Chapter 4

Electromechanical Indicating Instruments

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Classification of Instruments

1. Indicating Instruments

- **indicate** measured value at an instant of time
- by a pointer and a scale or digital (numerical) display
- instrument e.g.: ammeter, voltmeter, thermometer
- quantity e.g.: current (A), voltage (V), temperature (K)

2. Recording Instruments

- **record** measured value over a period of time
- instrument e.g.: chart recorders, X-Y recorder, plotters
- recording e.g.: I vs t, V vs t, T vs t, I vs V

3. Integrating instruments

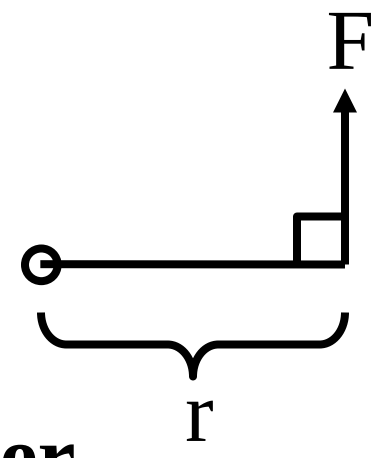
- **integrate** measured value over a period of time
- instrument e.g.: Watt-hour meter, ampere-hour meter
- quantity e.g.: energy (W-h), charge (A-h)

Essentials of indicating instruments

All deflection instruments consist of a ***pointer*** attached to a ***moving system*** that moves the pointer over a ***calibrated scale***.

The **moving system** is subjected by 3 torques:

- A deflecting torque
- A controlling torque
- A damping torque



Torque = force × distance from center

$$T = F \times r \text{ (N-m)}$$

Deflecting / Operating torque (T_d)

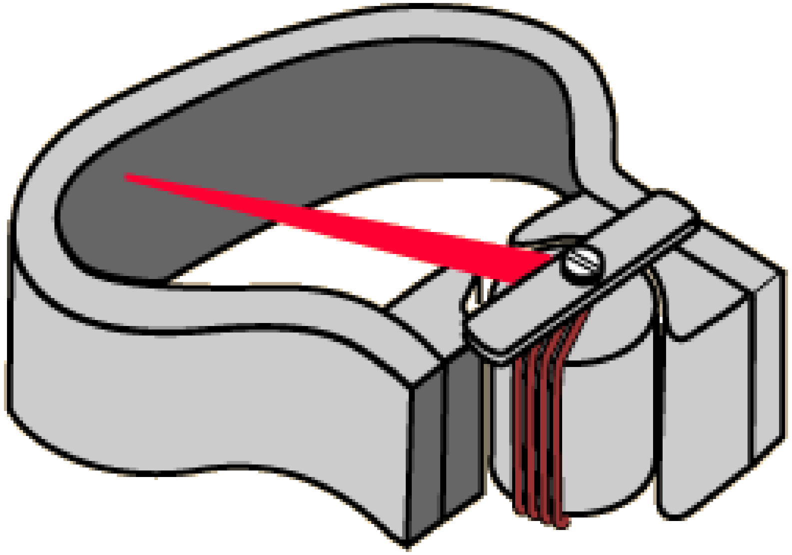
T_d is produced using one of the below effects:

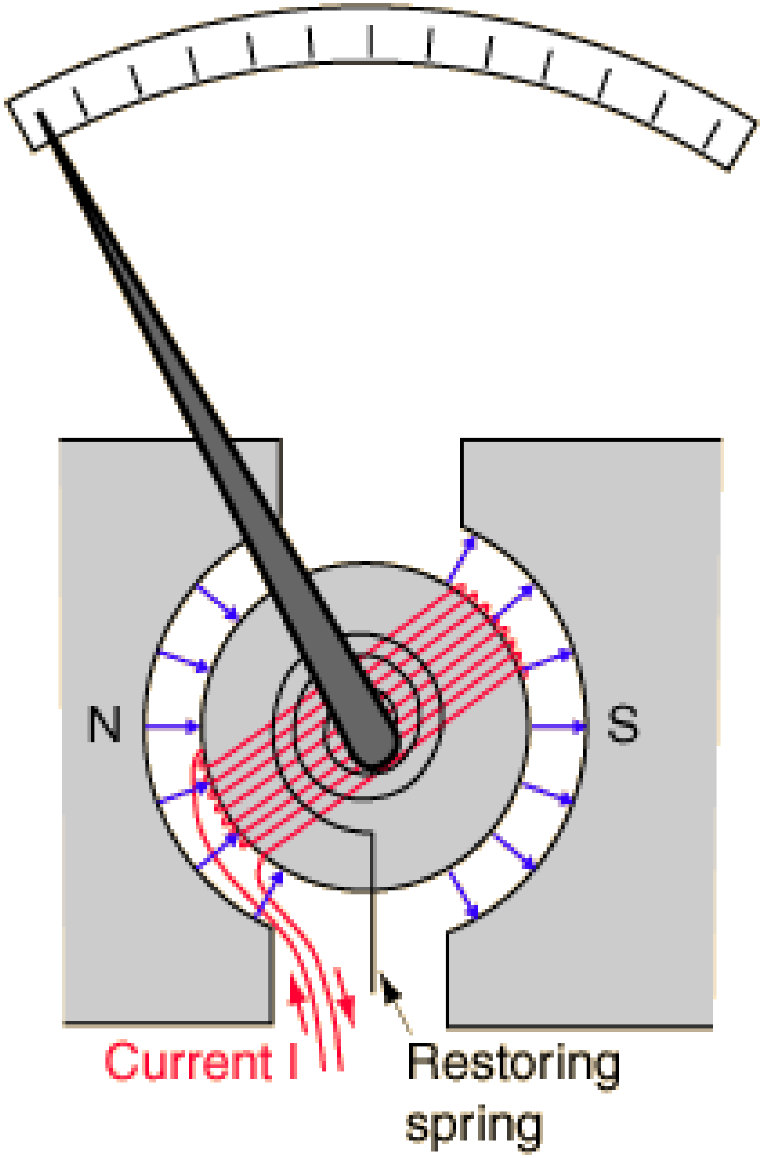
- electromagnetic
- electrodynamic
- inductive
- thermal
- electrostatic

1. All these effects can be related to electric current.
2. **T_d** causes the moving system to move from its zero position.
3. Some deflection instruments are totally not electrically related

   e.g.: Bourdon tube ***pressure meter***.

Galvanometer – Electric current **detector**





PMMC

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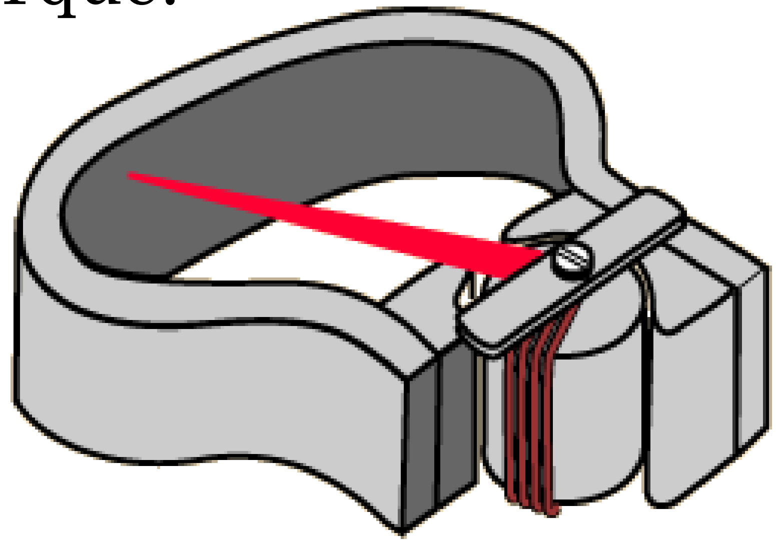
PMMC: Permenant Magnet Moving Coil (d'Arsonval Movement)

- The equation for the developed torque derived from the basic law for electromagnetic torque:
- $$T = B \times A \times I \times N$$



- **T**= Torque (N.m)
- **B**= Air-gap Flux density
- **A**= Effective coil area
- **I**= Current in the moving coil
- **N**= turns on the coil

Deflection Instrument Fundamentals

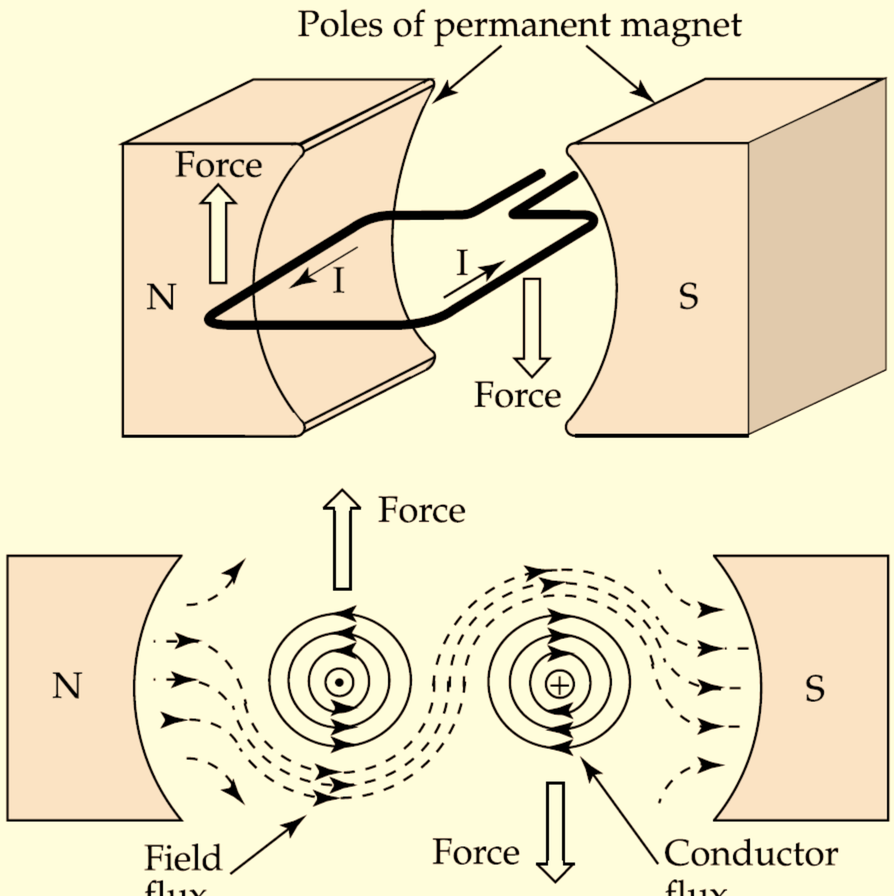


Figure 3-1 The deflecting force in a PMMC instrument is produced by the current in the moving coil. This sets up a magnet flux which interacts with the flux from the poles of the permanent magnet.

Deflection Instrument Fundamentals

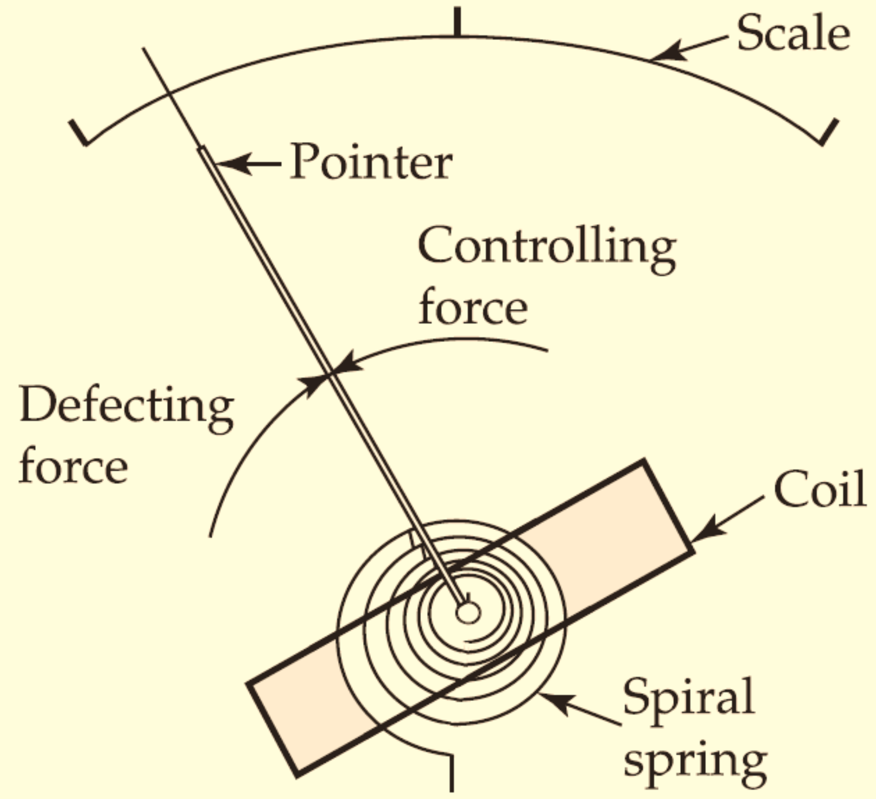
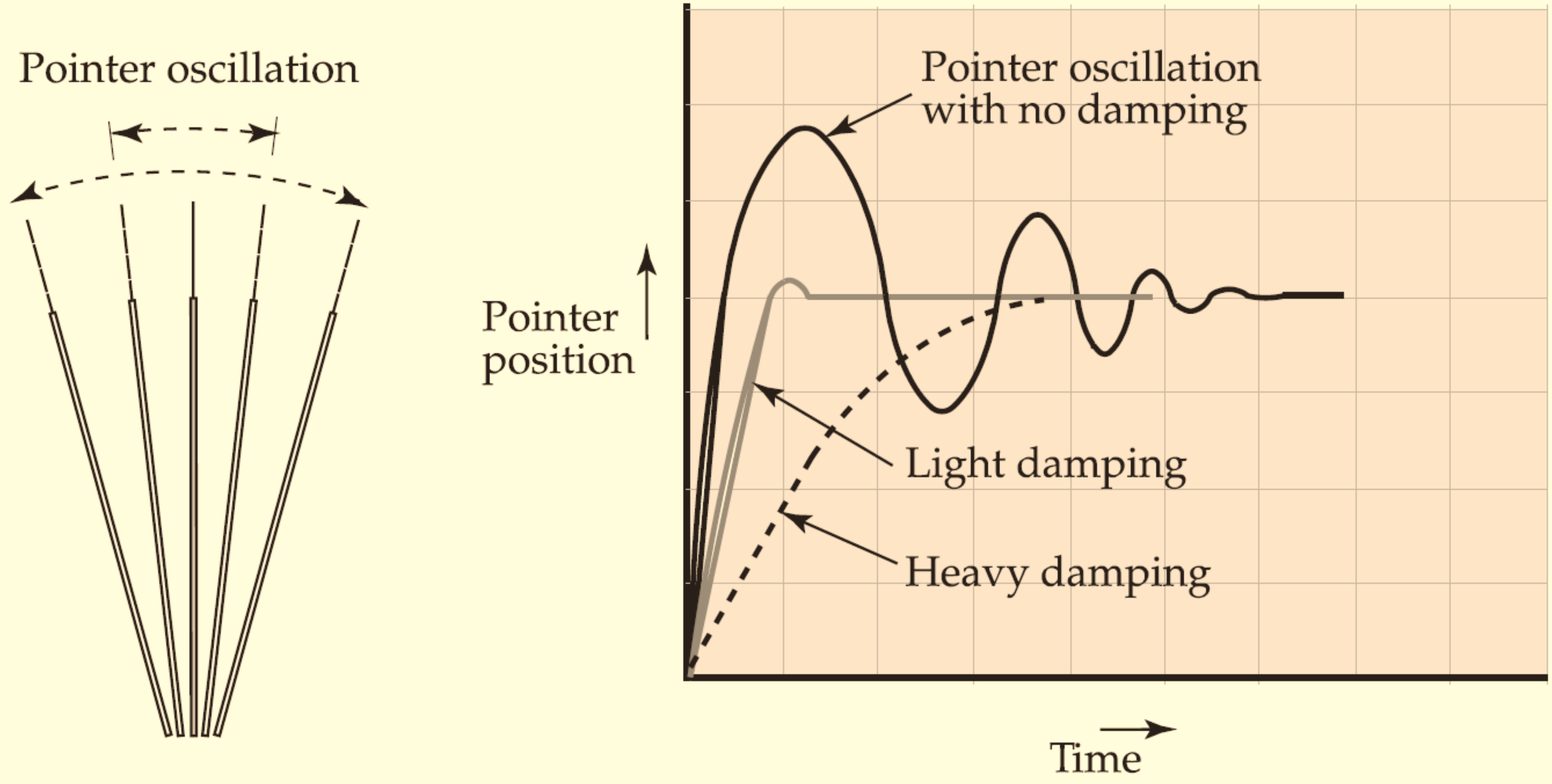


Figure 3-2 The controlling force in a PMMC instrument is provided by spiral springs. The two forces are equal when the pointer is stationary.

