ACCEP
Communication and Computer Engineering Program

BENHA UNIVERSITY
FACULTY OF ENGINEERING (SHOUBRA)
ELECTRONICS AND COMMUNICATIONS ENGINEERING

كلية الهندسة بشبرا
FACULTY OF ENGINEERING AT SHOUBRA

CCE 304

Measurements and Instrumentations

(2022 - 2023) term 231

Lecture 2: Electromechanical Instruments (part1).

Dr. Ahmed Samir
https://bu.edu.eg/staff/ahmedsaied

Chapter Outline:

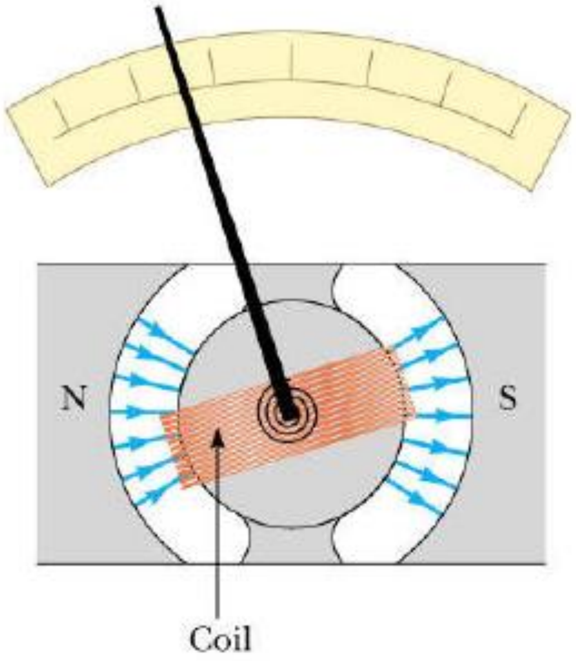
1) **Permanent Magnet Moving Coil (PMMC).**
2) Galvanometer.
3) DC Ammeters
4) DC Voltmeters
5) Ohmmeters
6) AC Voltmeters
7) AC Ammeters

3.1 Permanent Magnet Moving Coil (PMMC):

- Electromechanical instruments are **electrically operated mechanical instruments** used to measure **electrical quantities** (Volt, Ampere, Ohm).
- A Permanent Magnet Moving Coil (PMMC) is the **basic building block** of all electromechanical instruments: galvanometers, DC ammeters and voltmeters and ohmmeters.

Operation Principle of PMMC:

1. A light weight coil of copper wire suspended in the field of permanent magnet.
2. The current flowing in the wire produces a magnetic field by the coil which interacts with the field from the magnet thereby resulting in partial rotation of the coil.
3. The current flowing in the wire is indicated by the deflection on a calibrated scale through a pointer connected to the coil.

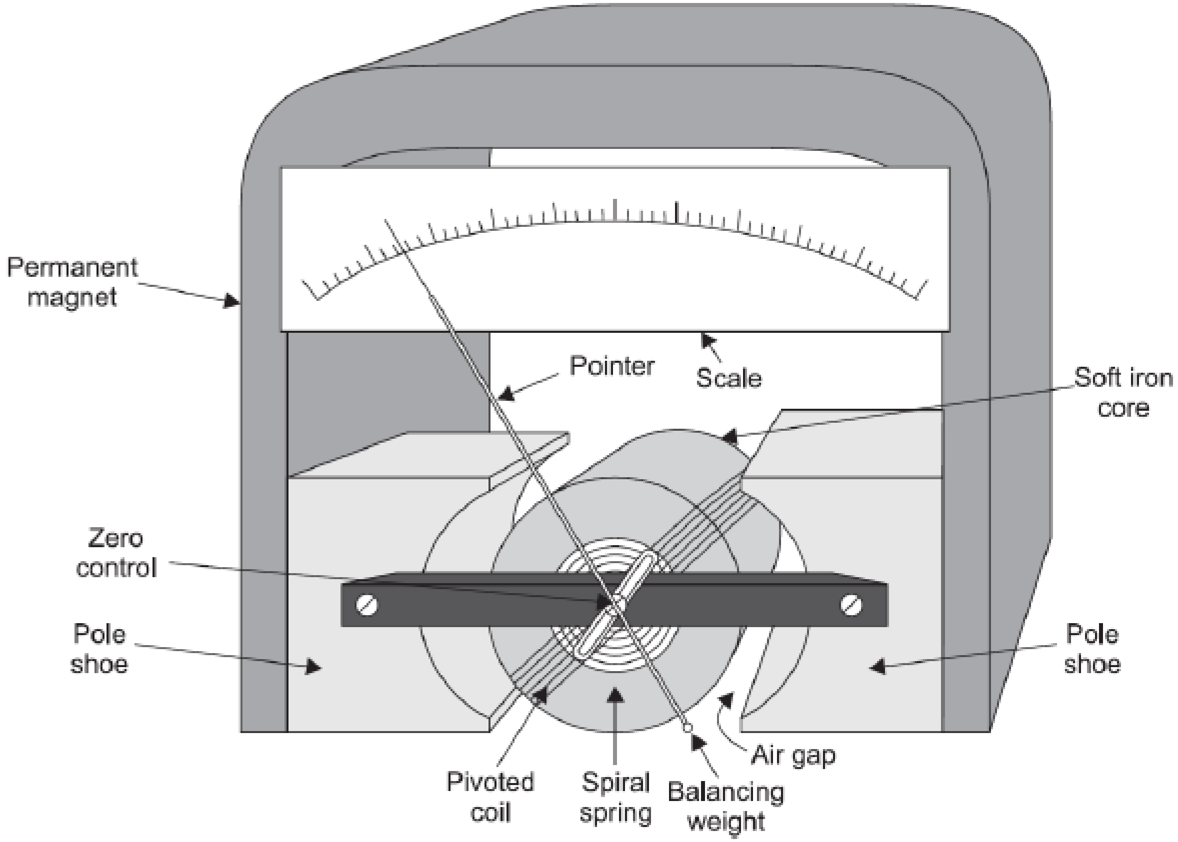


3.1 Permanent Magnet Moving Coil (PMMC):

Deflection Instrument Fundamentals:

To move the pointer in PMMC over the scale, three forces are required:

1. Deflection force.
2. Controlling force.
3. Damping force.



Construction of PMMC

3.1 Permanent Magnet Moving Coil (PMMC):

Deflection Instrument Fundamentals:

[1] Deflection force:

- It is the magnetic force that causes the pointer to move from its zero position when a current flows.
- This force is established due to the interaction between the magnetic field from the current flow in the coil and the field from the permanent magnet.

