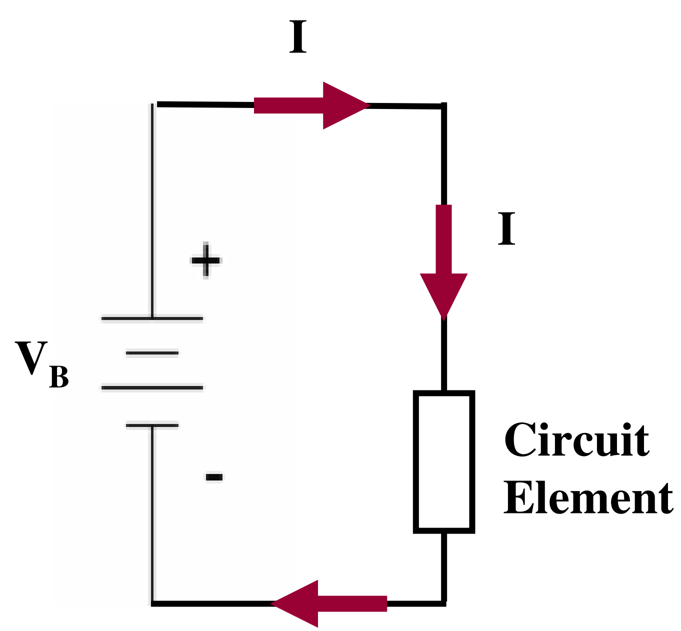
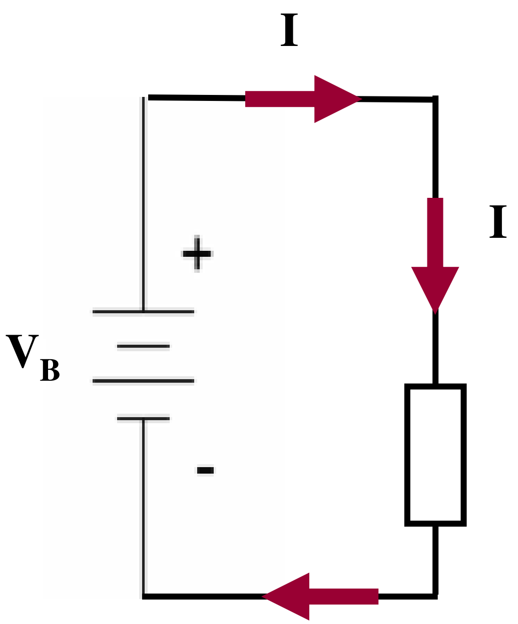
Current and Voltage Measurements

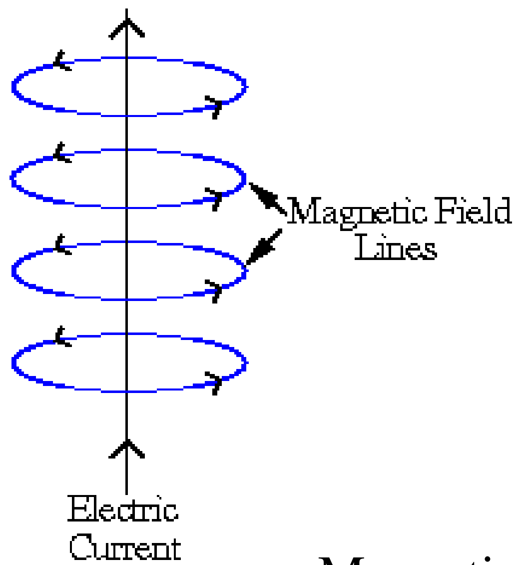
Current measurement

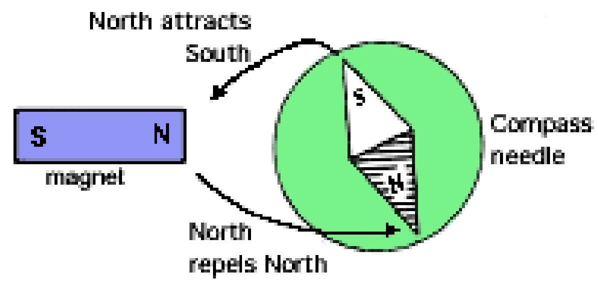
According to current continuity (i.e. charge conservation) law, the current can be measured in any portion of a single loop circuit.



Contact-less methods







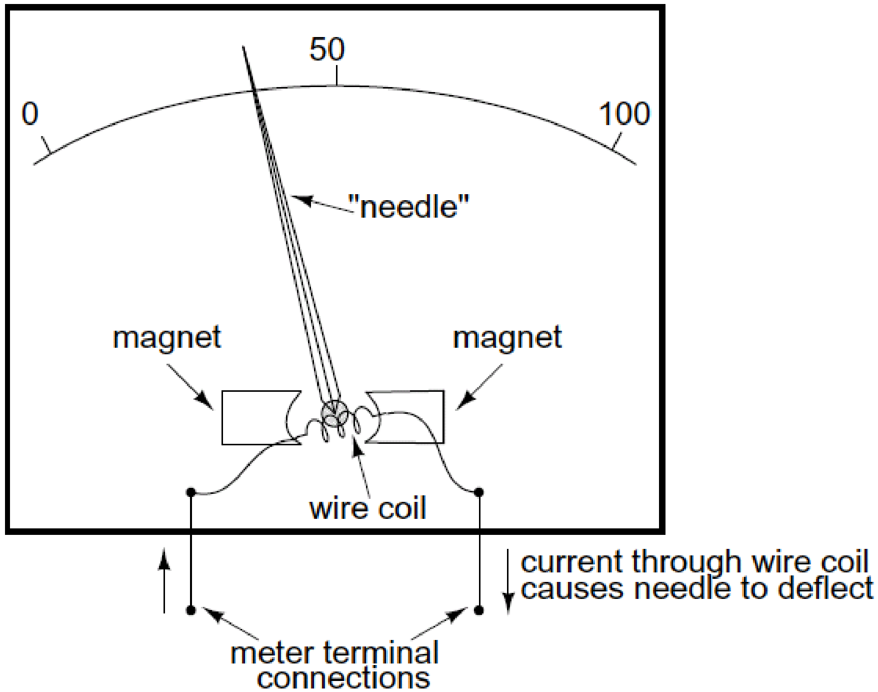
Magnetic field rotates the indicator (like a compass needle)

Any current produces a magnetic field.

