PHYSICS II

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Contents

Summary for Capacitance

Capacitor and Capacitance

- The capacitance of a capacitor is defined as:

$$q = CV$$

Determining Capacitance

- Parallel-plate capacitor:

$$C = \frac{\varepsilon_0 A}{d}.$$

- Cylindrical Capacitor:

$$C = 2\pi\varepsilon_0 \frac{L}{\ln(b/a)}.$$

- Spherical Capacitor:

$$C = 4\pi\varepsilon_0 \frac{ab}{b-a}.$$

- Isolated sphere:

$$C = 4\pi\varepsilon_0 R.$$

Capacitor in parallel and series

- In parallel:

$$C_{eq} = \sum_{j=1}^{n} C_j$$

- In series

$$\frac{1}{C_{eq}} = \sum_{j=1}^{n} \frac{1}{C_j}$$

Potential Energy and Energy Density

- Electric Potential Energy (U):

$$U = \frac{q^2}{2C} = \tfrac{1}{2}CV^2$$

- Energy density (*u*)

$$u = \tfrac{1}{2}\varepsilon_0 E^2.$$

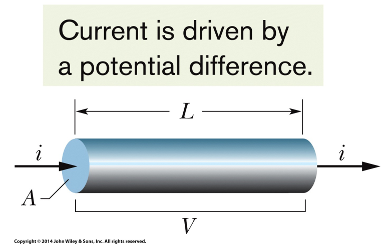
Summary for Resistivity & Resistance

Resistance is a property of an object. Resistivity is a property of a material.

The resistance R of a conducting wire of length L and uniform cross section is

$$R = \rho \frac{L}{A}.$$

Here A is the cross-sectional area.

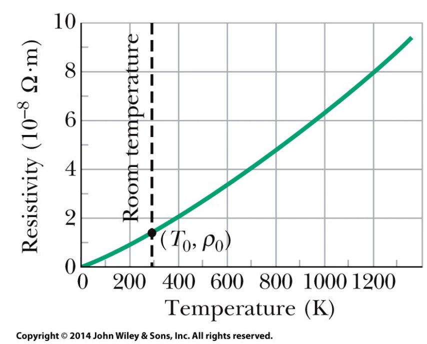


A potential difference V is applied between the ends of a wire of length L and cross section A, establishing a current i.

The resistivity ρ for most materials changes with temperature. For many materials, including metals, the relation between ρ and temperature T is approximated by the equation

$$\rho - \rho_0 = \rho_0 \alpha (T - T_0).$$

Here T_0 is a reference temperature, ρ_0 is the resistivity at T_0, and α is the temperature coefficient of resistivity for the material.



The resistivity of copper as a function of temperature.

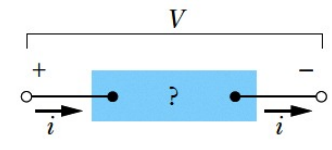
Summary for Ohm’s Law

Ohm’s law is an assertion that the current through a device is *always* directly proportional to the potential difference applied to the device.

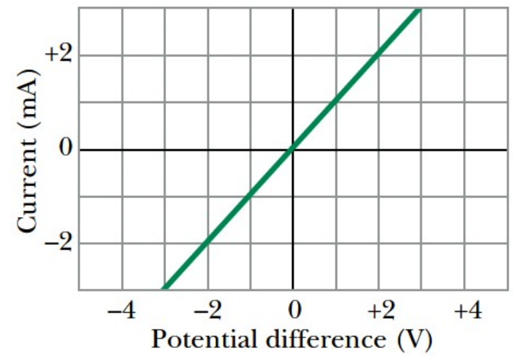
$I \sim V$ or $I = V/R$

A conducting device obeys Ohm’s law when the resistance of the device is independent of the magnitude and polarity of the applied potential difference.

A conducting material obeys Ohm’s law when the resistivity of the material is independent of the magnitude and direction of the applied electric field.



