Phys 100: The Physical World
Chapter 23

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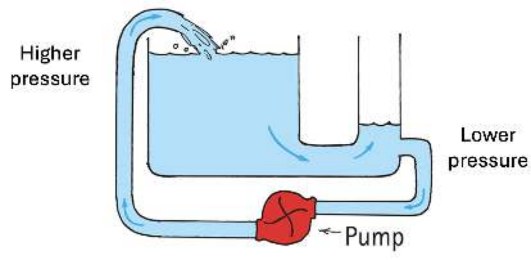
Misconceptions Regarding Current

The following statements are either wrong or imprecise.

(i) Electric current is the flow of free electrons only.
(ii) Electric current is stored in batteries.
(iii) Current gets "used up" in a circuit.
(iv) Electricity flows at the speed of electrons.
(v) Current always follows the path of least resistance.

Analogy with Water Current

All analogies are wrong, but some are useful. Charge will flow when a constant voltage is maintained across the ends of an electrical conductor. Analogous to water flowing from higher pressure to lower pressure. To sustain a flow of charge, a battery can be used to maintain the voltage. Analogous to a pump that maintains continuous flow by maintaining the difference in water levels and hence the difference in water pressures.



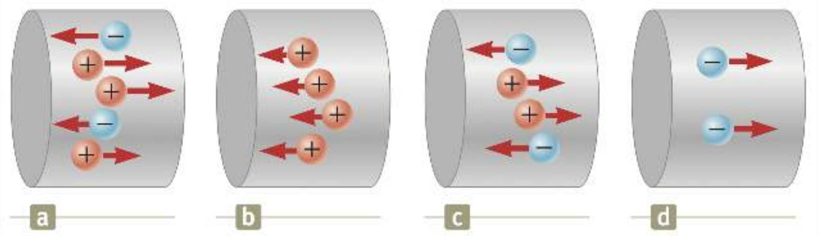
Electric Current

Electric current is the rate of net electric charge flow. In metal wires, conduction electrons are negative charge carriers that move throughout an underlying fixed atomic lattice. Protons are bound within the nuclei of lattice atoms and do not flow. In fluids, ions contribute both positive and negative charge carriers, and free electrons also contribute negative charge carriers to enable electric charge flow.

Electric current is measured in amperes (amps) where 1 amp is 1 coulomb per second. There are two basic kinds of current; (i) direct current (dc) happens when the voltage source maintains a steady voltage and (ii) alternating current (ac) happens when the voltage source varies with time. For reasons we'll discuss later, ac is easier to generate, transmit, and manipulate–hence why it is useful for large scale infrastructure.

Conceptual Question 1

When current flows in a wire, we assign the direction of current to be the same direction as the net flow of positive charge. Rank the current in the four regions below from highest to lowest if the positive and negative charges have equal magnitude. For each case, in which direction is the current in the wire?



Voltage Sources

Voltage, not current, is stored in batteries. It is only when a battery or other voltage source is connected across the ends of a conductor to form a complete circuit will charges that are already present in the conductor begin to flow.

A battery converts chemical energy into electrical energy using a type of reaction called a redox reaction. Inside the battery, the anode (negative terminal) undergoes oxidation, releasing electrons, while the cathode (positive terminal) undergoes reduction, accepting electrons. An electrolyte between the two allows ions to move internally, while electrons flow through an external circuit from the anode to the cathode.

A generator converts mechanical energy into electrical energy using the principle of electromagnetic induction. Generators naturally produce alternating current.

Lead Acid Batteries

Click here to watch video (4:57)

Conceptual Questions 2

Which of the following statements is true?

(a) Electric current is a flow of electric charge.

(b) Electric current is stored in batteries.

(c) Both A and B are true.

(d) Neither A nor B is true.

Electrical Conduction in Metals

When a constant voltage is applied across a metal at room temperature, it generates a steady current. The electric field inside the metal does not continuously accelerate the charges and lead to an infinite current.

In the 1820's, German physicist Georg Ohm experimentally discovered a linear relationship between applied voltage and the resulting current in many metals near room temperature. He introduced the concept of electrical resistance, which is an intrinsic property of a material that opposes the flow of charges. It is analogous to air resistance opposing the free fall motion of macroscopic objects near the Earth's surface.

Electrical Resistance and Ohm's Law

Inspired by his findings, Ohm defined electrical resistance quantitatively as the ratio of voltage across a conductor to the current running through it. A resistor is an electrical device (a conductor) with a relatively large and constant resistance.