Suspension



(a) Absence of damping force causes the pointer to oscillate

Permanent Magnet Moving Coil Instrument

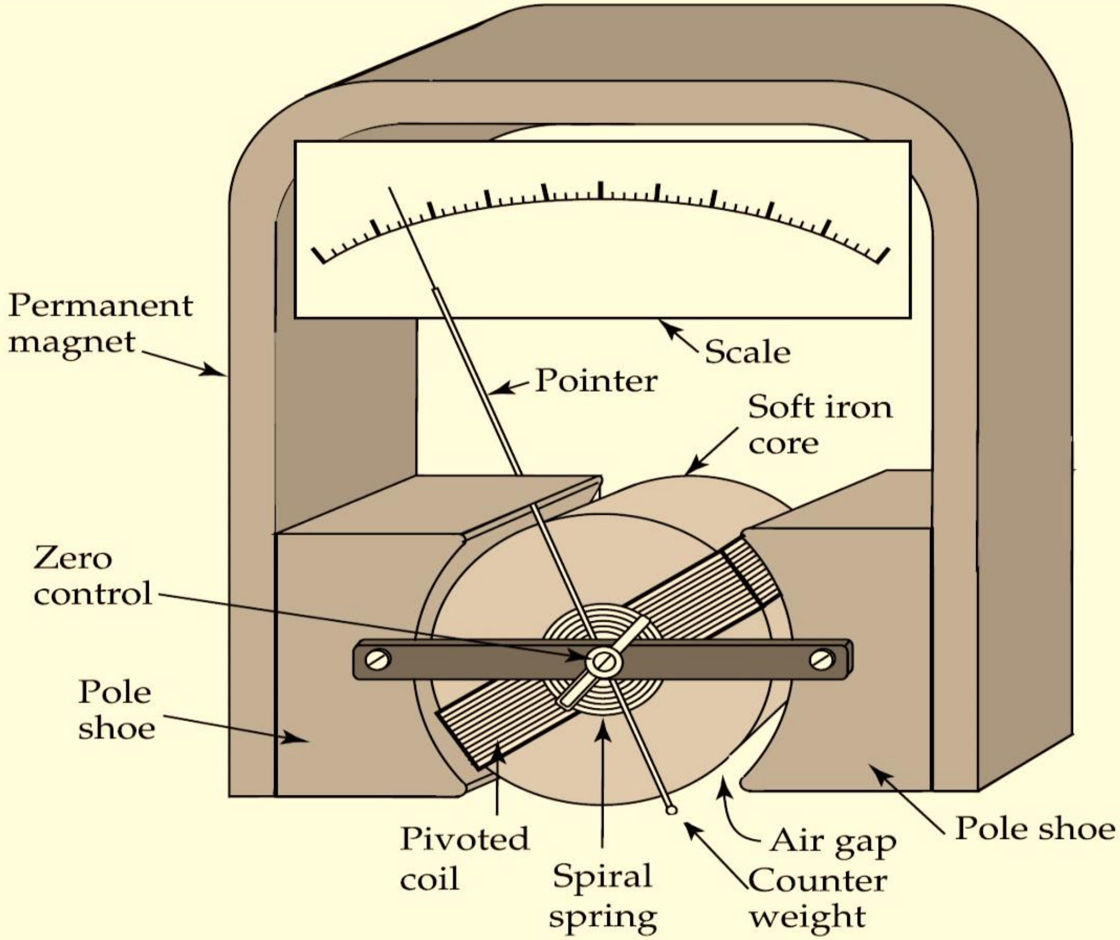


Figure 3-6 A typical PMMC instrument is constructed of a horseshoe magnet, soft-iron pole shoes, a soft-iron core, and a suspended coil that moves in the air gap between the soft-iron core and the pole shoes.

Construction of Permanent Magnet Moving Coil Instrument

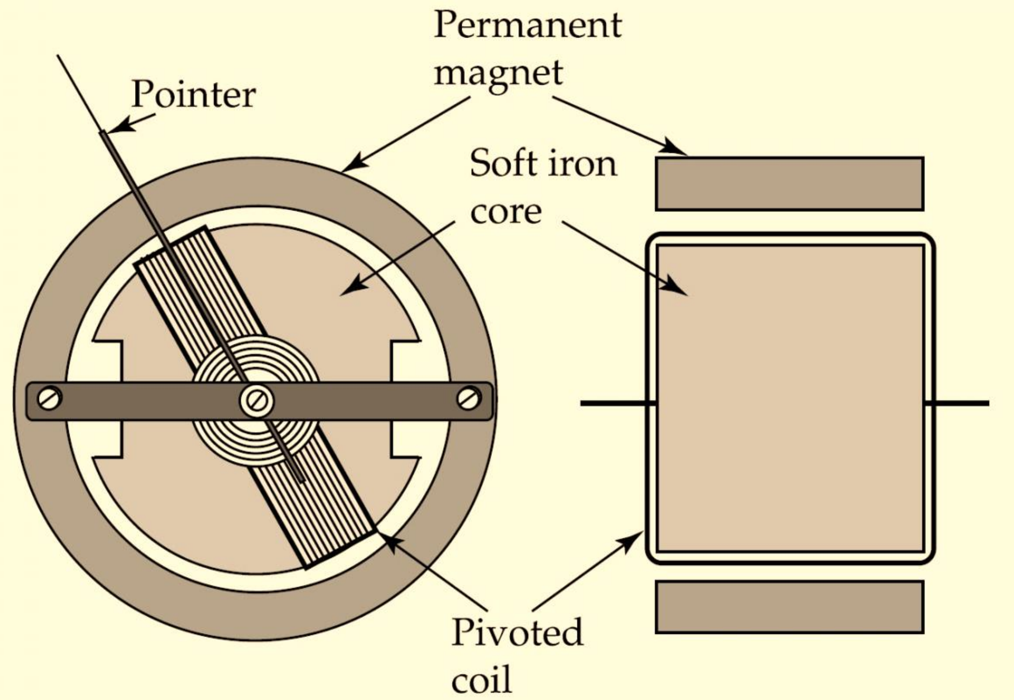
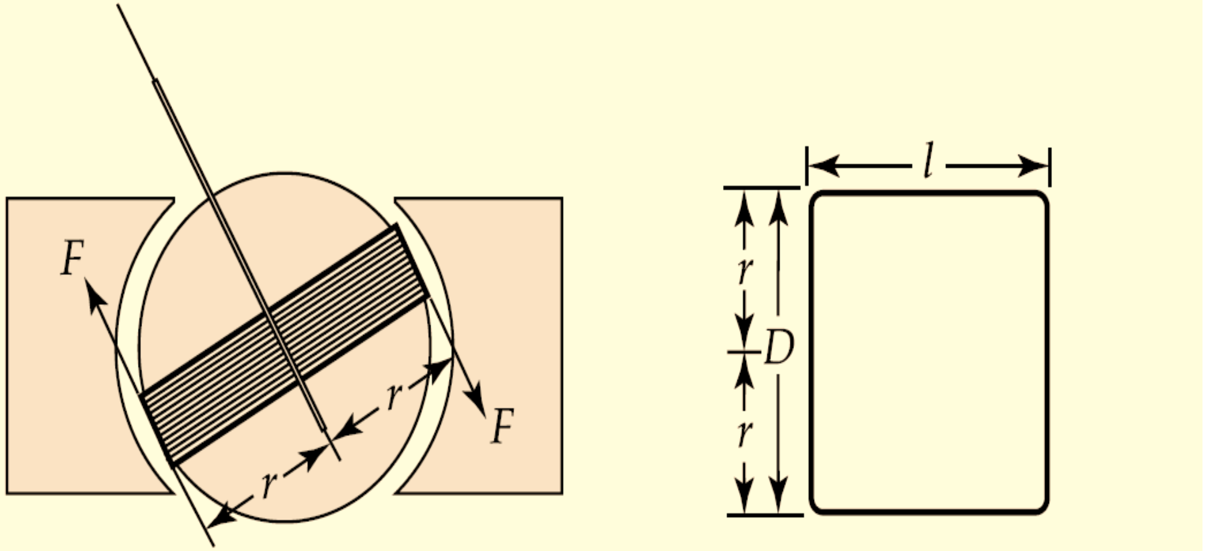


Figure 3-7 In a core-magnet PMMC instrument, the permanent magnet is located inside the moving coil, and the coil and magnet are positioned inside a soft-iron cylinder.

Torque Equation & Scale



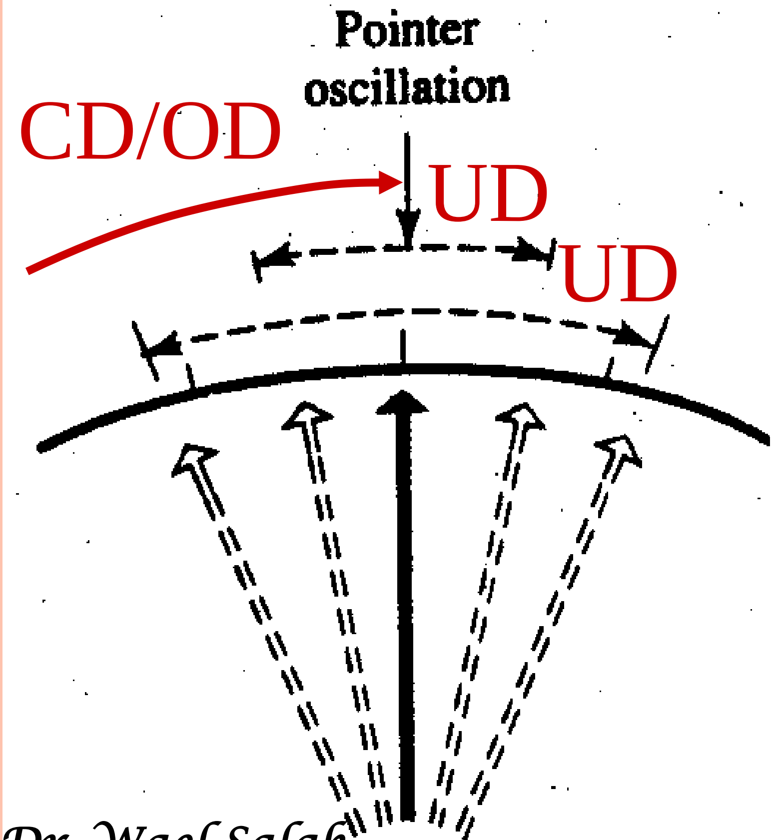
(a) Force F acts on each side of the coil

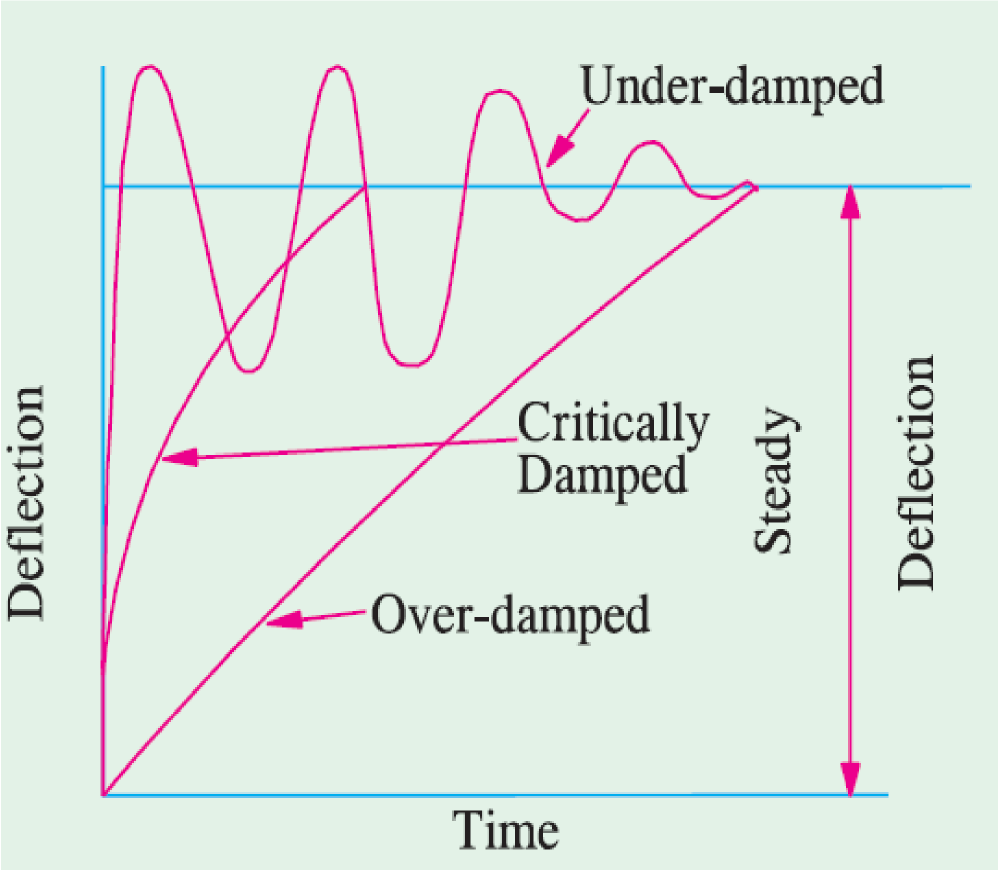
(b) Area enclosed by the coil

Figure 3-8 The deflecting torque on the coil of a PMMC instrument is directly proportional to the magnetic flux density, the coil dimensions, and the coil current. This gives the instrument a linear scale.

Damping Torque

- acts on the moving system only when it is moving and always **opposes** **its movement**
- Efficient damping: quickly reach final position without overshooting.





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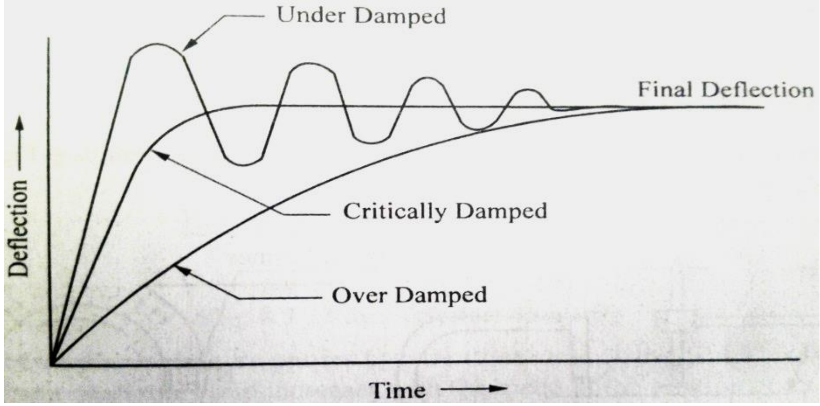
Over Damping:

The coil returns slowly to its rest position without overshoot or oscillation.

Under Damping:

The coil movement is subjected to sinusoidal oscillation.



Critical Damping:

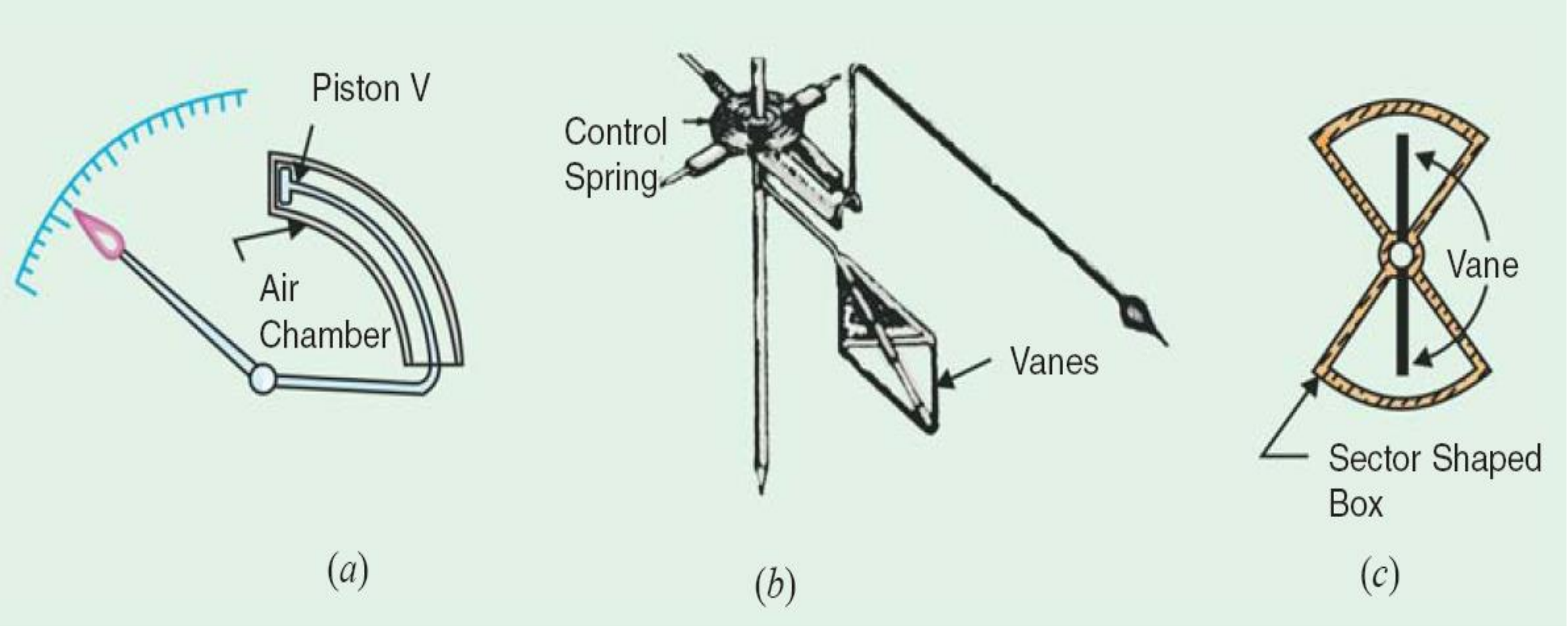
The coil returns immediately to its steady-state position without oscillation.

