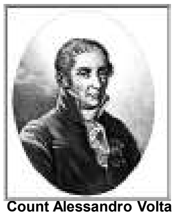
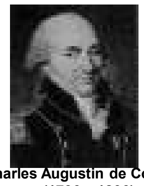
Electric Circuits



Count Alessandro Volta
(1745 - 1827)

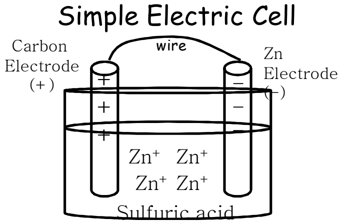
Georg Simon Ohm
(1787 - 1854)

André Marie AMPÈRE
(1775 - 1836)



Charles Augustin de Coulomb
(1736 – 1806)

Simple Electric Cell



- Two dissimilar metals or carbon rods in acid
- Zn^+ ions enter acid leaving terminal negative
- Electrons leave carbon leaving it positive
- Terminals connected to external circuit
- 'Battery' referred to several cells originally

Electric Current

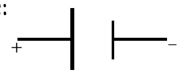
Electrons flow out of the negative terminal and toward the positive terminal → electric current. (We will consider conventional current – positive charges move

Electric current I is defined as the rate at which charge flows past a given point per unit time.

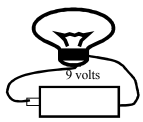
1 C/s = 1A (ampere)

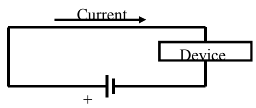
Electric Circuit

- It is necessary to have a complete circuit in order for current to flow.
- The symbol for a battery in a circuit diagram is:



"Conventional" current direction is opposite to actual electron flow direction which is – to +.





Ohm's Law

- For wires and other circuit devices, the current is proportional to the voltage applied to its ends:

  $I \propto V$
- The current also depends on the amount of resistance that the wire offers to the electrons for a given voltage V.
- We define a quantity called *resistance* R such that
- $I = \frac{V}{R}$ (Ohm's Law)
- The unit of resistance is the ohm which is represented by the Greek capital omega (Ω).

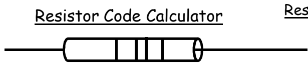
$$1\Omega = \frac{V}{A}$$

Resistors

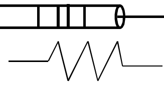
- A resistor is a circuit device that has a fixed resistance.

Resistor Code Calculator

Resistor Code

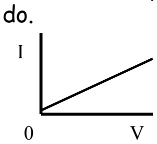


Resistor

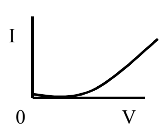


Circuit symbol

Resistors obey Ohm's law but not all circuit devices do.



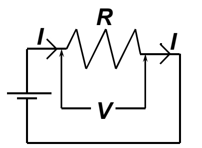
Resistor



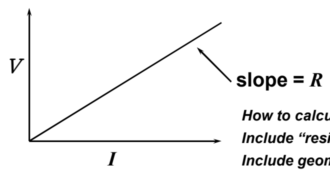
non-ohmic device

Ohm's Law

- **Demo:**
  - **Vary applied voltage V.**
  - **Measure current I**
  - **Does ratio $\frac{V}{I}$ remain constant?**



$$R \equiv \frac{V}{I}$$

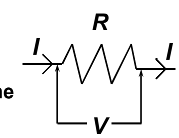


How to calculate the resistance?
Include "resistivity" of material
Include geometry of resistor

Resistance

- **Resistance**

  Resistance is defined to be the ratio of the applied voltage to the current passing through.



$$R \equiv \frac{V}{I}$$

UNIT: OHM = Ω

- **Increase the length → flow of electrons impeded**
- **Increase the cross sectional area → flow facilitated**
- **Compare to straws or pipes**

Two cylindrical resistors are made from the same material, and they are equal in length. The first resistor has diameter *d*, and the second resistor has diameter 2*d*.

1) Compare the resistance of the two cylinders.

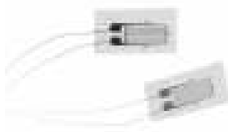
a) $R_1 > R_2$ b) $R_1 = R_2$ c) $R_1 < R_2$

2) If the same current flows through both resistors, compare the average velocities of the electrons in the two resistors:

a) $v_1 > v_2$ b) $v_1 = v_2$ c) $v_1 < v_2$

Strain Gauge

- A very thin metal wire patterned as shown is bonded to some structure.
- As the structure is deformed slightly, this stretches the wire (slightly).
  - When this happens, the resistance of the wire:



(a) decreases　　(b) increases　　(c) stays the same

Because the wire is slightly longer, $R \sim L/A$ is slightly increased. Also, because the overall volume of the wire is ~constant, increasing the length decreases the area A, which also increases the resistance.

By carefully measuring the change in resistance, the strain in the structure may be determined.

Power in Electric Circuits

- Electrical circuits can transmit and consume energy.
- When a charge Q moves through a potential difference V, the energy transferred is QV.
- Power is energy/time and thus:

$$P = power = \frac{energy}{time} = \frac{QV}{t} = \left(\frac{Q}{t}\right) V = IV$$

and thus:

$$P = IV$$

Notes on Power

•The formula for power applies to devices that provide power such as a battery as well as to devices that consume or dissipate power such as resistors, light bulbs and electric motors.

$$A \cdot V = \frac{C}{s} \cdot \frac{J}{C} = \frac{J}{s} = Watt(W)$$

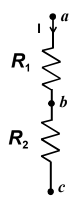
•The formula for power can be combined with Ohm's Law to give other versions:

$$P = IV = I^2 R = \frac{V^2}{R}$$

Household Power

- Electric companies usually bill by the **kilowatt-hour (kWh.)** which is the energy consumed by using 1.0 kW for one hour.
- Thus a 100 W light bulb could burn for 10 hours and consume 1.0 kWh.
- Electric circuits in a building are protected by a fuse or circuit breaker which shuts down the electricity in the circuit if the current exceeds a certain value. This prevents the wires from heating up when carrying too much current.

Resistors in Series



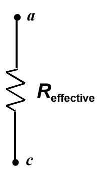
The Voltage "drops":

$V_a - V_b = IR_1$ $V_b - V_c = IR_2$

$V_a - V_c = I(R_1 + R_2)$

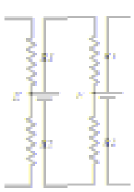
Whenever devices are in SERIES, the current is the same through both !

This reduces the circuit to:



Hence: $R_{effective} = (R_1 + R_2)$

Voltage Divider



Two resistors are connected in series to a battery with emf $\boldsymbol{E}$. The resistances are such that $R_1 = 2R_2$.

Compare the current through R_1 with the current through R_2:

a) $I_1 > I_2$

b) $I_1 = I_2$

c) $I_1 < I_2$

What is the potential difference across R_2?

a) $V_2 = \boldsymbol{E}$ b) $V_2 = 1/2\ \boldsymbol{E}$ c) $V_2 = 1/3\ \boldsymbol{E}$

Resistors in Parallel

- What to do? $V = IR$
- Very generally, devices in parallel have the same voltage drop
- But current through R_1 is not I ! Call it I_1. Similarly, $R_2 \leftrightarrow I_2$.

KVL ⇒ $V - I_1 R_1 = 0$

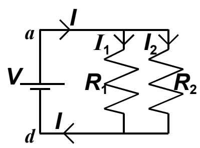
$V - I_2 R_2 = 0$

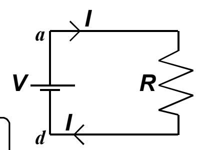
- How is I related to I_1 & I_2 ?

Current is conserved!

$$I = I_1 + I_2$$

$$\Rightarrow \frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} \Rightarrow \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$



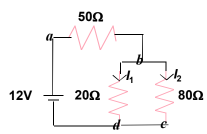


Circuit Practice

- Consider the circuit shown:

1 – What is the relation between V_a - V_d and V_a - V_c ?

(a) $(V_a - V_d) < (V_a - V_c)$
(b) $(V_a - V_d) = (V_a - V_c)$
(c) $(V_a - V_d) > (V_a - V_c)$



2 – What is the relation between I_1 and I_2?

(a) $I_1 < I_2$ (b) $I_1 = I_2$ (c) $I_1 > I_2$

Circuit Practice

- Consider the circuit shown:

1 – What is the relation between V_a - V_d and V_a - V_c ?

(a) $(V_a - V_d) < (V_a - V_c)$
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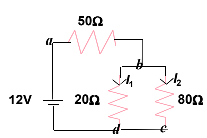
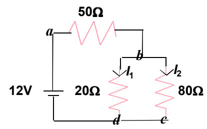


•Point d and c are the same, electrically

Circuit Practice

- **Consider the circuit shown:**
  - **What is the relation between $V_a - V_d$ and $V_a - V_c$?**



(a) $(V_a - V_d) < (V_a - V_c)$
(b) $(V_a - V_d) = (V_a - V_c)$
(c) $(V_a - V_d) > (V_a - V_c)$

2 – **What is the relation between I_1 and I_2?**

(a) $I_1 < I_2$ **(b)** $I_1 = I_2$ **(c)** $I_1 > I_2$

- **Note that:** $V_b - V_d = V_b - V_c$
  - **Therefore,**

$$I_1(20\,\Omega) = I_2(80\,\Omega) \implies I_1 = 4I_2$$

Summary of Simple Circuits

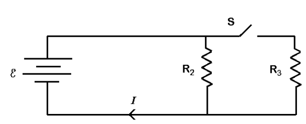
- **Resistors in series:** $R_{equivalent} = R_1 + R_2 + R_3 + \ldots$

  Current thru is same; Voltage drop across is IR_i

- **Resistors in parallel:** $\dfrac{1}{R_{equivalent}} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3} + \ldots$

  Voltage drop across is same; Current thru is V/R_i

Two identical light bulbs are represented by the resistors R_2 & R_3 ($R_2 = R_3$). The switch S is initially open.



If switch S is closed, what happens to the brightness of the bulb R_2?
a) It increases b) It decreases c) It doesn't change

What happens to the current I, after the switch is closed ?

a) $I_{after} = 1/2\ I_{before}$

b) $I_{after} = I_{before}$

c) $I_{after} = 2\ I_{before}$