(*a*)



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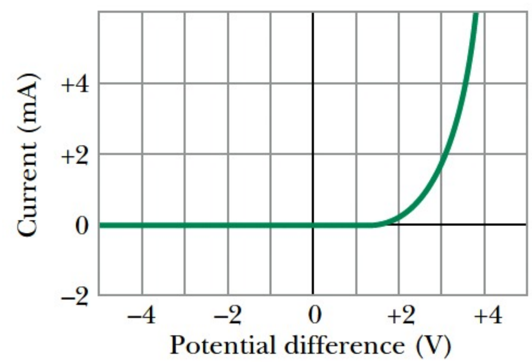


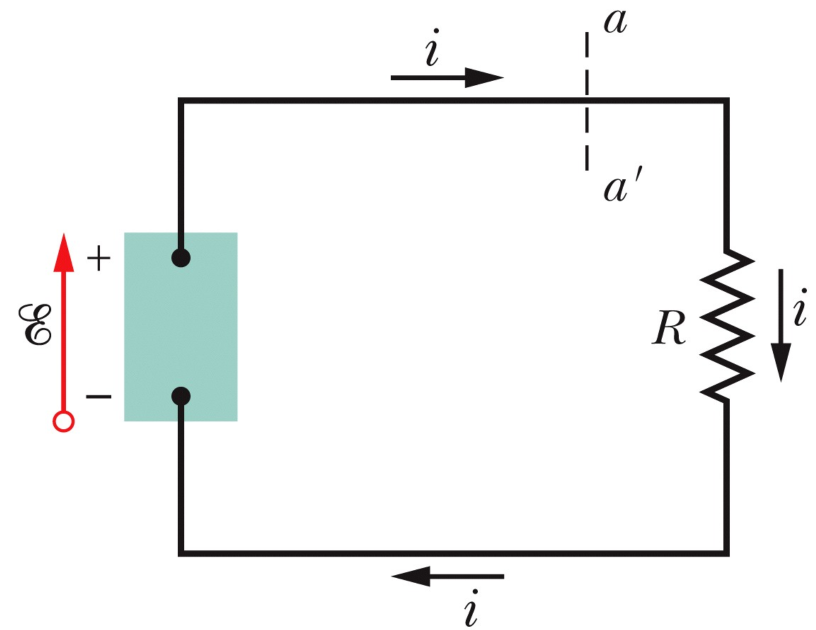
(*c*)

Circuits

Single-Loop Circuits

To produce a steady flow of charge, you need a "charge pump," a device that—by doing work on the charge carriers—maintains a potential difference between a pair of terminals. We call such a device an ***emf* device**, and the device is said to provide an *emf* $\mathscr{E}$, which means that it does work on charge carriers.

Figure shows an *emf* device (consider it to be a battery) that is part of a simple circuit containing a single resistance *R*. The *emf* device keeps one of its terminals (called the positive terminal and often labeled +) at a higher electric potential than the other terminal (called the negative terminal and labeled -). We can represent the *emf* of the device with an arrow that points from the negative terminal toward the positive terminal as in Figure. A small circle on the tail of the *emf* arrow distinguishes it from the arrows that indicate current direction.



