DC ANALOG MEASURING INSTRUMENTS

EE 306 – SS2016

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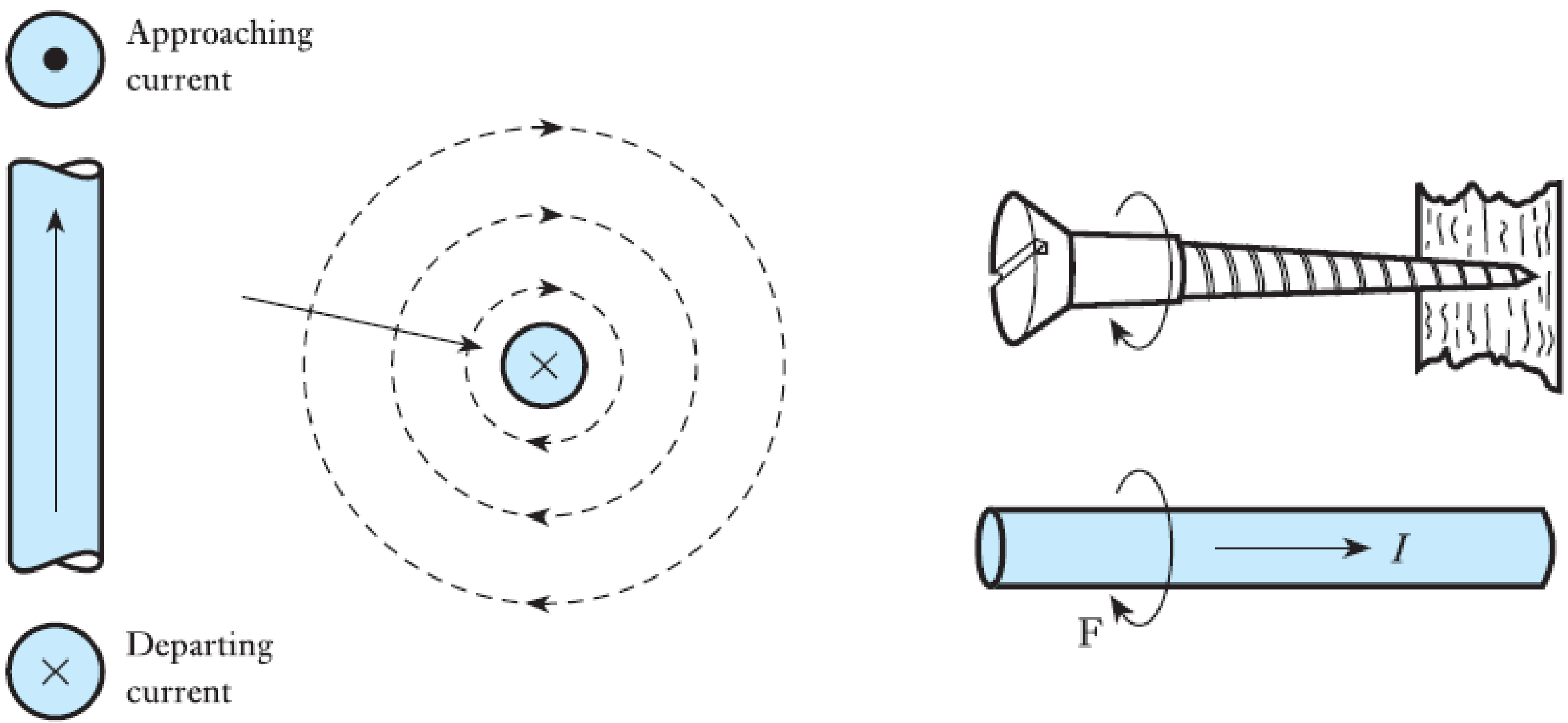
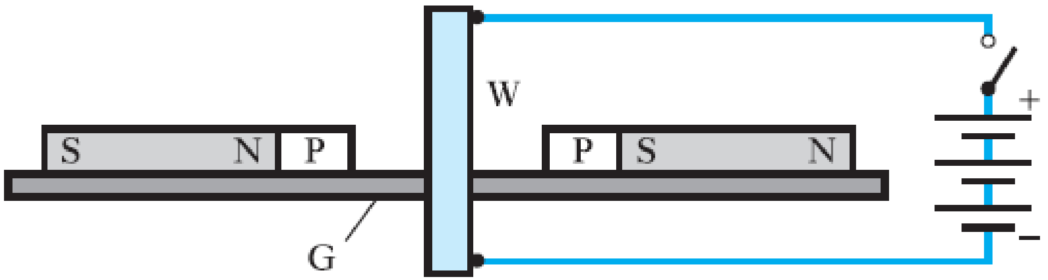
Basics: Magnetic Field Due to Electric Current

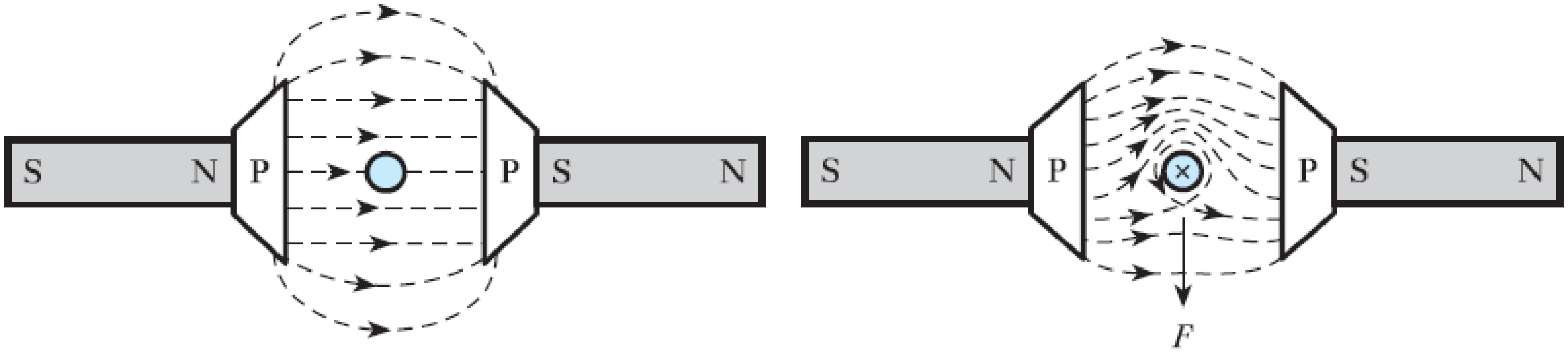
- When conductor carries electric current, magnetic field is produced around that conductor
  - Right-Hand Screw rule