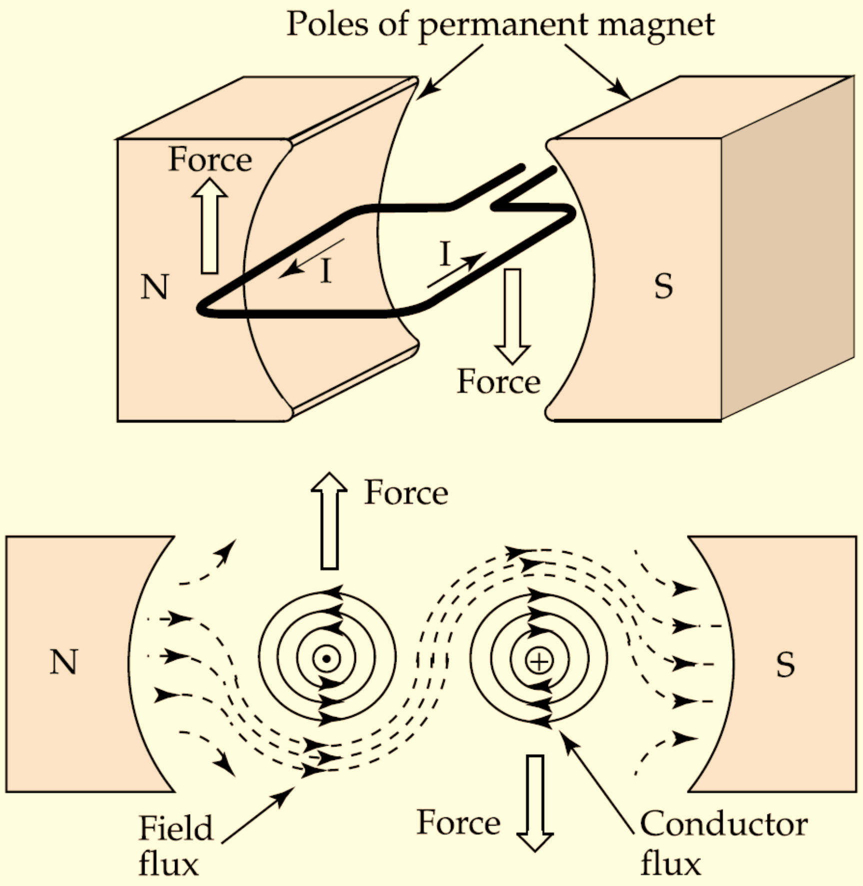
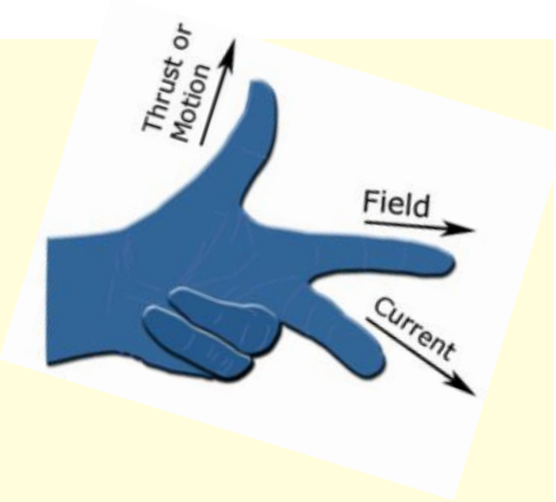


Figure 3-1 The deflecting force in a PMMC instrument is produced by the current in the moving coil. This sets up a magnet flux which interacts with the flux from the poles of the permanent magnet.



3.1 Permanent Magnet Moving Coil (PMMC):

Deflection Instrument Fundamentals:

[2] Controlling force:

- The controlling force in the PMMC instrument is provided by spiral springs. The springs retain the coil and pointer at their zero position when no current is flowing.
- The coil and pointer stop rotating when the controlling force becomes equal to the deflecting force.
- The spring material must be nonmagnetic to avoid any magnetic field influence on the controlling force.
- The springs are also used to make electrical Connection to the coil, they must have a low resistance. Phosphor bronze is the material usually employed.

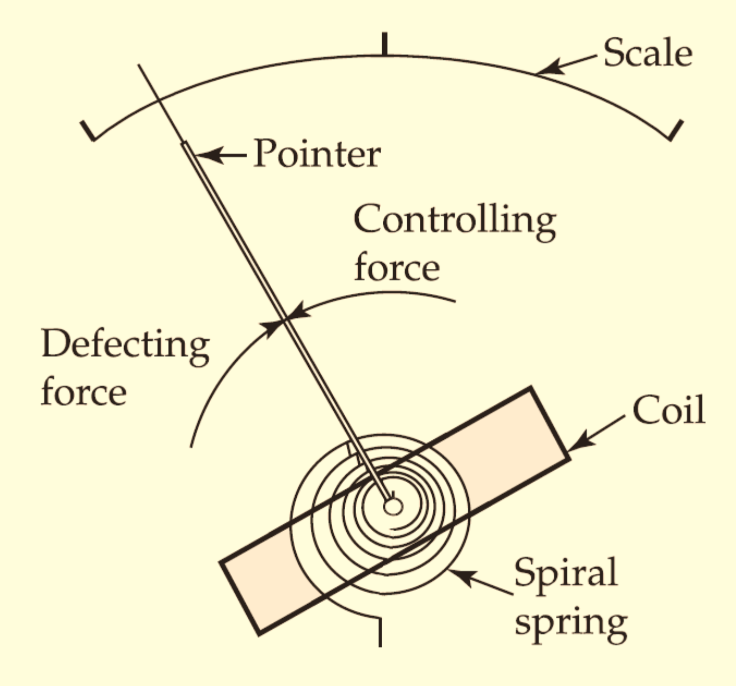


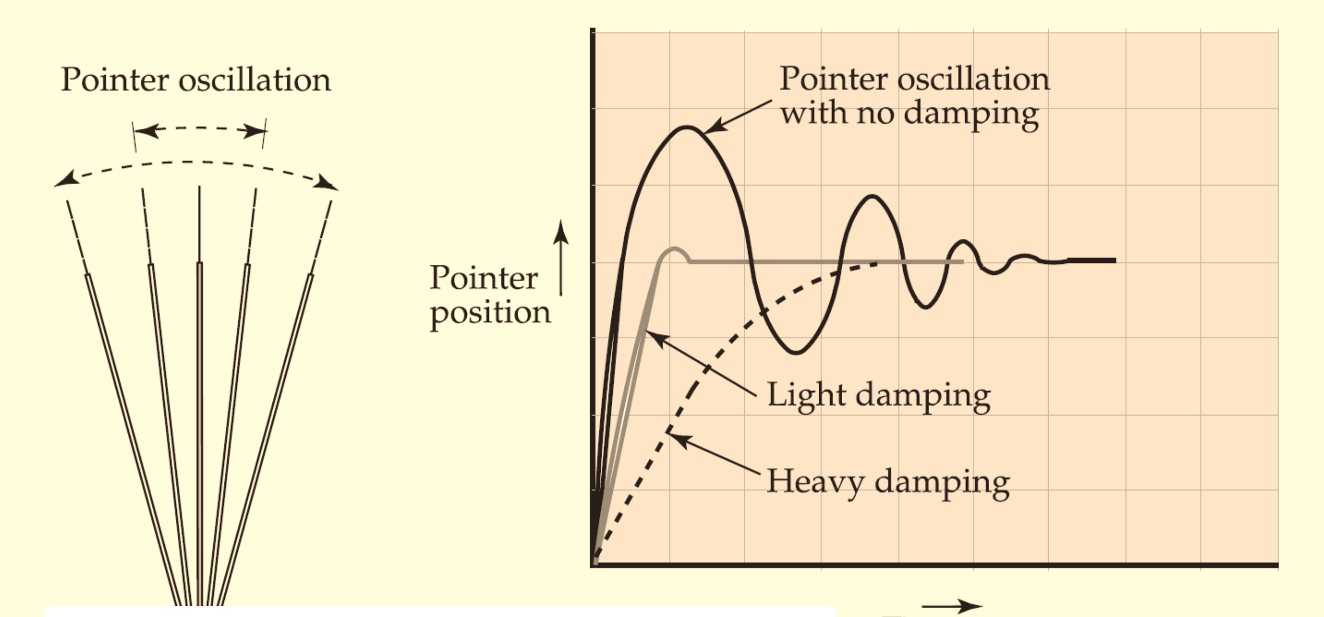
Figure 3-2 The controlling force in a PMMC instrument is provided by spiral springs. The two forces are equal when the pointer is stationary.

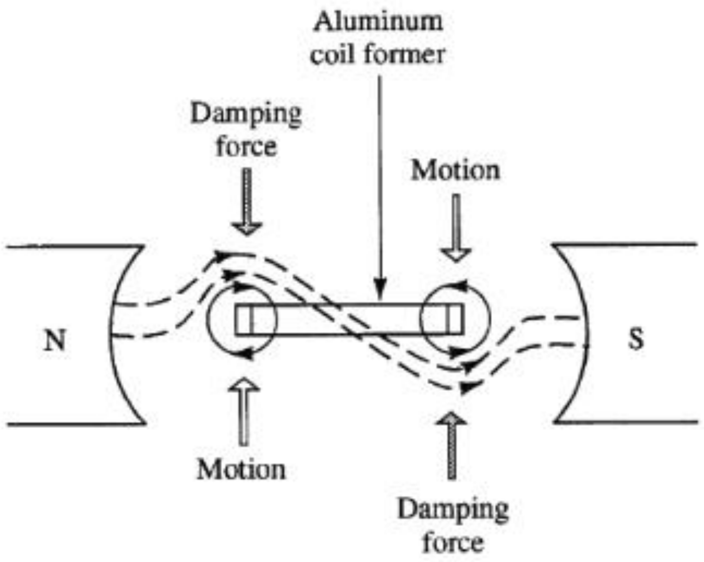
3.1 Permanent Magnet Moving Coil (PMMC):

Deflection Instrument Fundamentals:

[3] Damping force:

- A damping force is required to **minimize** (or **damp out**) **the pointer oscillations** that could occur before stopping at a certain reading.
- This damping is applied by the **Eddy Current** established in the aluminum frame of the coil.
- Eddy currents induced in the coil former set up a magnetic flux that **opposes the coil motion**, thus **damping the oscillations** of the coil and the pointer.
- This force is provided only **when the coil is moving.**





3.1 Permanent Magnet Moving Coil (PMMC):

Construction of PMMC:

Zero Control:

the zero-position control can be adjusted to calibrate the coil and pointer position when no coil current is flowing.

