General Physics

Lecture Four / Theoretical

Electricity

First stage

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The primary function of an X-ray imaging system (Figure 1) is to convert electric energy into electromagnetic energy. Electric energy is supplied to the x-ray imaging system in the form of well-controlled electric current. A conversion takes place in the x-ray tube, where most of this electric energy is transformed into heat, some of it into x-rays.

Electrostatics

Electric charge comes in discrete units that are positive or negative. Electrons and protons are the smallest units of electric charge. The electron has one unit of negative charge; the proton has one unit of positive charge. Thus, the electric charges associated with an electron and a proton have the same magnitude but opposite signs. Because of the way atoms are constructed, electrons often are free to travel from the outermost shell of one atom to another atom. Protons, on the other hand, are fixed inside the nucleus of an atom and are not free to move. Consequently, nearly all discussions of electric charge deal with negative electric charges—that associated with the electron.

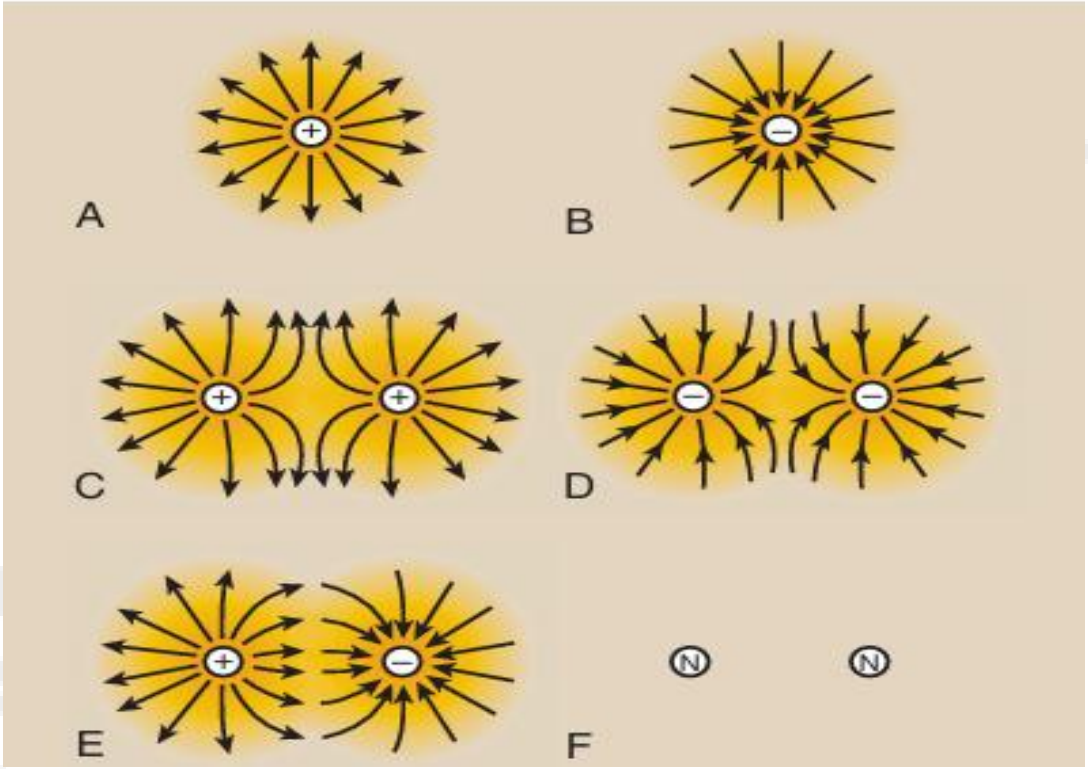
Electrostatics is the study of stationary electric charges.

Electrostatic Laws

When two similar electric charges—negative and negative or positive and positive—are brought close together, their electric fields are in opposite directions, which cause the electric charges to repel each other.

When unlike charges—one negative and one positive— are close to each other, the electric fields radiate in the same direction and cause the two charges to attract each other. The force of attraction between unlike charges or repulsion between like charges is attributable to the electric field. It is called an electrostatic force.