Basics: Force on Current-Carrying Conductor

- When a current-carrying conductor is placed in a magnetic field, the field from the current distorts the original field
  - Distorted flux acts like stretched elastic cords: lines of flux try to return to the shortest straight line paths thereby exerting force *F* urging the conductor out of the way





Basics: Force Determination

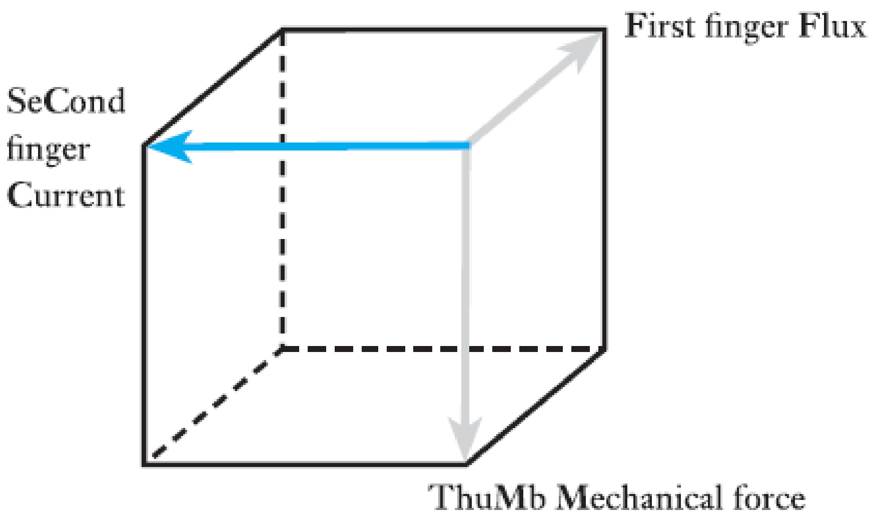
- Assume conductor carrying current at right angle to magnetic field
- Direction: Left-Hand Rule
- Magnitude: $F\,[\text{newtons}] \propto \text{flux density} \times l\,[\text{metres}] \times I\,[\text{amperes}]$

$$F = BlI$$

B: magnetic flux density in Tesla (T)

l: Length of conductor (m)

I: Current (A)



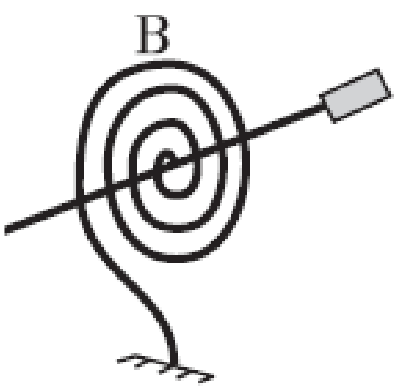
A conductor carries a current of 800 A at right angles to a magnetic field having a density of 0.5 T. Calculate the force on the conductor in newtons per metre length.

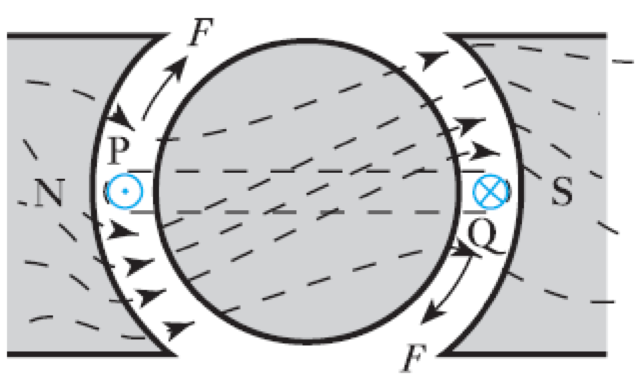
Analog Measurement Instruments

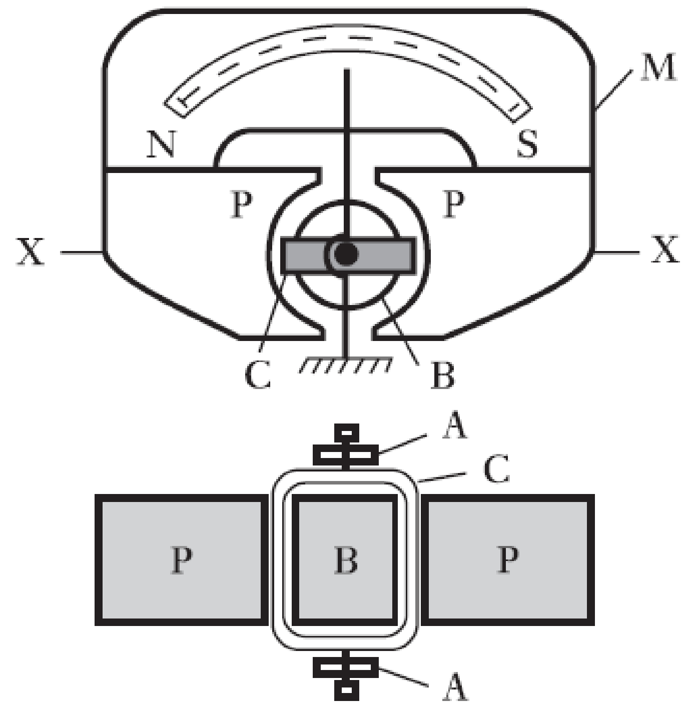
- Indicating analogue instruments possess three essential features:
  1. A deflecting device whereby a mechanical force is produced by the electric current, voltage or power.
  2. A controlling device whereby the value of the deflection is dependent upon the magnitude of the quantity being measured.
  3. A damping device to prevent oscillation of the moving system and enable the latter to reach its final position quickly.

