter



Working of induction type wattmeter / energy meter

- **Driving system –** consists two electromagnets i.e. shunt & series magnets. Core is made up of silicon steel. PC is connected across the supply mains. Current coil is U shaped and connected across one of the line in series with load.

- **Moving system –** consists rotating aluminum disc mounted on vertical spindle and supported on sapphire cup. Magnetic field produced by shunt electromagnet is pulsating in character and cuts through the rotating disc and induces eddy current there in, but normally does not itself produce any driving force. The reaction b/w these two magnetic field and eddy currents set up a driving toque in the disc.

Contin…..

- Breaking system
- Registering system