Ohm's law states the current through a resistor is directly proportional to the voltage across the resistor. In other words, the electrical resistance is a constant that depends only on geometry, material properties, and temperature of a resistor.

The resistance of a resistor is inversely proportional to its cross-sectional area, directly proportional to its length, and increases with increasing temperature. A thin resistor has more resistance than a thick one, and a long resistor has more resistance than a short one. Resistance also depends on the material; rubber has more resistance than copper for the same size and shape.

Conceptual Question 3

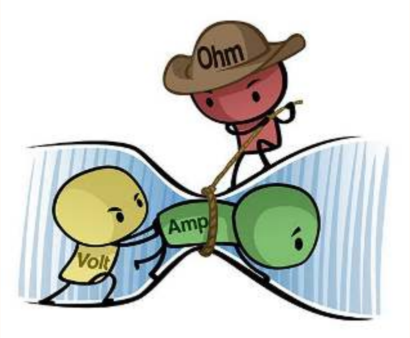
A long cylindrical wire is uniformly squished along its length until its radius doubles and its length reduces by one-fourth (this ensures the volume remains constant). As a result, its electrical resistance

(a) is the same
(b) doubles
(c) quadruples
(d) halves
(e) reduces by one-fourth
(f) none of the above

Ohm's Law

Resistance is measure in ohms (Ω) where 1 ohm equals 1 volt per ampere. In equation form, Ohm's law can be written as

$$I = \frac{V}{R} = \frac{\text{voltage from source}}{\text{resistance of resistor}}$$



Conceptual Question 4

Resistance is defined as the voltage across an inductor divided by the current running through it. When you double the voltage across a resistor, you double the

(a) current

(b) resistance

(c) both (a) and (b)

(d) neither (a) nor (b)

Source of Electrical Resistance

Electrical resistance happens when electrons moving through a wire bump into things that slow them down. In a metal, electrons move freely, but they can still scatter off vibrating atoms (especially at higher temperatures), impurities, or defects in the material. These collisions make it harder for electrons to flow smoothly, which turns some electrical energy into heat.

In 1911, Dutch physicist Heike Onnes discovered the electrical resistance of mercury goes to zero below a certain temperature. This was the very first observation of the phenomenon of superconductivity. Below the critical temperature, atoms vibrate less and electrons are able to behave in such a way that they glide through the conductor without bumping into anything!

Superconductors

Click here to watch video (4:53)

Speed of Electricity

When we flip a light switch on a wall, an electric field is established inside conductors in a supply circuit. While the following picture is not exactly correct, we can imagine the electrons in the wires undergo random jiggling motion while simultaneously being nudged by the electric field. Current establishes through the wires at nearly the speed of light, but its not the electrons that move that fast down the wire. Instead, its the electric field that can travel through a circuit at nearly the speed of light! Electrons in a typical conductor drift along the wire at speeds on the order of only millimeters per second.

If you're having trouble understanding why the electric field can propagate so fast, imagine pulling on one end of a very long rope. The force that you exert on one end will transmit to the other end very quickly.

Conceptual Question 5

A conducting wire at room temperature can carry a very large current because

(a) it carries many electrons per unit volume.

(b) the electrons are moving very fast in the wire.

(c) both (a) and (b)

(d) neither (a) nor (b)

Electrical Power

The rate at which electrical energy is converted into another form is called electrical power. Since voltage is energy per charge and current is charge per second. Hence,

$$\text{power} = \text{current} \times \text{voltage}$$

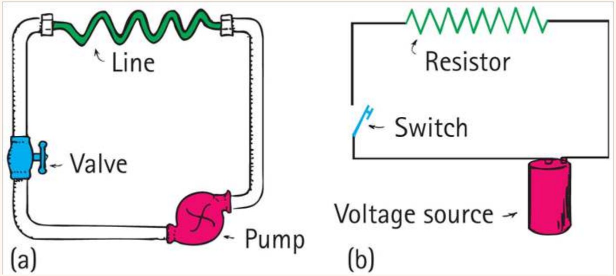
Recall the standard unit of power is the watt (W) equal to one joule per second. In a resistor, electrical energy does work on moving charges, which then collide with vibrating atoms to produce heat. The rate at which energy is dissipated by the resistor can be found by algebraically substituting Ohm's law:

$$P = IV = I \times (IR) = I^2 R$$

Energy is dissipated four times faster if the current is doubled.