Moving-Coil (MC) Instrument

- MC Instrument is an analog electromechanical transducer that produces a rotary deflection of some type of pointer in response to electric current flowing through its coil
  - Instrument for detecting and measuring electric current (Ammeter)
  - Deflecting: electromechanical force
  - Controlling: spiral spring
  - Damping: eddy current



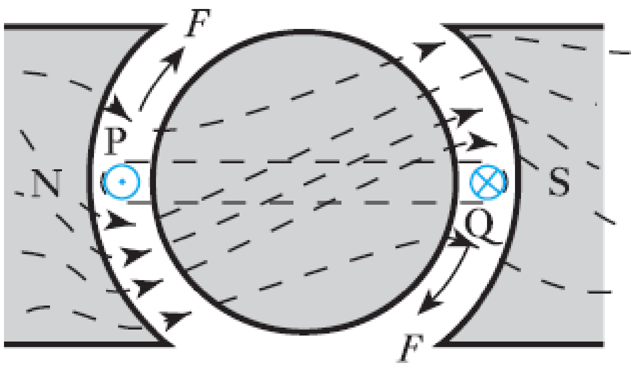




Moving-Coil Instrument Analysis

- Deflecting Force: $F = B\,l\,I$
- For N turns and coil width w (where coil area $A = l\,w$), resultant deflecting torque = N F w , such that:

$$T_{EM} = N\,B\,I\,A$$

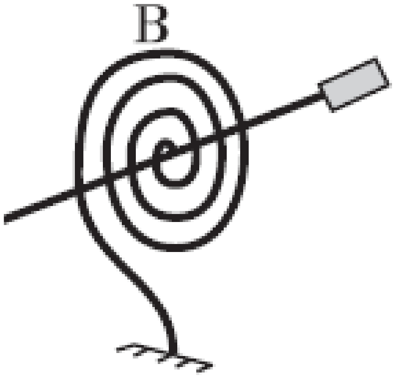


- Spring torque is given as:

$$T_{SP} = k\,\theta$$

  - k = spring constant

- At equilibrium, torques balance: $T_{EM} = T_{SP}$



$$\theta = (N\,B\,A / k)\;I$$

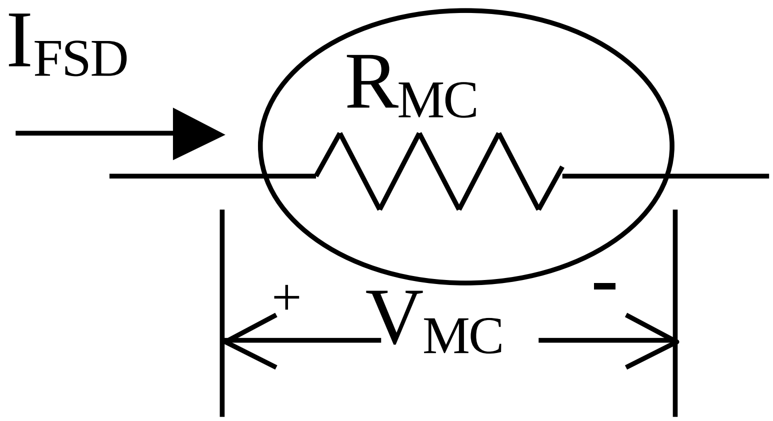
Example

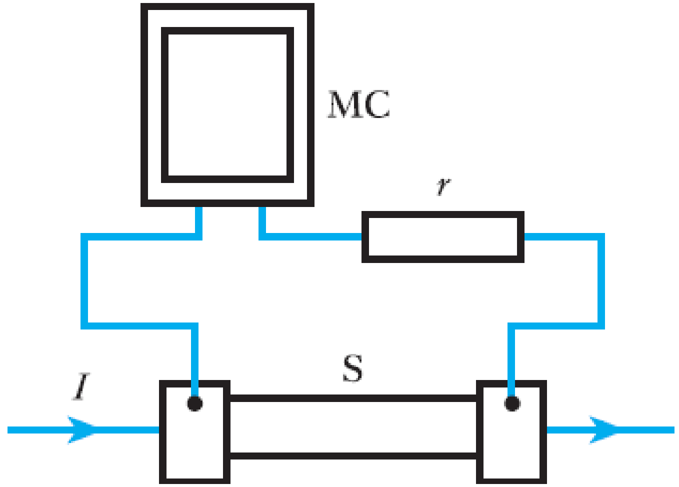
A moving coil has following parameters: Area A= 2 cm2, B= 0.2 Tesla, coil resistance= 50 Ω, current I = 1 mA. Calculate:

a. Power dissipated by coil
b. The electromagnetic torque established.
c. Assume the electromagnetic torque is compensated by a spring torque and the spring constant k= 3.6x10-8 N.m/degrees. Find the angle of deflection of the coil at equilibrium