Method of Damping

1- Mechanical

- **Air** friction (used if eddy current is not suitable)
- **fluid** friction (not often used)

Air friction damping: Air-chamber and Vanes



Method of Damping

2- Electromagnetic

Eddy current (very efficient)

3- Electrical

CDRE: Critical Damping Resistance External

The CDRE connected in parallel with the coil.

Controlling / restoring / balancing torque (T_C)

T_C opposes T_d

T_C increases with deflection angle (θ)

When $T_C = T_d$, the moving system will be at rest.

When T_d is removed, the moving system will be returned (restored) back its zero position by T_C.

If T_C is not introduced to the moving system, the moving system will move ***continuously*** over its maximum deflection position, as long as $\mathbf{T_d > 0}$.

Two methods for T_C:

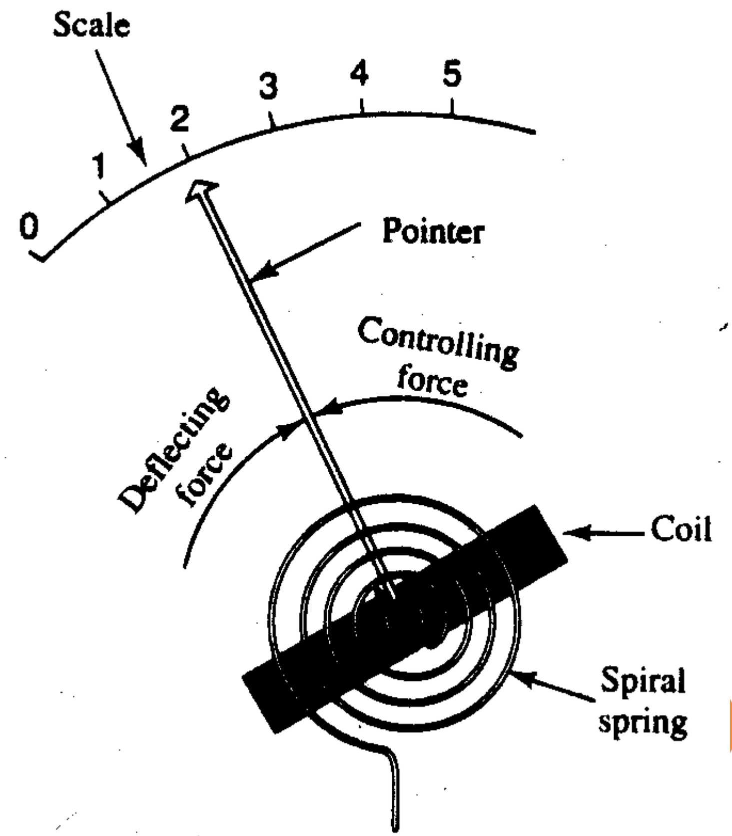
- A **spring** - spring control
- A **weight** - gravity control

Methods for Controlling Torque (T_C) ....

1) Spring control

A spirally wound hair-spring is used.

When the spring is twisted from it equilibrium position, a restoring torque (T_C) is produced.



Example:

Permanent-magnet moving coil (PMMC) instruments:

$T_d \propto I$

However, $T_C \propto \theta$

At $T_C = T_d$, $\theta \propto I$

or $I \propto \theta$ (the scale is linear)

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Spiral spring characteristics:

The number of turns is fairly large so that no deformation on the spring occurs. Then

$T_C = K\theta \quad \text{for } 0 \le \theta \le \theta_{max}$

K = spring constant (N-m/degree)

θ = deflection angle from $T_C = 0$ position.

Materials to make the spring must be:

- non-magnetic
- not subject to much deterioration with time
- low temperature coefficient of spring constant

Hence, phosphor-bronze material is used.

2) **Gravity control** (seldom used nowadays)

Based on adding some **weights** to control the movement of the indicator.

Temperature Compensation

- **Magnetic Field strength** decrease with temp
- **Spring Tension** decrease with temp
- **Coil Resistance** increase with temp.

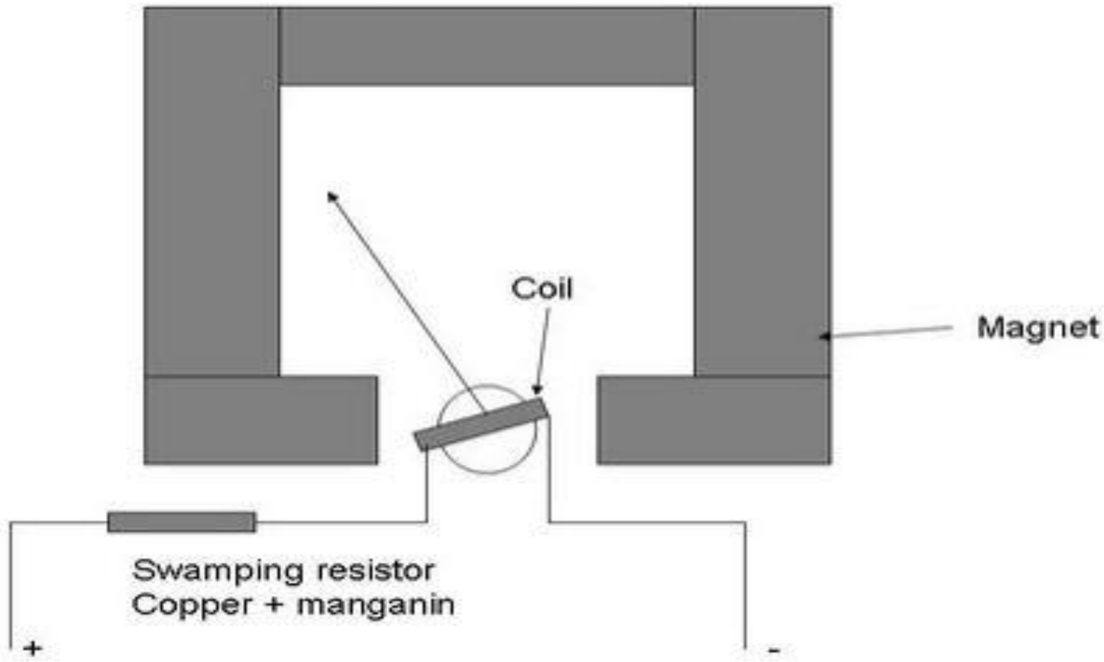
These factors causes the pointer to read low for a given current with respect to magnetic field strength.

The temperature may be compensated by appropriate use of series and shunt resistors with the moving coil.

Temperature Compensation ……………….

The simple temperature compensation circuit for PMMC uses a resistance in series with a movable coil, as shown in the figure. The resistor is called swamping resistor. It is made up of manganin having practically zero temperature coefficients, combined with copper in the ratio of 20/1 or 30/1.

Simple temperature compensation for PMMC

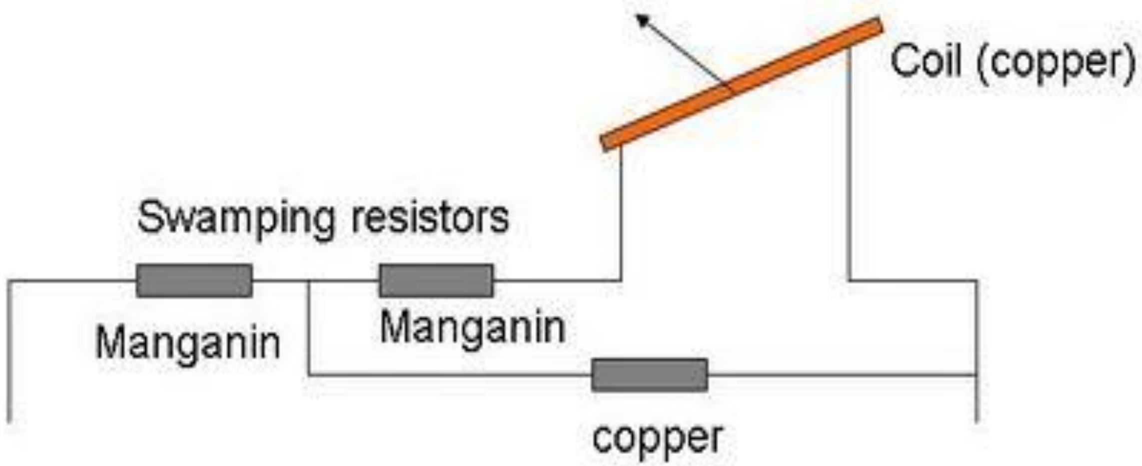


The resultant resistance of the coil and the swamping resistor increases slightly as temperature increases, just enough to compensate the change in springs and magnet due to temperature. Thus the effect of temperature is compensated.

Temperature Compensation …………

More complicated but complete cancellation of temperature effects can be obtained by using the swamping resistors in series and parallel combination as shown in figure.

Improved temperature Compensation



In this circuit, by correct proportioning of copper and manganin parts, complete cancellation of the temperature effects can be achieved.

Indicating instruments for current and voltage measurements

First Exam on

30/03/2015

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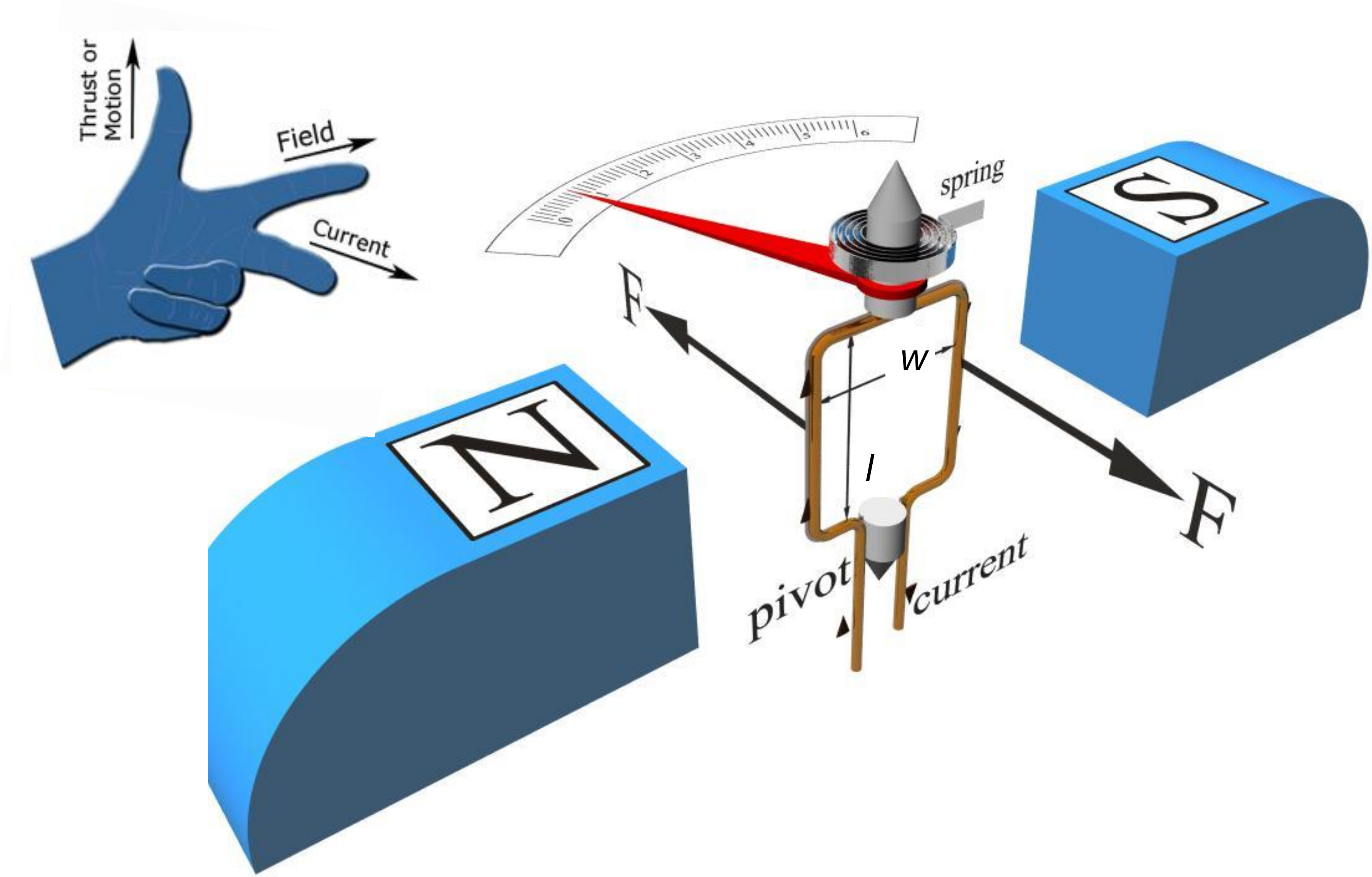
Moving Coil Instruments as DC or AC ammeters & voltmeters

1. ***Permanent magnet moving coil* (PMMC)**
   - a moving coil & a pair of permanent magnets (basically for DC measurements)
2. ***Dynamometer* or *electrodynamic***
   - a moving coil and a pair of fixed coils (for **DC** and **AC** measurements)

PMMC - low N (hence low L_{coil}), R_{coil} and V_{drop}

Dynamometer - large N, moderate R_{coil} and moderate L_{coil}

PMMC



Reference: http://physbin.com/portfolio/imgs2/index_imgs_topic-051mag-g-elecdyn.htm

Current range extension

DC Ammeters: by a **shunt** (low R)

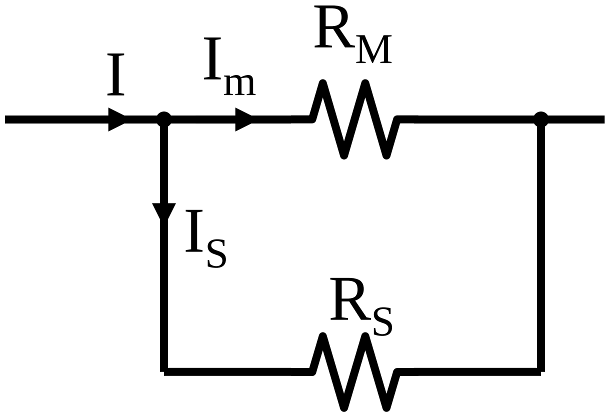
Multiplying power (Meter current very low)

$I_m = I_{FSD}$

$V_{shunt} = V_{movement}$

$I_s R_s = I_m V_m$

$$R_s = \frac{I_m R_m}{I_S}$$



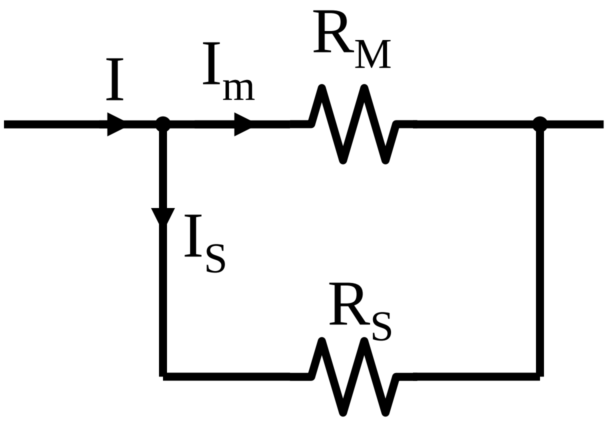
$I_s = I - I_m$

$$R_s = \frac{I_m R_m}{I - I_m}$$

Example:

A 1 mA meter movement with internal resistance of 100 ohm, is to be converted into a 0-100 mA ammeter. Calculated the value of shunt resistor required.