Counter weight:

It provides correct mechanical balance of the moving pointer so that there is no gravitational effect on the accuracy of the instrument.

PMMC is Polarized:

The current in the coil of a PMMC instrument must flow in one particular direction to cause the pointer to move (positively) from the zero position over the scale.

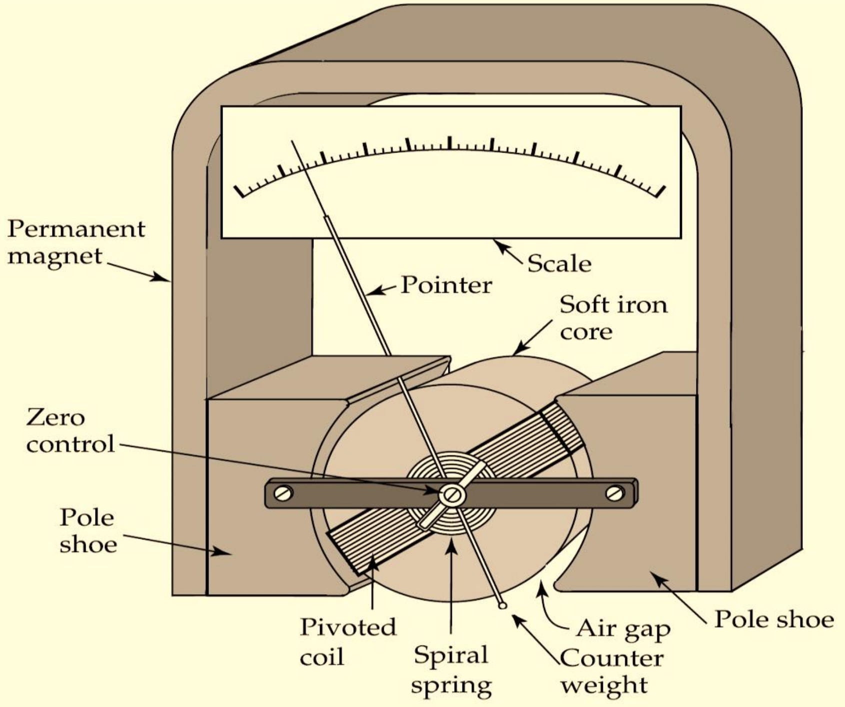


Figure 3-6 A typical PMMC instrument is constructed of a horseshoe magnet, soft-iron pole shoes, a soft-iron core, and a suspended coil that moves in the air gap between the soft-iron core and the pole shoes.

3.1 Permanent Magnet Moving Coil (PMMC):

Torque equation and scale

- When a current I flows through a one-turn coil situated in a magnetic field, a force F is exerted on each side of the coil:

$$F = BIL \ \ newtons$$

Where B is the magnetic flux density in tesla,
I is the current in amperes, and
L is the length of the coil in meters

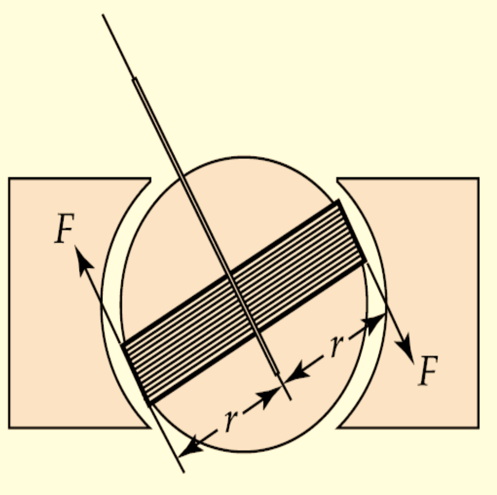
Since for a coil of N turns for two sides

$$F = 2BILN \ \ \ newtons$$

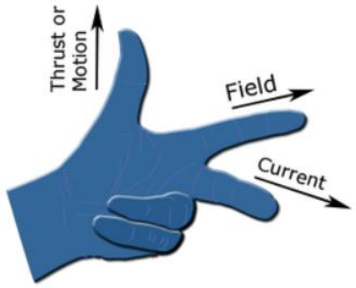
Deflecting torque:

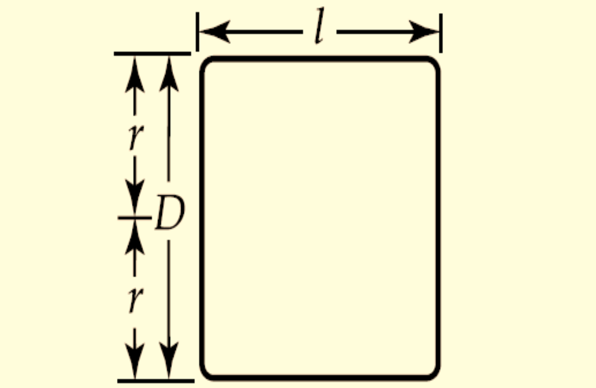
$$T_D = 2BILNr \ \ \ N.m$$

$$T_D = BILN(2r) \ \ \ N.m \Rightarrow T_D = BILND \ \ \ N.m$$



(a) Force F acts on each side of the coil





(b) Area enclosed by the coil

3.1 Permanent Magnet Moving Coil (PMMC):

Torque equation and scale (Cont.)

- The controlling torque exerted by the spiral springs is directly proportional to the deformation of the springs. Thus, the controlling torque is proportional to the actual angle of deflection of the pointer:

$$T_C = K\theta \qquad N.m$$ Where K is a constant

For a given deflection, the controlling and deflecting torques are equal:

The pointer stops when $T_d = T_c$:

$$K\theta = BILND$$

All quantities are constant except θ and I

- ✓ Then, the deflection angle is

$$\theta = CI$$ Where C is a constant

3.1 Permanent Magnet Moving Coil (PMMC):

Torque equation and scale (Cont.)

$$\theta = CI$$

This equation shows that the pointer deflection is always proportional to the coil current.

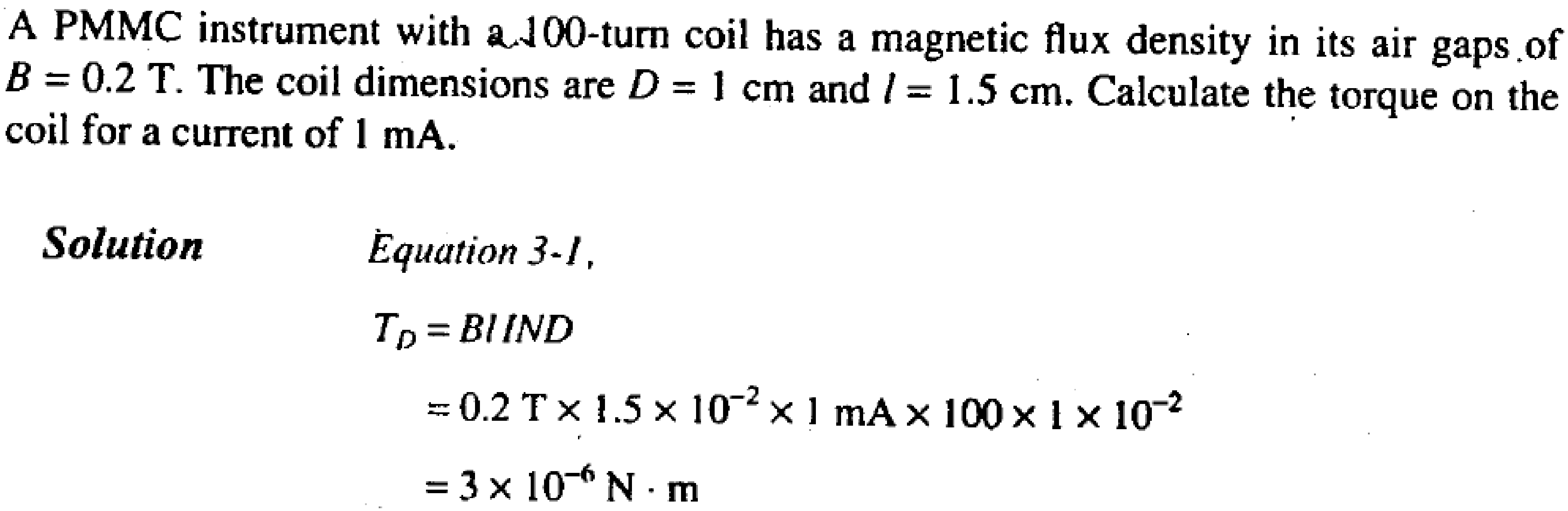
Consequently, the scale of the instrument is linear, or uniformly divided; that is, if 1 mA produces a 1 cm movement of the pointer from zero, 2 mA produces a 2 cm movement, and so on.