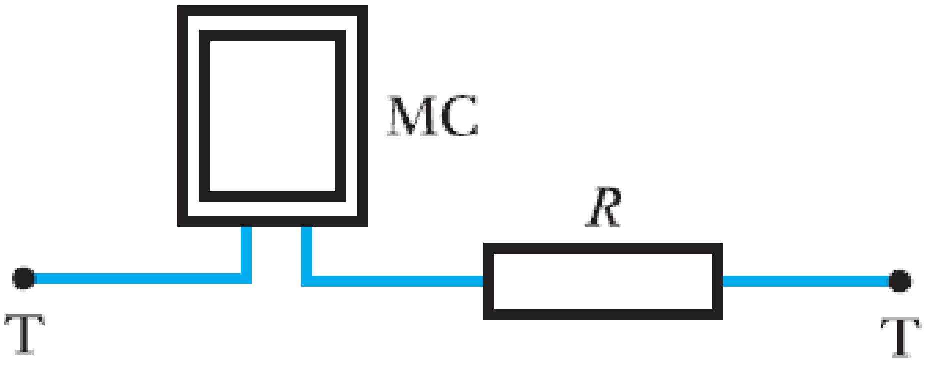
MC in Analog Electrical Measuring Instruments

- MC model:
  - Coil resistance
  - Current for full-scale deflection (FSD)
  - Voltage (derived from the above two)



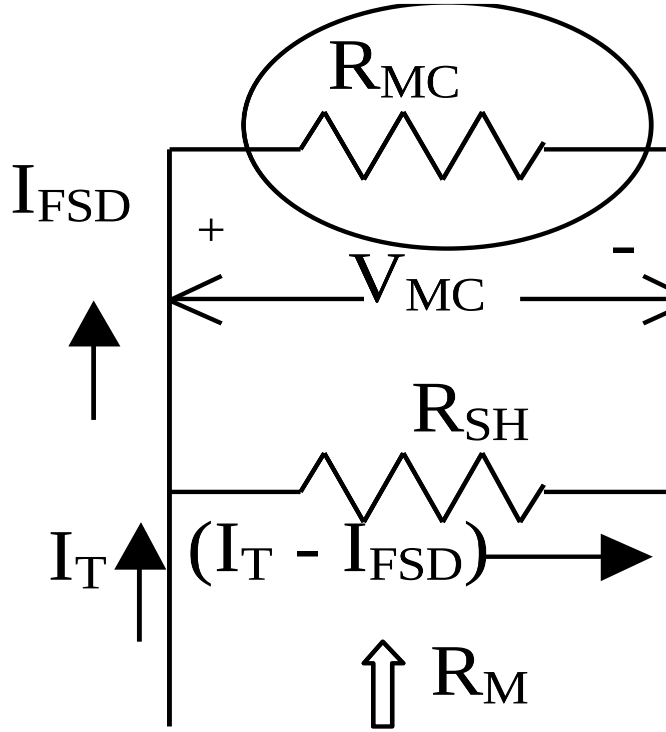


Ammeter Configuration



Voltmeter Configuration

Basic DC Ammeter

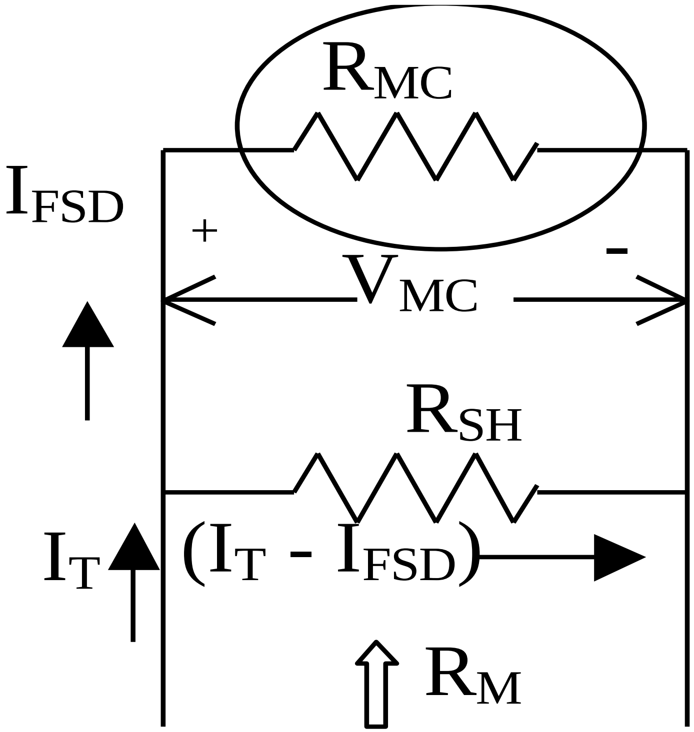


$$V_{MC} = I_{FSD} R_{MC} = \left(I_T - I_{FSD}\right) R_{SH}$$

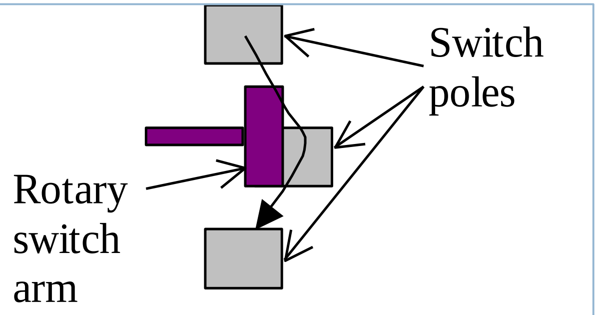
Example

Calculate the multiplying power of a shunt of 200 Ω resistance used with a galvanometer of 1000 Ω resistance as shown.