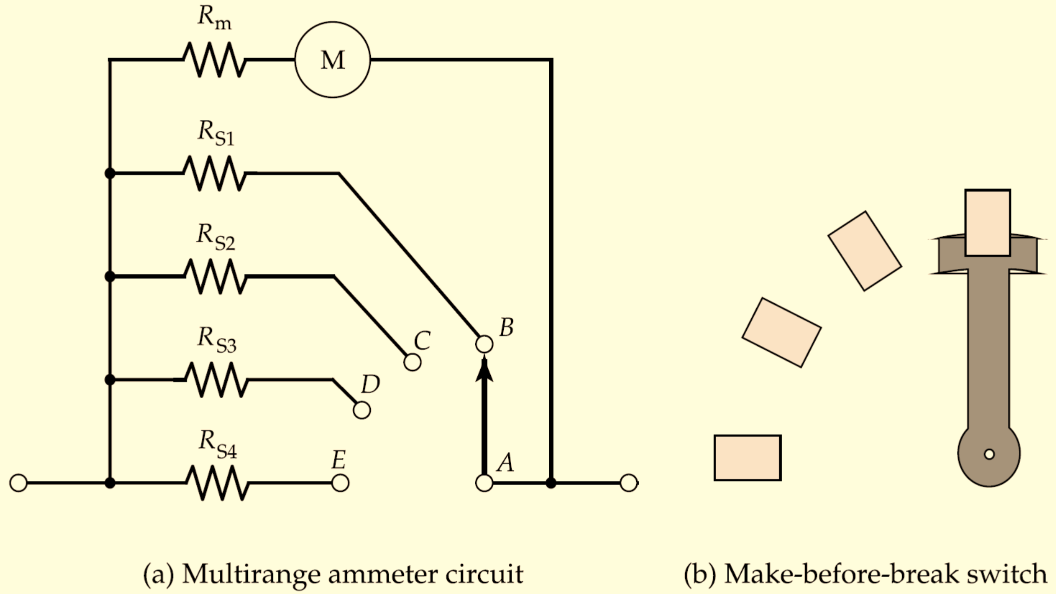
$$R_s = \frac{I_m R_m}{I - I_m} = \frac{1 \times 10^3 \times 100}{100mA - 1mA} = 1.01\Omega$$



Current range extension

*** The current range of a dc ammeter can be further extended by range switch to form multiage ammeter.**

- **R1,…R4 gives different current ranges.**



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

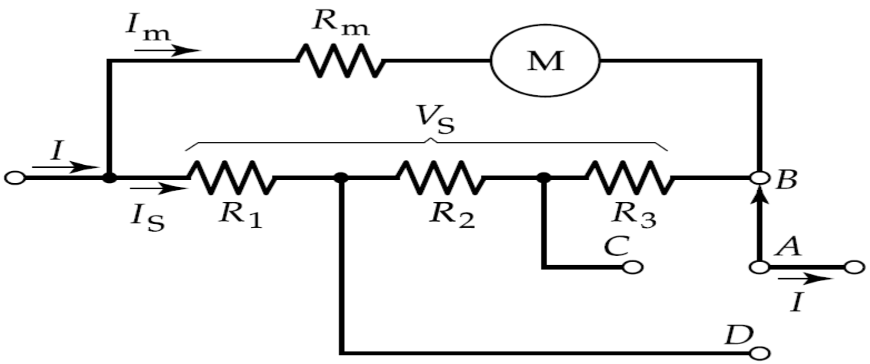
Figure 4-3 A multirange ammeter consists of a PMMC instrument, several shunts, and a switch that makes contact with the next shunt before losing contact with the previous one when range switching.

For this type: During changing the shunt by selector switch the meter is connected directly without shunt ➔ This may cause the damage of the meter.

Ayrton (Universal) Shunt

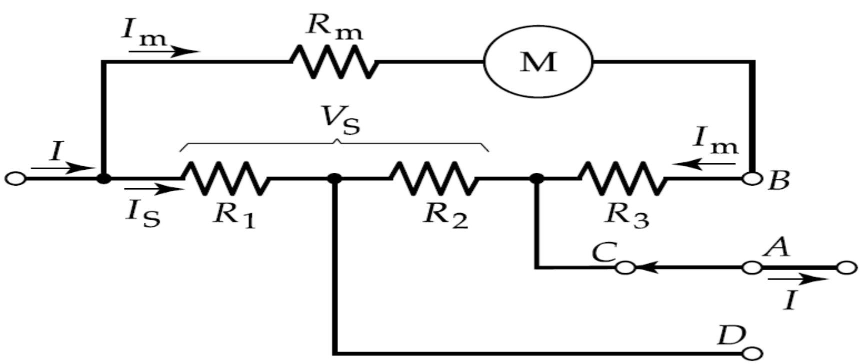
➔ This connection will eliminate the possibility of having the meter circuit without shunt.

➔ For higher current range the shunt resistor should be lower



(a) Ayrton shunt and meter

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



(b) Switch at terminal C

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

Example:

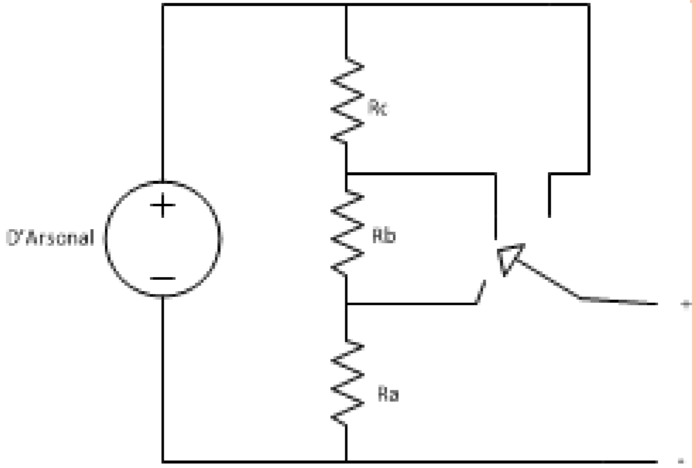
Design an Ayrton shunt Ammeter using D'Arsonal movement to measure current with ranges of 1A, 5A and 10A. Given that the meter internal resistance Rm=50 Ω and the Full Scale Deflection current is 1 mA.

$$I_s = I - I_m = 1A - 1mA = 999\ mA$$

$$R_a + R_b + R_c = \frac{1 \times (50\Omega)}{999} = 0.050005\Omega$$

$$R_a + R_b = \frac{1 \times (R_c + 50\Omega)}{4.999}$$

$$R_a = \frac{1 \times (R_b + R_c + 50\Omega)}{9.999}$$

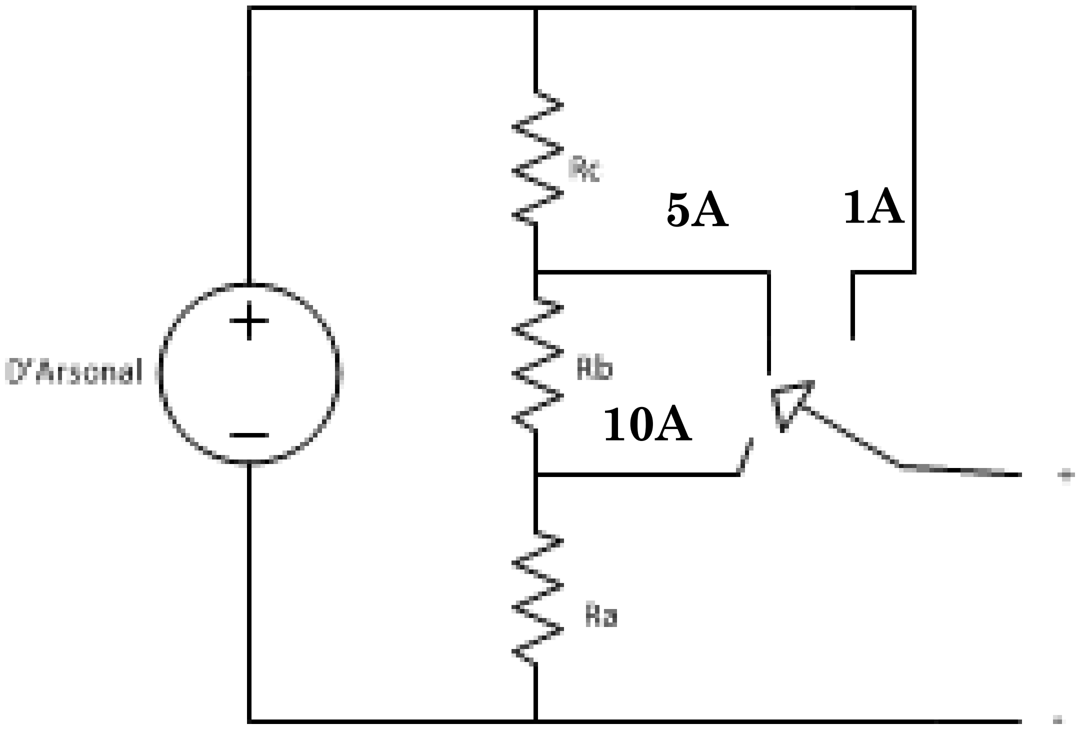


Solving Equations 1, 2 and 3 giving:

$$R_a = 0.0050005\Omega$$

$$R_b = 0.0050005\Omega$$

$$R_c = 0.04004\Omega$$



For lager current value we need smaller resistor

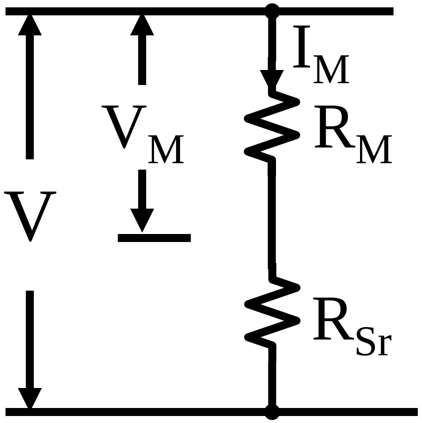
Voltage range extension

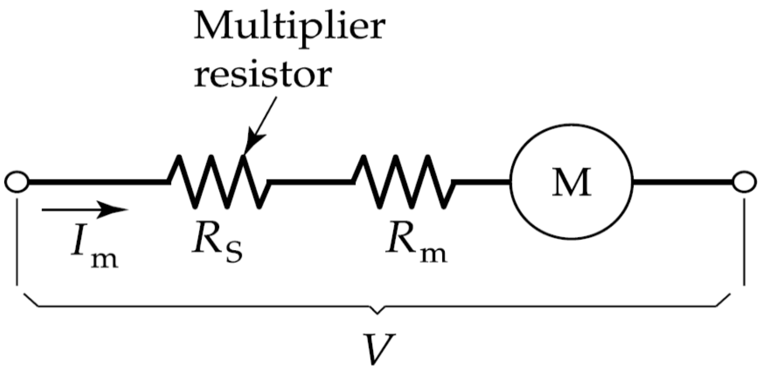
DC Voltmeters: by a **multiplier** (high R)

Voltage magnification

$$V = I_m (R_s + R_m)$$

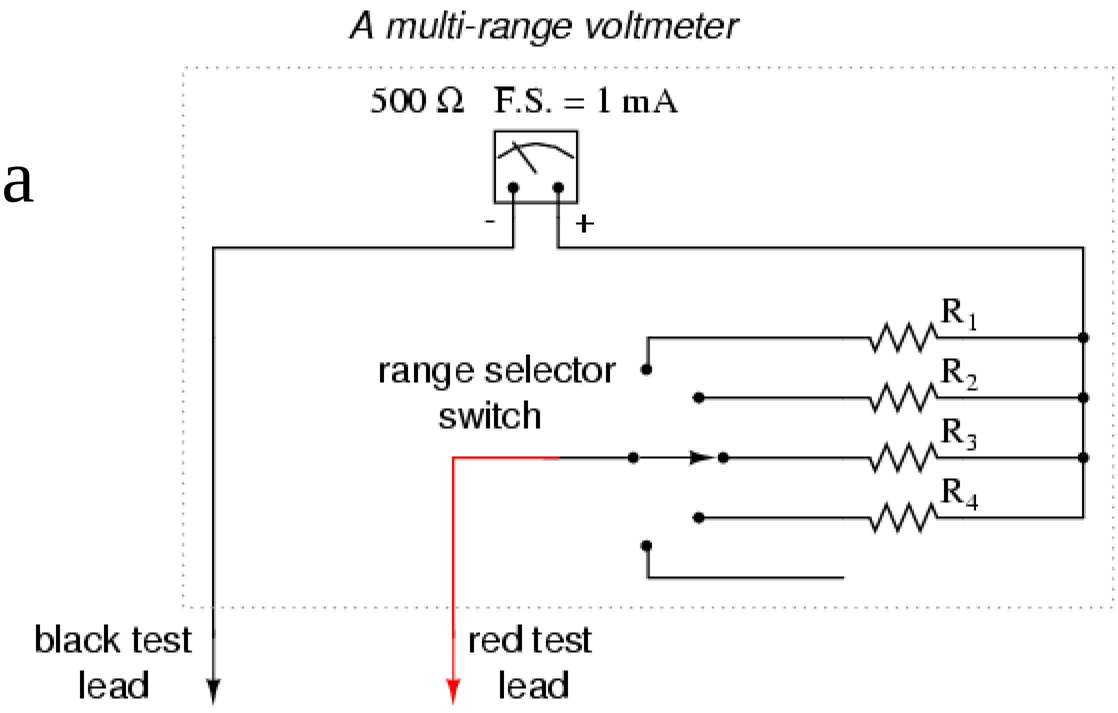
$$R_s = \frac{V - I_m R_m}{I_m} = \frac{V}{I_m} - R_m$$



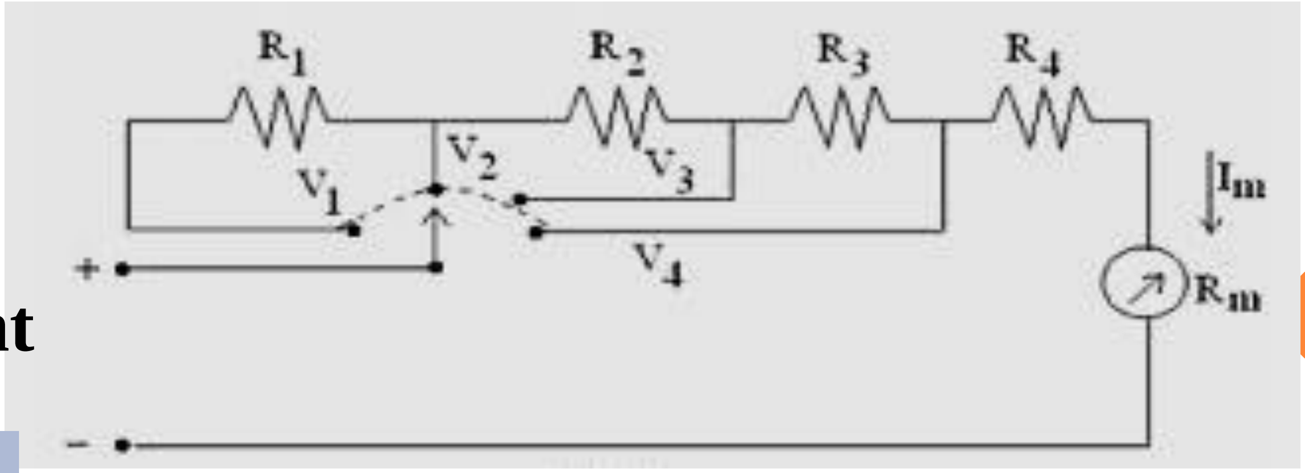


Multi range Voltmeter

DC Voltmeters: by a **multiplier** (high R)

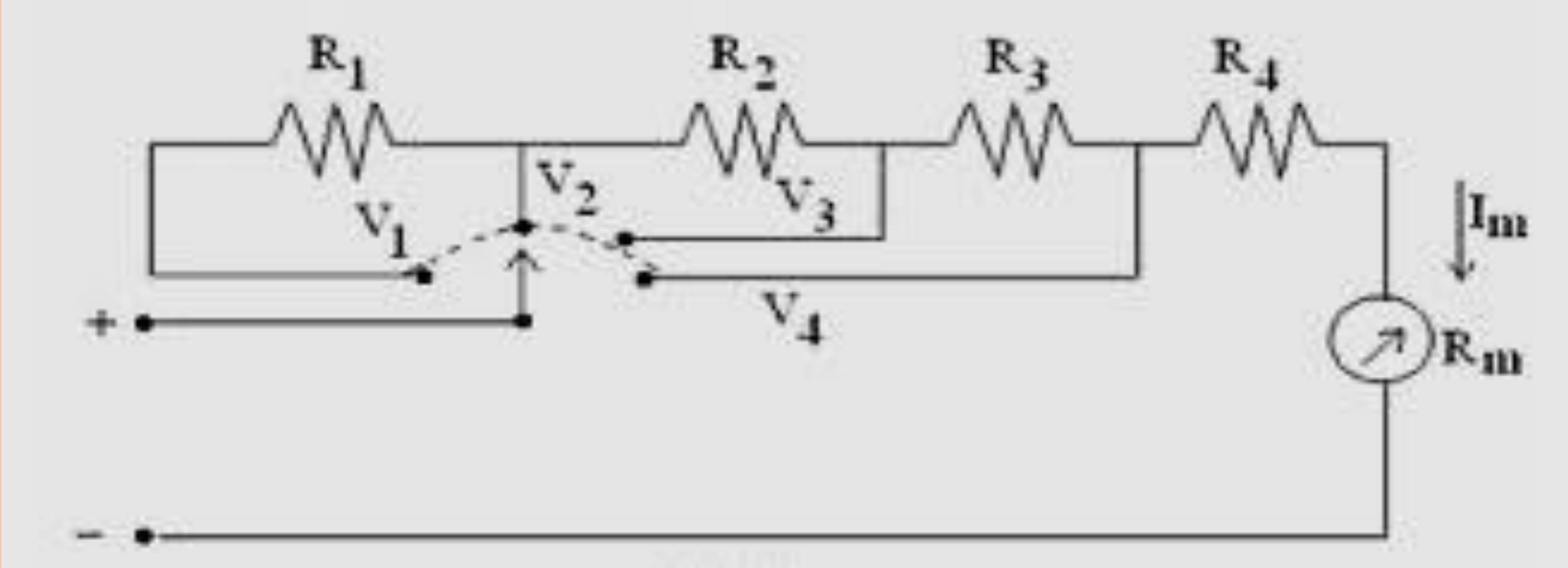


More practical arrangement



More practical arrangement

- Resistors are connected in series
- Advantage: All multiplier resistor except 1st (R4) one have standared resistor values.