The pointer deflection is always proportional to the coil current and the scale is linear.

3.1 Permanent Magnet Moving Coil (PMMC):

Torque equation and scale (Cont.)

- **Example 3.1 :**



A PMMC instrument with a 100-turn coil has a magnetic flux density in its air gaps of $B = 0.2$ T. The coil dimensions are $D = 1$ cm and $l = 1.5$ cm. Calculate the torque on the coil for a current of 1 mA.

Solution *Equation 3-1,*

$$T_D = BlIND$$

$$= 0.2\ \text{T} \times 1.5 \times 10^{-2} \times 1\ \text{mA} \times 100 \times 1 \times 10^{-2}$$

$$= 3 \times 10^{-6}\ \text{N} \cdot \text{m}$$

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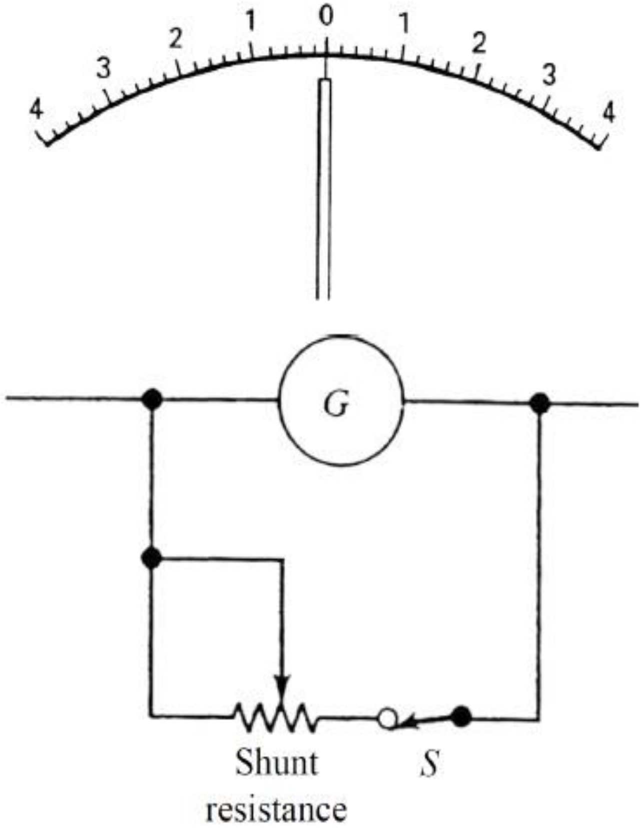
1) Permanent Magnet Moving Coil (PMMC).
2) **Galvanometer.**
3) DC Ammeters
4) DC Voltmeters
5) Ohmmeters
6) AC Voltmeters
7) AC Ammeters

3.2 Galvanometer:

- A galvanometer is essentially a PMMC instrument designed to be **sensitive to extremely low currents** (microamperes).
- Its scale is a **center-zero scale**. The pointer can be deflected to either **right or left** of zero, depending on the direction of current through the moving coil.
- Galvanometers are often employed to detect zero **current or voltage** in a circuit rather than to measure the actual level of current or voltage.

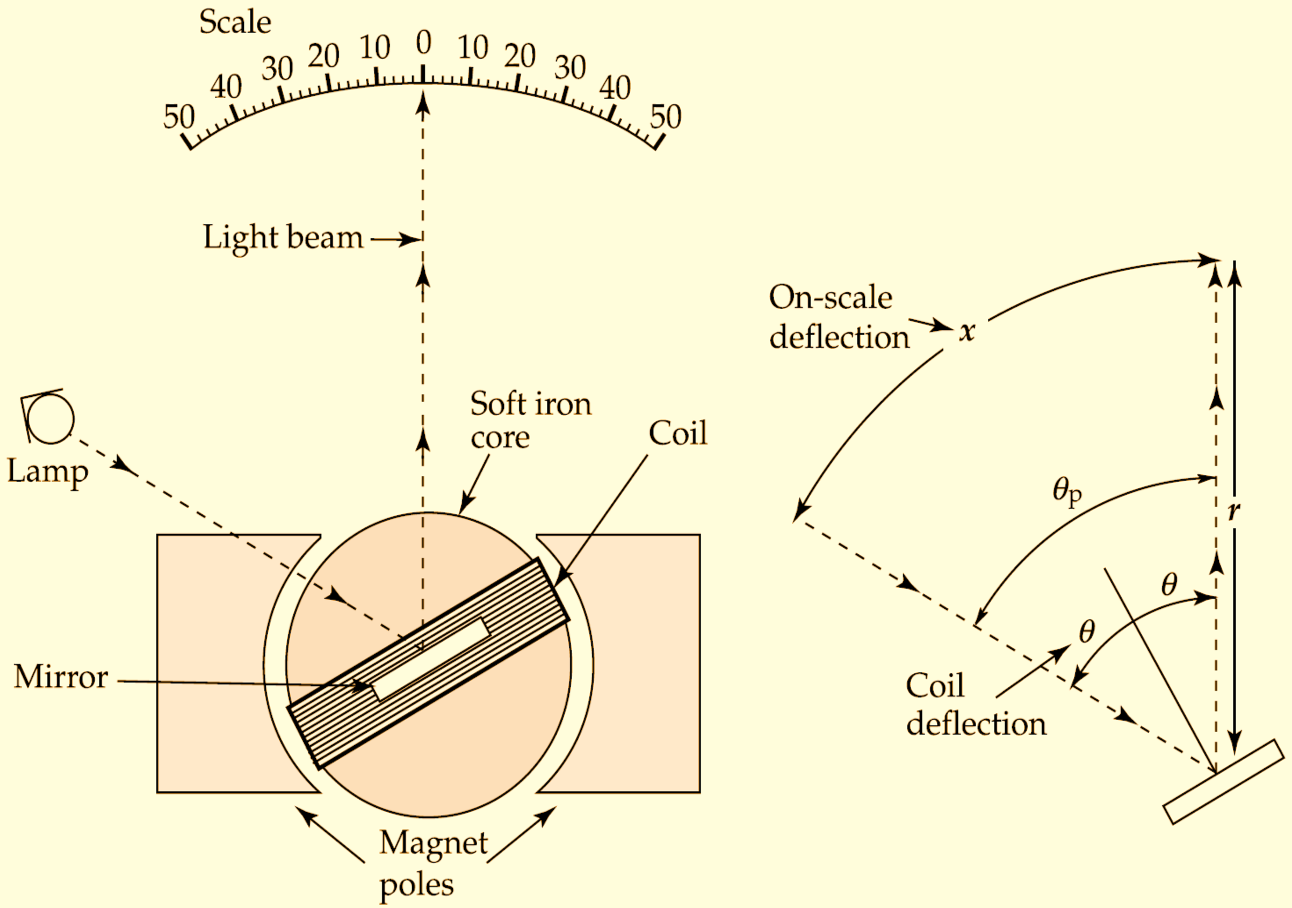


Protection of Galvanometer:

A galvanometer must be protected from the excessive current flow. Protection is provided by an adjustable resistance connected in shunt with the instrument to limit the input current.