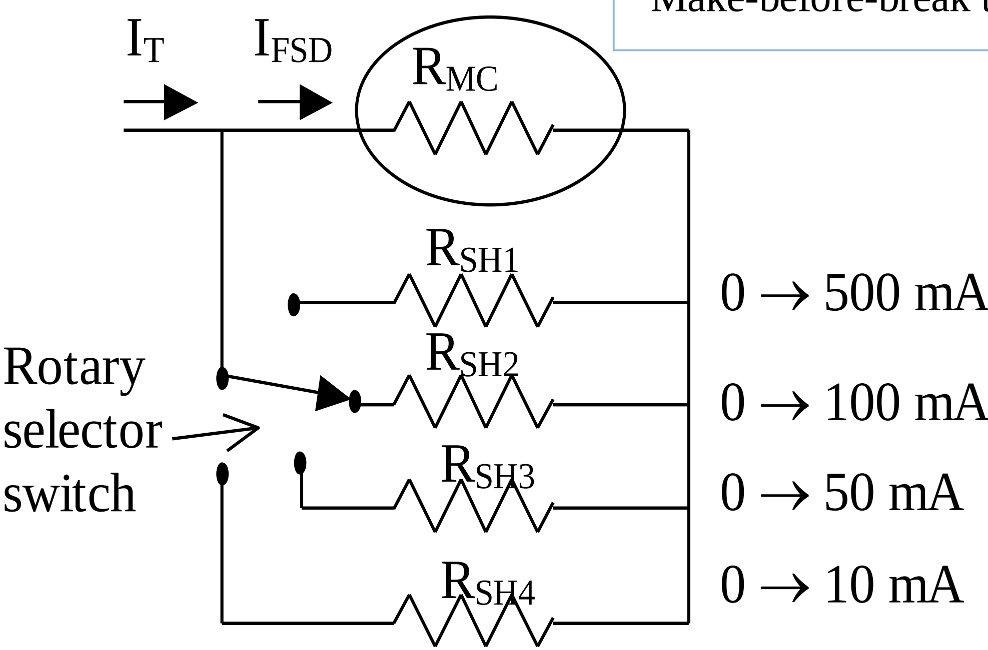
Also, determine the value of shunt resistance to give a multiplying factor of 50.



