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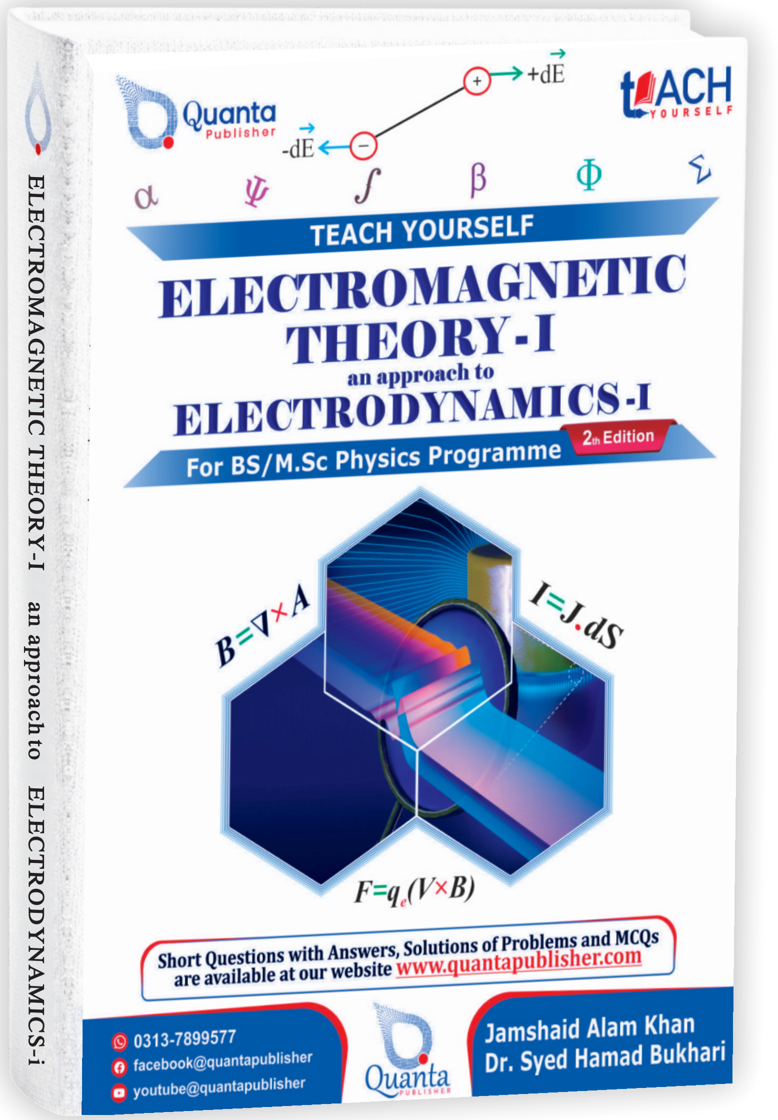

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ELECTROMAGNETIC THEORY - I

an approach to

ELECTRODYNAMICS - I

2nd Edition

For **BS/M.Sc Physics** students of all Pakistani Universities/Colleges

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Chapter 1

Vector Calculus and Dirac Delta Function

1.1 Introduction to Vector Algebra and Calculus

Physical Quantities

The quantities which can be observed, described and measured, known as physical quantities. In most of the physical systems, we deals with the physical quantities in two different ways: Scalar and Vector.

1. Scalar

The physical quantities which are described by magnitude and proper units are called scalars. For example, mass, length, time, density, energy, work, temperature and charge are the examples of scalars. Scalars can be added, multiplied and subtracted by ordinary rules of algebra.

2. Vector

The physical quantities which are completely described by magnitude, with proper unit and direction are called vectors. For example, force, velocity, acceleration, momentum, torque, electric field intensity and magnetic field induction are the examples of vectors. Vectors can be added, subtracted by head to tail rule i.e. head of first vector is coincides with the tail of the second vector to get the resultant vector. Vectors have specific symbols for representations.

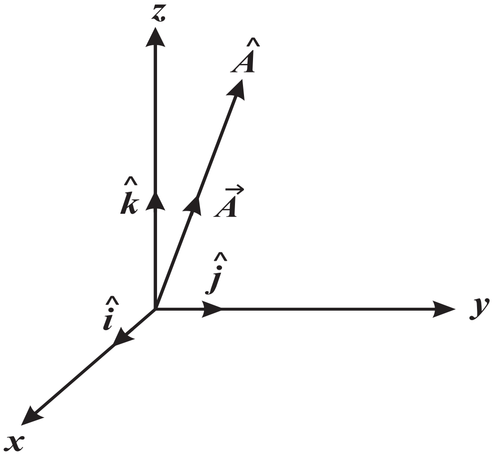

Fig. 1.1. The schematic picture for unit vectors along x, y and z- axes.