Coulomb's Law. The magnitude of the electrostatic force is given by Coulomb's law as follows:



Coulomb's Law

$$F = k\frac{Q_A Q_B}{d^2}$$

where F is the electrostatic force (newton), Q_A and Q_B are electrostatic charges (coulomb), d is the distance between the charges (meter), and k is a constant of proportionality.

Electric potential (voltage)

The discussion of potential energy in Lecture 3 emphasized the relationship of such energy to work. A system that possesses potential energy is a system with stored energy. Such a system can do work when this energy is released. Electric charges have potential energy.

The unit of electric potential is the volt (V).

Electric potential is sometimes called voltage; the higher the voltage, the greater is the potential to do work.

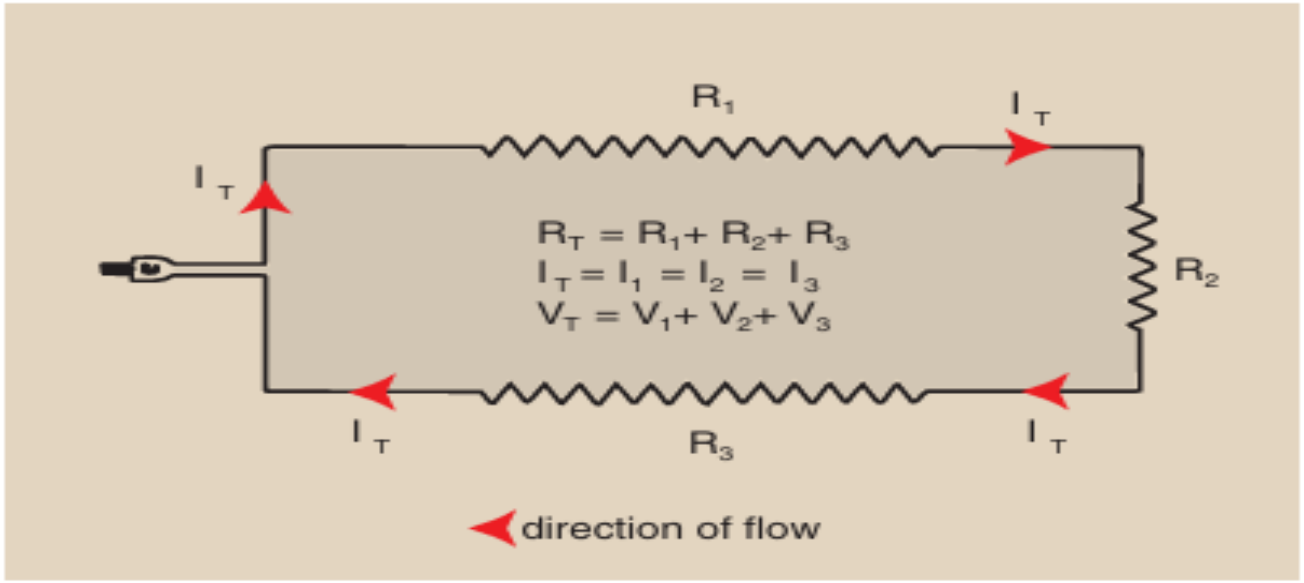
In the United States, the electric potential in homes and offices is 110 V. X-ray imaging systems usually require 220 V or higher. The volt is potential energy/unit charge, or joule/coulomb (1 V = 1 J/C).

Electrodynamics

Electrodynamics is the study of electric charges in motion. If an electric potential is applied to objects such as copper wire, then electrons move along the wire. This is called an electric current, or electricity.