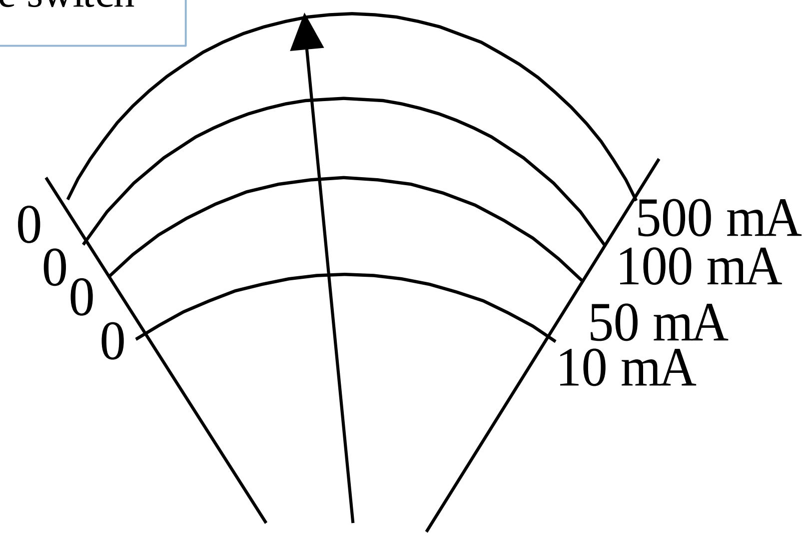
Multi-Range Ammeter



Make-before-break type switch



Multi-range ammeter circuit



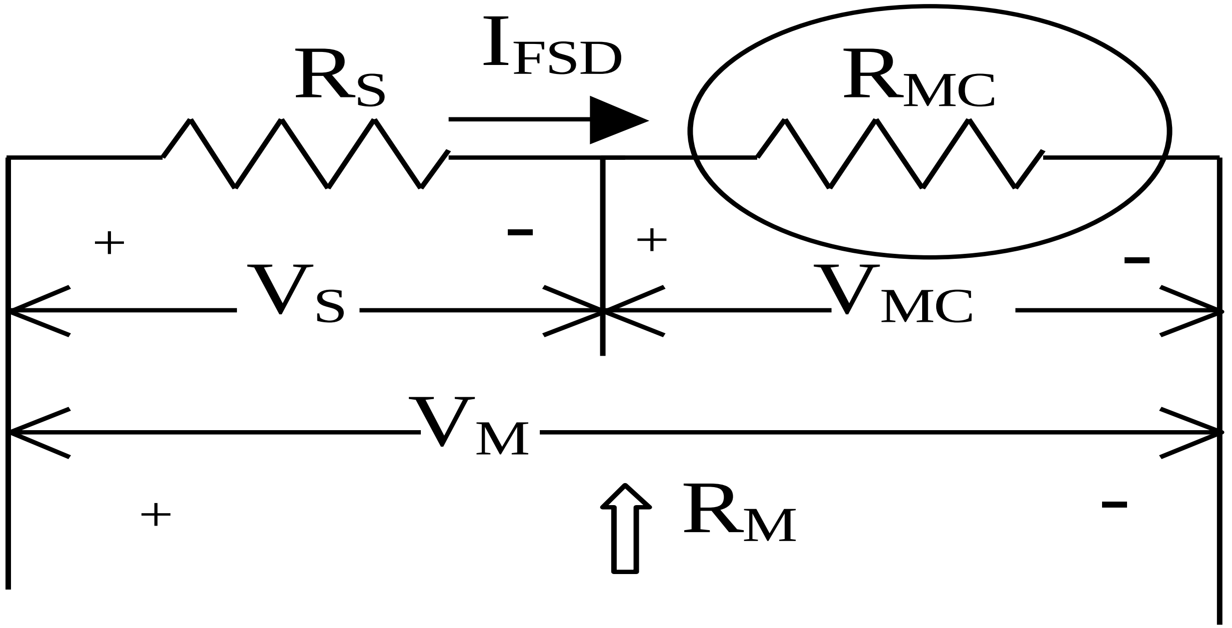
Multi-range ammeter scale

Basic DC Voltmeter

$V_M = I_{FSD} (R_S + R_{MC})$

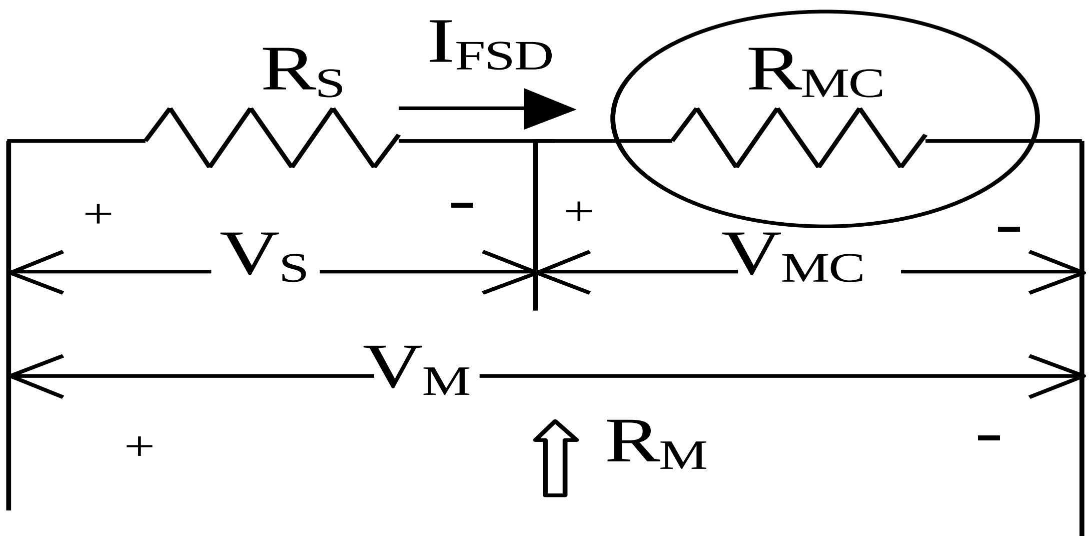
$R_M = R_S + R_{MC}$

Usually $R_S >> R_{MC}$ ⇨ $V_M \cong I_{FSD} R_S$

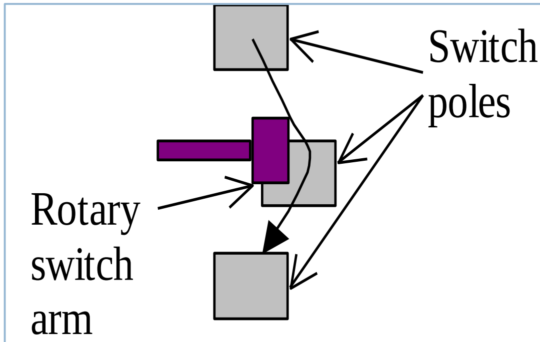


Example

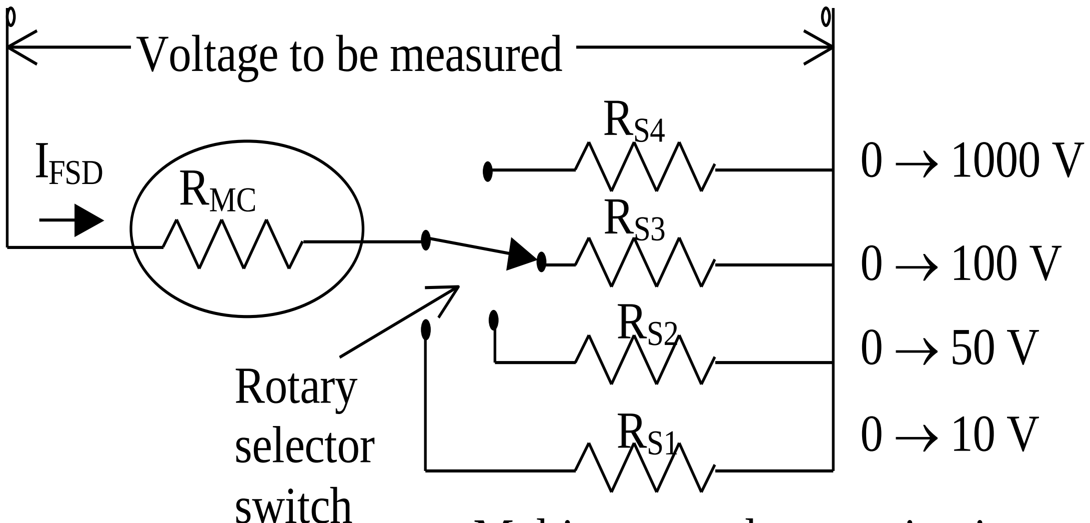
- A moving coil instrument gives full-scale deflection of 10 mA when the potential difference across its terminals is 100 mV. Calculate the resistance for full scale reading of 1000 V.