Example:

A basic D'Arsonal movement with an internal resistance of 100Ω, and full scale current of 1mA, to be converted into a multirange dc voltmeter with series connected resistor to measure voltages ranges 10V, 50V, 250V and 500V.

10 V (posisi V4)

$$R_T = \frac{10V}{1mA} = 10\ k\Omega$$

$$R_4 = R_T - R_m = 10\ k\Omega - 100k\Omega = 9{,}900\Omega$$

50 V (posisi V3)

$$R_T = \frac{50\ V}{1\ mA} = 50\ k\Omega$$

$$R_3 = R_T - (R_4 + R_m) = 50\ k\Omega - 10k\Omega = 40k\Omega$$

250 V (posisi V2)

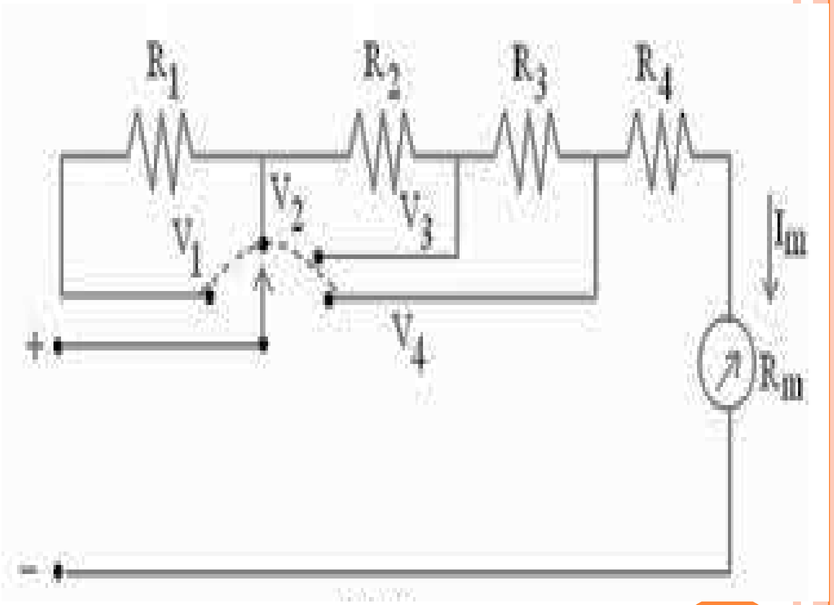
$$R_T = \frac{250\ V}{1\ mA} = 250\ k\Omega$$

$$R_2 = R_T - (R_3 + R_4 + R_m) = 250k\Omega - 50k\Omega = 200k\Omega$$

500 V (posisi V1)

$$R_T = \frac{500V}{1\ mA} = 500k\Omega$$

$$R_1 = R_T - (R_2 + R_3 + R_4 + R_m) = 500\ k\Omega - 250k\Omega = 250k\Omega$$

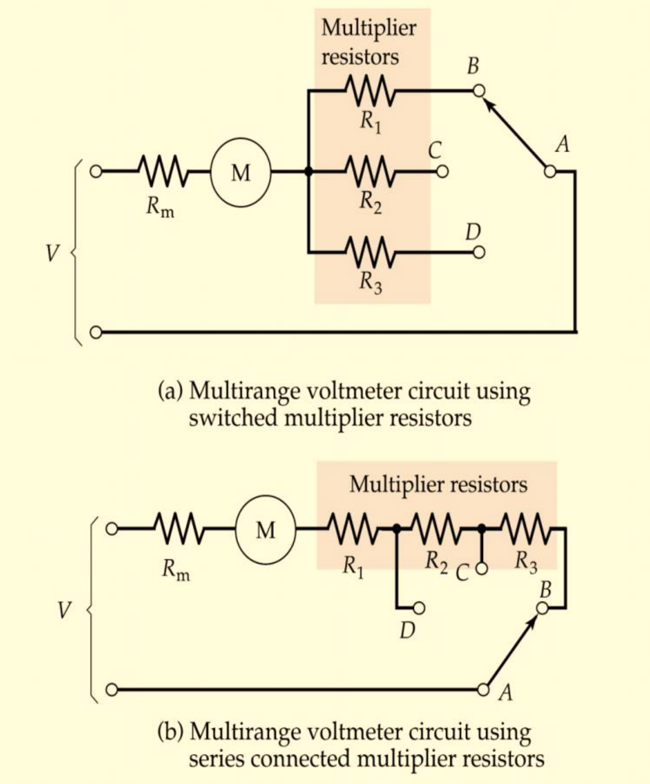


Voltmeter Sensitivity

Voltmeter Sensitivity: ratio of the total resistance / range of voltage

Example 10KΩ / 10V = 1000 Ω / V (for last example)

$$S = \frac{1}{I_{fsd}} \frac{\Omega}{V}$$



(a) Multirange voltmeter circuit using switched multiplier resistors

(b) Multirange voltmeter circuit using series connected multiplier resistors

S = Sensitivity of the voltmeter
V = Voltage range
Rm = Movement internal resistance + R4
Rs= Resistance of the multiplier.

$$R_T = S \times V$$

$$R_S = (S \times V) - R_m$$

Example: with reference to the previous example

$$S = \frac{1}{I_{fsd}} = \frac{1}{0.001A} = 1{,}000\frac{\Omega}{V}$$

R4 $$R_S = (\frac{1000\Omega}{V}) \times 10V - 100\Omega = 9{,}900\Omega$$

R3 $$R_S = (\frac{1000\Omega}{V}) \times 50V - 10{,}000\Omega = 40k\Omega$$

R2 $$R_S = (\frac{1000\Omega}{V}) \times 250V - 50k\Omega = 200k\Omega$$

R1 $$R_S = (\frac{1000\Omega}{V}) \times 500V - 250k\Omega = 250k\Omega$$

Voltmeter Loading Effect

Low Sensitivity meter may give correct reading when measuring voltage in low resistance circuits.

But it produce unreliable reading in high resistance circuits.

The voltmeter acts as a SHUNT for that portion of the circuit
- **➔ thus reduces the equivalent resistance**
- **➔ gives a lower indication of the voltage**

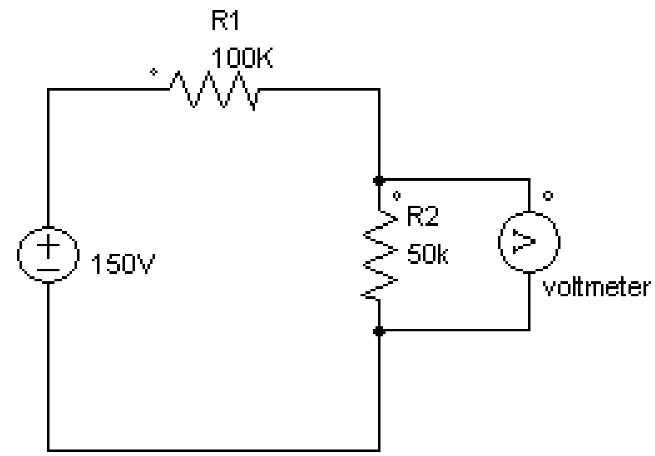
This called loading effect

Thus voltmeter with low sensitivity gives higher error

Voltmeter Loading Effect

The voltage across a 50kΩ resistor in a circuit. Two voltmeters are available for measurement. Voltmeter 1 with sensitivity 1,000Ω/V and voltmeter 2 with sensitivity 20,000Ω/V. Both meters are used on their 50V range.

- **Calculate the reading for each meter.**
- **Calculate the %Error in each reading.**



Solution:

$$V_{R2} = \frac{50k\Omega}{150k\Omega} \times 150V = 50V_{True\_Value}$$

$$V_{R2} = \frac{25k\Omega}{125k\Omega} \times 150V = 30V_{Meter1}$$

$$V_{R2} = \frac{46.6k\Omega}{146.6k\Omega} \times 150V = 48.36V_{Meter2}$$

$$R_{meter} = V_{range} \times S$$

$$R_{meter} \parallel R_2$$

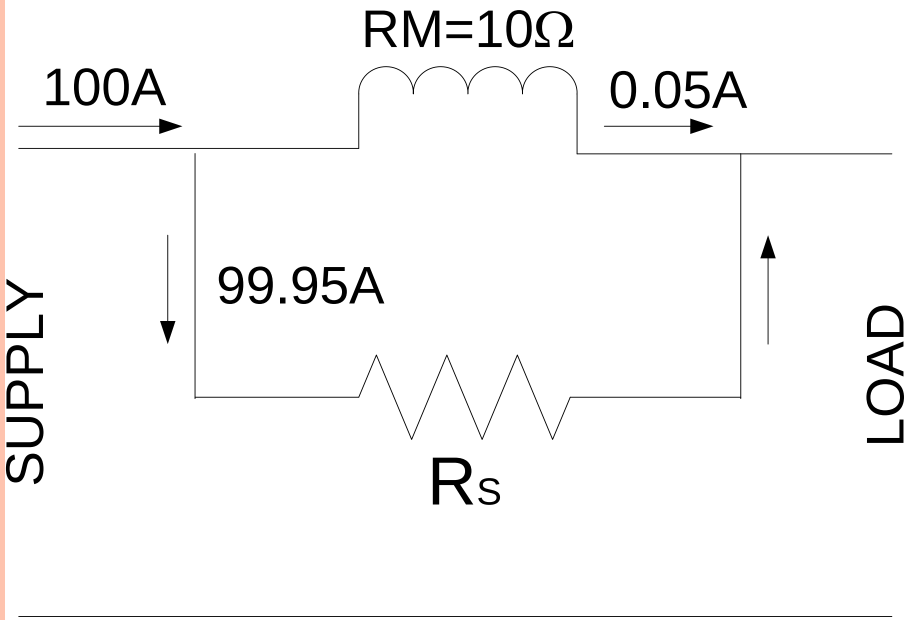
- **% Error 1 = 50-30/50*100% = 40%**
- **% Error 2 = 50-48.36/50*100% = 3.28%**

EXAMPLE:

A moving-coil instrument has a resistance of 10Ω and gives full-scale deflection when carrying a current of 50-mA.

Show how it can be adopted to measure voltages up to 750V and currents up to 100A.

SOLUTION:



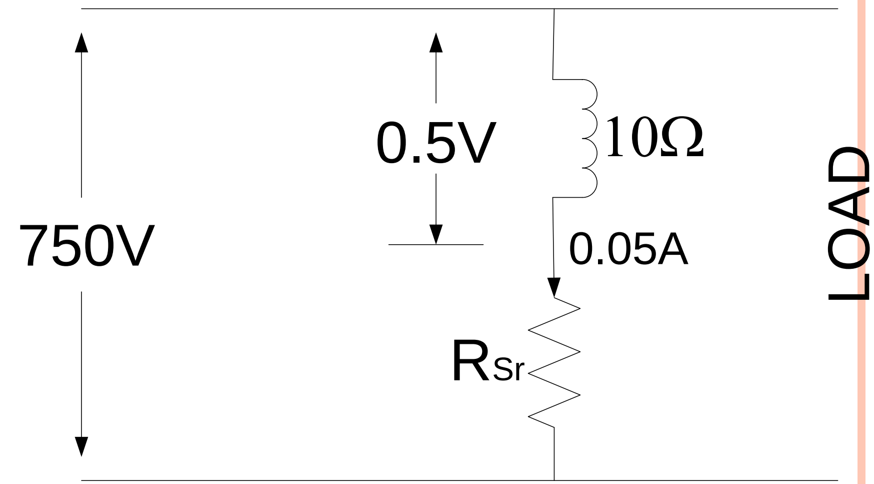
As ammeter:

Current range can be extended by using a shunt resistor across the instrument.

Obviously,

$10 \times 0.05 = R_S \times 99.95$

$\therefore \mathbf{R_S = 0.005\Omega}$



As voltmeter:

The range can be extended by using a high resistance placed in series with the instrument, R_{Sr}

Obviously, R_{Sr} must drop a voltage of (750 - 0.5)V = 749.5V while carrying 0.05A

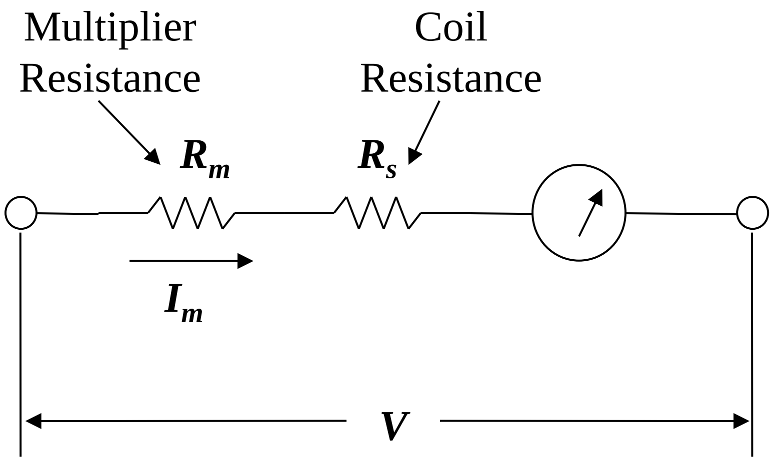
$\therefore \mathbf{0.05R_{Sr} = 749.5 \text{ or } R_{Sr} = 14.99k\Omega}$

EXERCISE:

A PMMC instrument with FSD of 100μA and a coil resistance of 30kΩ is to be converted into a voltmeter.

-Calculate the multiplier resistance required for the voltmeter to measure 10V at full scale.

-Determine the applied voltage when the instrument indicates 0.5 FSD and 0.1 FSD.



SOLUTION:

- At $V = 10\text{V FSD}$

$$I_m = 100\mu A$$

$$R_s = \frac{V}{I_m} - R_m = \frac{10V}{100\mu A} - 30k\Omega = 70k\Omega$$

- At $V = 0.5\text{ FSD}$

$$I_m = 0.5 \times 100\mu A = 50\mu A$$

$$V = I_m(R_m + R_s) = 50\mu A(70k\Omega + 30k\Omega) = 5V$$

- At $V = 0.1\text{ FSD}$

$$I_m = 0.1 \times 100\mu A = 10\mu A$$

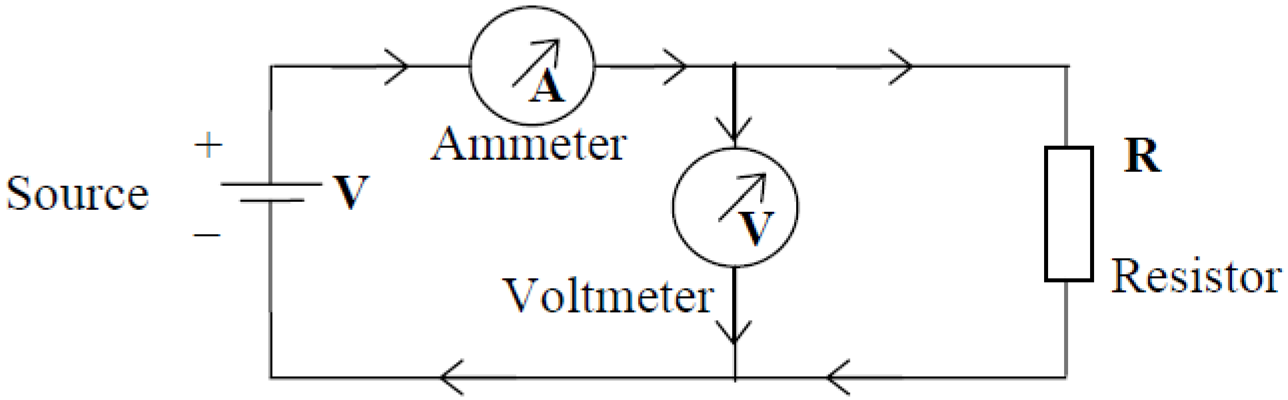
$$V = I_m(R_m + R_s) = 10\mu A(70k\Omega + 30k\Omega) = 1V$$

Indicating instruments for Resistance measurements

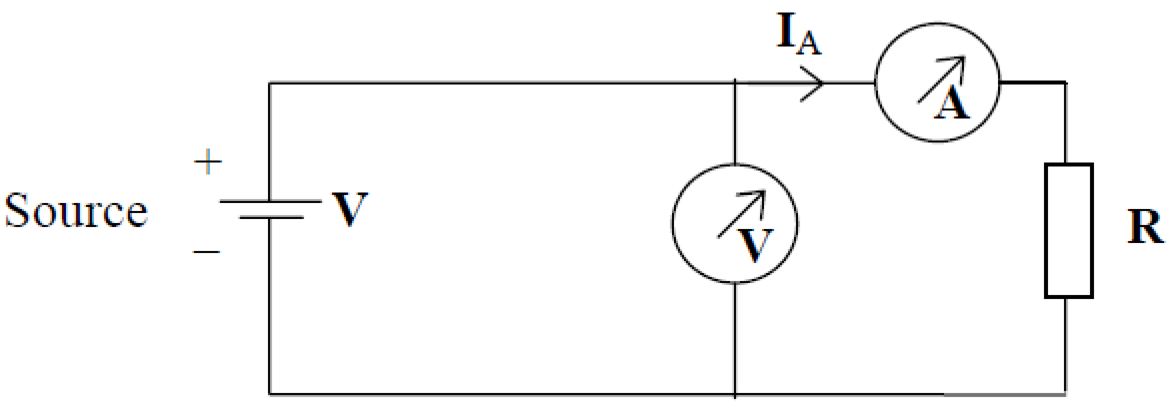
Dr. Wael Salah

Voltmeter Ammeter Method for Measuring Resistance

Low R



High R



Resistance

the potential difference appearing across a device is proportional to the current flowing through it.