Chapter 2

Electric Field

Why negative charge is not taken as test charge? It is because of following reasons.

1. All these assumptions were taken before discovery of electron.

2. Convenience.

3. We can take negative charge as well, but that has an additional burden of reversing the directions.

4. All previous proofs are with positive test charge.

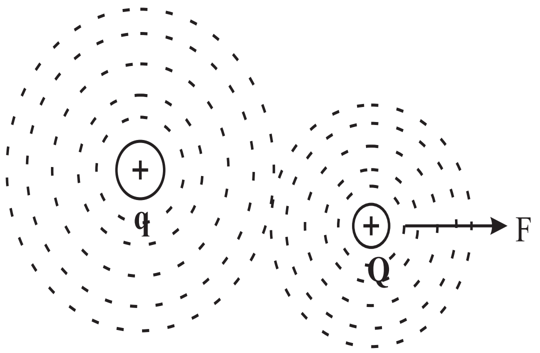

Fig. 2.1. Test charge Q present in the field of charge $+q$.

2.1 Electric Field

From Newtons law of gravitation and Coulombs law ($F = \frac{Gm_1m_2}{r^2}$ $F = K\frac{q_1q_2}{r^2}$), we calculate the magnitude and direction of gravitational and electric force. However, two question arises here:

1. What is the origin of these forces?

2. How these forces are transmitted from one mass/charge to another?

The answer to the first question is still unknown, to answer the second question, Michael Faraday introduce the concept of electric field. The space around the charge in which it exerts a force on other charges is called an **Electric Field**.

The interaction of charges produces an electric force. A charge produce an electric field in its surrounding as shown in Fig.(2.1). When a test charge Q is bought in the field of source charge it interacts with Q and produces an electric force. The dots surrounding the positive charge indicate the presence of the electric field. The density of the dots is proportional to the strength of the electric field at different locations.

Chapter 3

Electrostatic Potential and Energy

Electric field is a very special kind of vector function. Here, we use this special property of electric fields to reduce a vector problem to a much simpler scalar problem. This theorem asserts that: Any vector whose curl is zero is equal to the gradient of some scalar. Because

$E = 0$, so the line integral of E around the closed loop should be zero in accordance to stocks theorem, as shown in the Fig.(3.1):

$$\oint E \;\; d \quad = 0$$

But if we move from point a and b and then return to point a and obtain $\oint E \;\; d \quad = 0$, because the line integral is independent of path, we can define a function:

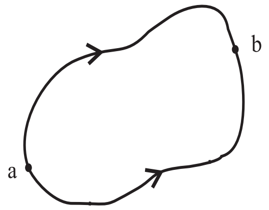

Fig. 3.1. Closed path between point a and b.

$$V(r) = \quad \int_0^r E \;\; d$$

Here zero is the reference point and V is the electric potential that depends on r. The potential difference between two points a and b is:

$$V(b) \quad V(a) = \quad \int_0^b E \;\; d \; + \int_0^a E \;\; d \quad = \quad \int_0^b E \;\; d \quad \int_a^0 E \;\; d \quad = \quad \int_a^b E d \tag{3.1}$$

Now fundamental theorem of gradient stated that:

$$V(b) \quad V(a) = + \int_a^b (\quad V) \;\; d \tag{3.2}$$

V slope of potential at some specific point. Comparing Eq.(3.1) and Eq.(3.2):

$$\int_a^b (\quad V) \;\; d \quad = \quad \int_a^b E \;\; d$$

Hence:

$$E = \qquad V \tag{3.3}$$

The word potential reminds us about potential energy. There is a connection between the two and are different terms. We will establish it in latter section. A surface over which

Chapter 4

Solutions of Electrostatic Problems

4.1 Poissons Equation

The primary task of electrostatics is to find the electric field of a given stationary charge distribution. This can be accomplish using Coulomb law:

$$E(\ r\ ) = \frac{1}{4\quad_o}\int\frac{r}{r^2}\ \ (r\ )d$$

It is difficult to evaluate this integral. Gausss law helps us to solve such problems by expoliting symmetry. But it is better to calculate the potential first.

