Electrical Indicating Instruments: DC

EIE 240 Electrical and Electronic Measurement
Class 4, January 5, 2012
werapon.chi@kmutt.ac.th

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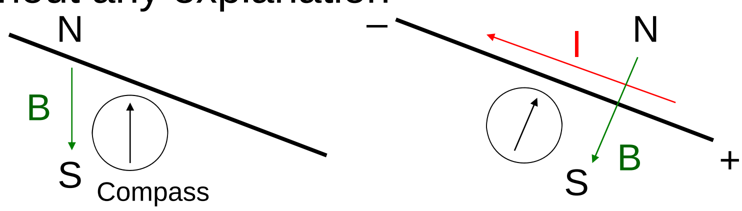
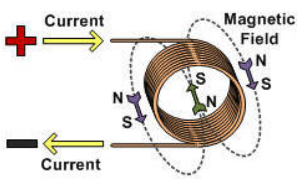
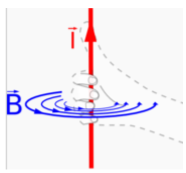
Analogue Meter's Concept

- Han Oersted, in 1820, noted his finding without any explanation



- Lord Kelvin made more sensitivity to a current





Right-hand Rule

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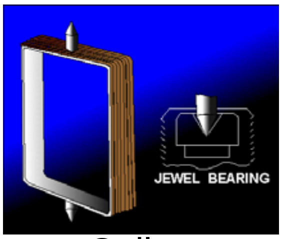
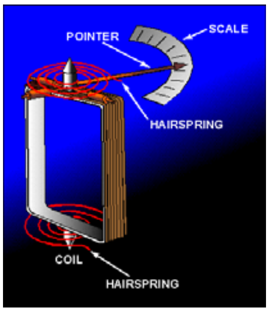
Direct Current Meters

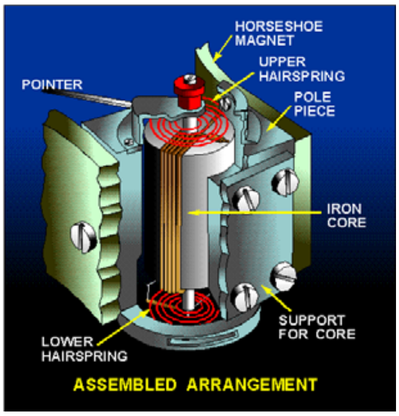
- Permanent-Magnet Moving-Coil (PMMC) developed in 1881



Coil



Pointer



Permanent Magnet

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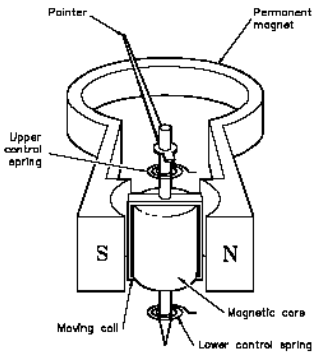
- A wire coil is attached to a shaft that pivots on two jewel bearing.
- The coil can rotate in a space between a cylindrical soft-iron core and two permanent magnetic pole pieces.
- The rotation is opposed be two fine hairsprings.



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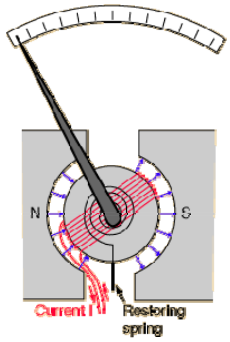
- Jacques D’Arsonval’s Movement (Galvanometer)

When a current is passed through the coil it rotates, the angle through which it rotates being proportional to the current (0.0000001 – 1 μA).

The magnetic field is designed (magnetic pole piece’s shape) that it is always at the right angles to the coil sides no matter what angle the coil has rotated through.