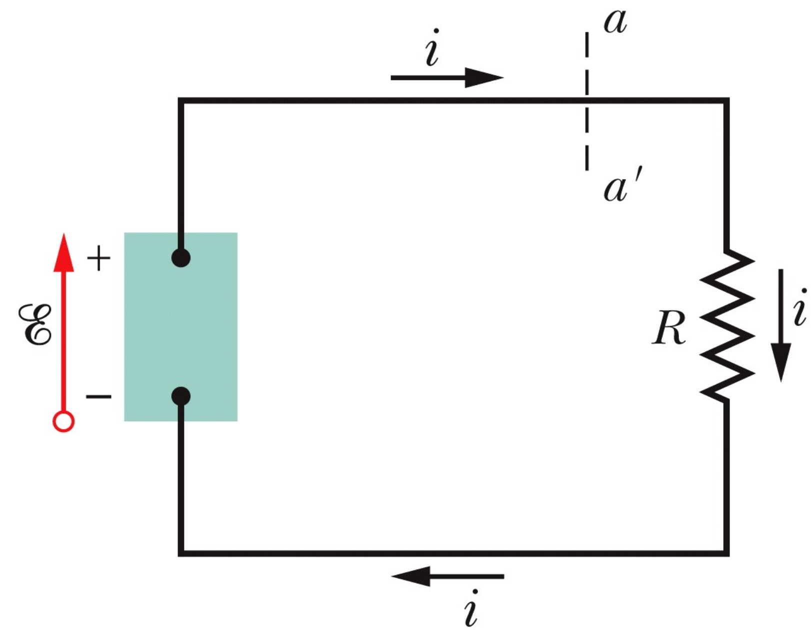
Single-Loop Circuits

An emf device does work on charges to maintain a potential difference between its output terminals. If *dW* is the work the device does to force positive charge *dq* from the negative to the positive terminal, then the *emf* (work per unit charge) of the device is

$$\mathscr{E} = \frac{dW}{dq} \quad \text{(definition of } \mathscr{E}\text{).}$$

An **ideal *emf* device** is one that lacks any internal resistance. The potential difference between its terminals is equal to the *emf*.

A **real *emf* device** has internal resistance. The potential difference between its terminals is equal to the *emf* only if there is no current through the device.



Single-Loop Circuits

Calculating Current in a Single-Loop Circuits

Energy Method

Equation, $P=i^2R$, tells us that in a time interval dt an amount of energy given by $i^2R\,dt$ will appear in the resistor (shown in the figure) as thermal energy. This energy is said to be **dissipated**. (Because we assume the wires to have negligible resistance, no thermal energy will appear in them.)

During the same interval, a charge $dq = i\,dt$ will have moved through battery B, and the work that the battery will have done on this charge is

$$dW = \mathscr{E}\,dq = \mathscr{E}i\,dt.$$

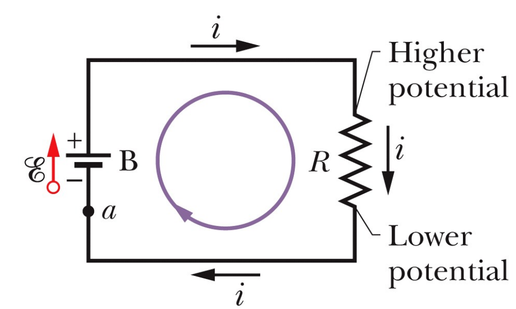
From the principle of conservation of energy, the work done by the (ideal) battery must equal the thermal energy that appears in the resistor:

$$\mathscr{E}i\,dt = i^2R\,dt.$$

Which gives us

$$i = \frac{\mathscr{E}}{R}.$$

The battery drives current through the resistor, from high potential to low potential.



Single-Loop Circuits

Calculating Current in a Single-Loop Circuits

Potential Method

In the figure, let us start at point a, whose potential is V_a, and mentally walk clockwise around the circuit until we are back at point a, keeping track of potential changes as we move. Our starting point is at the low-potential terminal of the battery. Because the battery is ideal, the potential difference between its terminals is equal to $\mathscr{E}$. When we pass through the battery to the high-potential terminal, the change in potential is + $\mathscr{E}$.

After making a complete loop, our initial potential, as modified for potential changes along the way, must be equal to our final potential; that is,

$$V_a + \mathscr{E} - iR = V_a.$$

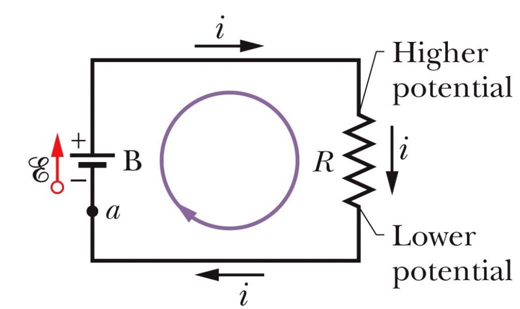
The value of V_a cancels from this equation, which becomes

$$\mathscr{E} - iR = 0.$$

Which gives us

$$i = \frac{\mathscr{E}}{R}.$$

The battery drives current through the resistor, from high potential to low potential.