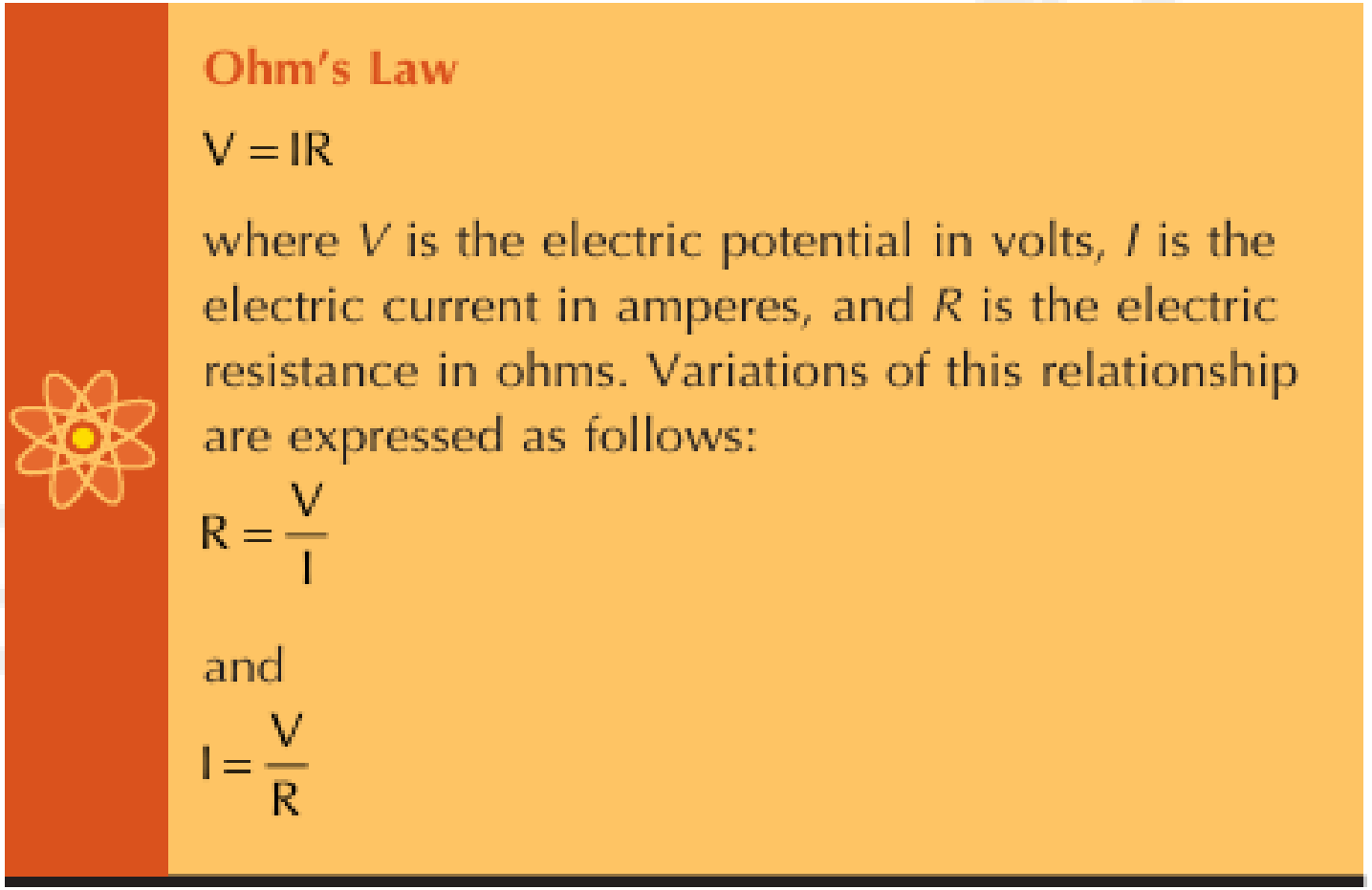
Electric Circuits

Modifying a conducting wire by reducing its diameter (wire gauge) or inserting different material (circuit elements) can increase its resistance. When this resistance is controlled and the conductor is made into a closed path, the result is an electric circuit.



Ohm’s law

Ohm’s law: The voltage across the total circuit or any portion of the circuit is equal to the current times the resistance.



Question: If a current of 0.5 A passes through a conductor that has a resistance of 6 Ω, what is the voltage across the conductor?

Answer:

$$V = IR$$
$$= (0.5\ A)(6\ \Omega)$$
$$= 3\ V$$

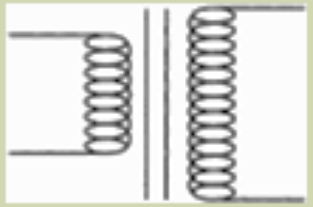
Question: A kitchen toaster draws a current of 2.5 A. If the household voltage is 110 V, what is the electric resistance of the toaster?