3.2 Galvanometer (Cont.)

- The weight of the pointer can create a problem. This is solved in many instruments by mounting a small mirror on the moving coil instead of a pointer. The mirror reflects a beam of light on to a scale, as illustrated in the figure.
- So, light-beam galvanometers sensitive to much lower current levels than pointer instruments.



(a) Galvanometer using light-beam pointer

(b) The mirror and coil deflection is half that of the light-beam deflection

Figure 3-21 A galvanometer is simply an extremely sensitive PMMC instrument with a center-zero scale. For maximum sensitivity, the mass of the moving system is minimized by using a pointer that consists of a light beam reflected from a mirror fastened to the coil.

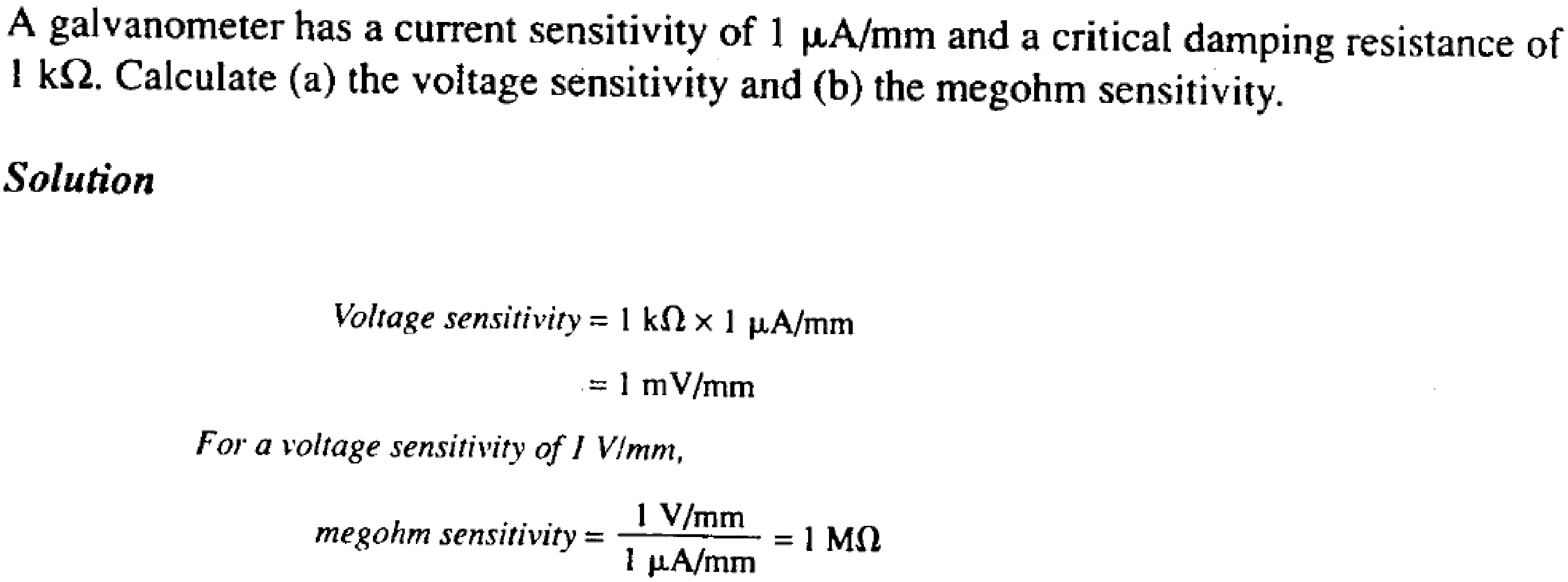
3.2 Galvanometer (Cont.)

There are two types of sensitivity:

1. Galvanometer voltage sensitivity is often expressed for a given value of critical damping resistance. This is usually stated in microvolts per millimeter.
2. A megohm sensitivity: this is the value of resistance that must be connected in series with the instrument to restrict the deflection to one scale division when a potential difference of 1 V is applied across its terminals.

2.3 Galvanometer (Cont.)

Example 3.2:



A galvanometer has a current sensitivity of 1 μA/mm and a critical damping resistance of 1 kΩ. Calculate (a) the voltage sensitivity and (b) the megohm sensitivity.

Solution

$$\text{Voltage sensitivity} = 1\ \text{k}\Omega \times 1\ \mu\text{A/mm}$$

$$= 1\ \text{mV/mm}$$

For a voltage sensitivity of 1 V/mm,

$$\text{megohm sensitivity} = \frac{1\ \text{V/mm}}{1\ \mu\text{A/mm}} = 1\ \text{M}\Omega$$

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4) DC Voltmeters
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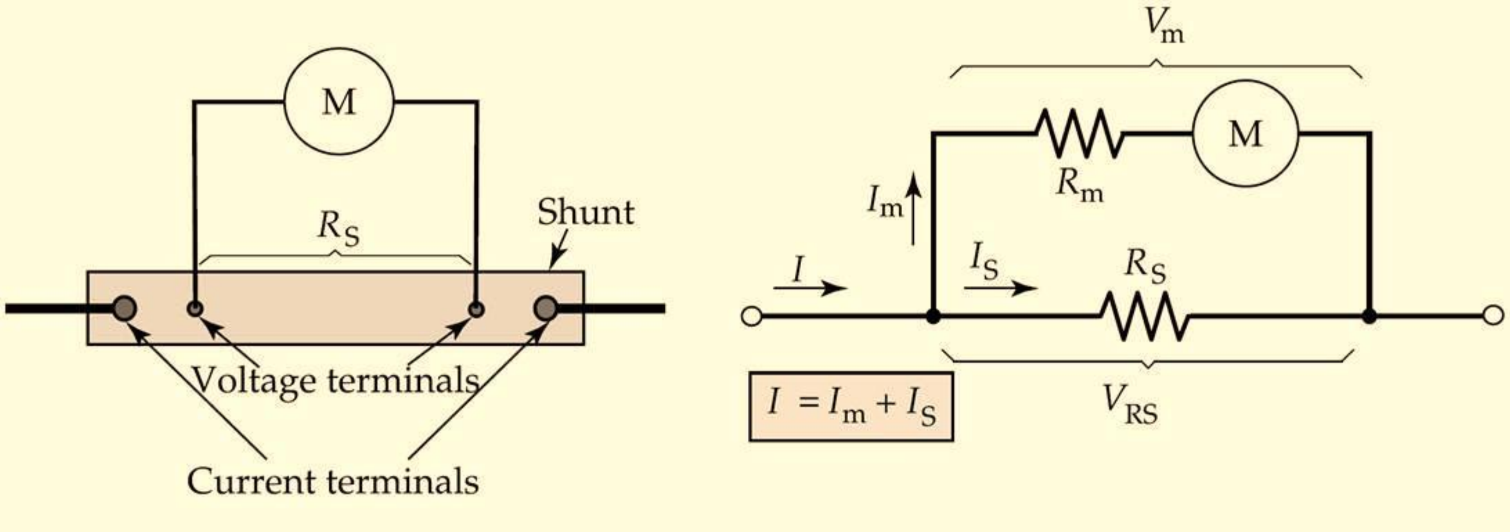
3.3 DC Ammeters: Ammeter Circuit:

- The PMMC instrument can be used as an ammeter to **measure DC current**. However, the PMMC wire could be quickly **destroyed by large currents**.
- For large currents, a PMMC is modified by adding **a parallel (shunt) resistance** R_s .
- Most of the measured current will pass through R_s and a small portion of it will pass through the moving coil.

Shunt Resistance

It is a small resistance connected in parallel with PMMC to allow measuring large currents. It is a four-terminal resistance to neglect the resistance of the current terminal.