The connecting relationships is known as

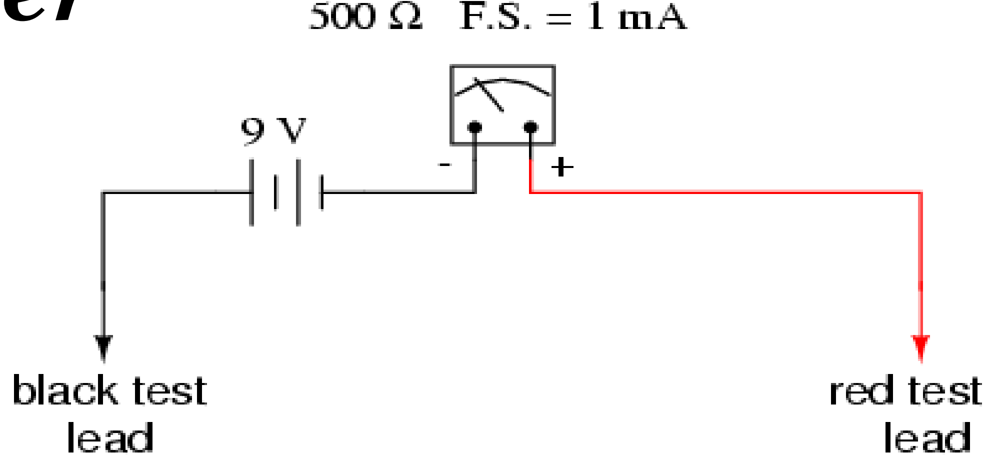
Ohm's law and is written:

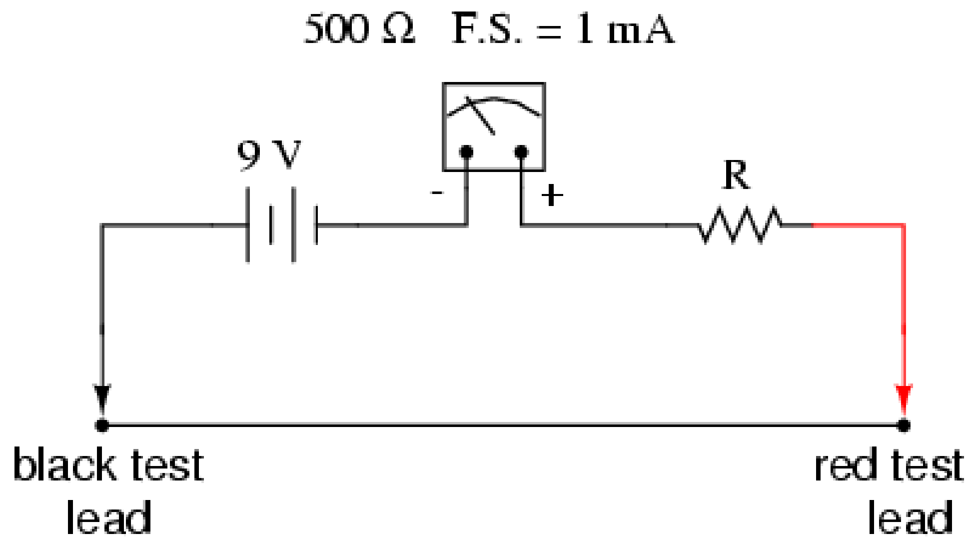
$$V = IR$$

where R is the resistance and is measured in ohms (Ω).

Simple Voltmeter

A simple ohmmeter





If the test leads of this ohmmeter are directly **shorted** together **(measuring zero Ω),** the meter movement will have a **maximum** amount of current through it, limited only by the battery **voltage** and the movement's internal **resistance**

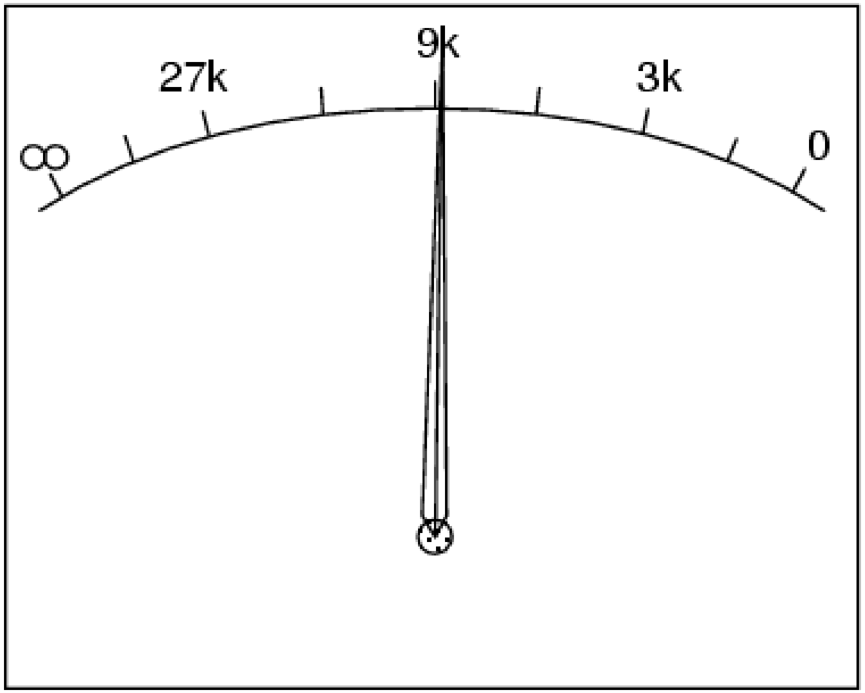
Simple Voltmeter

To determine the proper **value for R**, we calculate the total circuit resistance needed to limit current to 1 mA (full-scale deflection on the movement) with 9 volts of potential from the battery, then subtract the movement's internal resistance from that figure:

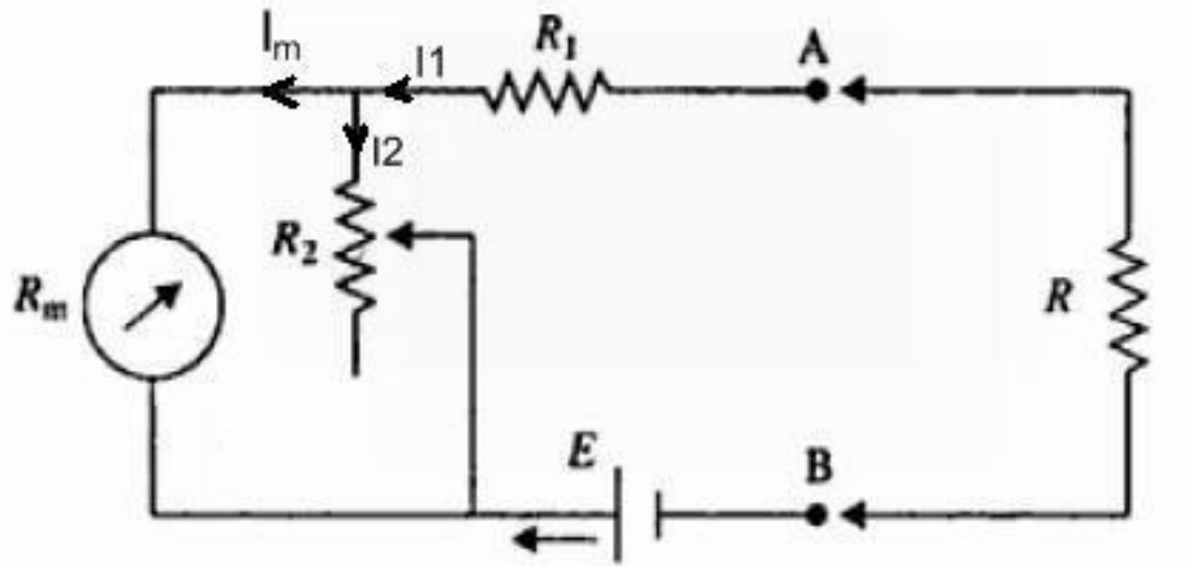
$$R_{total} = \frac{E}{I} = \frac{9\ V}{1\ mA}$$

$$R_{total} = 9\ k\Omega$$

$$R = R_{total} - 500\ \Omega = 8.5\ k\Omega$$



Series-Type Ohmmeter



Basic series type ohmmeter.

R1 = current limiting resistor,
R2 = zero adjusting resistor,
E = emf of internal battery,
Rm = internal resistance of d'Arsonval movement,
R = the unknown resistor

Series-Type Ohmmeter

- The current the the meter depends on the value of unknown resistor.
- Calibration problem should be taken into account.
- When R=0 Ω (terminals A and B are shorted).
- R=0 Ω ➔ indicated the full-scale current I_{fsd}
- R= ∞, indicates zero current
- The disadvantage of this type is that battery voltage decreases with time and age. Though not giving zero reading when shorted.
- Change of the value of R1 : could change the calibration along the scale.
- The solution for battery aging is by zero adjustment using R2.

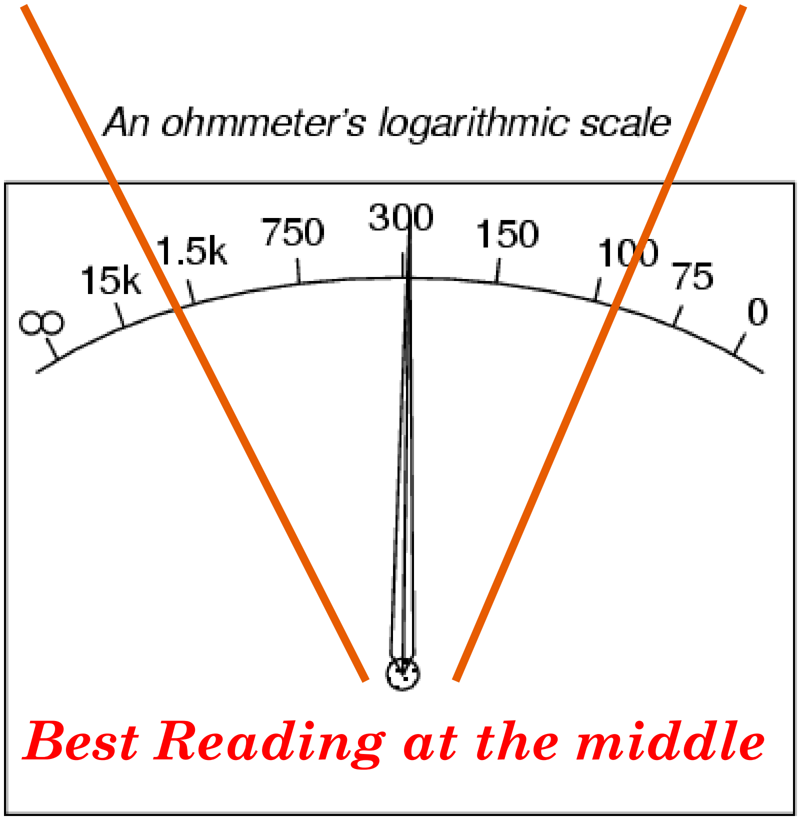
logarithmic scale

The scale of an ohmmeter does not smoothly progress from **zero to infinity** as the needle sweeps from right to left.

The scale starts out "expanded" at the right-hand side, with the successive resistance values growing **closer and closer to each other toward the left** side of the scale

Infinity cannot be approached in a linear (even) fashion, because the scale would ***never*** get there!

With a logarithmic scale, **the amount of resistance spanned for any given distance on the scale** increases as the scale progresses toward infinity, making infinity an attainable goal.



- In the design of series-type ohmeter, the design based on the value of unknown resistor (R) that cause half-scale current I_{hsd}

$$R = R_h$$

- R_h should be equal to the total ohmmeter resistance

$$R_h = R_1 + \frac{R_2 R_m}{R_2 + R_m}$$

- Rh reduces meter current to 0.5 I_{fsd}

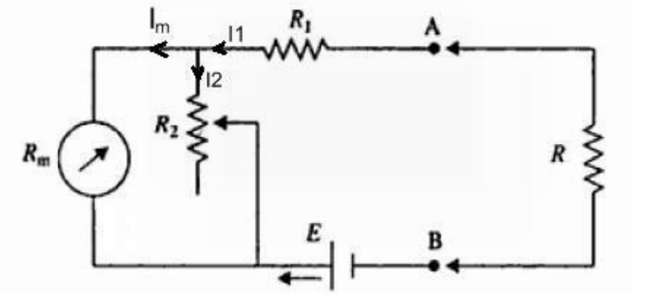
$$I_T = \frac{E}{2R_h} = 2I_h$$

- The total resistance presented to the battery $R_T = 2R_h$

$$I_h = \frac{E}{2R_h}$$

$$V_{R2} = V_m \implies R_2 = \frac{I_{fsd} R_m}{I_T - I_{fsd}} = \frac{I_{fsd} R_m R_h}{E - I_{fsd} R_h}$$

$$R_1 = R_h - \frac{I_{fsd} R_m R_h}{E}$$



Basic series type ohmmeter.

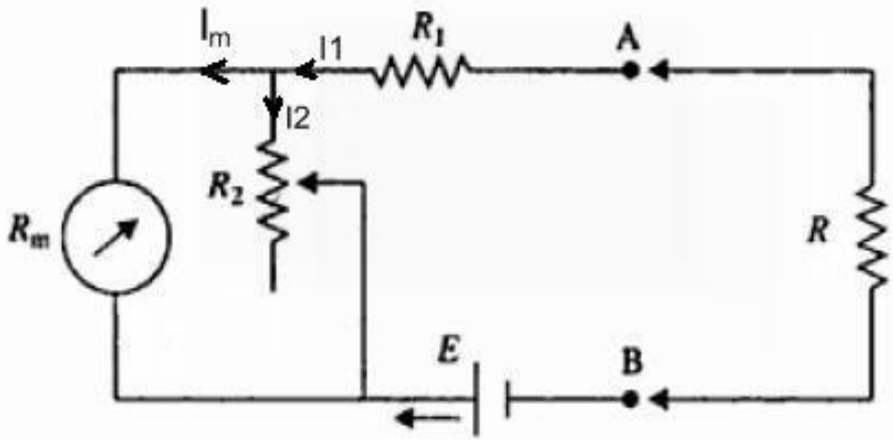
Example 4-7

The ohmmeter of Fig. 4-21 uses a 50-Ω basic movement requiring a full-scale current of 1 mA. The internal battery voltage is 3 V. The desired scale marking for half-scale deflection is 2,000 Ω. Calculate (a) the values of R_1 and R_2; (b) the maximum value of R_2 to compensate for a 10% drop in battery voltage; (c) the scale error at the half-scale mark (2,000 Ω) when R_2 is set as in (b).

Solution

(a) The total battery current at full-scale deflection is (Rx = 0 Ω)

$$I_t = \frac{E}{R_h} = \frac{3\ \text{V}}{2{,}000\ \Omega} = 1.5\ \text{mA} \quad (4\text{-}16)$$



Basic series type ohmmeter.

