

Module 12: Electric Potential and Electric Energy (PHY 1200)

Introduction

In the previous module we studied electric forces and electric fields. These ideas describe how electric charges interact with each other.

Another useful way to describe electric interactions is through energy.

In many physical systems, it is often easier to analyze how energy changes rather than calculating forces directly.

Electric potential and electric potential energy provide a framework for understanding how charges store and transfer energy in electric fields.

These ideas are important in many areas of science and technology, including:

- electric circuits
- electronic devices
- energy storage systems
- particle accelerators

Electric Potential Energy

Electric potential energy is the energy associated with the position of a charged object in an electric field.

When charges interact with each other, energy may be stored in the system.

For example:

Two like charges placed close together store electric potential energy because they repel each other.

If one of the charges is released, the stored energy can be converted into motion.

Analogy with Gravitational Energy

Electric potential energy is similar to gravitational potential energy.

For example:

When a ball is lifted above the ground, gravitational potential energy is stored.

If the ball is released, the stored energy converts into kinetic energy as the ball falls.

Similarly, when electric charges are separated, energy can be stored in the electric field.

Electric Potential

Electric potential describes how much electric potential energy exists per unit charge.

The equation is:

$$V = U / q$$

where

V = electric potential

U = electric potential energy

q = charge

Electric potential is measured in volts (V).

One volt represents one joule of energy per coulomb of charge.

Voltage

The term voltage refers to the difference in electric potential between two points.

Voltage tells us how much energy a charge gains or loses when moving between two points in an electric field.

Voltage differences are what cause electric charges to move in circuits.

For example, a battery provides a voltage difference that drives current through a circuit.

Electric Potential Due to a Point Charge

The electric potential created by a point charge is given by:

$$V = k (q / r)$$

where

V = electric potential

k = Coulomb constant

q = charge

r = distance from the charge

Unlike electric force and electric field equations, electric potential depends on $1/r$, not $1/r^2$.

Worked Example

A charge of 2×10^{-6} C produces an electric potential at a distance of 3 meters.

Find the electric potential.

Use equation:

$$V = k (q / r)$$

Substitute values:

$$V = (9 \times 10^9)(2 \times 10^{-6}) / 3$$

Calculate numerator:

$$9 \times 10^9 \times 2 \times 10^{-6} = 18 \times 10^3$$

Divide by 3:

$$V = 6 \times 10^3$$

Electric potential = 6000 volts

Relationship Between Electric Field and Potential

Electric fields and electric potential are closely related.

An electric field represents how strongly a charge is pushed or pulled.

Electric potential represents how much energy a charge has at a particular location.

When a charge moves through an electric field, its potential energy changes.

Work Done by Electric Forces

When a charge moves in an electric field, work may be done by the electric force.

The work done is related to the change in electric potential energy.

If a positive charge moves toward a lower electric potential, the electric field does work on the charge.

If a charge moves against the electric field, work must be supplied to move it.

Equipotential Surfaces

An equipotential surface is a region where the electric potential is constant.

If a charge moves along an equipotential surface:

- the electric potential does not change
- no work is done by the electric field

Equipotential surfaces are always perpendicular to electric field lines.

These surfaces help visualize electric potential in space.

Electric Potential in Circuits

Electric potential plays a crucial role in electrical circuits.

A battery creates a voltage difference between two terminals.

This voltage difference causes electric charges to move through the circuit.

As charges move through circuit components such as resistors, energy is transferred to other forms such as heat or light.

Example

A battery provides a voltage of 12 volts.

This means that each coulomb of charge moving through the battery gains 12 joules of energy.

Voltage therefore describes the energy available to drive electric current.

Practice Problems

1. What is electric potential energy?
2. What is the relationship between electric potential and electric potential energy?
3. What unit is used to measure electric potential?
4. Write the equation for electric potential produced by a point charge.
5. What does voltage represent in an electric circuit?

Calculation Practice

1. A charge of 3×10^{-6} C produces an electric potential at a distance of 2 meters. Calculate the potential.
2. If a charge of 2 coulombs moves through a potential difference of 10 volts, how much energy is transferred?

Challenge Problems

1. Explain the relationship between electric potential and electric fields.
2. Why are equipotential surfaces always perpendicular to electric field lines?
3. If a battery provides 9 volts, how much energy does one coulomb of charge gain?