Electrical Circuit

An electric circuit is a path, involving wires and electric components, through which electric current flows. A circuit must be complete (or closed) to allow current to flow continuously.



Series and Parallel Combinations

Circuit elements may be connected in two common ways. A series connection involves a single pathway for current flow through a sequence of two-terminal components. A parallel connection involves branches, each providing a separate path for current flow, which is split and divided among the branches before recombining.

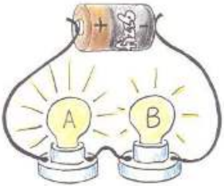
(i) All elements that are in series have the same current.
This is due to conservation of charge.

(ii) All elements that are in parallel have the same voltage.
This is due to conservation of energy.

Conceptual Question 6

Next-Time Question

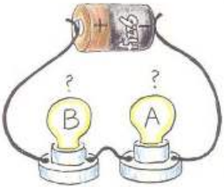
When the series circuit shown to the right is connected, Bulb A is brighter than Bulb B. If the positions of the bulbs were reversed,



a) Bulb A would again be brighter

b) Bulb B would be brighter.

c) either of the above could occur.

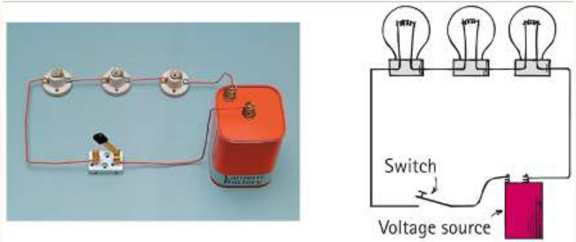


CONCEPTUAL Physics

ARBOR SCIENTIFIC

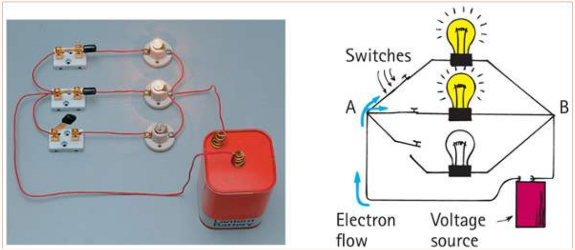
thanx to Dean Baird

Resistors in Series



The total resistance is the sum of individual resistances. The sum of the voltages across each device is equal to the total voltage across the circuit. The relative voltage across a given component is proportional to its relative resistance.

Resistors in Parallel



The total current into the circuit divides among the parallel branches. The relative current in each branch is inversely proportional to the relative resistance of that branch. The total current in the circuit equals the sum of the currents in its parallel branches. As the number of parallel branches increases, the overall resistance of the circuit decreases.

Conceptual Question 7

When two identical lamps in a circuit are connected in parallel, the total resistance is

(a) less than the resistance of either lamp.

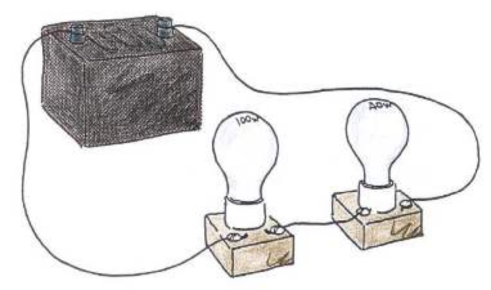
(b) the same as the resistance of each lamp.

(c) less than the resistance of each lamp.

(d) None of the above is correct.

Conceptual Question 8

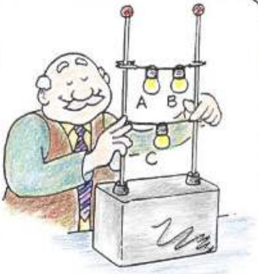
The wattage rating on a light bulb in the United States assumes a standard 120 V electrical system (the voltage from the socket in your room varies with time, but we can treat the 120 V figure as a constant). With that in mind, when a 40-watt bulb and a 100-watt bulb are connected in series, which will glow brighter?



Example 1

Next-Time Question

Three identical lamps of resistance 12 ohms are connected to the 12-V automobile battery demo as shown.



1. What is the current in each lamp?
2. What is the voltage across each lamp?
3. What is the power dissipated in each lamp?
4. How does the power dissipated in lamp C change if lamp A is unscrewed?
5. What happens to the power dissipated in lamp A if lamp C is unanswered?

Conceptual Physics

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