Electrical Instruments

Galvanometer – measures current

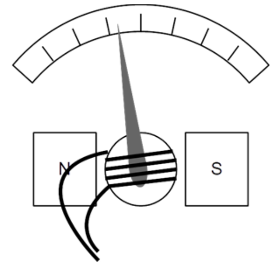
Voltmeter – measures potential difference

Ammeter – measures current

Ohmmeter – measures resistance

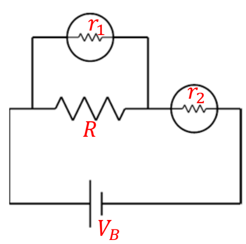
Electrical Instruments

Galvanometer – Current through coil creates a magnetic field that interacts with field due to other magnets. Needle deflection is proportional to current.



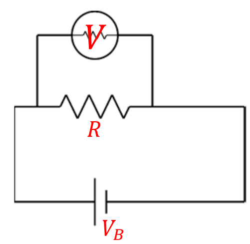
Electrical Instruments

Adding an instrument changes the circuit. The measurement is of the circuit with the instrument and not of the original circuit.



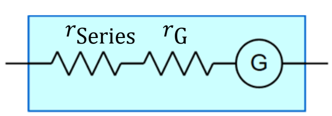
Voltmeter

- Voltmeter connected in parallel to measure potential difference between two points.
- r_V must be large to minimize change from original circuit.



Voltmeter

Creating a voltmeter from a galvanometer



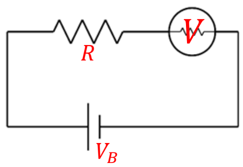
$$r_{\text{V}} = r_{\text{Series}} + r_{\text{G}}$$

Given that $I_{\max}$ creates a full-scale deflection, select r_{Series} such that $V_{\max}$ produces $I_{\max}$ through the galvanometer.

Example: A galvanometer has an internal resistance of 12Ω and experiences full deflection with a current of 0.4A. Design a voltmeter using the galvanometer that will read full scale at 20V.

Voltmeter

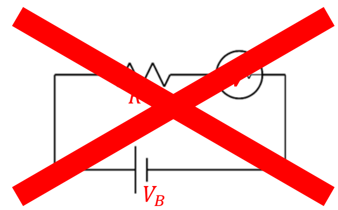
What happens if a voltmeter is connected in series?



Voltmeter

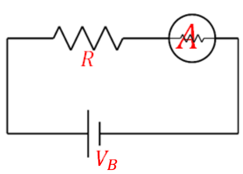
What happens if a voltmeter is connected in series?

- Circuit is drastically changed.
- Very little current flows.



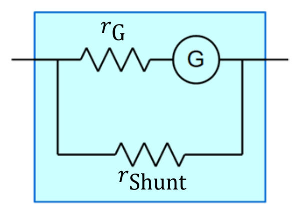
Ammeter

- Ammeter connected in series to measure current through resistor.
- r_A must be small to minimize change from original circuit.



Ammeter

Creating an ammeter from a galvanometer



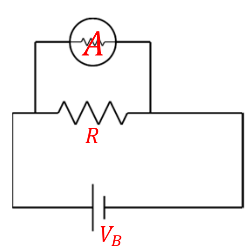
$$\frac{1}{r_{\mathrm{A}}} = \frac{1}{r_{\mathrm{Shunt}}} + \frac{1}{r_{\mathrm{G}}}$$

Given that $I_{\mathrm{G-max}}$ creates a full-scale deflection, select r_{Shunt} such that $I_{\mathrm{A-max}}$ produces $I_{\mathrm{G-max}}$ through the galvanometer.

Example: A galvanometer has an internal resistance of 12Ω and experiences full deflection with a current of $0.4\mathrm{A}$. Design an ammeter using the galvanometer that will read full scale at $10\mathrm{A}$.

Ammeter

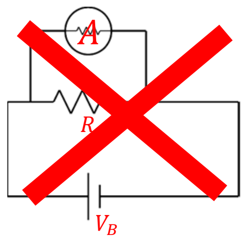
What happens if an ammeter is connected in parallel?



Ammeter

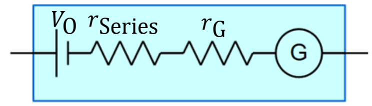
What happens if an ammeter is connected in parallel?

- Circuit is drastically changed.
- Massive current flows.
- Flash
- Noise
- Smoke
- Smell
- Loss of ammeter
- Angry instructor



Ohmmeter

Creating an ohmmeter from a galvanometer. Connected to a resistor in isolation, the ohmmeter forms a circuit with the unknown resistor.

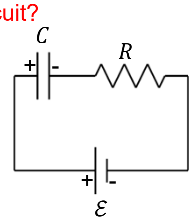


$$R_{\mathrm{T}} = r_{\mathrm{Series}} + r_{\mathrm{G}} + R$$

Solve $V_{\mathrm{O}} = IR_{\mathrm{T}}$ to determine R.

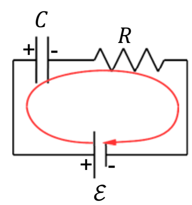
RC Circuits

What happens when capacitor is connected to a resistor in a circuit?



RC Circuits

Apply Kirchhoff's loop rule.



$$\mathcal{E} - \frac{Q}{C} - IR = 0$$

RC Circuits

$$\mathcal{E} - \frac{Q}{C} - IR = 0$$

$$I = +\frac{dQ}{dt}$$

Positive because current through the resistor is associated with an increase of charge on the capacitor.

$$\mathcal{E} - \frac{Q}{C} - \frac{dQ}{dt}R = 0$$

RC Circuits

$$\mathcal{E} - \frac{Q}{C} - \frac{dQ}{dt}R = 0$$

$$\mathcal{E} - \frac{Q}{C} = \frac{dQ}{dt}R$$

$$\frac{\mathcal{E}C - Q}{RC} = \frac{dQ}{dt}$$

$$\frac{dt}{RC} = \frac{dQ}{\mathcal{E}C - Q}$$

RC Circuits

$$\frac{dt}{RC} = \frac{dQ}{\mathcal{E}C - Q}$$

$$\int_0^t \frac{dt}{RC} = \int_0^Q \frac{dQ}{\mathcal{E}C - Q}$$

$$\frac{t}{RC} = -\ln[\mathcal{E}C - Q]_0^Q$$

$$-\frac{t}{RC} = \ln\left(\frac{\mathcal{E}C - Q}{\mathcal{E}C}\right)$$

RC Circuits

$$-\frac{t}{RC} = \ln\left(\frac{\mathcal{E}C - Q}{\mathcal{E}C}\right)$$

$$e^{-\frac{t}{RC}} = \frac{\mathcal{E}C - Q}{\mathcal{E}C}$$

$$\mathcal{E}Ce^{-\frac{t}{RC}} = \mathcal{E}C - Q$$

$$Q = \mathcal{E}C\left(1 - e^{-\frac{t}{RC}}\right)$$

RC Circuits

$$-\frac{t}{RC} = \ln\left(\frac{\mathcal{E}C - Q}{\mathcal{E}C}\right)$$

$$e^{-\frac{t}{RC}} = \frac{\mathcal{E}C - Q}{\mathcal{E}C}$$

$$\mathcal{E}Ce^{-\frac{t}{RC}} = \mathcal{E}C - Q$$

$$Q = \mathcal{E}C\left(1 - e^{-\frac{t}{RC}}\right)$$

$$Q = Q_f\left(1 - e^{-\frac{t}{RC}}\right)$$

RC Circuits

Charging a capacitor

- Charge on capacitor

$$Q = Q_f\left(1 - e^{-\frac{t}{\tau}}\right)$$

- Voltage across capacitor

$$V = \frac{Q}{C} = \mathcal{E}\left(1 - e^{-\frac{t}{\tau}}\right)$$

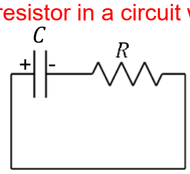
- Current through resistor

$$I = \frac{dQ}{dt} = \frac{\mathcal{E}}{R}e^{-\frac{t}{\tau}}$$

$(\tau \equiv RC)$

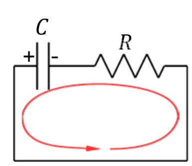
RC Circuits

What happens when charged capacitor is connected to a resistor in a circuit without a battery?



RC Circuits

Apply Kirchhoff's loop rule.



$$\frac{Q}{C} - IR = 0$$

RC Circuits

$$\frac{Q}{C} - IR = 0$$

$$I = -\frac{dQ}{dt}$$

Negative because current through the resistor is associated with a decrease of charge on the capacitor.

$$\frac{Q}{C} + \frac{dQ}{dt}R = 0$$

RC Circuits

$$\frac{Q}{C} + \frac{dQ}{dt}R = 0$$

$$\frac{dQ}{Q} = -\frac{dt}{RC}$$

$$\ln\left(\frac{Q}{Q_0}\right) = -\frac{t}{RC}$$

$$Q = Q_0 e^{-\frac{t}{RC}}$$

RC Circuits

Discharging a capacitor

- Charge on capacitor

$$Q = Q_0 e^{-\frac{t}{\tau}}$$

- Voltage across capacitor

$$V = \frac{Q}{C} = \frac{Q_0}{C} e^{-\frac{t}{\tau}}$$

- Current through resistor

$$I = -\frac{dQ}{dt} = \frac{Q_0}{RC} e^{-\frac{t}{\tau}} \qquad (\tau \equiv RC)$$

Example: An 8μF capacitor is connected in series with a 50Ω resistor and a 60V battery. (a) When does the capacitor become fully charged? (b) What is the charge on the capacitor when it is fully charged? (c) When does the capacitor hold half of its ultimate full charge? (d) What is the current in the resistor when the capacitor holds half of its ultimate full charge?