(a) Dc ammeter construction

(b) Ammeter equivalent circuit

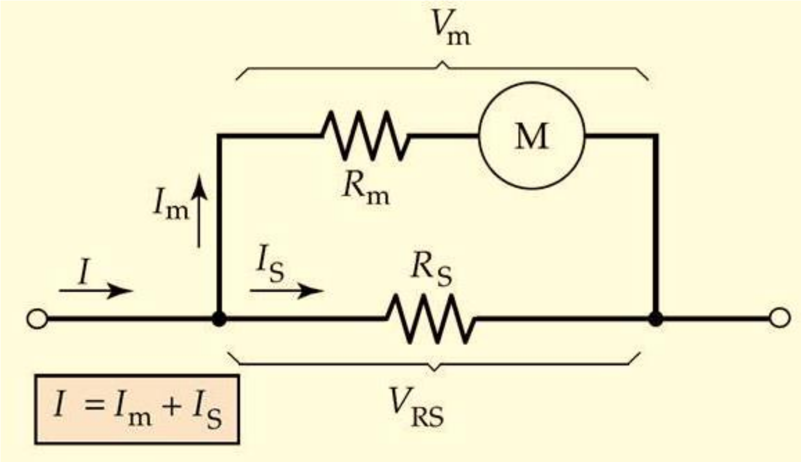
Figure 4-1 A dc ammeter consists of a PMMC instrument and a low-resistance shunt. The meter current is directly proportional to the shunt current, so that the meter scale can be calibrated to indicate the total ammeter current.

3.3 DC Ammeter (Cont.)

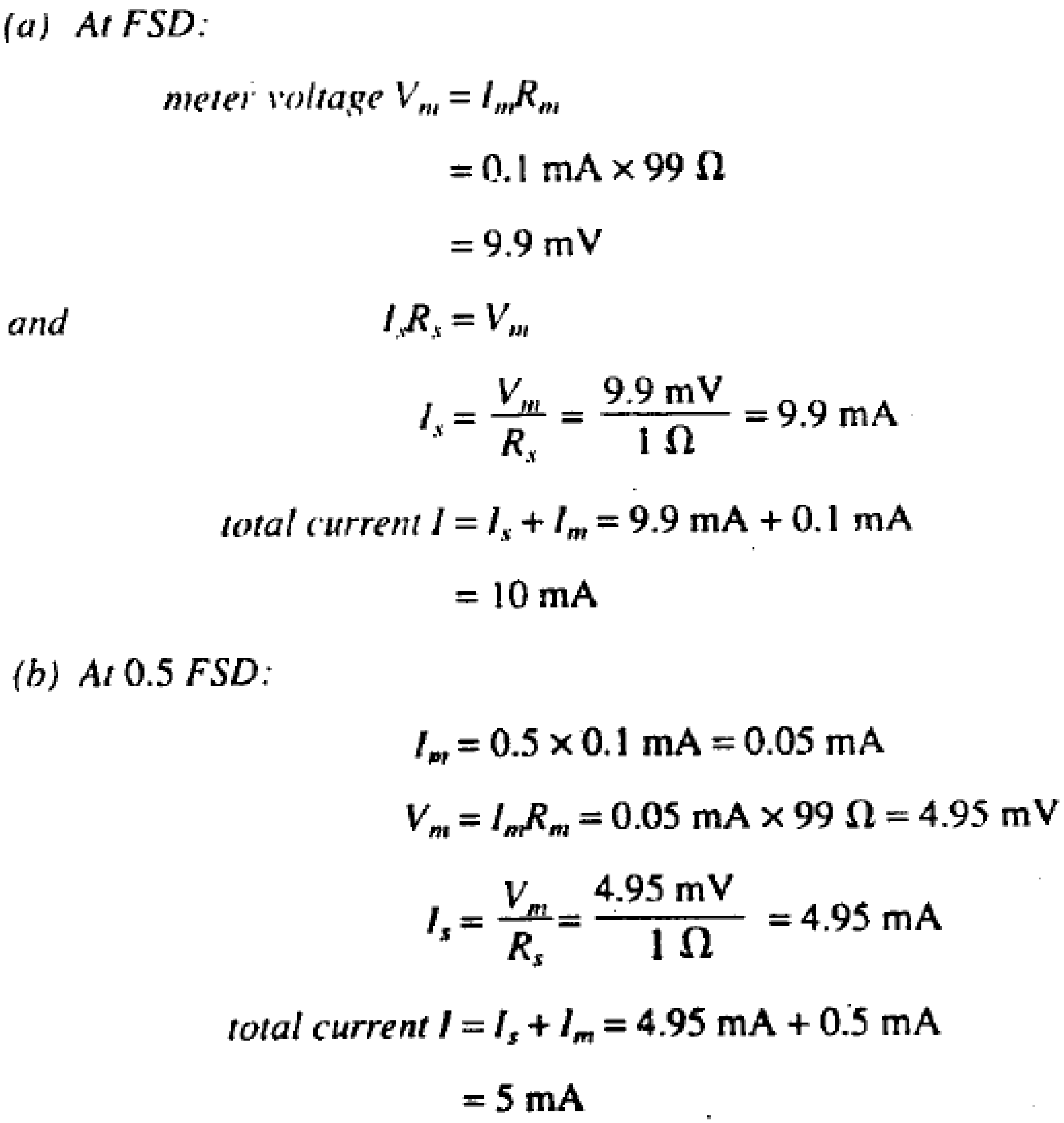
Example 3.3:

- An ammeter has a PMMC instrument with a coil resistance of R_m =99 Ω and full-scale deflection (FSD) current of 0.1 mA. Shunt resistance R_s = 1 Ω. **Determine** the total current passing through the ammeter at:

(a) FSD (b) 0.5 FSD (c) 0.25 FSD



Solution



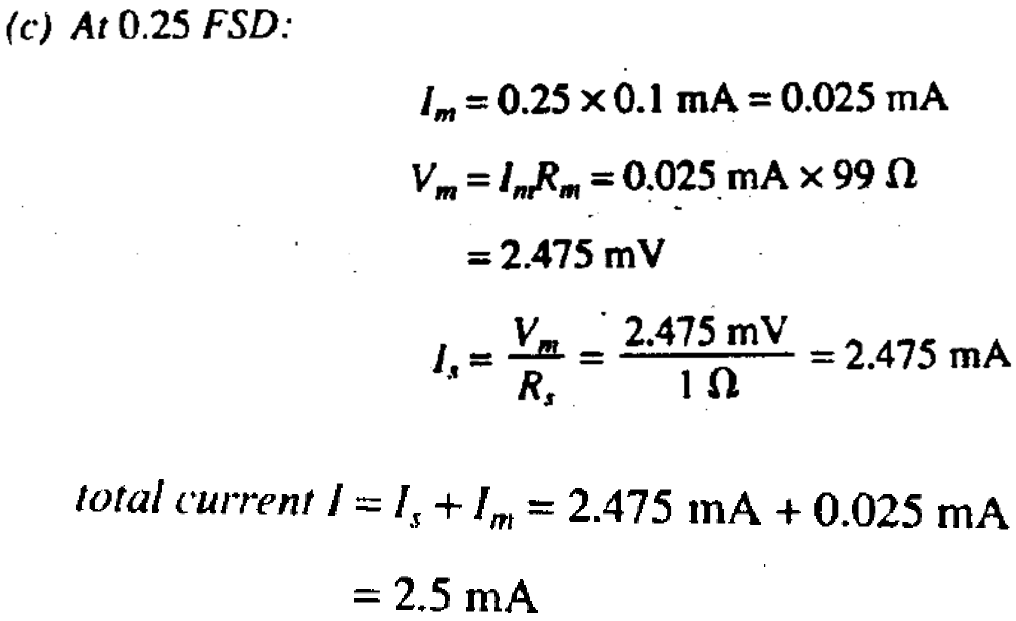
(a) At FSD:

$$\text{meter voltage } V_m = I_m R_m$$
$$= 0.1 \text{ mA} \times 99\ \Omega$$
$$= 9.9 \text{ mV}$$

and
$$I_s R_s = V_m$$
$$I_s = \frac{V_m}{R_s} = \frac{9.9 \text{ mV}}{1\ \Omega} = 9.9 \text{ mA}$$
$$\text{total current } I = I_s + I_m = 9.9 \text{ mA} + 0.1 \text{ mA}$$
$$= 10 \text{ mA}$$