The current through the zero-adjust resistor R_2 then is

$$I_2 = I_t - I_{fsd} = 1.5 \text{ mA} - 1 \text{ mA} = 0.5 \text{ mA}$$

The value of the zero-adjust resistor R_2 is

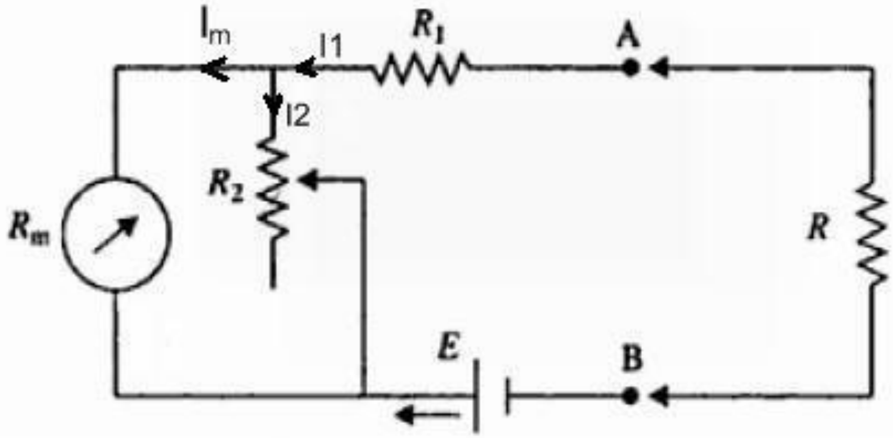
$$R_2 = \frac{I_{fsd} R_m}{I_2} = \frac{1 \text{ mA} \times 50\ \Omega}{0.5 \text{ mA}} = 100\ \Omega$$

The parallel resistance of the movement and the shunt (R_p) is

$$R_p = \frac{R_2 R_m}{R_2 + R_m} = \frac{50 \times 100}{150} = 33.3\ \Omega$$

The value of the current-limiting resistor R_1 is

$$R_1 = R_h - R_p = 2{,}000 - 33.3 = 1{,}966.7\ \Omega$$



(b) At a 10% drop in battery voltage,

$$E = 3\ \text{V} - 0.3\ \text{V} = 2.7\ \text{V}$$

The total battery current I_t then becomes

$$I_t = \frac{E}{R_h} = \frac{2.7\ \text{V}}{2{,}000\ \Omega} = 1.35\ \text{mA}$$

The shunt current I_2 is

$$I_2 = I_t - I_{fsd} = 1.35\ \text{mA} - 1\ \text{mA} = 0.35\ \text{mA}$$

and the zero-adjust resistor R_2 equals

$$R_2 = \frac{I_{fsd} R_m}{I_2} = \frac{1\ \text{mA} \times 50\ \Omega}{0.35\ \text{mA}} = 143\ \Omega$$

(c) The parallel resistance of the meter movement and the new value of R_2 becomes

$$R_p = \frac{R_2 R_m}{R_2 + R_m} = \frac{50 \times 143}{193} = 37\ \Omega$$

Since the half-scale resistance R_h is equal to the total internal circuit resistance, R_h will increase to

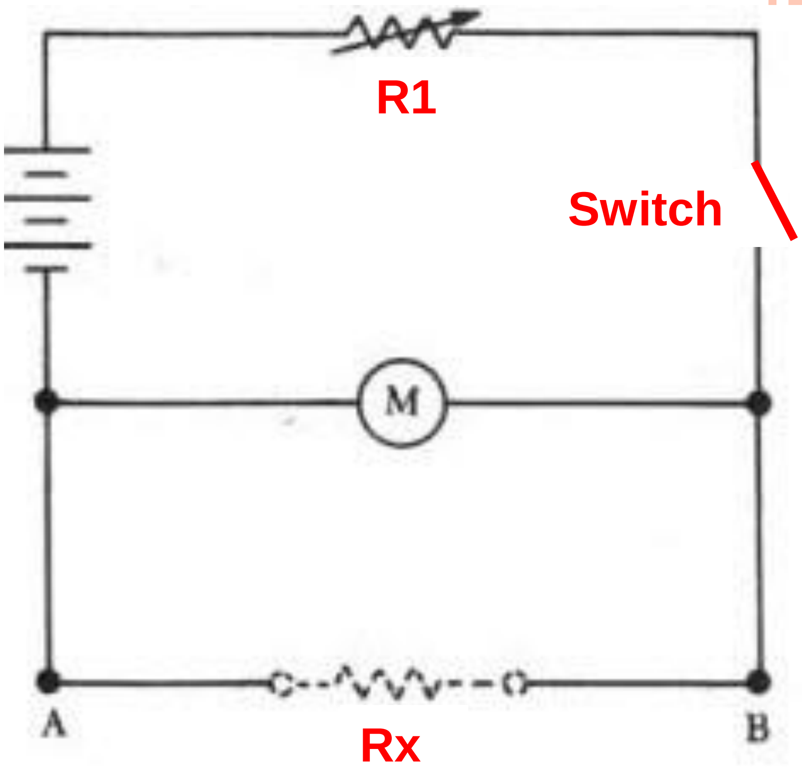
$$R_h = R_1 + R_p = 1{,}966.7\ \Omega + 37\ \Omega = 2.003.7\ \Omega$$

Therefore the true value of the half-scale mark on the meter is 2,003.7 Ω whereas the actual scale mark is 2,000 Ω. The percentage error is then

$$\%error = \frac{2{,}000 - 2{,}003.7}{2{,}007.3} \times 100\% = -0.185\%$$

Shunt-Type Ohmmeter

- Not commonly used.
- The shunt type mainly used for measuring **low vale** resistors.
- *ON/Off* Switch is placed to connect and disconnect the battery.
- The full scale reading depends on R1 and Rm.
- Designed same as the same the series type based on half-scale reading **Rh**.



Multirange Ohmmeter Circuit

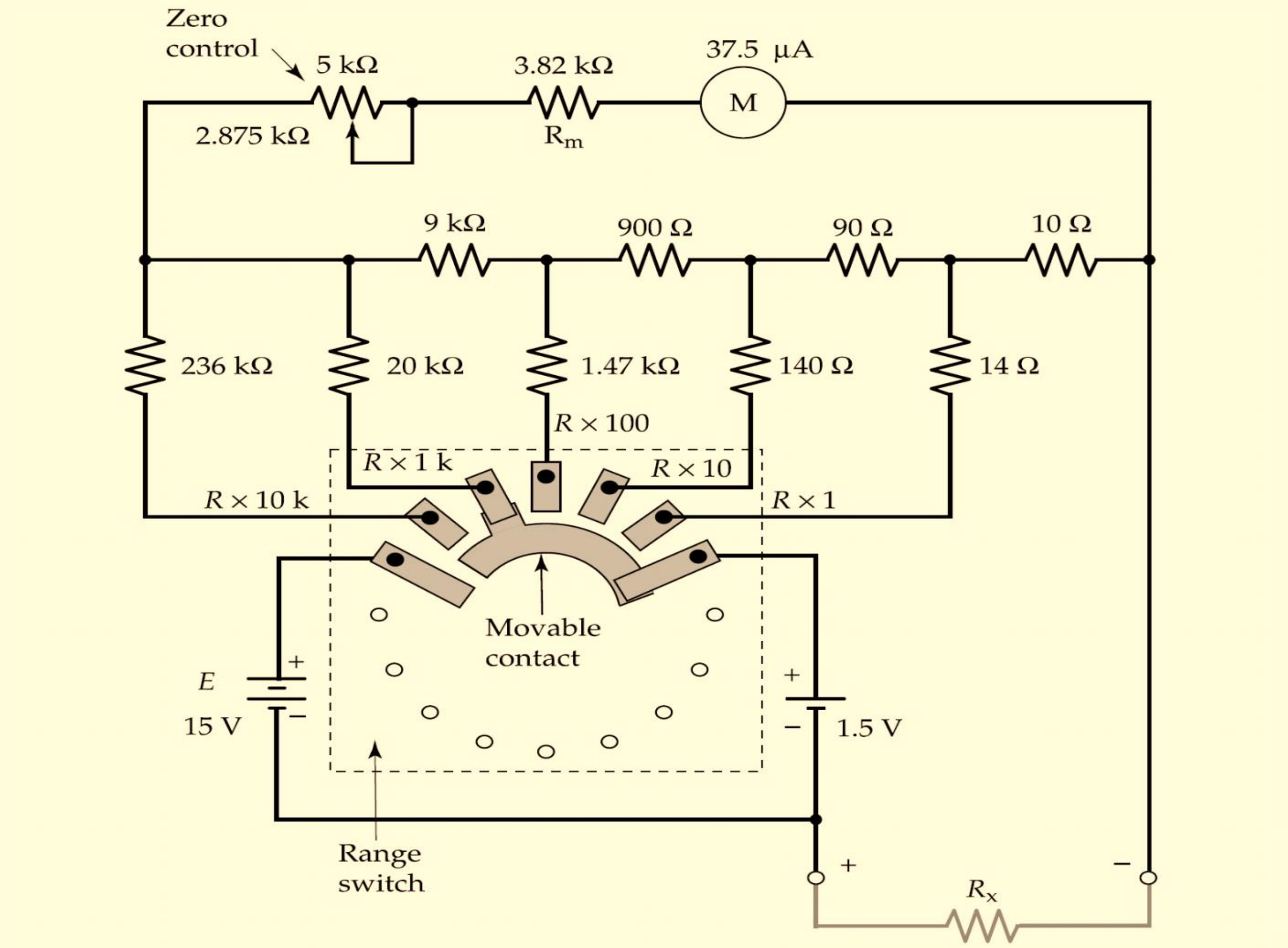


Figure 4-13 Circuit for a typical multirange shunt ohmmeter as used on a multifunction analog instrument. The 15 V battery is used only on the $R \times 10$ kΩ range, and the 1.5 V battery is the supply for all other ranges.

Scale & Range Switch for a Typical Multirange Ohmmeter

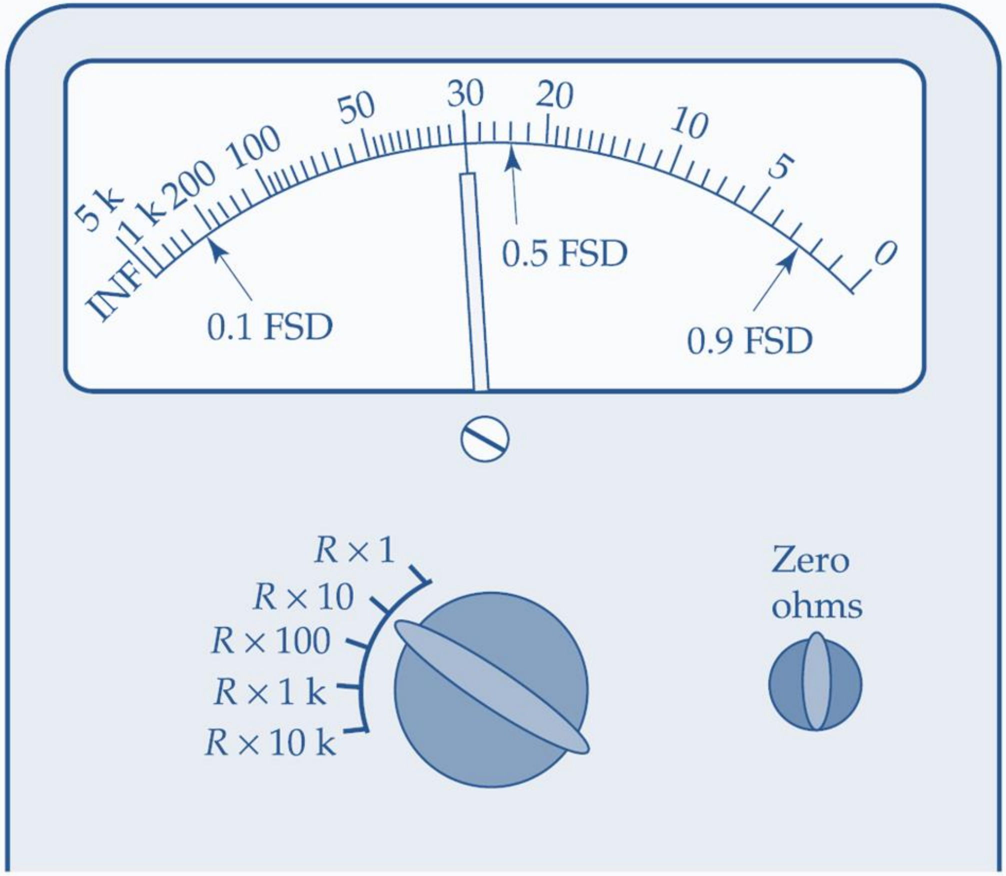
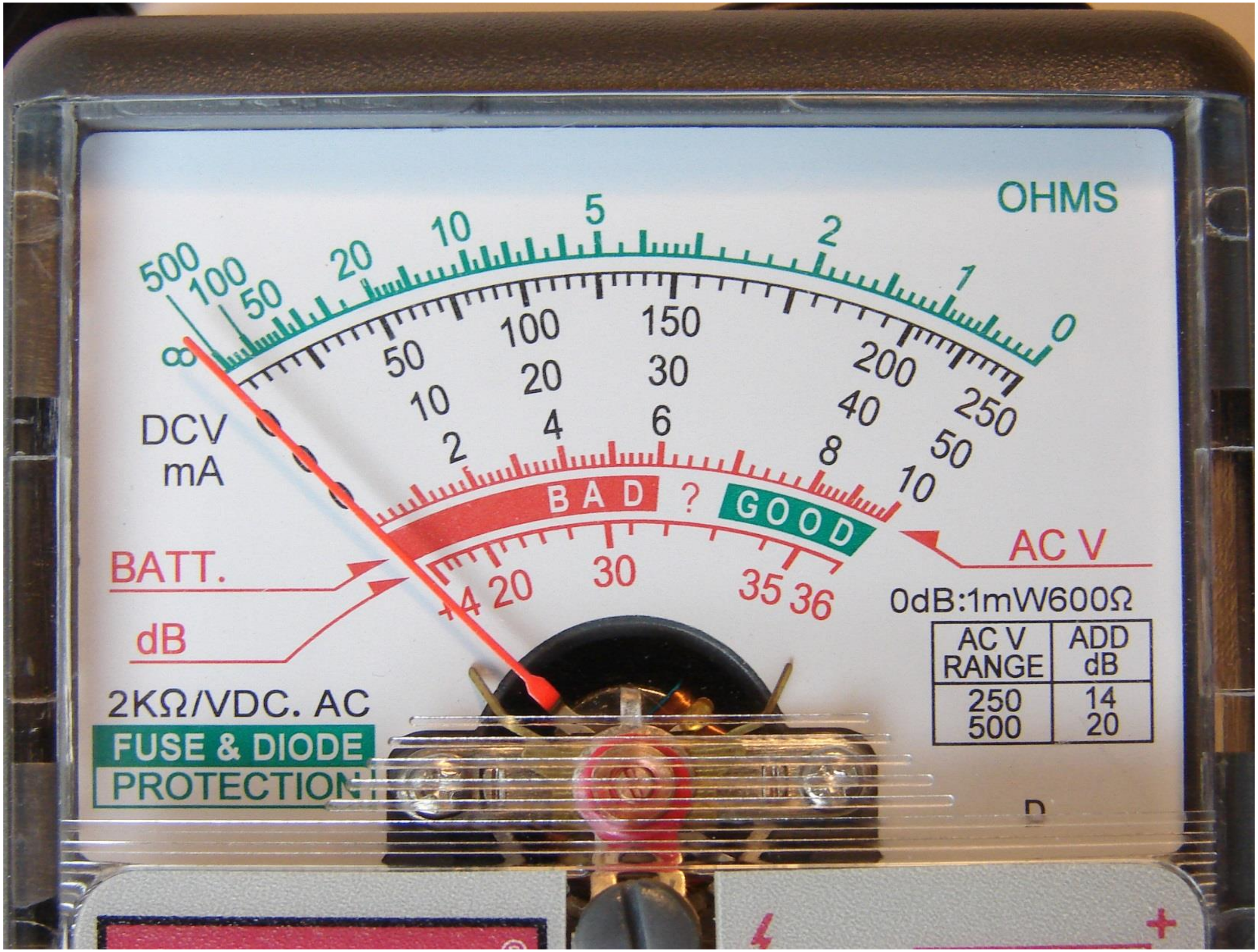
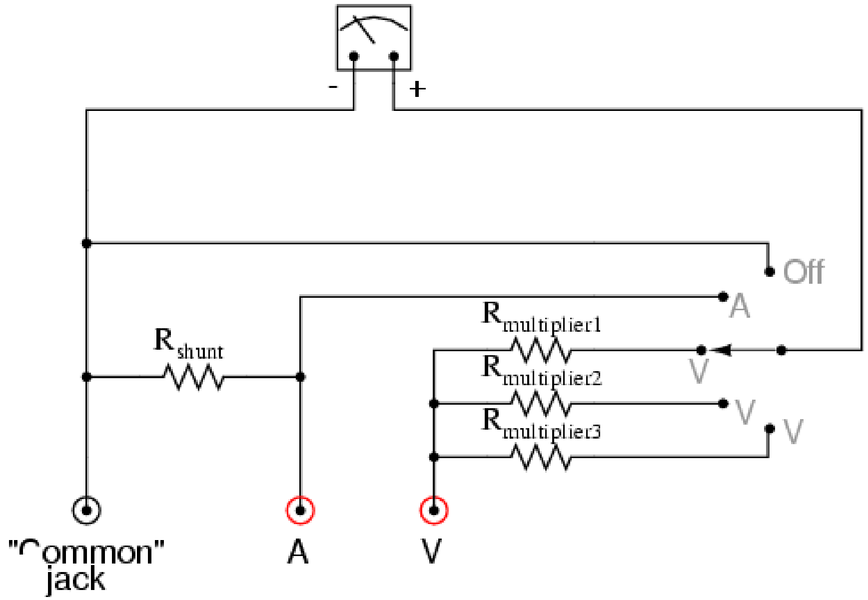


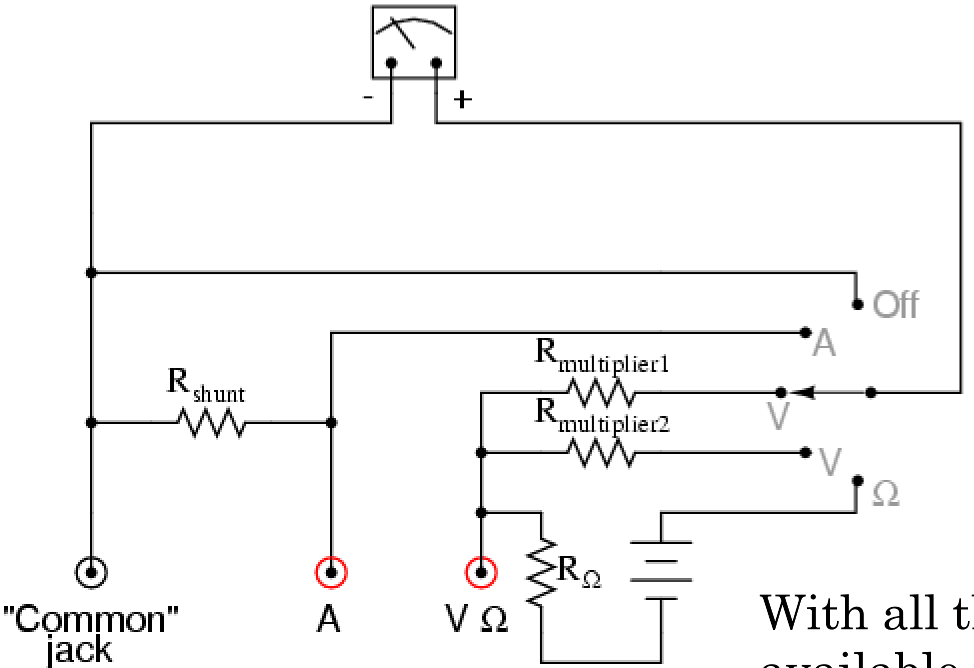
Figure 4-14 Scale and range switch for a typical multirange shunt ohmmeter as used on an analog VOM.