Single-Loop Circuits

Calculating Current in a Single-Loop Circuits

LOOP RULE: The algebraic sum of the changes in potential encountered in a complete traversal of any loop of a circuit must be zero.

RESISTANCE RULE: For a move through a resistance in the direction of the current, the change in potential is $-iR$; in the opposite direction it is $+iR$.

EMF RULE: For a move through an ideal emf device in the direction of the emf arrow, the change in potential is $+\mathscr{E}$; in the opposite direction it is $-\mathscr{E}$.

Single-Loop Circuits

Internal Resistance

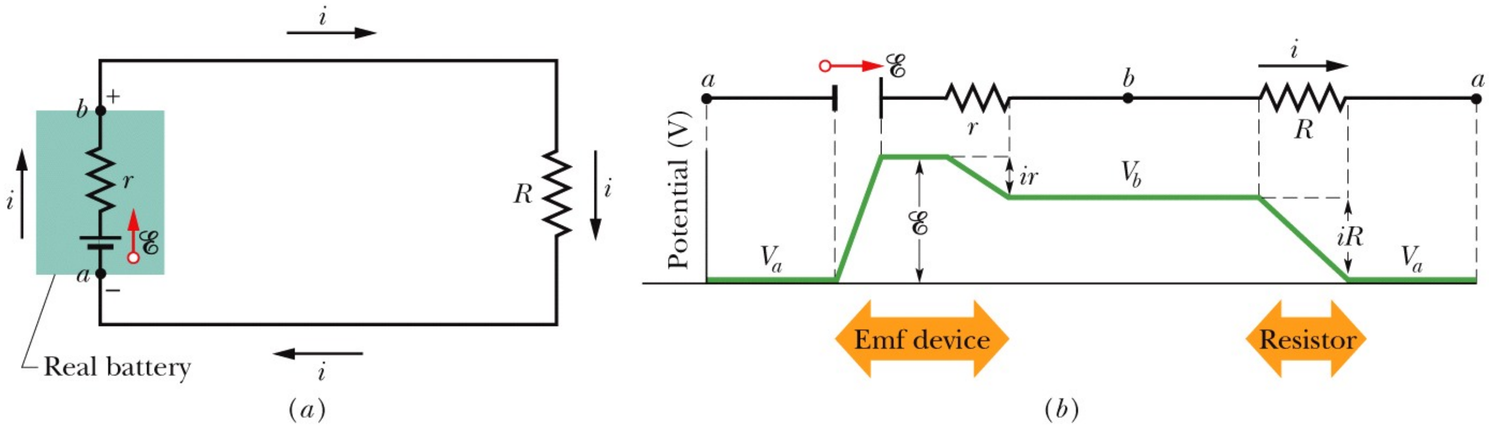


Figure (a) shows a real battery, with internal resistance *r*, wired to an external resistor of resistance *R*. The internal resistance of the battery is the electrical resistance of the conducting materials of the battery and thus is an un removable feature of the battery. Figure (b) shows graphically the changes in electric potential around the circuit. Now if we apply the loop rule clockwise beginning at point a, the changes in potential give us

$$\mathscr{E} - ir - iR = 0.$$

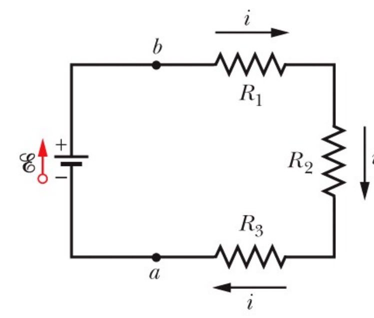
Solving for the current we find,

$$i = \frac{\mathscr{E}}{R + r}.$$

Single-Loop Circuits

Resistance in Series

Figure (a) shows three resistances connected in series to an ideal battery with *emf* $\mathscr{E}$. The resistances are connected one after another between a and b, and a potential difference is maintained across a and b by the battery. The potential differences that then exist across the resistances in the series produce identical currents *i* in them. To find total resistance R_{eq} in Fig. (b), we apply the loop rule to both circuits. For Fig. (a), starting at a and going clockwise around the circuit, we find