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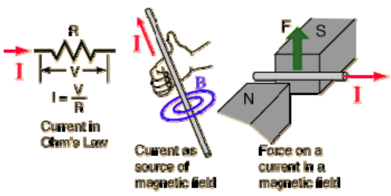
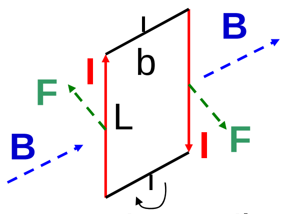
- Electric Current





Moving Coil

- Fleming’s Left-Hand Rule

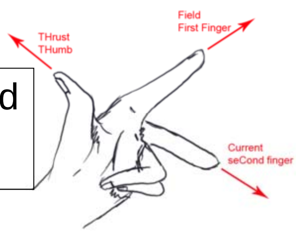
$$F = L\,I \times B$$

Force (Newton)

Coil Side Length (Metre)

Current (Ampere)

Magnetic Field (Tesla)



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- Torque (moment) is an angular force defined by linear force multiplied by a radius.

Damping Torque in Coil = F (b/2)

$= B\ I\ L\ b\ /\ 2$

$$Torque_{total} = 2\ (B\ I\ L\ b\ /\ 2) = B\ I\ L\ b$$

$$= B\ I\ A \qquad ,\ \text{Area}\ A = Lb$$

for N coils, $Torque_{total} = N\ B\ I\ A$

$$= K_{coil}\ I \qquad ,\ K_{coil} = NBA$$

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- Controlling torque in springs

$$Torque_{spring} = K_s\ \theta$$

- Critical damping or balancing forces (Newton's 3rd Law)

Action = Reaction

$$Torque_{total} = Torque_{spring}$$

$$K_{coil}\ I = K_s\ \theta$$

$$\theta = (K_{coil}\ /\ K_s\ )\ I$$

- If the magnetic field is not uniform throughout the entire region, the scales are nonlinear!

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Galvanometer

- Galvanometer with a zero at the center of the scale used in DC instruments that can detect current flow in either direction
- Galvanometer with a zero at the left end of the scale indicates an upscale reading only for the proper way of connecting the meter into the circuit

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Equivalent Ammeter Circuit

- The resistance of the meter coil and leads introduces a departure from the ideal ammeter behavior. The model usually used to describe an ammeter in equivalent circuit is a resistance R_g in series with an ideal ammeter (no resistance)

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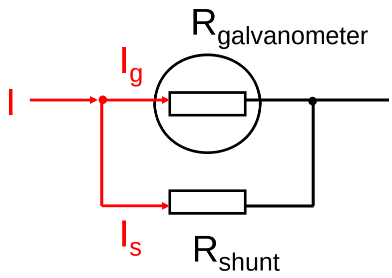
Full-Scale-Deflection Currents

- Current range is 10 μA – 20 mA
- Shunt resistor connected in parallel

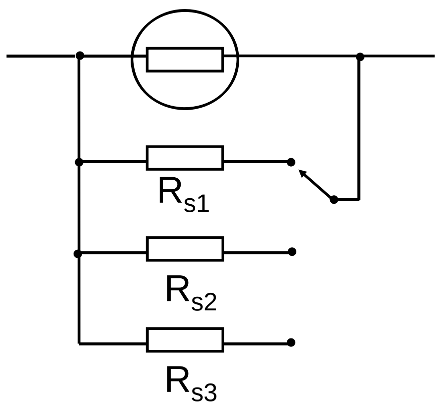
$$V_s = V_g$$

$$(I - I_g)R_s = I_g R_g$$

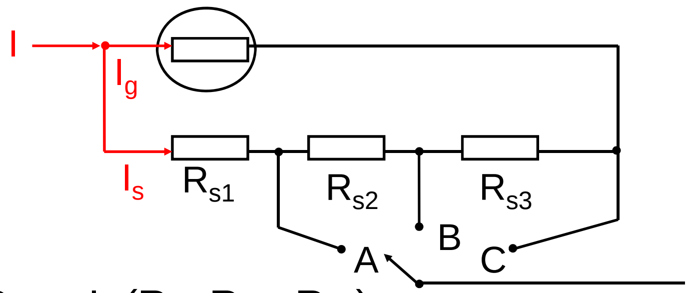
$$I = \underbrace{(R_s+R_g)/R_s}_{\text{Scaling factor}}\, I_g$$



- Multi-range shunt can be made by switching into a circuit



- Universal shunt (Ayrton shunt)



A: $(I - I_g)R_{s1} = I_g\,(R_g+R_{s2}+R_{s3})$

$$I = (R_g+R_{s1}+R_{s2}+R_{s3})/R_{s1}\; I_g$$

B: $(I - I_g)(R_{s1}+R_{s2}) = I_g\,(R_g+R_{s3})$

$$I = (R_g+R_{s1}+R_{s2}+R_{s3})/(R_{s1}+R_{s2})\; I_g$$

C: $$I = (R_g+R_{s1}+R_{s2}+R_{s3})/(R_{s1}+R_{s2}+R_{s3})\; I_g$$

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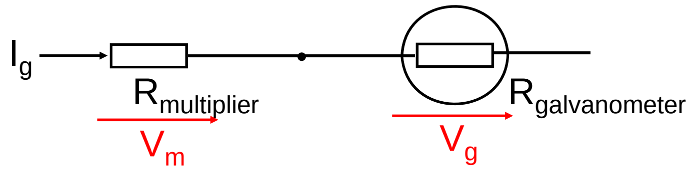
Full-Scale-Deflection Voltages

- Since V = IR, the response of a moving coil meter responding to a current is also proportional to the potential difference across the meter.
- However, because R_g and I_g are low, it can only be used for low voltages (≈ 0.05 V).
- Multiplier resistor can be connected in series



$$V = I_gR_m + I_gR_g = (R_m+R_g)\, I_g$$

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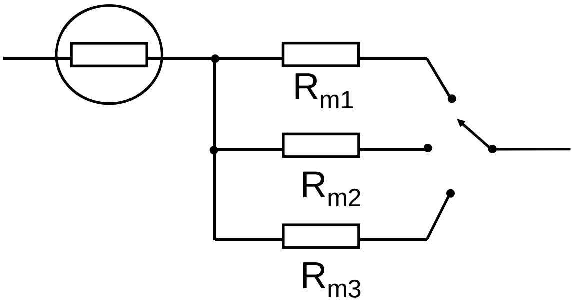
- Multi-range voltmeter



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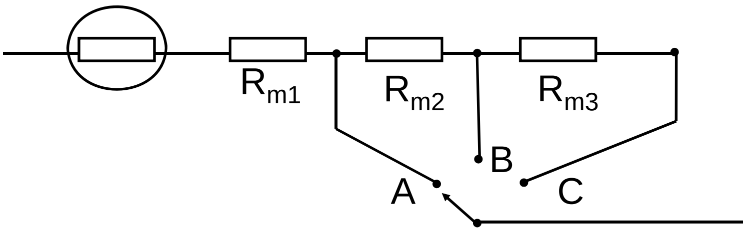
- Multi-range voltmeter with a chain arrangement



A: $V = I_gR_g + I_gR_{m1} = (R_m+R_g)\ I_g$

B: $V = I_gR_g + I_gR_{m1} + I_gR_{m2} = (R_{m1}+R_{m2}+R_g)\ I_g$

C: $V = I_gR_g + I_gR_{m1} + I_gR_{m2} + I_gR_{m3}$
$\quad = (R_{m1}+R_{m2}+R_{m3}+R_g)\ I_g$

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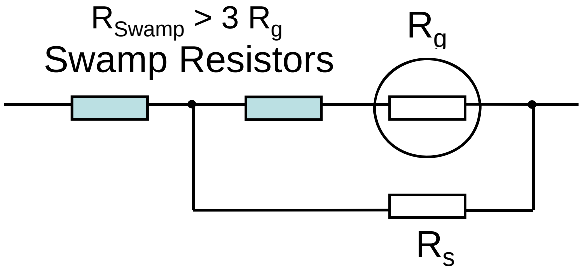
Temperature on Moving-Coil Meter

- Higher temperature of coil, higher resistance, lower reading $\Rightarrow$ decrease spring tension
- Measured value is decreased 0.2% for increasing of 1°C temperature.
- Swamp resistor (manganin wire), whose resistance changes slowly with temperature, connected in series
- However, the sensitivity is decreased.



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Sensitivity on Moving-Coil Meter

- Sensitivity = Pointer Change / Input Change

$$S = \theta / I$$

or

$$S = 1 / I_{fsd}$$
$$= R / V_{fsd}$$

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Ammeter & Voltmeter Loading

- Systematic Error => Calculation by using
  Thévenin's theorem
  in Chapter 3