Multimeters

volt - ohm - Ampere

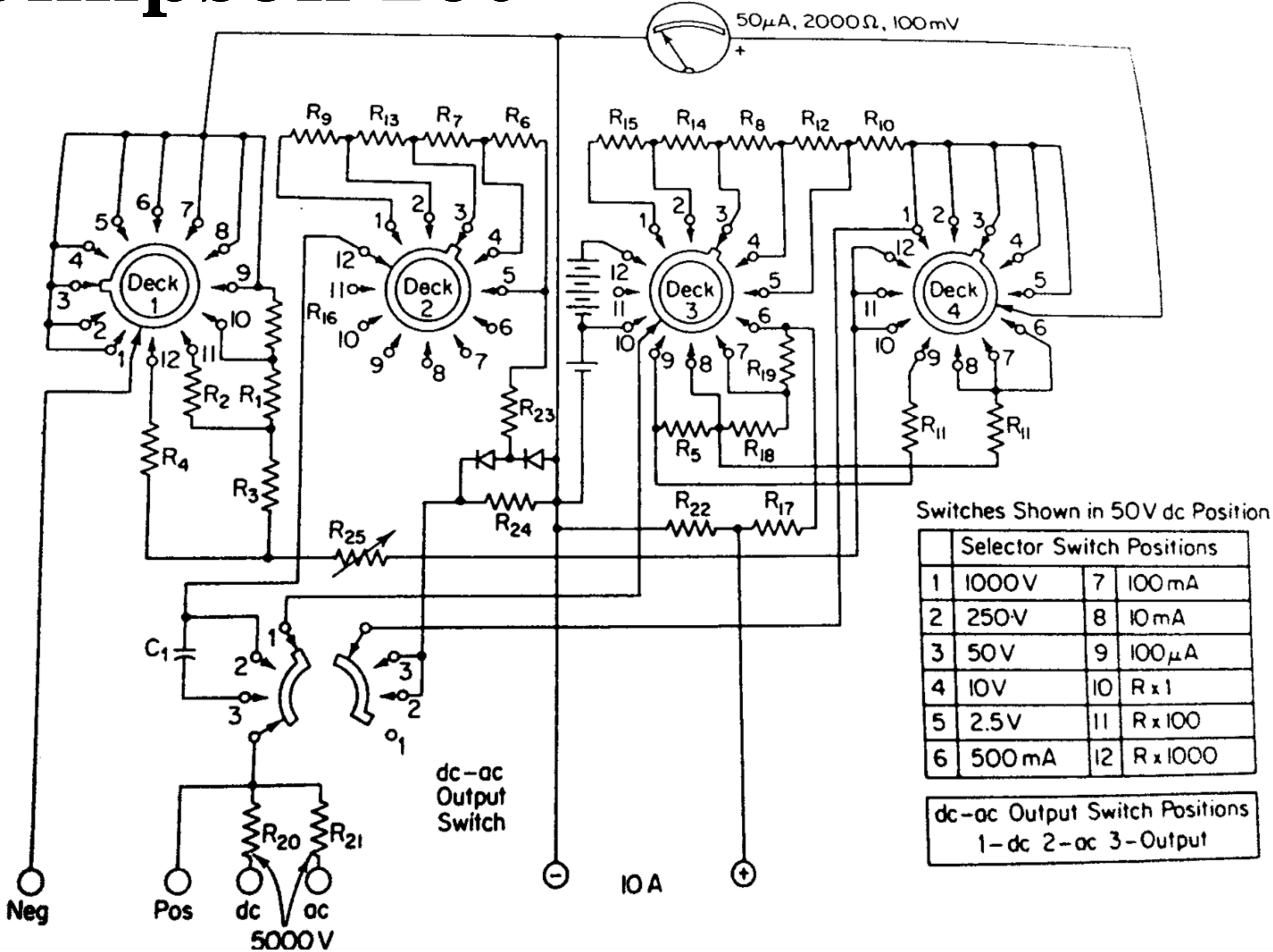






With all three fundamental functions available, this multimeter may also be known as a ***volt-ohm-milliammeter***.

Multimeter Example : Simpson 260



	Selector Switch Positions		
1	1000V	7	100mA
2	250V	8	10mA
3	50V	9	100μA
4	10V	10	R x 1
5	2.5V	11	R x 100
6	500mA	12	R x 1000

dc–ac Output Switch Positions
1–dc 2–ac 3–Output

Multimeter Example : Simpson 260

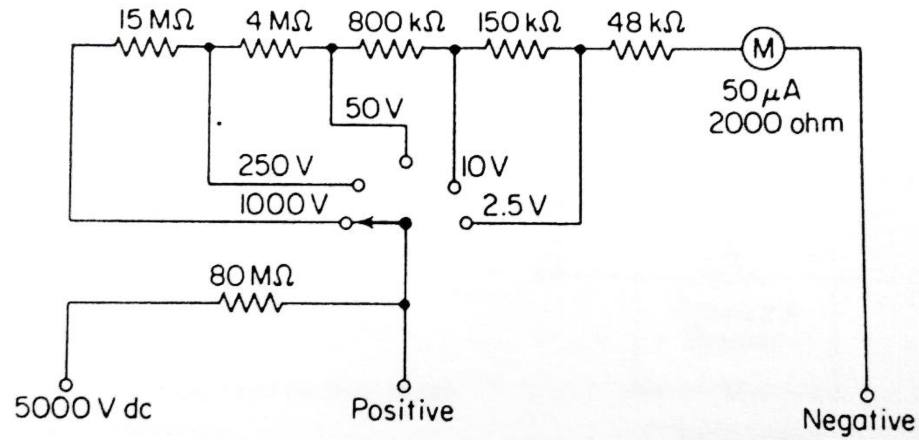


Figure 4-25 Dc voltmeter section of the Simpson Model 260 multimeter (courtesy Simpson Electric Company).

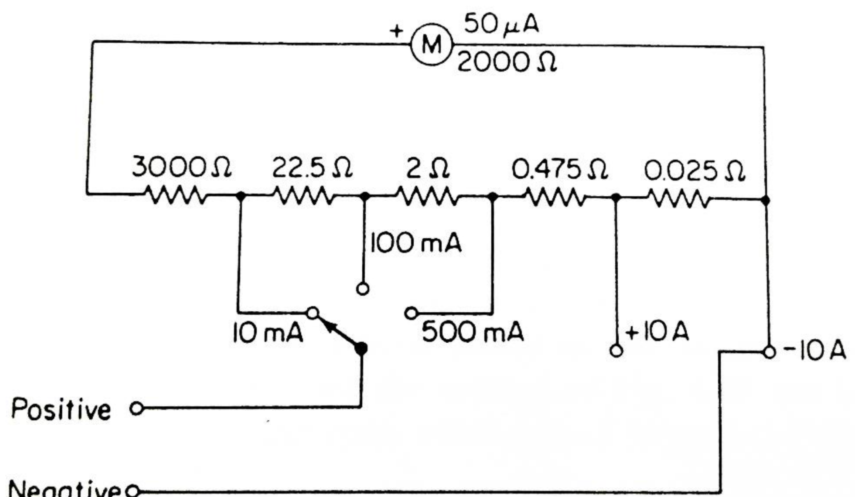
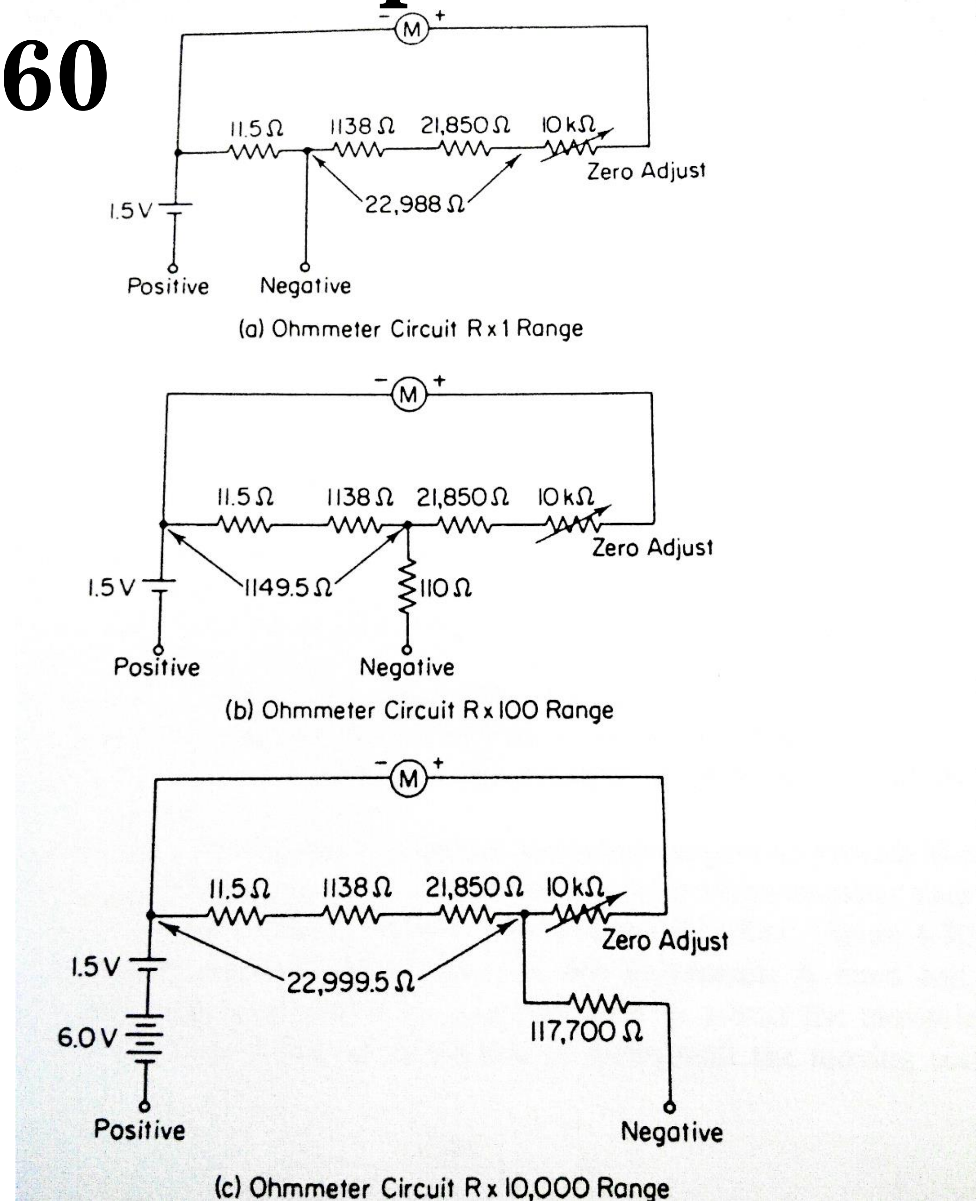


Figure 4-26 Dc ammeter section of the Simpson Model 260 multimeter (courtesy Simpson Electric Company).

Multimeter Example : Simpson 260

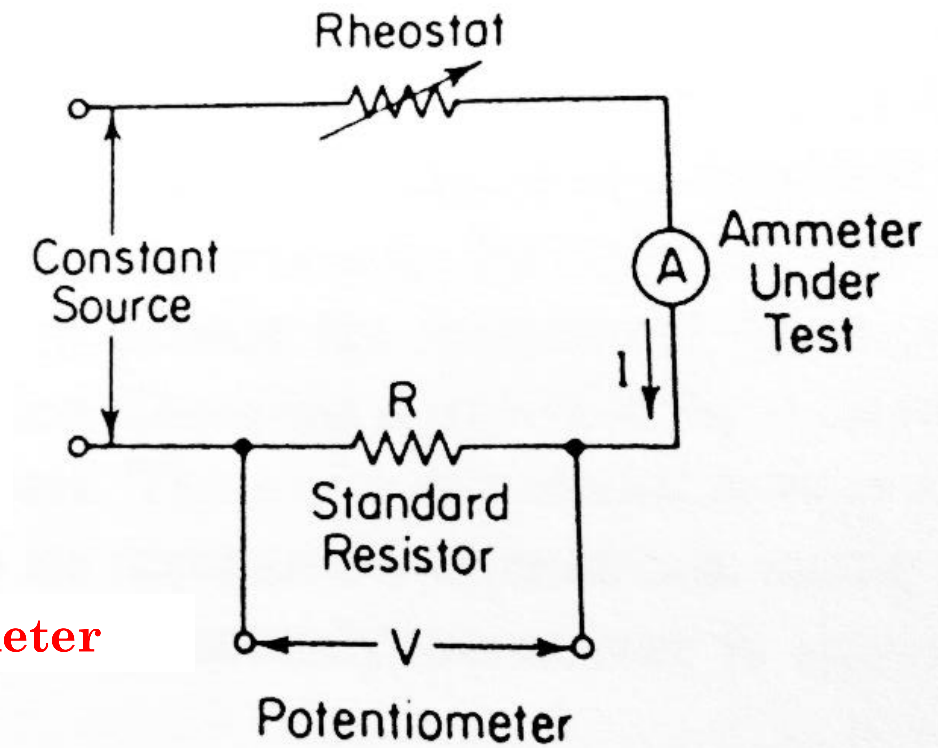


Calibration of DC Instruments (Ammeter)

DC Ammeter **Calibration**

Based on ohm's Law

Compare the current calculated with the meter reading.



DC Ammeter

Calibration of DC Instruments (Voltmeter)

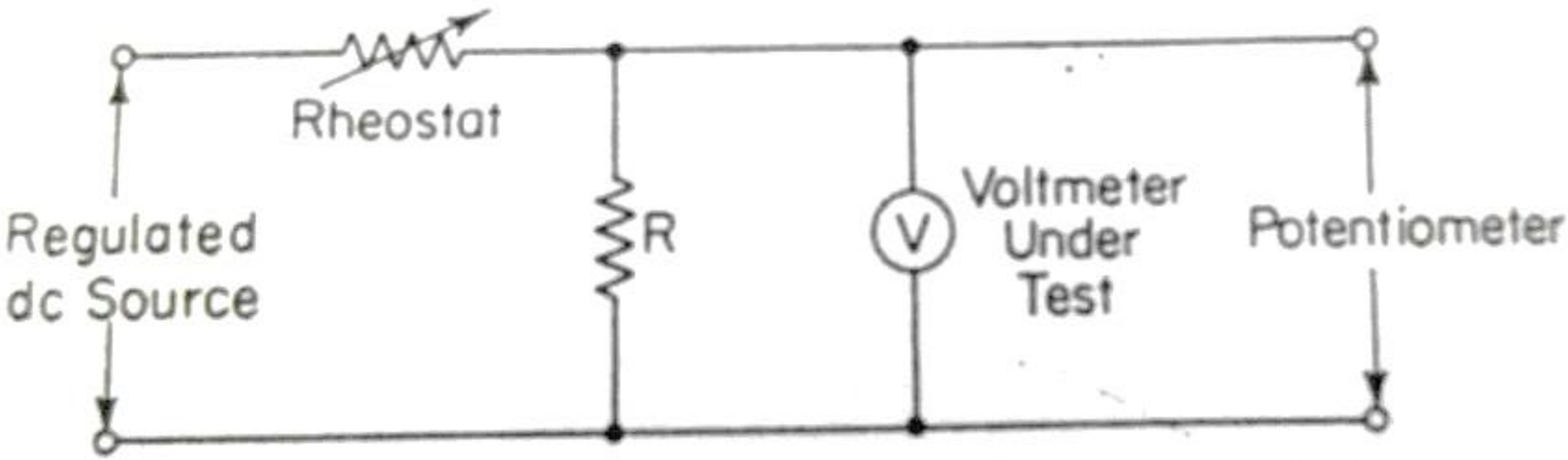


Figure 4-29 Potentiometer method of calibrating a dc voltmeter.

The potentiometer voltage should be = Meter voltage

Calibration of DC Instruments (Ohm Meter)

Ohm meter calibrated using standard resistor.

First Exam on **30/03/2015**