The sensitivity and loading effect of voltmeter.

Theory :

The sensitivity of a voltmeter is defined as the reciprocal or inverse of the full-scale deflection current (I_{fsd}) of the basic movement. It is denoted by the symbol S and expressed in Ω/V.

$$Voltmeter\ Sensitivity, S = \frac{1}{I_{fsd}}\ \Omega/V$$

Where I_{fsd} is the amount of current required to deflect the pointer of the basic meter to its full-scale position.

The sensitivity of a voltmeter can be expressed as the ratio of the total resistance of the circuit R_t to the voltage range V of the voltmeter.

$$i.e., S = \frac{R_t}{V}$$

$$= \frac{R_m + R_s}{V}$$

$$[\because R_t = R_m + R_s]$$

Where,

- R_m = Internal resistance of movement
- R_s = series resistance

Example *Calculate the sensitivity of a 200 μA meter movement which is to be used as a dc voltmeter.*

Solution. Given: $I_{fsd} = 200\ \mu A$

We know that the sensitivity,

$$\text{Sensitivity} = \frac{1}{I_{fsd}}$$

$$= \frac{1}{200\ \mu A} = 5\ k\Omega/V\ \textbf{Ans.}$$

Example *In the circuit shown in Fig. 3.17, the voltage across the resistor of value 25 kΩ is to be measured by using a voltmeter of sensitivity of 1 kΩ/V. Calculate the reading of the voltmeter in each case and the % error in the measurement.*

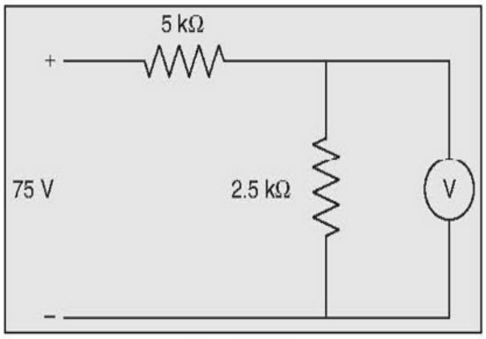


Fig. 3.17.

Solution. Given: $S = 1$ kΩ V

True value of the voltage across 2.5 kΩ $= 75 \times 2.5k / (5k + 2.5k) = 25$ V.

Voltmeter resistance in 25 V range $= 25 \times 1\ k\Omega = 25\ k\Omega$

We know that the voltage measured by the voltmeter

$$= \frac{2.5\ k\Omega \,||\, 25\ k\Omega}{5.0\ k\Omega + (2.5\ k\Omega \,||\, 25\ k\Omega)} \times 75 = 23.44 \text{ V } \textbf{Ans.}$$

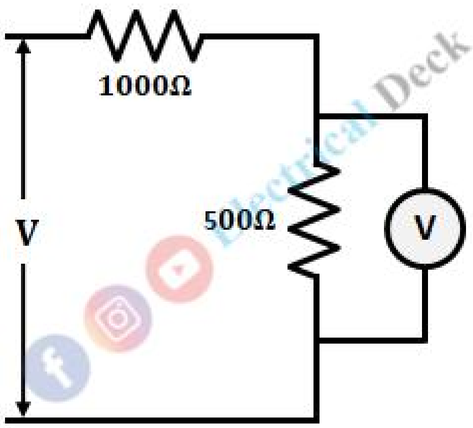
We also know that the % error in the measurement.

$$\%\text{ error} = \frac{25 - 23.44}{25} \times 100 = 6.24\ \%\ \textbf{Ans.}$$

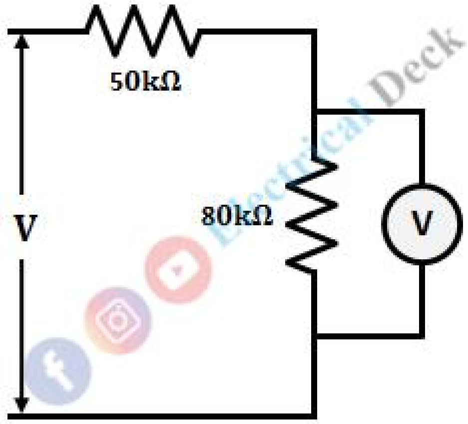
Loading Effect of Voltmeter :

The loading effect of a dc voltmeter refers to the phenomenon in which a negative error is produced in the voltmeter reading (measured voltage), due to the low internal resistance (i.e., low sensitivity of the voltmeter).
Sensitivity is the main factor in selecting the voltmeters for measuring the voltages of the desired range. If the sensitivity of the voltmeter is low, then the voltmeter gives accurate readings for a low resistance circuit and inaccurate and unreliable readings for a high resistance circuit, which is known as loading effect.

Let us consider two circuits, in which voltmeter connected across the resistance.



In the figure shown above, the resistance of the voltmeter is considered to be 50 kΩ and the resistance across which voltage is to be measured is low compared to the resistance of the voltmeter i.e., 500 Ω. As current flows through the path of low resistance, maximum of the current flows through the low resistance and only a part of the current flows through the resistance of the voltmeter. Hence, the voltmeter gives the true value of the reading.



In the figure shown above, the resistance of the voltmeter is 50 kΩ and the resistance across which the voltage is to be measured is very high i.e., 8O kΩ. In this circuit, most of the current flows through the voltmeter, and less current flows through the resistance across which the voltage has to be measured.
This is because the current always chooses a low resistance path (voltmeter path). Due to this the voltage drop across the resistor will be less when compared to the actual voltage drop before the voltmeter has connected. Hence the voltmeter shows a value that is lower than the true value of the reading.

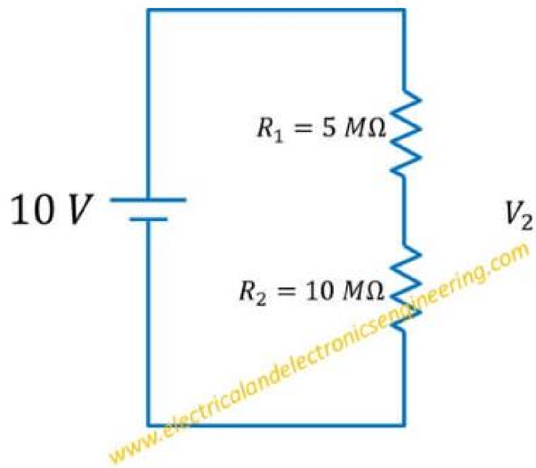
From the above, if a voltmeter having a low sensitivity is used to measure the voltage,

- For low resistance circuits, it provides correct readings.
- For high resistance circuits, the voltmeter acts as a shunt for that portion of the circuit, and hence, the equivalent resistance of that portion decreases. As a result, the voltmeter indicates a voltage value lower than the actual voltage. This effect lead to provide inaccurate reading

To avoid the loading effect, a voltmeter of high sensitivity should be used or it can be eliminated to some extent by using a voltmeter with a very high resistance when compared to that of the resistance in the circuit.

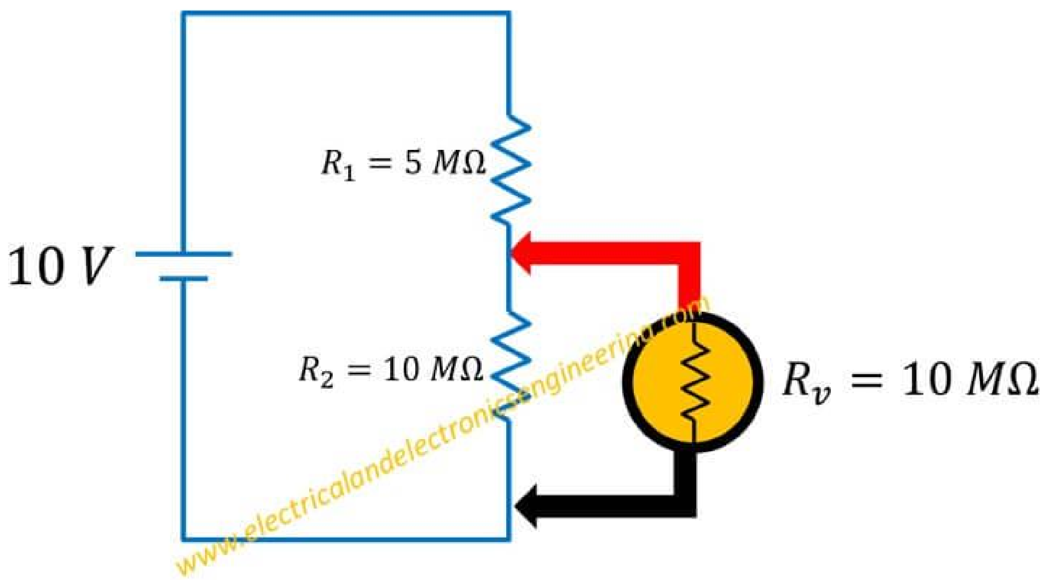
Loading effect of the voltmeter is the difference between actual voltage that exists in the circuit without connecting the voltmeter and the voltage that appears after connecting voltmeter.

To understand this consider a series circuit containing two resistors (R1 and R2) of 5 MΩ and 10 MΩ. Ideally the resistor R2 dissipates 6.66 volts across it (Using voltage divider rule).



$$V_2 = \frac{10\ M\Omega}{5\ M\Omega + 10\ M\Omega} * 10\ V = 6.66\ V$$

Let's consider that a voltmeter having an internal resistance of 10 MΩ is connected across R2. The internal resistance of voltmeter appears in parallel to the R2 resistance. Now using voltage divider rule:



$$V_2 = \frac{(10\ M\Omega\ ||10\ M\Omega)}{5\ M\Omega + (10\ M\Omega||10\ M\Omega)} * 10\ V = 5\ V$$

The real voltage that appears across the voltmeter is 5 Volts. This difference of voltage after adding voltmeter in the circuit is the loading effect of the voltmeter.

Example *Fig. 3.18 shows a simple series circuit of R_1 and R_2 connected to a 100 V dc source. If the voltage across R_2 is to be measured by voltmeter having*

(a) A sensitivity of 1000 Ω/V, and

(b) A sensitivity of 20,000 Ω/V,

Find which voltmeter will read the accurate value of voltage across R_2. Both meters are used on the 50 V range.

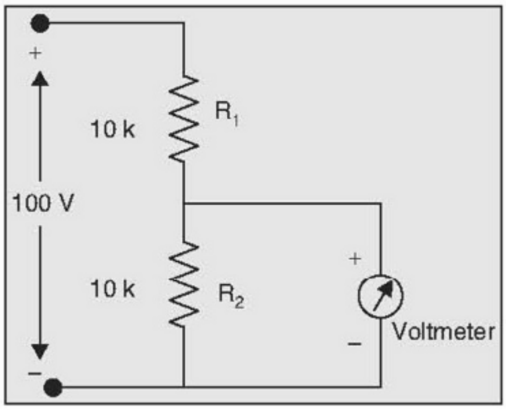


Fig. 3.18.

Solution. Given: R_1 = 10 kΩ; R_2 = 10 kΩ and V = 100 V.

We know that the voltage across R_2 resistance is

$$= \frac{10\text{ k}}{10\text{ k} + 10\text{ k}} \times 100 = 50 \text{ V}$$

True voltage of resistance R_2 is 50 V

(a) *Voltmeter with sensitivity of 1000 Ω/V*

It has resistance of 1000 × 50 = 50 kΩ on its 50 V range

Voltmeter is connected across R_2, then equivalent parallel resistance is given by

$$R_{eq} - \frac{10\text{ k} \times 50\text{ k}}{10\text{ k} + 50\text{ k}}$$

$$= 8.33 \text{ k}\Omega$$

We know that the voltage across total combination,

$$V_1 = \frac{R_{eq}}{R_1 + R_{eq}}$$

$$= \frac{8.33\text{ k}}{10\text{ k} + 8.33\text{ k}} \times 100 \text{ V} = 45.43 \text{ V}$$

Thus the voltmeter with sensitivity of 1000 Ω/V will indicate 45.43 V.

(b) *Voltmeter with sensitivity of 20,000 Ω/V*

It has resistance of 20,000 × 50 = 1000 MΩ on its 50 V range

Voltmeter is connected across R_2, then equivalent parallel resistance is given by

$$R_{eq} = \frac{10\text{ k} \times 1\text{ M}}{10\text{ k} + 1\text{ M}} = 9.9 \text{ k}\Omega$$

Voltage across total combination,

$$V_2 = \frac{R_{eq}}{R_1 + R_{eq}}$$

$$= \frac{9.9\text{ k}}{10\text{ k} + 9.9\text{ k}} \times 100 \text{ V} = 49.74 \text{ V}$$

Thus the voltmeter with sensitivity of 20000 Ω/V will indicate 49.74 V.

The reading 49.74 V is near to 50 V. Thus the reading of high sensitivity voltmeter is near to the true voltage of resistance R_2.

Discussion :

1.Derive the unit of the sensitivity .

2.How we can minimize the loading effect on voltmeter ?

3. Define the loading effect of the voltmeter

4. If a voltmeter having a low sensitivity is used to measure the voltage, for low and high resistance, which reading will be more accurate?