Answer:

$$R = \frac{V}{I}$$
$$= \frac{110\ V}{2.5\ A}$$
$$= 44\ \Omega$$

X-ray circuits are also complicated and contain a number of different types of circuit elements. Table 1 identifies some of the important types of circuit elements, the functions of each, and their symbols.

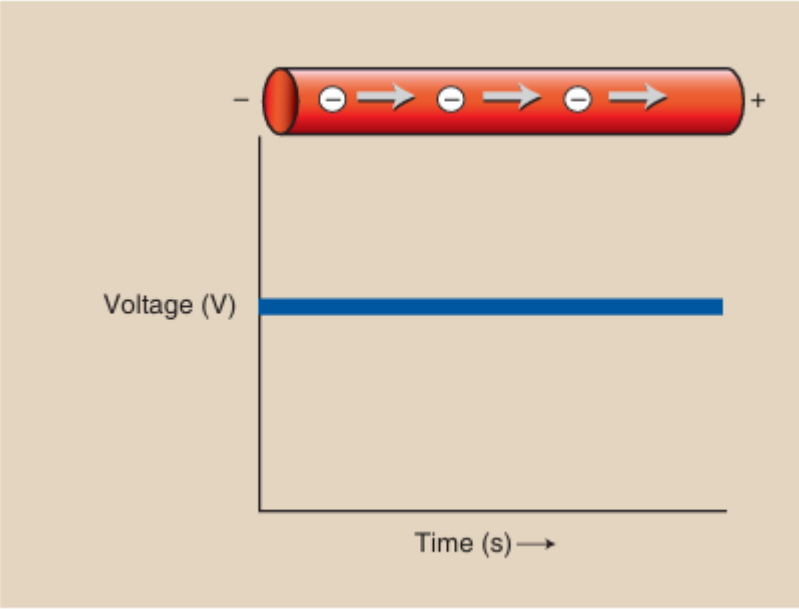
TABLE 4-2 Symbol and Function of Electric Circuit Elements

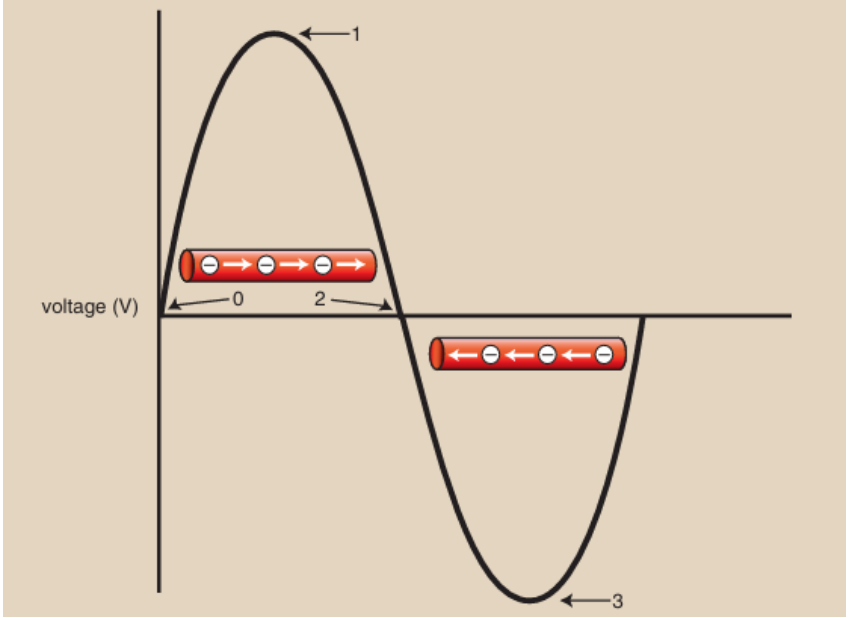
Circuit Element	Symbol	Function
Resistor		Inhibits flow of electrons
Battery		Provides electric potential
Capacitor		Momentarily stores electric charge
Transformer		Increases or decreases voltage by fixed amount (AC only)
Diode		Allows electrons to flow in only one direction

Direct current (DC), Alternating current (AC).