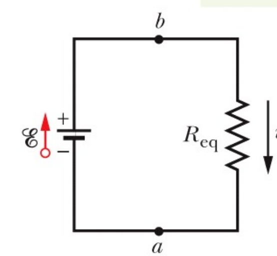


(a)

Series resistors and their equivalent have the same current ("ser-i").

$$\mathscr{E} - iR_1 - iR_2 - iR_3 = 0, \quad \text{or} \quad i = \frac{\mathscr{E}}{R_1 + R_2 + R_3}.$$

For Fig. (b), with the three resistances replaced with a single equivalent resistance R_{eq}, we find



(b)

$$\mathscr{E} - iR_{eq} = 0, \quad \text{or} \quad i = \frac{\mathscr{E}}{R_{eq}}.$$

Equating them, we get,

$$R_{eq} = R_1 + R_2 + R_3.$$

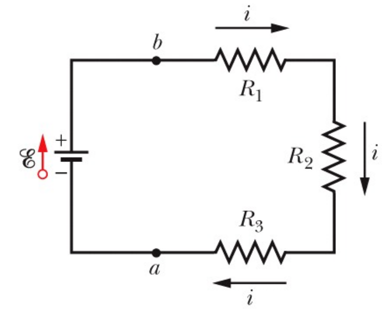
$$R_{eq} = \sum_{j=1}^{n} R_j \quad (n \text{ resistances in series}).$$

Single-Loop Circuits

Resistance in Series

When a potential difference V is applied across resistances connected in series, the resistances have identical currents i. The sum of the potential differences across the resistances is equal to the applied potential difference V.

Resistances connected in series can be replaced with an equivalent resistance R_{eq} that has the same current i and the same *total* potential difference V as the actual resistances.



(a)

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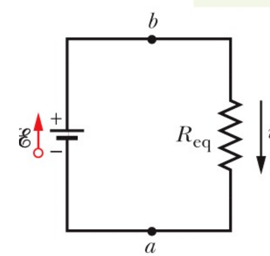


(b)

Checkpoint 2

In Fig. a, if $R_1 > R_2 > R_3$, rank the three resistances according to (a) the current through them and (b) the potential difference across them, greatest first.

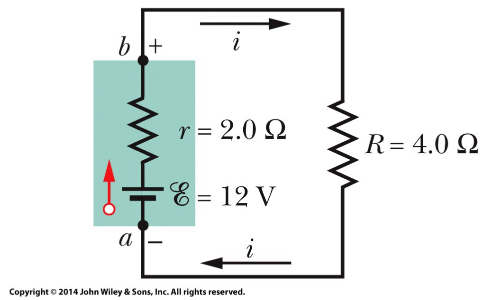
Answer: (a) current is same for all resistors in series.

(b) V_1, V_2, and V_3

Potential Difference

To find the potential between any two points in a circuit, start at one point and traverse the circuit to the other point, following any path, and add algebraically the changes in potential you encounter.

The internal resistance reduces the potential difference between the terminals.



Potential Difference across a real battery: In the Figure, points a and b are located at the terminals of the battery. Thus, the potential difference V_b - V_a is the terminal-to-terminal potential difference V across the batter and is given by:

$$V = \mathscr{E} - ir.$$

Grounding a Circuit: Grounding a circuit usually means connecting one point in the circuit to a conducting path to Earth's surface (actually to the electrically conducting moist dirt and rock below ground)

Power of *emf* Device: The rate P_{emf} at which the *emf* device transfers energy both to the charge carriers and to internal thermal energy is

$$P_{\text{emf}} = i\mathscr{E} \quad \text{(power of emf device).}$$

Next lecture

Multiloop circuits