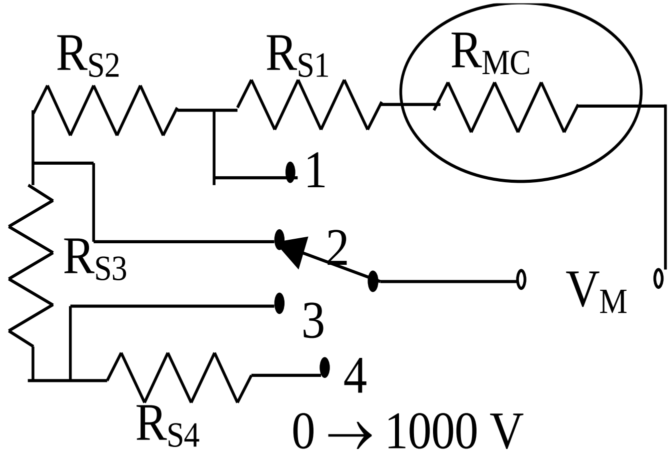
Multi-Range Voltmeter



Break-before-make type switch

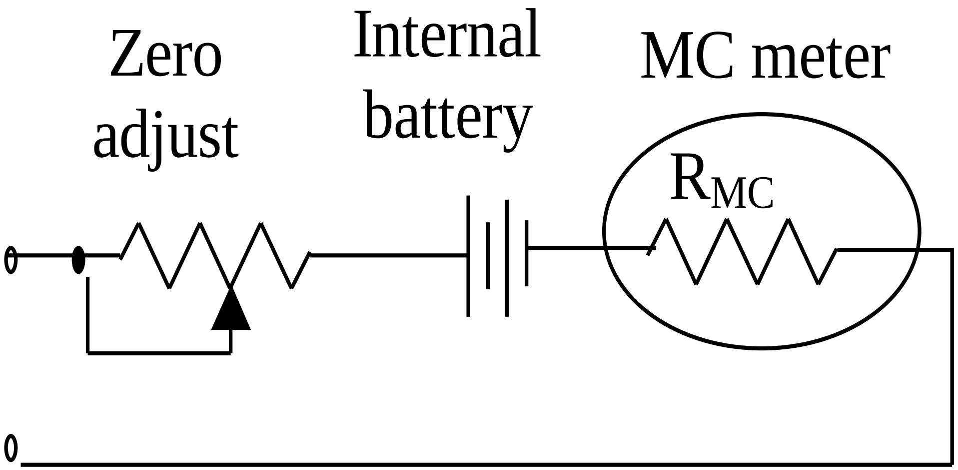


Multi-range voltmeter circuit
Parallel connection

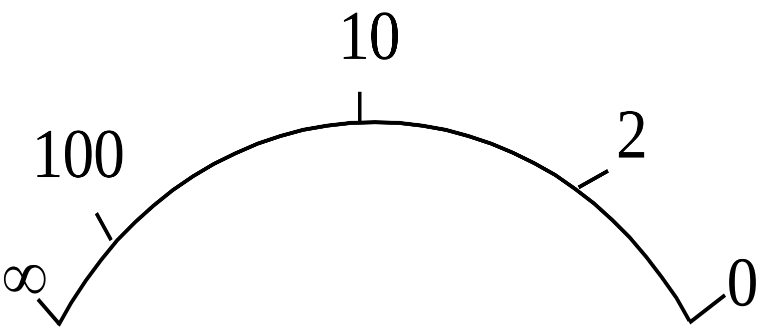


Multi-range voltmeter circuit
Series connection

Analog Ohmmeter

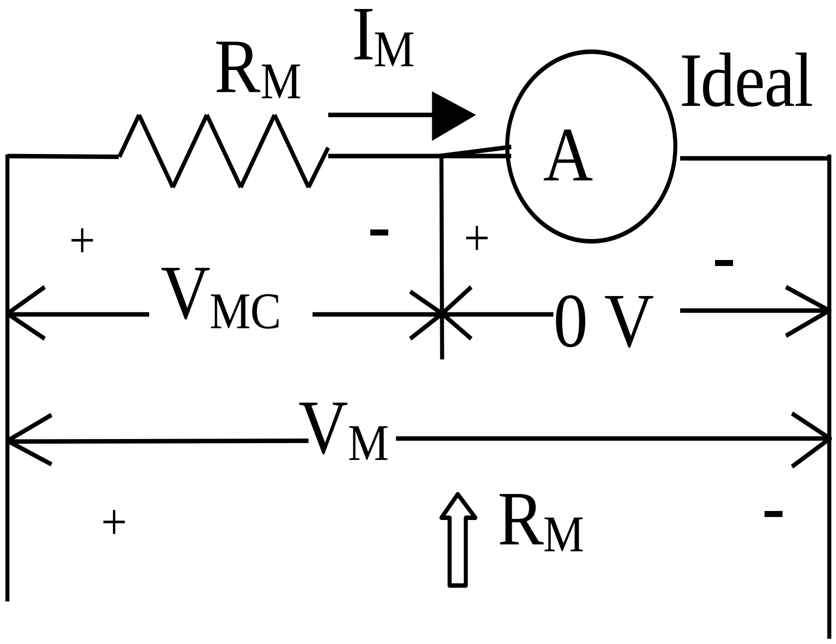


Basic series ohmmeter circuit

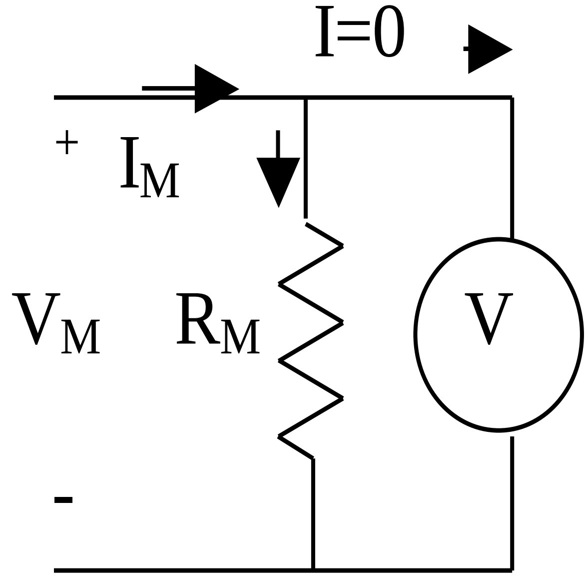


Series ohmmeter scale

Instrument Loading

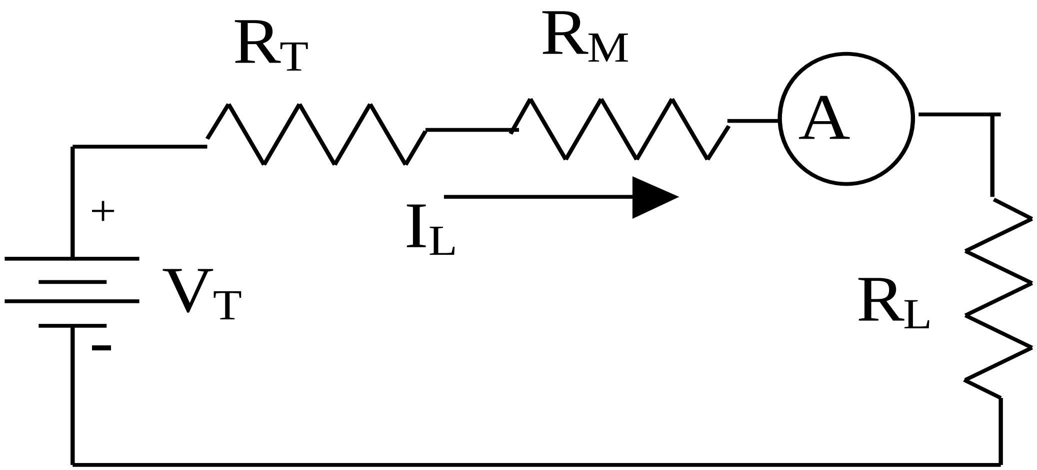


Practical ammeter



Practical voltmeter

Loading Errors in Ammeters



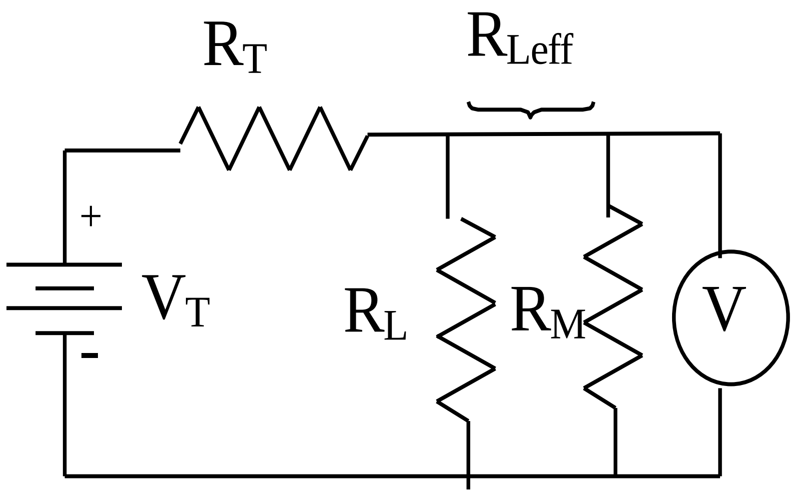
$$I_L = \frac{V_T}{R_T + R_L + R_M}$$

$$I_{LT} = \frac{V_T}{R_T + R_L}$$

$$\%\, loading\ error = \frac{measured - true}{true} \times 100$$