Electric current, or electricity, is the flow of electrons through a conductor. These electrons can be made to flow in one direction along the conductor, in which case the electric current is called direct current (DC). Most applications of electricity require that the electrons be controlled so that they flow first in one direction and then in the opposite direction. Current in which electrons oscillate back and forth is called alternating current (AC).

Electrons that flow in only one direction constitute DC; electrons that flow alternately in opposite directions constitute AC.





Electric Power

Electric power is measured in watts (W). An x-ray imaging system requires 20 to 150 kW of electric power.

Electric Power

$$P = IV$$

where P is the power in watts, I is the current in amperes, and V is the electric potential in volts; alternatively,

$$P = IV = IIR$$

therefore,

$$P = I^2R$$

where R is resistance in ohms.

Question: An x-ray imaging system that draws a current of 80 A is supplied with 220 V. What is the power consumed?

Answer:
$$P = IV$$
$$= (80\ A)(220\ V)$$
$$= 17{,}600\ W$$
$$= 17.6\ kW$$

Question: The overall resistance of a mobile x-ray imaging system is 10Ω. When plugged into a 110-V receptacle, how much current does it draw and how much power is consumed?

Answer:
$$P = IV$$
$$= (11A)(110\ V)$$
$$= 1210\ W$$
or
$$P = I^2R$$
$$= (11A)^2 10$$
$$= 1210\ W$$

Comprehensive Set of MCQs

1. **What is the primary function of an X-ray imaging system?**

A) To measure electric potential
B) To convert electric energy into electromagnetic energy
C) To store electric charge
D) To generate static electricity
E) To amplify electric signals

Answer:

2. What is the study of stationary electric charges called?

- A) Electrodynamics
- B) Electrostatics
- C) Electromagnetism
- D) Circuit theory
- E) Quantum mechanics

Answer:

3. What is the effect of increasing resistance in a circuit while keeping voltage constant?

- A) Current increases
- B) Current decreases
- C) Current remains constant
- D) Voltage increases
- E) Voltage decreases

Answer:

4. What is the primary characteristic of electrostatic forces?

- A) They are always attractive
- B) They are always repulsive
- C) They can be both attractive and repulsive
- D) They are negligible
- E) They are only present in conductors

Answer:

5.What is the role of protons in an atom?

- A) They are free to move
- B) They are fixed in the nucleus
- C) They carry negative charge
- D) They generate electric fields
- E) They are responsible for electric potential

Answer:

6. What is the primary function of a capacitor in an electric circuit?

- A) To generate electric current
- B) To store electric charge
- C) To convert energy
- D) To measure voltage
- E) To resist current

Answer:

7. What is the primary cause of electric current in a conductor?

- A) Movement of protons
- B) Movement of electrons
- C) Movement of neutrons
- D) Static charge
- E) Magnetic fields

Answer:

8. What is the primary function of a resistor in an electric circuit?

- A) To store energy
- B) To generate electric current
- C) To limit current flow
- D) To convert energy
- E) To measure voltage

Answer:

9. What is the typical voltage supplied to homes in the United States?

- A) 220 V
- B) 110 V
- C) 50 V
- D) 440 V
- E) 12 V

Answer:

10. What happens to the electric field when a charged object is moved away from another charged object?

- A) The electric field increases
- B) The electric field decreases
- C) The electric field remains constant
- D) The electric field becomes zero
- E) The electric field fluctuates

Answer:

11. What is the primary function of a diode in an electric circuit?

- A) To store energy
- B) To allow current to flow in one direction
- C) To resist current flow
- D) To measure voltage
- E) To convert energy

Answer:

12. What is the study of electric charges in motion called?

- A) Electrostatics
- B) Electrodynamics
- C) Electromagnetism
- D) Electrochemistry
- E) Electric potential

Correct Answer:

13. What is the unit of electric potential?

- A) Ampere
- B) Ohm
- C) Volt
- D) Coulomb
- E) Joule

Correct Answer:

14. What is the relationship defined by Ohm's Law?

- A) Voltage = Current + Resistance
- B) Voltage = Current × Resistance
- C) Current = Voltage + Resistance
- D) Resistance = Voltage × Current
- E) Current = Voltage / Resistance

Correct Answer: