Q.1(a)

Accuracy:- It is defined as the closeness with which the measured value approaches the true value.

Precision:- It is defined as the ability of the instrument to give an identical o/p when repeated measurements are made with the same i/p.

Resolution:- The measurement precision of an instrument defines the smallest change in measured quantity that can be observed. This smallest change is the resolution of the instrument.

Relative error:- The relative error is defined as the absolute error relative to the size of the measurement.

if e_r = relative error.

$$e_r = \frac{e_a}{x_t}$$

where

e_a = absolute error

$$= \frac{|x_m - x_t|}{x_t}$$

x_t = true value

x_m = measured value

$$\% \text{ relative error} = \frac{|x_m - x_t|}{x_t} \times 100\%$$

Absolute error: It is defined as the magnitude of the difference between the measured value and the true value.

if e_a = absolute error

x_m = measured value

x_t = true value

$$\boxed{e_a = |x_m - x_t|}$$

Significant figures:-

The significant figures of a number are digits that carry meaning contributing to its measurement precision.

A count on the precision of an instrument can be made by looking at the number of significant digit in the measurement.

For example:-

180 → 3 significant digit.

180.00 → 5 " "

180.0 → 4 " "

→ lower the number of significant digit lower will be the precision.

→ Higher the number of significant digit higher will be the precision.

1.(b):-

True Value = 81 V
Measured Value = 80 V

(1). Absolute error $= |\text{Measured value} - \text{True Value}|$

$= |80 - 81|\ V$

$= 1\ V$

(2). % Error $= \dfrac{|M.V. - T.V.|}{T.V.} \times 100\%$

$= \dfrac{|80 - 81|}{81} \times 100\%$

$= 1.23\%$

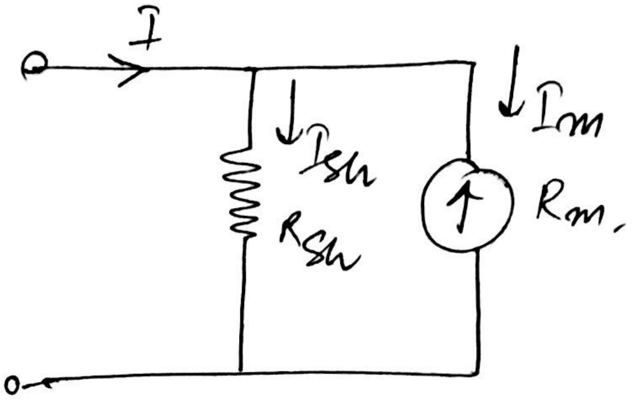
(3). Relative accuracy :- $\dfrac{M.V.}{T.V.} = \dfrac{80}{81}$

$= 0.987$

(4). % accuracy $= \dfrac{M.V.}{T.V} \times 100\%$

$= 98.7\%$

2. (a) :-



R_m = internal resistance of the movement

I_{sh} = shunt current

I_m = full scale deflection current

I = Total current

Since the shunt resistance is in parallel with the meter movement, the voltage drop across the shunt and movement must be the same

$$V_{sh} = V_m.$$

$$\Rightarrow I_{sh} R_{sh} = I_m R_m$$

$$\Rightarrow R_{sh} = \frac{I_m R_m}{I_{sh}}.$$

But $I_{sh} = I - I_m$.

$$\therefore \boxed{R_{sh} = \frac{I_m R_m}{I - I_m}}$$

2.(b) :-

given.

$$I_m = 100 \mu A$$
$$R_m = 500 \Omega$$
$$I = 100 mA$$

The shunt resistor

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

$$= \left(\frac{100 \times 10^{-6} \times 500}{100 \times 10^{-3} - 100 \times 10^{-6}} \right) \Omega$$

$$= 0.50 \Omega$$

Q.3. :- given. $I_m = 1 mA$, $R_m = 100 \Omega$

case 1 :- For the range (0–10) mA

$$R_{sh_1} = \frac{I_m R_m}{I - I_m}$$

$$= \left(\frac{1 mA \times 100 \Omega}{10m - 1m} \right) \Omega$$

$$= 11.11 \Omega$$

Case-2:- For the range (0-20) mA

$$R_{sh_2} = \left(\frac{1m \times 100}{20m - 1m}\right)\Omega$$

$$= 5.2\,\Omega$$

Case-3:- For the range (0-50) mA

$$R_{sh_3} = \left(\frac{1m \times 100}{50m - 1m}\right)\Omega$$

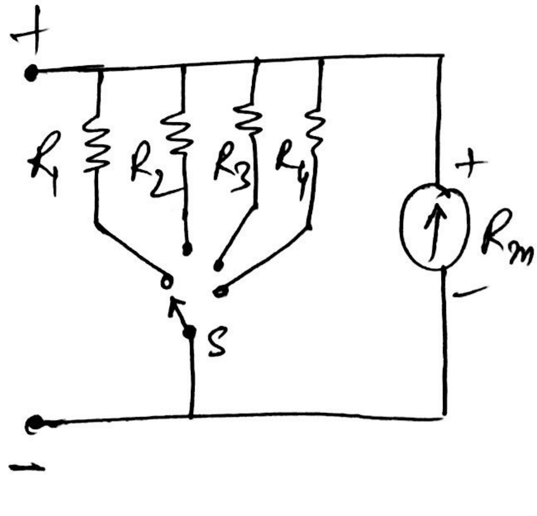
$$= 2.041\,\Omega$$

Case-4:- For the range (0-100) mA

$$R_{sh_4} = \frac{1m \times 100}{100m - 1m}$$

$$= \frac{100}{99}$$

$$= 1.01\,\Omega$$



———x———

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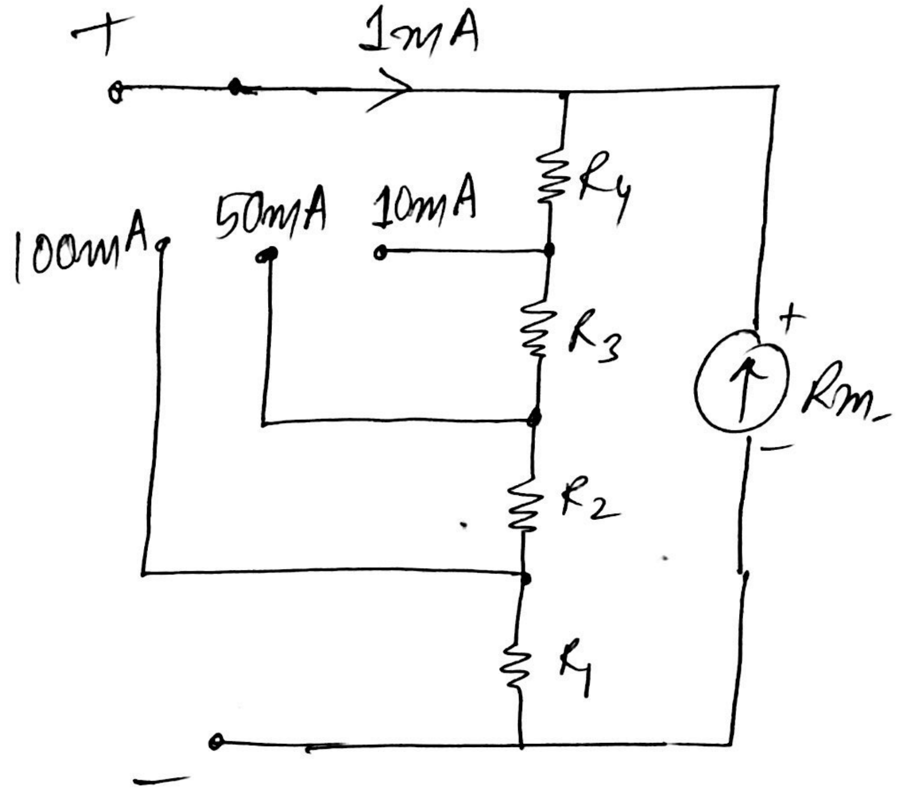
Q. 4



given. $R_m = 100\Omega$, $I_m = 50\mu A$

For (0-1)mA range.

$$R_1 + R_2 + R_3 + R_4 = \left(\frac{50\mu \times 100}{1m - 50\mu} \right) \Omega$$

$$\Rightarrow R_1 + R_2 + R_3 + R_4 = 5.26\,\Omega \quad \text{---} (1)$$

For (0-10)mA range.

$$R_1 + R_2 + R_3 = \frac{50\mu(100 + R_4)}{10m - 50\mu}$$

$$R_1 + R_2 + R_3 = 5m(100 + R_4) \quad \text{---} (2)$$

For (0-50) mA

$$R_1+R_2 = \frac{50\mu(100+R_4+R_3)}{50m-50\mu}$$

$$\Rightarrow R_1+R_2 = 1m(100+R_4+R_3) \quad \text{——— } (3)$$

For (0-100) mA

$$R_1 = \frac{50\mu(100+R_4+R_3+R_2)}{100m-50\mu}$$

$$\Rightarrow R_1 = 0.5m(100+R_4+R_3+R_2) \quad \text{——— } (4)$$

From eq^n (1).

$$R_2+R_3+R_4 = 5.26 - R_1$$

$\therefore$ from eq^n (4) -

$$R_1 = 0.5m(100+5.26-R_1)$$

$$\Rightarrow R_1 = 0.05 + (2.63\times10^{-3}) - (0.5\times10^{-3})R_1$$

$$\Rightarrow R_1 \cong 0.05263\ \Omega$$

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From eq^n ①

$$R_3 + R_4 = 5.26 - R_2 - R_1$$

$$\Rightarrow R_3 + R_4 = 5.26 - 0.05263 - R_2$$

$$\Rightarrow R_3 + R_4 = 5.207 - R_2$$

Now using eq^n ③

$$0.05263 + R_2 = 1m(100 + 5.207 - R_2)$$

$$\Rightarrow R_2 = 0.05263\ \Omega$$

Again, from eq^n ①

$$R_4 = 5.26 - R_1 - R_2 - R_3$$

$$\Rightarrow R_4 = 5.1547 - R_3$$

using eq^n ②

$$0.05263 + 0.05263 + R_3 = 5m(100 + 5.1547 - R_3)$$

$$\Rightarrow 0.10526 + R_3 = 5m(105.1547 - R_3)$$

$$\Rightarrow R_3 = 0.4147\ \Omega$$

From eqn (1)

$R_4 = 4.74\,\Omega$

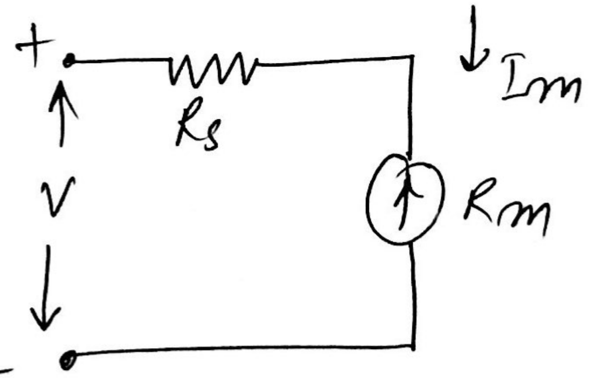
$R_1 = 0.05263\ \Omega$

$R_2 = 0.05263\ \Omega$

$R_3 = 0.4147\,\Omega$

$R_4 = 4.74\,\Omega$

Q.6. (a)



where

I_m = full scale deflection current of the movement.

R_m = internal resistance of movement

R_s = multiplier resistance (or) Series resistance

V = full range voltage of the instrument

From the circuit

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

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

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

Q. 6. (b)

Given. $I_m = 10 mA$

$R_m = 500 \Omega$

Case-1 For the range of (0-20) V

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

$$= 1.5 k\Omega$$

Case-2 for the range of (0-50) V

$$R_s = \frac{50}{10 \times 10^{-3}} - 500 = 4.5 k\Omega$$

Case-3 for the range of (0-100)V

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

$$= \frac{100}{10 \times 10^{-3}} - 500$$

$$= 9.5 k\Omega$$

Example 4.13 *Find the voltage reading and % error of each reading obtained with a voltmeter on (i) 5 V range, (ii) 10 V range and (iii) 30 V range, if the instrument has a 20 kΩ/V sensitivity and is connected across R_b of Fig. 4.8 (a).*

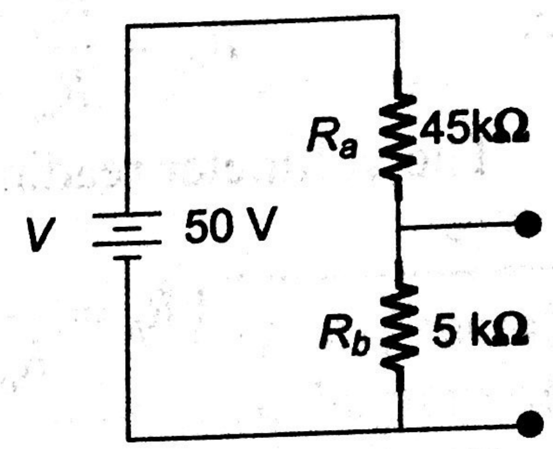


Fig. 4.8 (a)

Solution The voltage drop across R_b without the voltmeter connected is calculated using the voltage equation

$$VR_b = \frac{R_b}{R_a + R_b} \times V = \frac{5\text{ k}}{45\text{ k} + 5\text{ k}} \times 50 = \frac{50 \times 5\text{ k}}{50\text{ k}} = 5\text{ V}$$

On the 5 V range

$$R_m = S \times \text{range} = 20\text{ k}\Omega \times 5\text{ V} = 100\text{ k}\Omega$$

$$\therefore \quad R_{eq} = \frac{R_m \times R_b}{R_m + R_b} = \frac{100\text{ k} \times 5\text{ k}}{100\text{ k} + 5\text{ k}} = \frac{500\text{ k}}{105\text{ k}} = 4.76\text{ k}\Omega$$

The voltmeter reading is

$$VR_b = \frac{R_{eq}}{R_a + R_{eq}} \times V = \frac{4.76\text{ k}}{45\text{ k} + 4.76\text{ k}} \times 50 = 4.782\text{ V}$$

The % error on the 5 V range is

$$\%\text{ Error} = \frac{\text{Actual voltage} - \text{Voltage reading in meter}}{\text{Actual voltage}}$$

$$= \frac{5\text{ V} - 4.782\text{ V}}{5\text{ V}} \times 100 = \frac{0.217\text{ V}}{5\text{ V}} \times 100 = 4.34\,\%$$

On 10 V range

$$R_m = S \times \text{range} = 20\text{ k}\Omega/\text{V} \times 10\text{ V} = 200\text{ k}\Omega$$

$$\therefore \quad R_{eq} = \frac{R_m \times R_b}{R_m + R_b} = \frac{200\text{ k} \times 5\text{ k}}{200\text{ k} + 5\text{ k}} = 4.87\text{ k}\Omega$$

The voltmeter reading is

$$VR_b = \frac{R_{eq}}{R_{eq} + R_a} \times V = \frac{4.87\text{ k}}{4.87\text{ k} + 45\text{ k}} \times 50 = 4.88\text{ V}$$

The % error on the 10 V range $= \dfrac{5\text{ V} - 4.88\text{ V}}{5\text{ V}} \times 100 = 2.34\%$

On 30 V range

$$R_m = S \times \text{range} = 20\text{ k}\Omega/\text{V} \times 30\text{ V} = 600\text{ k}$$

$$\therefore \quad R_{eq} = \frac{R_m \times R_b}{R_m + R_b} = \frac{600\text{ k} \times 5\text{ k}}{600\text{ k} + 5\text{ k}} = \frac{3000\text{ k} \times 1\text{ k}}{605\text{ k}} = 4.95\text{ k}$$

The voltmeter reading on the 30 V range

$$VR_b = \frac{R_{eq}}{R_{eq} + R_a} \times V = \frac{4.95\text{ k}}{45\text{ k} + 4.95\text{ k}} \times 50 = 4.95\text{ V}$$

The % error on the 30 V range

$$= \frac{5\text{ V} - 4.95\text{ V}}{5\text{ V}} \times 100 = \frac{0.05}{5\text{ V}} \times 100 = 1\,\%$$

RF AMMETER (THERMOCOUPLE)

3.6.1 Thermocouple Instruments

Thermocouples consists of a junction of two dissimilar wires, so chosen that a voltage is generated by heating the junction. The output of a thermocouple is delivered to a sensitive dc microammeter.

(Calibration is made with dc or with a low frequency, such as 50 cycles, and applies for all frequencies for which the skin effect in the heater is not appreciable. Thermocouple instruments are the standard means for measuring current at radio frequencies.)

The generation of dc voltage by heating the junction is called thermoelectric action and the device is called a thermocouple.

3.6.2 Different Types of Thermocouples

In a thermocouple instrument, the current to be measured is used to heat the junction of two metals. These two metals form a thermocouple and they have the property that when the junction is heated it produces a voltage proportional to the heating effect. This output voltage drives a sensitive dc microammeter, giving a reading proportional to the magnitude of the ac input.

The alternating current heats the junction; the heating effect is the same for both half cycles of the ac, because the direction of potential drop (or polarity) is always be the same. The various types of thermocouples are as follows.

1 **Mutual Type (Fig. 3.6 (a))** In this type, the alternating current passes through the thermocouple itself and not through a heater wire. It has the disadvantages that the meter shunts the thermocouple.

2 **Contact Type (Fig. 3.6 (b))** This is less sensitive than the mutual type. In the contact type there are separate thermocouple leads which conduct away the heat from the heater wire.

3 **Separate Heater Type (Fig. 3.6 (c))** In this arrangement, the thermocouple is held near the heater, but insulated from it by a glass bead. This makes the instrument sluggish and also less sensitive because of temperature drop in the glass bead. The separate type is useful for certain applications, like RF current measurements. To avoid loss of heat by radiation, the thermocouple arrangement is placed in a vacuum in order to increase its sensitivity.

4 **Bridge Type (Fig. 3.6 (d))** This has the high sensitivity of the mutual type and yet avoids the shunting effect of the microammeter.

The sensitivity of a thermocouple is increased by placing it in a vacuum since loss of heat by conduction is avoided, and the absence of oxygen permits operation at a much higher temperature. A vacuum thermocouple can be designed to give a full scale deflection of approximately 1 mA. A similar bridge arrangement in air would require about 100 mA for full scale deflection.

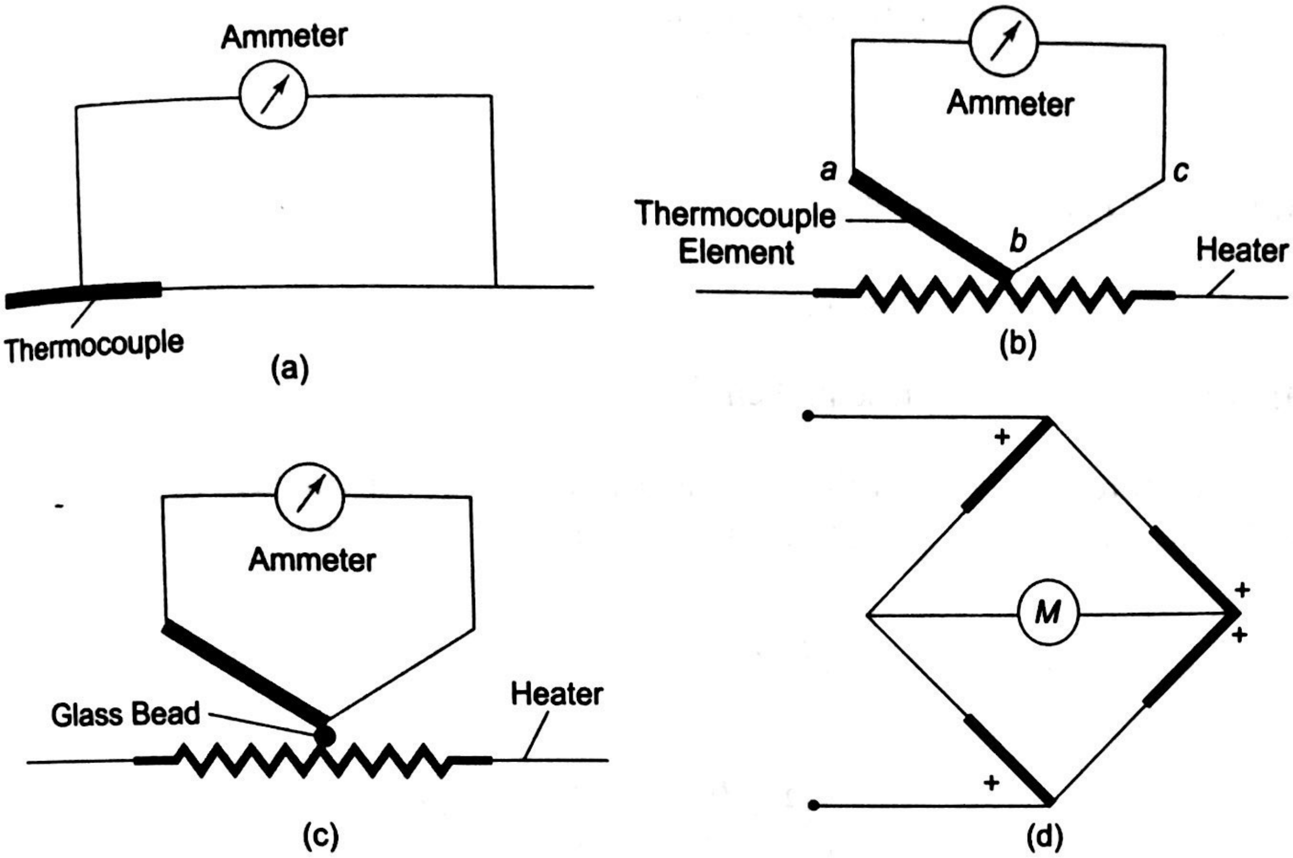


Fig. 3.6 (a) Mutual type (b) Contact type (c) Separate heater type (d) Bridge type thermocouple

Material commonly used to form a thermocouple are constantan against copper, manganin or a platinum alloy. Such a junction gives a thermal emf of approximately 45 μV/°C.

The heating element of open air heaters is typically a non-corroding platinum alloy. Carbon filament heaters are used in vacuum type.

Thermocouple heaters operate so close to the burnout point under normal conditions, that they can withstand only small overloads without damage, commonly up to 50%. This is one of the limitations of the thermocouple instrument.

(Commonly used metal combinations are copper-constantan, iron-constantan, chromel-constantan, chromel-alumel, and platinum-rhodium. Tables are available that show the voltages produced by each of the various metal combination at specific temperatures.)

LIMITATIONS OF THERMOCOUPLES 3.7

Following are the limitations of thermocouples

1. Heaters can stand only small overload.
2. A rise in temperature (higher operating temperatures) causes a change in the resistance of the heater.
3. Presence of harmonics changes meter reading, because the heating effect is proportional to the square of current.