$$\%\ \text{loading error for ammeter} = \frac{\dfrac{V_T}{R_T + R_L + R_M} - \dfrac{V_T}{R_T + R_L}}{\dfrac{V_T}{R_T + R_L}} \times 100 = \frac{-100 R_M}{R_T + R_L + R_M}$$

Loading Errors in Voltmeters



$$V_{LT} = \frac{V_T R_L}{R_T + R_L}$$

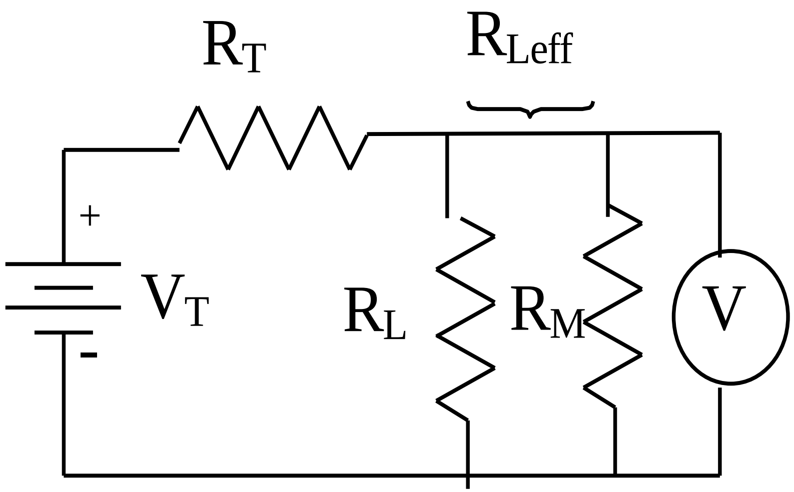
$$R_{Leff} = \frac{R_L R_M}{R_L + R_M}$$

$$V_L = V_{Lind} = \frac{V_T \dfrac{R_L R_M}{R_L + R_M}}{R_T + \dfrac{R_L R_M}{R_L + R_M}}$$

$$\%\,loading\,error = \frac{V_{Lind} - V_{LT}}{V_{LT}} x100$$

Example

- A voltmeter has a resistance of 20 kΩ/V is used to measure the voltage on the circuit shown on a 0-10 V range. Find the percentage loading error. Let $R_T = R_L = 10\ k\Omega$.



Suggested Readings and Exercises

- Hughes textbook – 6.4, 6.6, 6.7, 46.2, 46.3, 46.4, 46.5
- Exercise 46 (Hughes)
  - Problems 1, 2, 5, 6, 7, 8, 9