Issues: Not very accurate. Low-sensitive – only applicable to high-current circuits

Current measurement device – Ammeter

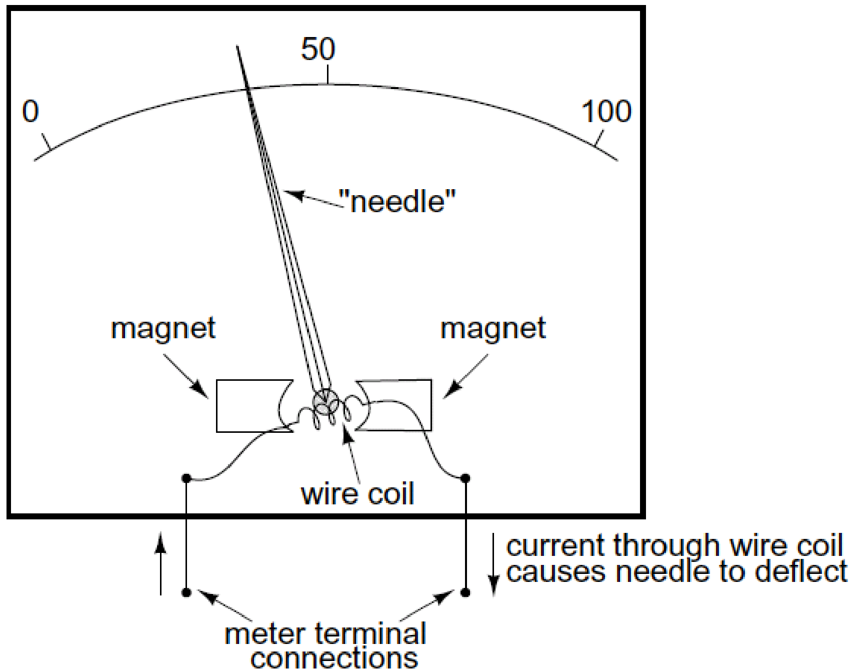
Magneto-electric ammeter



The ammeter uses the magnetic field created by the current to deflect the needle.

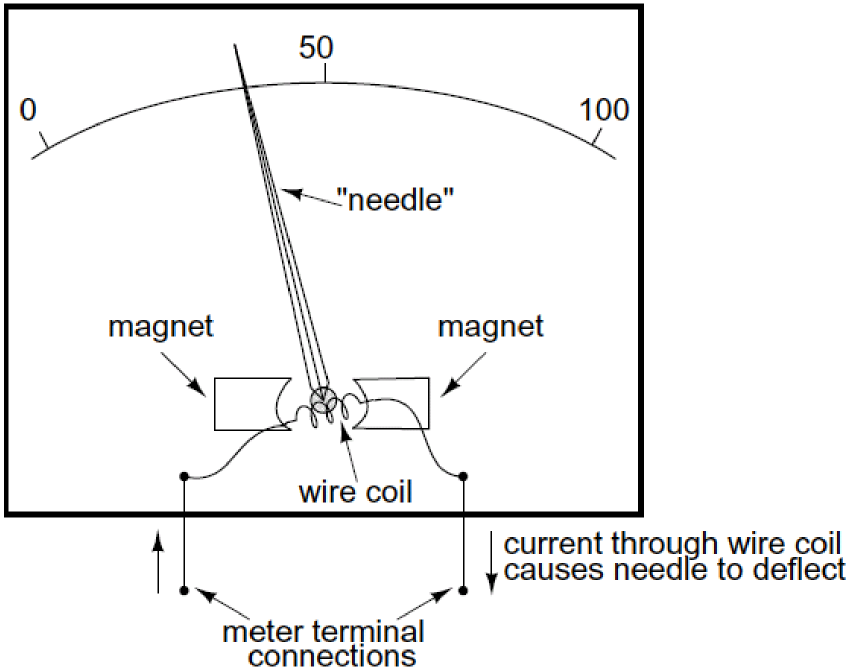
The coil attached to the needle increases the magnetic field of the current.

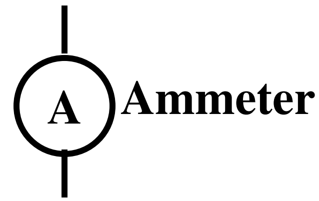
Current measurement device - Ammeter



- The magnetic field of the coil is proportional to the electric current
- The deflection angle is proportional to the magnetic field
- Hence, the deflection angle is proportional to the current
- The maximum current that can be measured depends on the full scale deflection (f.s.d) of the ammeter

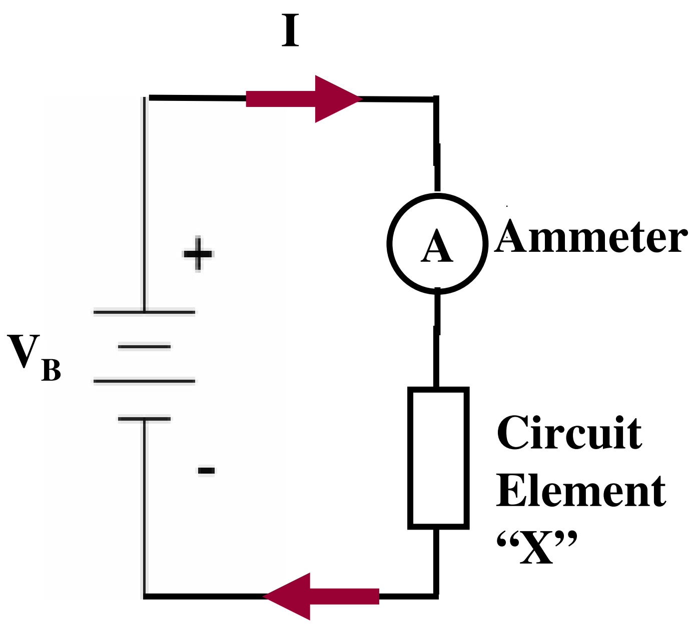
Current measurement device - Ammeter





On a circuit diagrams, an ammeter is shown as an A in a circle.

Series resistance method –
most commonly used in all modern instruments



1. Break the circuit (or a branch)

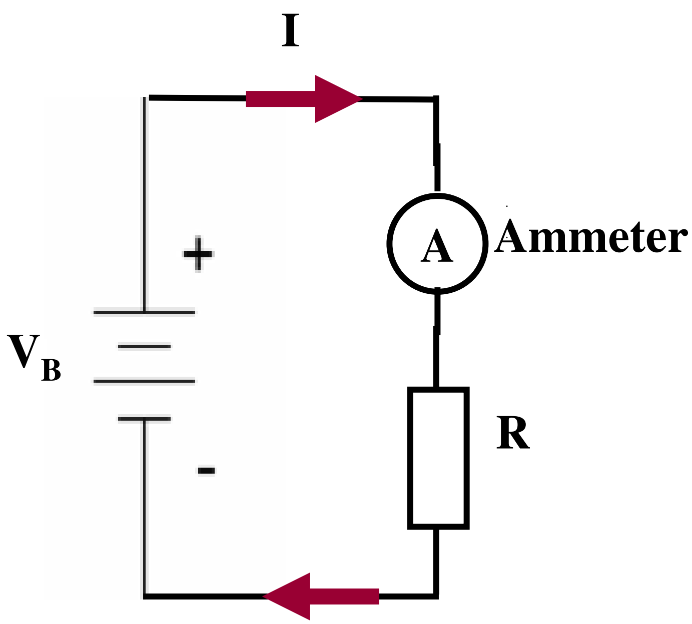
2. Insert an ammeter

3. The current through the ammeter is measured by the needle deflection angle.

4. The current through the resistor or any circuit component X is the same as that through the ammeter

5. Electronic instruments are used to display or transmit the results

Distortions introduced by Measurement



The resistor R is shown by rectangle here to emphasize that the method can be applied to ANY circuit component, not to resistors only.

The ammeter inserted in the circuit changes the actual current in it.

Let the resistance of the Element "X" be

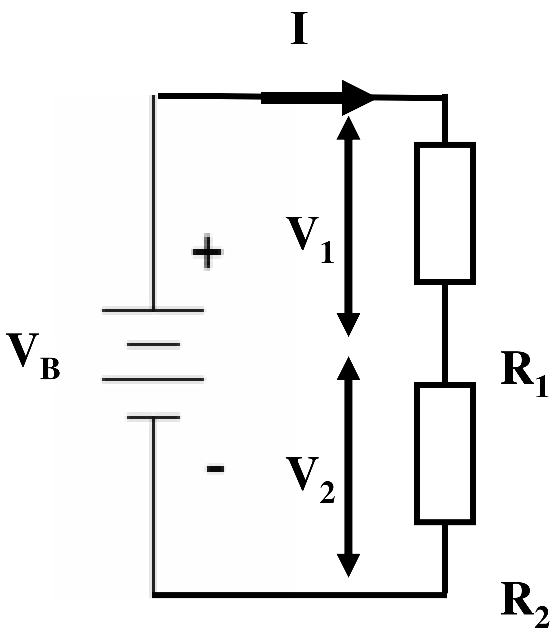
R

The actual circuit current is

$$\mathbf{I = V_B/R}$$

After insertion of the ammeter, the total circuit resistance changes and so does the current.

Reminder: Series electric circuit



For the resistor 1: $I_1 = V_1/R_1;$

For the resistor 2: $I_2 = V_2/R_2;$

From the current continuity:

$$I_1 = I_2 = I;$$

$$V_1 = I \times R_1;\ V_2 = I \times R_2 \qquad (1)$$

From the energy conservation:

$$V_B = V_1 + V_2; \qquad (2)$$

From (1) and (2):

$$V_B = I \times R_1 + I \times R_2 = I \times (R_1 + R_2) \qquad (3)$$

Solve (3) for the current

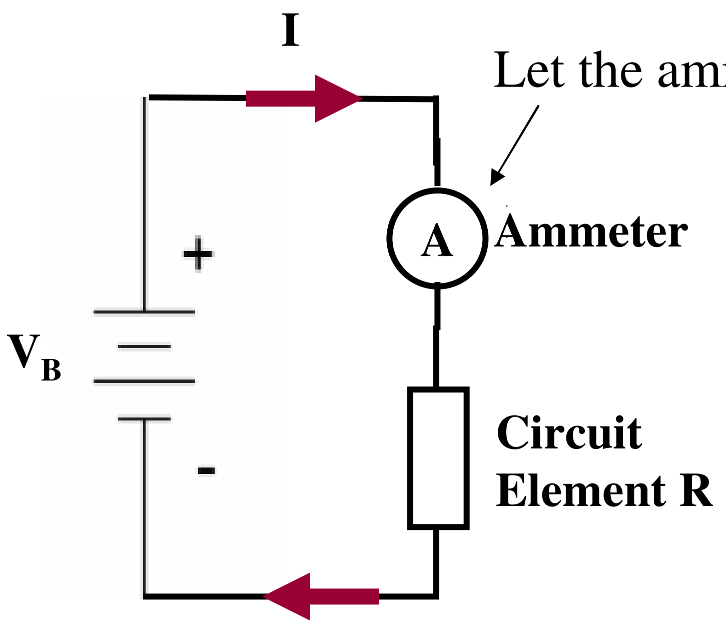
$$I = \frac{V_B}{R_1 + R_2}$$

Find V_1 and V_2 from (1)

$$V_1 = I \times R_1 = R_1 \frac{V_B}{R_1 + R_2} = V_B \frac{R_1}{R_1 + R_2}$$

$$V_2 = V_B \frac{R_2}{R_1 + R_2}$$

Distortions introduced by current measurement



Let the ammeter resistance (the resistance of the coil) be R_A

The actual circuit current is

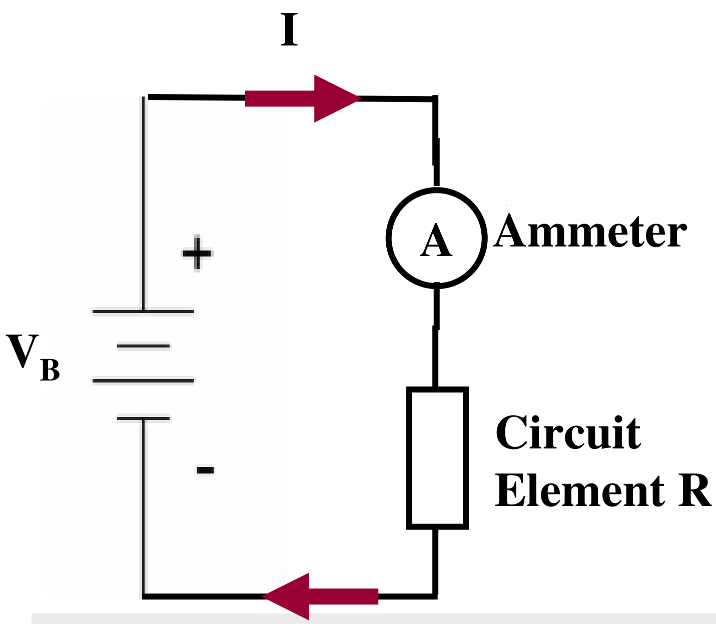
$$I = \frac{V_B}{R}$$

The measured current,

$$I_M = \frac{V_B}{R + R_A} < I$$

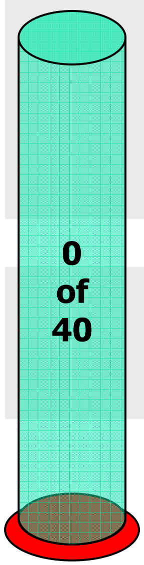
The measured current is less than the actual current in the circuit

Problem 1

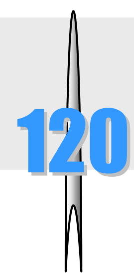


The resistor 2 kOhm is connected to a 9V battery. The Ammeter connected in series with the resistor indicates the current 4 mA flowing through the circuit.

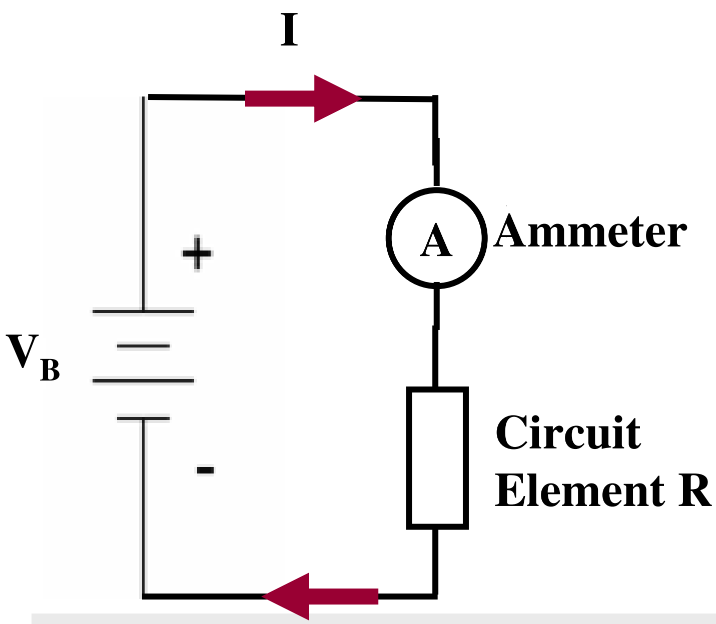
What is the actual current in the original circuit (without the ammeter) in mA?



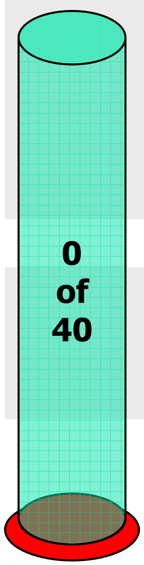
Timed response



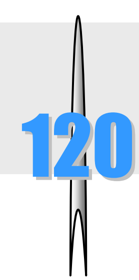
Problem 2



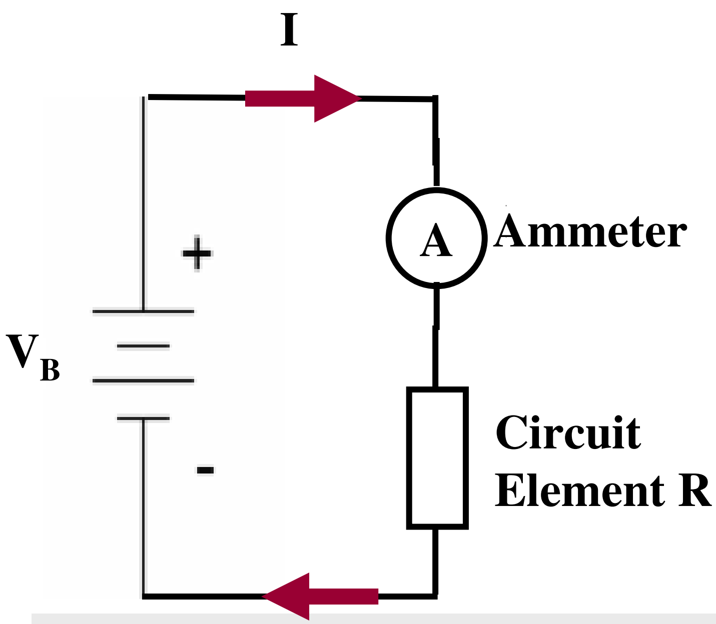
The resistor 2 kOhm is connected to a 9V battery. The Ammeter connected in series with the resistor indicates the current
4 mA flowing through the circuit.
What is the Ammeter internal resistance in Ohms?



Timed response



Problem 3



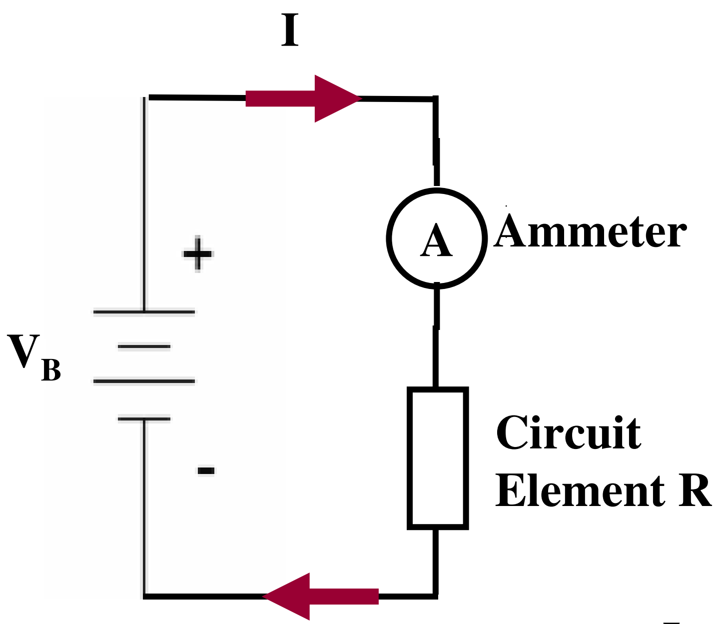
A resistor is connected to a 9V battery. The Ammeter connected in series with the resistor indicates the current 4.5 mA in the circuit. The Ammeter internal resistance is 100 Ohm. **What is the actual current in the circuit (without the ammeter) in mA**?

0 of 40

120

Timed response

Distortions introduced by current measurement



The actual circuit current is

$$I = \frac{V_B}{R}$$

The measured current

$$I_M = \frac{V_B}{R + R_A} < I$$

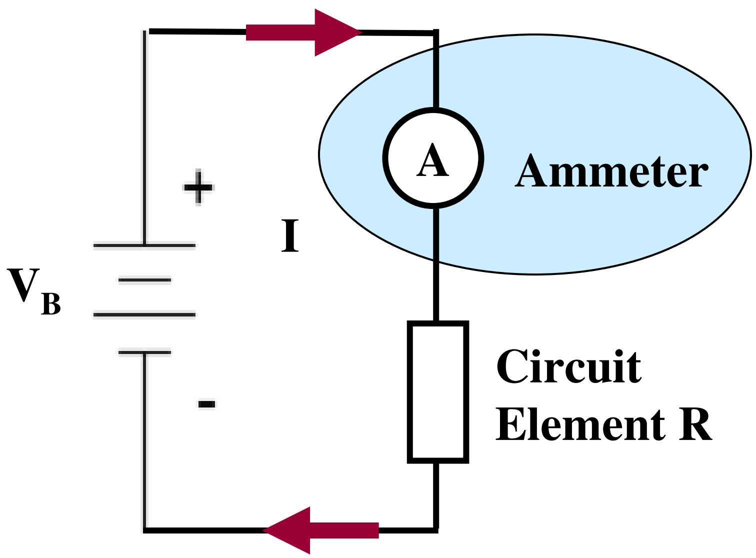
The actual / measured current ratio

$$\frac{I}{I_M} = \frac{V_B}{R} / \left(\frac{V_B}{R + R_A} \right) = \frac{R + R_A}{R} = 1 + \frac{R_A}{R}$$

The relative measurement error

$$\frac{\Delta I}{I_M} = \frac{I - \bar{I}_M}{I_M} \approx \frac{I}{I_M} - 1 = \frac{R_A}{R}$$

Requirements for accurate current measurements



$$\frac{\Delta I}{I_M} \approx \frac{R_A}{R}$$

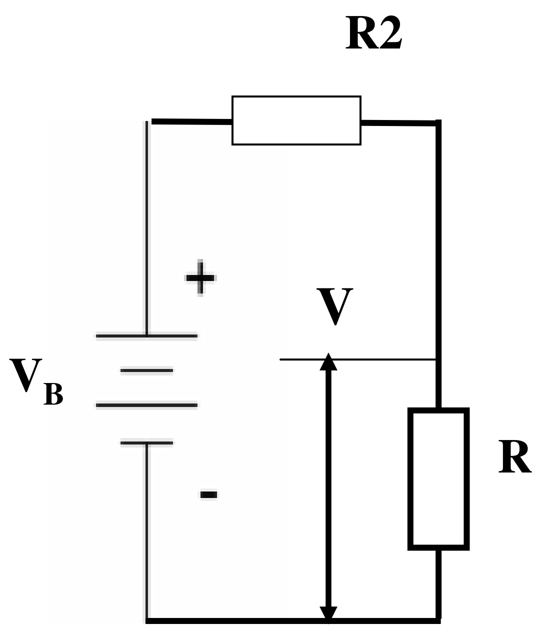
For accurate measurements,
The AMMETER resistance must be << R

Example

What is the relative current measurement error if the ammeter resistance $R_A = 0.001 \times R$?

$$\frac{\Delta I}{I_M} \approx \frac{R_A}{R} = 0.001 = 0.1\%$$

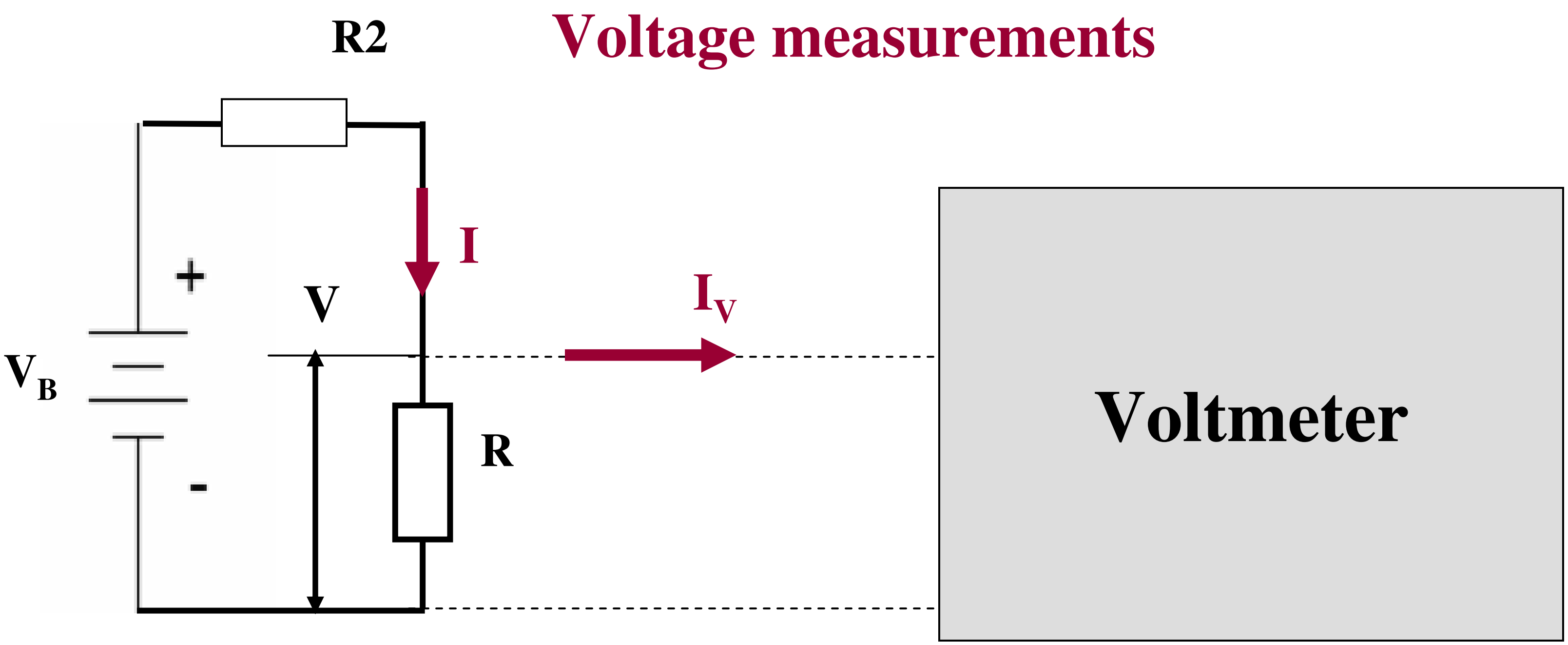
Voltage measurements



- To measure the voltage, we need to *probe* the voltage between two nodes in the circuit.
- Various types of analog and digital electronics instruments are capable of amplifying or attenuating the input signals.
- Since voltage measurement does not need any “intrusion” it does not seem to make distortions

NOT TRUE!

Voltage measurements

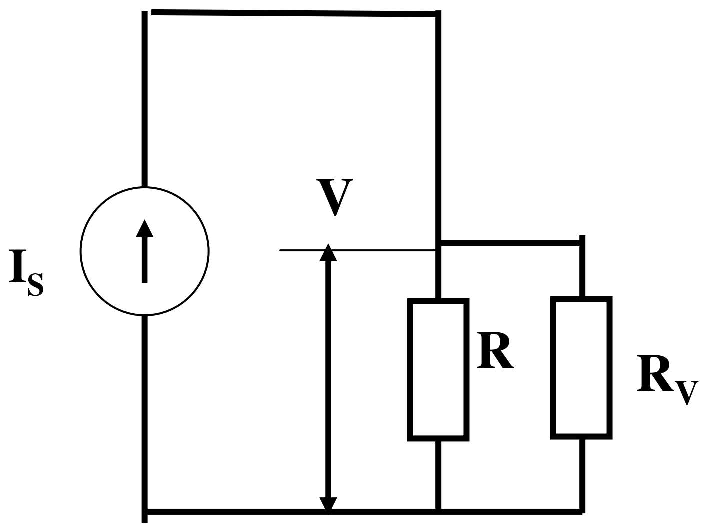


When the voltage is applied to the input of any instrument, there is a current $\mathbf{I_V}$ flowing into the input.

According to the charge conservation law, this current reduces the current through the test element.

Therefore, the voltage V changes, too.

Voltage measurements



Assume the voltmeter internal resistance R_V.

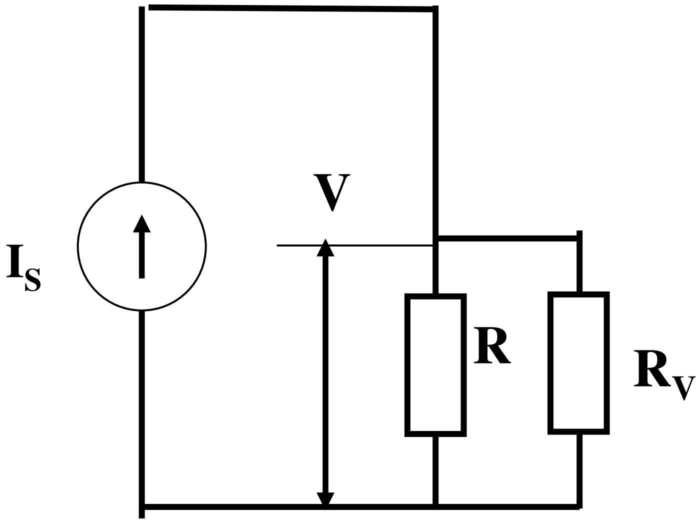
The total resistance with the voltmeter connected,

$$R_{EQ} = \frac{R \times R_V}{R + R_V} < R$$

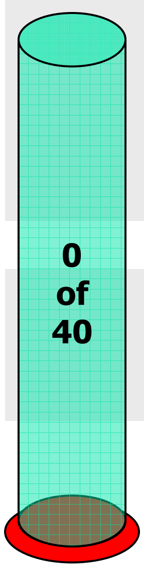
The voltage measured by the voltmeter, $V_M = I_S * R_{EQ}$

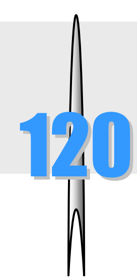
The actual voltage, $V = I_S * R > V_M$

Problem 4



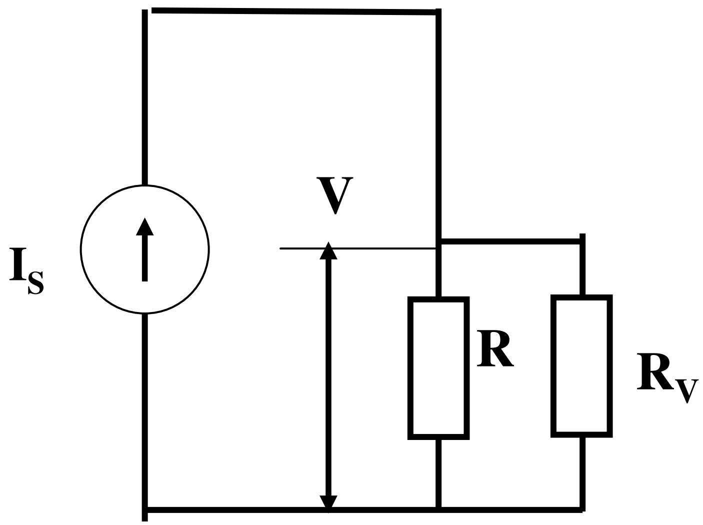
Resistor 1k is connected to a 10 mA current source.
The voltmeter connected in in parallel with the resistor indicates the voltage 9.5 V
What is the actual voltage across the resistor (with no voltmeter connected) in V?





Timed response

Problem 5



Resistor 1k is connected to a current source. The voltmeter with internal resistance 10k connected in in parallel with the resistor indicates the voltage 9.09 V

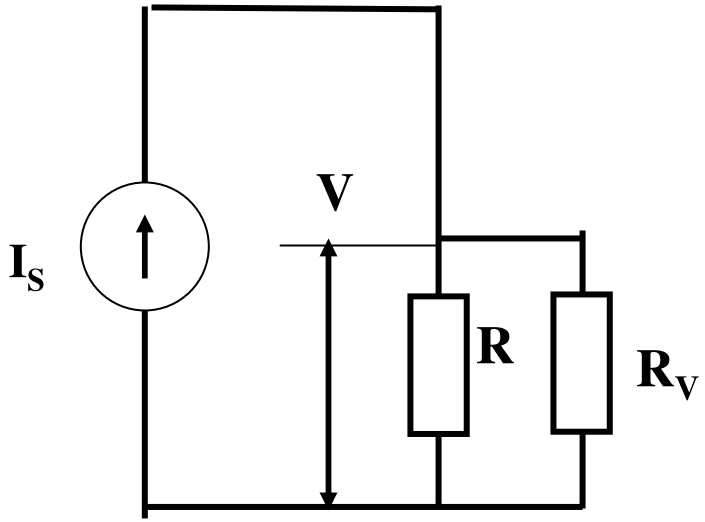
What is the actual voltage across the resistor (with no voltmeter connected) in V?

0 of 40

Timed response

120

Voltage measurements



The actual voltage: $V = I_S \times R$

The measured voltage:

$$V_M = I_S \times R_{EQ} = I_S \frac{R \times R_V}{R + R_V}$$

$$\frac{V}{V_M} = \frac{I_S}{I_S} \frac{(R + R_V) R}{R \times R_V} = \frac{R + R_V}{R_V} = 1 + \frac{R}{R_V}$$

The error introduced by the measurement:

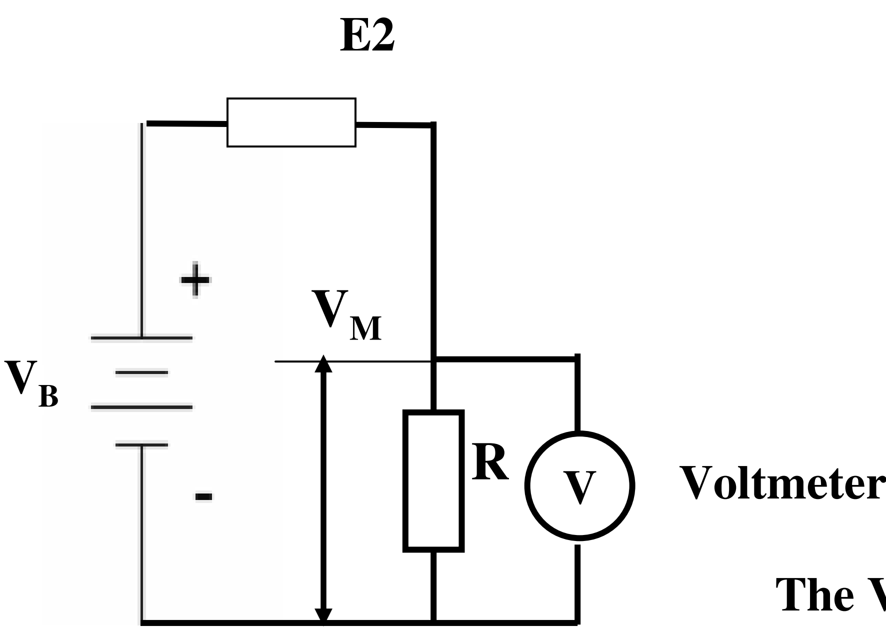
$$\frac{\Delta V}{V_M} = \frac{V - V_M}{V_M} = \frac{V}{V_M} - 1;$$

$$\boxed{\frac{\Delta V}{V_M} = \frac{R}{R_V}}$$

Voltage measurements

$$\frac{\Delta V}{V_M} = \frac{V}{V_M} - 1 = \frac{R}{R_V}$$

In order to achieve less than 0.1% error in measurements, what values of R_V is needed?



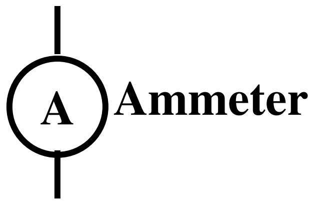
$$\frac{R}{R_V} < 0.1\% = 0.001;$$

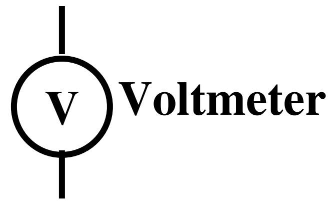
$$R_V > 1000 \times R.$$

The VOLTMETER resistance must be >> R

On a circuit diagram, a voltmeter is shown as an V in a circle.

Voltmeter and ammeter comparison

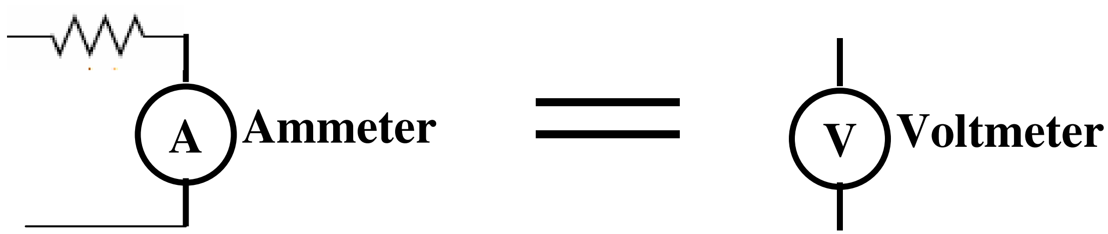




The ammeter resistance R_A must be much lower than the resistance R of the circuit to be measured

The voltmeter resistance R_V must be much higher than the resistance R of the circuit to be measured

Ammeter connected to a large series resistor can be used as a voltmeter



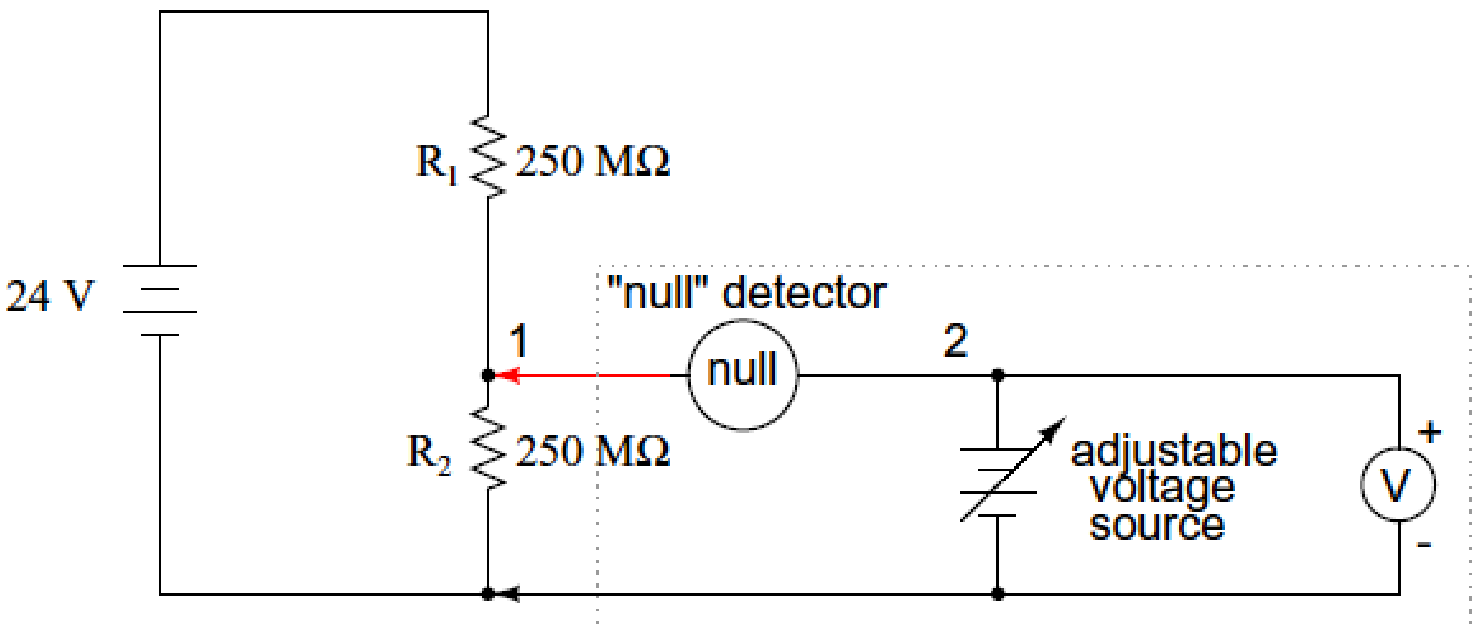
Summary

- For accurate **current measurements**, the resistance of the current meter (connected in series with the circuit element under testing), must be **much smaller** than that of the tested element.
- For accurate **voltage measurements**, the resistance of the voltmeter (connected in parallel with the circuit element under testing), must be **much greater** than that of the tested element.
- The current and voltage measurement errors (relative) are given by:

$$\frac{\Delta I}{I_M} \approx \frac{I}{I_M} - 1 = \frac{R_A}{R}$$

$$\frac{\Delta V}{V_M} = \frac{V}{V_M} - 1 = \frac{R}{R_V}$$

“Smart” voltmeter circuit – zero current consumption



Adjust voltage source until null detector registers zero.
Then, read voltmeter indication for voltage across R_2.