(b) At 0.5 FSD:

$$I_m = 0.5 \times 0.1 \text{ mA} = 0.05 \text{ mA}$$
$$V_m = I_m R_m = 0.05 \text{ mA} \times 99\ \Omega = 4.95 \text{ mV}$$
$$I_s = \frac{V_m}{R_s} = \frac{4.95 \text{ mV}}{1\ \Omega} = 4.95 \text{ mA}$$
$$\text{total current } I = I_s + I_m = 4.95 \text{ mA} + 0.5 \text{ mA}$$
$$= 5 \text{ mA}$$



(c) At 0.25 FSD:

$$I_m = 0.25 \times 0.1 \text{ mA} = 0.025 \text{ mA}$$
$$V_m = I_m R_m = 0.025 \text{ mA} \times 99\ \Omega$$
$$= 2.475 \text{ mV}$$
$$I_s = \frac{V_m}{R_s} = \frac{2.475 \text{ mV}}{1\ \Omega} = 2.475 \text{ mA}$$
$$\text{total current } I = I_s + I_m = 2.475 \text{ mA} + 0.025 \text{ mA}$$
$$= 2.5 \text{ mA}$$

3. DC Ammeter (Cont.)

Example 3.4: A PMMC instrument has FSD of 100 μA and a coil resistance of 1 kΩ. Calculate the required shunt resistance value to convert the instrument into an ammeter with (a) FSD = 100 mA and (b) FSD = 1 A.

Solution

(*a*) *FSD* = 100 mA:

$$V_m = I_m R_m = 100\ \mu\text{A} \times 1\ \text{k}\Omega = 100\ \text{mV}$$

$$I = I_s + I_m$$

$$I_s = I - I_m = 100\ \text{mA} - 100\ \mu\text{A} = 99.9\ \text{mA}$$

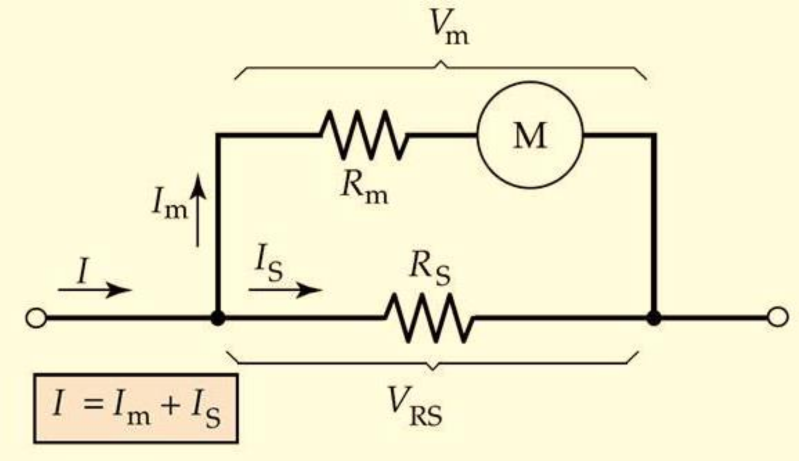
$$R_s = \frac{V_m}{I_s} = \frac{100\ \text{mV}}{99.9\ \text{mA}} = 1.001\ \Omega$$

(*b*) *FSD* = 1 A:

$$V_m = I_m R_m = 100\ \text{mV}$$

$$I_s = I - I_m = 1\ \text{A} - 100\ \mu\text{A} = 999.9\ \text{mA}$$

$$R_s = \frac{V_m}{I_s} = \frac{100\ \text{mV}}{999.9\ \text{mA}} = 0.10001\ \Omega$$



3.3 DC Ammeters: Swamping Resistance:

- The moving coil in a PMMC instrument is wound with thin copper wire, and its resistance can change with the temperature.
- Any such change in coil resistance will introduce an error in ammeter current measurements.
- To minimize the effect of temperature change on the PMMC resistance, a swamping resistance is connected in series with PMMC.
- The swamping resistance is made from constantan that have zero temperature coefficients.
- If the swamping resistance is nine times the coil resistance, a 1 % change in coil resistance would result in a total resistance change of 0.1 %.

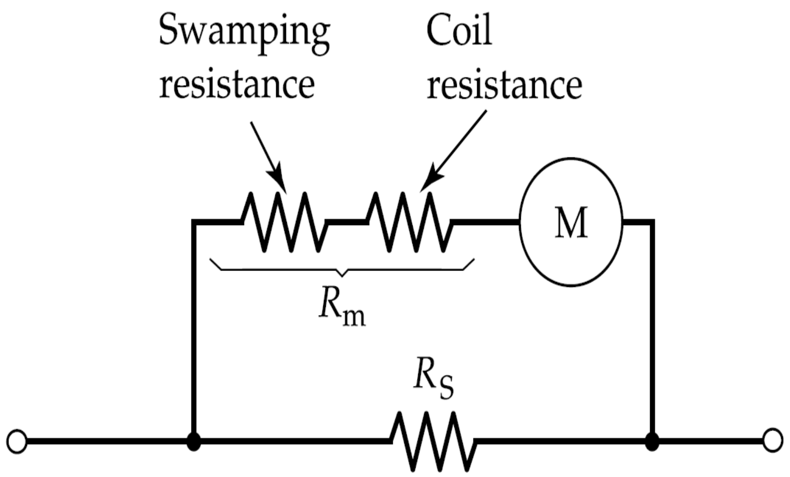
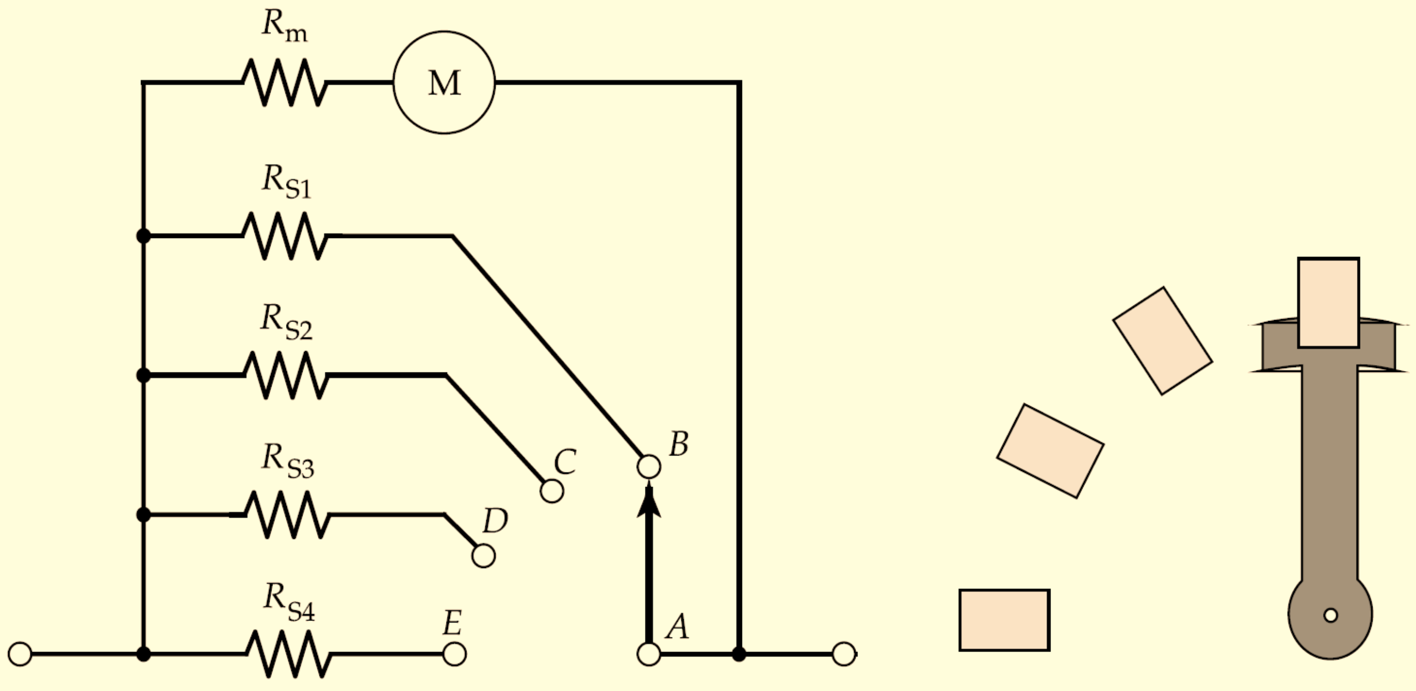


Figure 4-2 A swamping resistance made of a material with a near-zero temperature coefficient can be connected in series with the coil of a PMMC instrument to minimize temperature errors.

3.3 DC Ammeters: Multirange Ammeter:

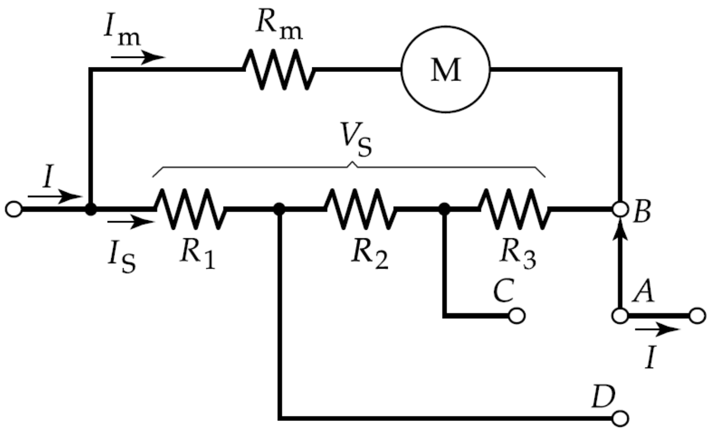
- A rotary switch is employed to select anyone of several shunt resistances with different values.
- A **make-before-break** switch must be used so that the instrument is not left without a shunt in parallel with it even for a brief instant.
- A make before-break switch makes contact with the next terminal before it breaks contact with the previous terminal.



(a) Multirange ammeter circuit (b) Make-before-break switch

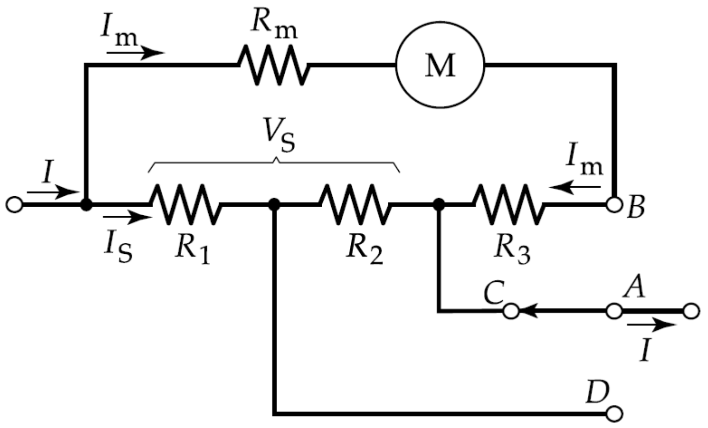
Figure 4-3 A multirange ammeter consists of a PMMC instrument, several shunts, and a switch that makes contact with the next shunt before losing contact with the previous one when range switching.

3.3 DC Ammeters: Multirange Ammeter (Cont.):



(a) Ayrton shunt and meter

$(R_1+R_2+R_3)\|R_m$



(b) Switch at terminal C

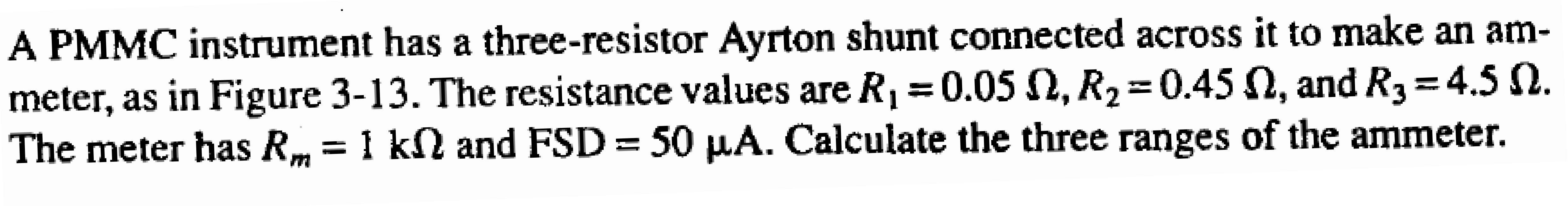
$(R_1+R_2)\|(R_m+R_3)$

Figure 4-4 An Ayrton shunt used with an ammeter consists of several series-connected resistors all connected in parallel with the PMMC instrument. Range change is effected by switching between the resistor junctions.

- Figures show another method of protecting the deflection instrument from excessive current during switching

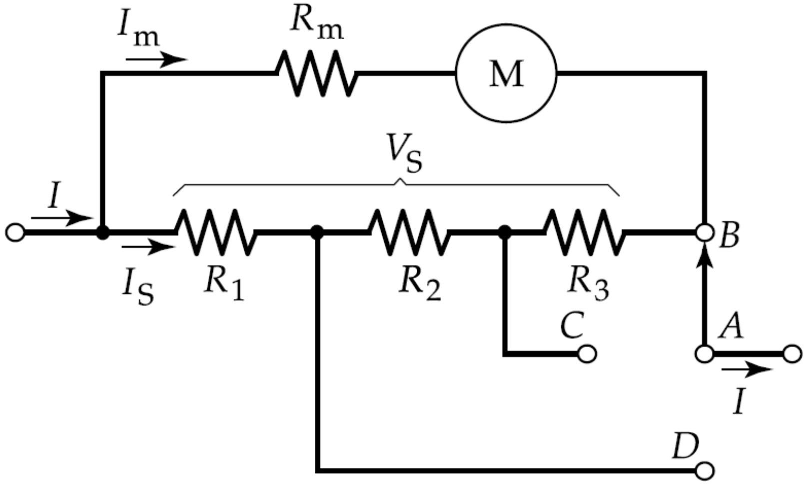
3.3 DC Ammeters: Multirange Ammeter (Cont.):

Example 3.5:



A PMMC instrument has a three-resistor Ayrton shunt connected across it to make an ammeter, as in Figure 3-13. The resistance values are $R_1 = 0.05\ \Omega$, $R_2 = 0.45\ \Omega$, and $R_3 = 4.5\ \Omega$. The meter has $R_m = 1\ \text{k}\Omega$ and FSD = 50 μA. Calculate the three ranges of the ammeter.

Solution



(a) Ayrton shunt and meter

Solution

1. *Switch at contact B:*

$$V_s = I_m R_m = 50\ \mu\text{A} \times 1\ \text{k}\Omega = 50\ \text{mV}$$

$$I_s = \frac{V_s}{R_1 + R_2 + R_3}$$

$$= \frac{50\ \text{mV}}{0.05\ \Omega + 0.45\ \Omega + 4.5\ \Omega} = 10\ \text{mA}$$

$$I = I_m + I_s = 50\ \mu\text{A} + 10\ \text{mA}$$

$$= 10.05\ \text{mA}$$

Ammeter range $\simeq$ 10 mA.

2. *Switch at contact C:*

$$V_s = I_m(R_m + R_3)$$

$$= 50\ \mu\text{A}(1\ \text{k}\Omega + 4.5\ \Omega)$$

$$\simeq 50\ \text{mV}$$

$$I_s = \frac{V_s}{R_1 + R_2}$$

$$= \frac{50\ \text{mV}}{0.05\ \Omega + 0.45\ \Omega}$$

$$= 100\ \text{mA}$$

$$I = 50\ \mu\text{A} + 100\ \text{mA}$$

$$= 100.05\ \text{mA}$$

Ammeter range $\simeq$ 100 mA.

3. *Switch at contact D:*

$$V_s = I_m(R_m + R_3 + R_2)$$

$$= 50\ \mu\text{A}(1\ \text{k}\Omega + 4.5\ \Omega + 0.45\ \Omega)$$

$$\simeq 50\ \text{mV}$$

$$I_s = \frac{V_s}{R_1} = \frac{50\ \text{mV}}{0.05\ \Omega}$$

$$= 1\ \text{A}$$

$$I = 50\ \mu\text{A} + 1\ \text{A}$$

$$= 1.00005\ \text{A}$$

Ammeter range $\simeq$ 1 A.

END OF LECTURE

BEST WISHES