$$V(\ r\ ) = \frac{1}{4\quad_o}\int\frac{1}{r}\ \ (r\ )d$$

Still even this integral is often too tough to handle analytically. Moreover in problems involving conductors itself may not be known in advance; since charge is free to move around, the only thing we control directly is the total charge (or perhaps the potential) of each conductor. In such cases, it is fruitful to recast the problem in differential form. We know differential form of Gausss law:

$$E = \frac{}{_o} \tag{4.1}$$

In pure electrostatic field, E may be expressed as negative of potential gradient.

$$E = \qquad V \tag{4.2}$$

Use Eq.(4.2) in E.(4.1), we get:

$$(\qquad V) = \frac{}{_o} \qquad ; \qquad {}^2V = \quad \frac{}{_o} \tag{4.3}$$

The divergence of the gradient, is written as a single operator ^{2}, called Laplacian operator. The Eq.(4.3) is the potential differential equation and is known as Poissons equation. It may be solved once we known the fundamental dependence of and the appropriate boundary conditions. Poissons equation in terms of:

Chapter 5

Electric Fields in Dielectric Media

5.1 Electric Fields in Matter

Matters of course comes in many varieties solids, liquids, gases and plasma. The substance like metals, wood and glasses do not respond in the same way to electrostatic fields. Nevertheless, most everyday objets belong to one of the two large classes.

Conductors and Insulators (or Dielectric)

Conductors are substances that contain an unlimited supply of charges that are free to move about through the material. It means electrons are not attached particularly to any nucleus but roam around at will. In dielectrics by contrast all charges are attached to specific atoms or molecules. They are in a tight leash and all they can do is move a bit within the atoms or molecules. Such microscopic displacements are not as dramatic as the wholesale rearrangement of charge in a conductor but their cumulative effects account for the characteristic behaviour of dielectric materials. There are actually two principal mechanism by which electric fields can distort the charge distribution of a dielectric atom of molecule:

1. Stretching **2.** Rotating

Polarization

Electric polarization is observed in materials having no free charges (electrons) known as dielectric. Consider such a material is placed in an external electric field. The molecules of dielectric which are composed of atomic nuclei (say positive) and electrons (say negative) are attached by the presence of electric field. The positive particles are displaced in the direction of the electric field and the negative particles in the opposite direction. This become some sort of dipole configuration. In dipoles, two equal and opposite charges separated by the small distance. Hence the dielectric containing positive and negative particles of each molecules are from their equilibrium position is said to be polarized. In

Chapter 6

Microscopic Theory of Dielectrics

6.1 Microscopic Theory of Dielectric

In previous chapters, we were concerned with the **microscopic aspects of dielectric polarization** and it was shown that how in many cases the polarization could be taken into account through the introduction of dielectric constant. In this way the electric field could be computed directly from the consideration of the external charge distribution. We should now like to **examine the molecular nature of the dielectric** and see **how the electric field responsible for polarizing the molecule?** related to the macroscopic electric field.

Molecular Filed in Dielectric (Clausius Mossothi Equation)

The electric field that is responsible for polarizing a molecules of the dielectric is called molecular field ($\boldsymbol{E}_m$). It is the field at the position of a molecule in the dielectric, and it is produced by all the molecules polarized in the dielectric and external source except of the one molecule at the point under consideration. The molecular field (E_m) can be calculated in following ways

Let us cut out a small piece of dielectric leaving **a spherical cavity surrounding the point at which the molecular field is to be computed.** The dielectric that is left will be treated as continuum, that is from the macroscopic point of view. Now we put dielectric back into the cavity molecule by molecule, except for the molecule at the center

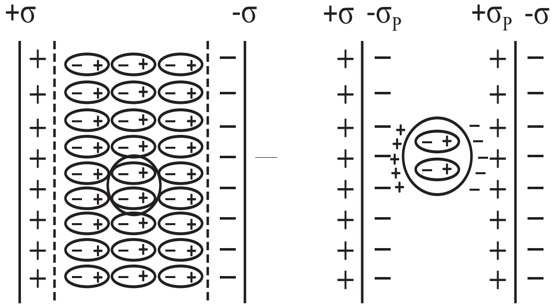

Fig. 6.1. Polarized dielectric and its equivalent model.

Chapter 7

Electric Current

7.1 Nature of Current

Electric current is defined as the rate of flow of negative charge of the conductor. In other words, the continuous flow of electrons in an electric circuit is called an electric current. The conducting material consists of a large number of free electrons which move from one atom to the other at random.

Unit of Current

Since the charge is measured in coulombs and time in seconds, so the unit of electric current is Coulomb/second ($C\ \ s$) or Ampere (A). The ampere is the SI unit of conductor. The I is the symbolic representation of the current. If $Q = 1$ coulomb, $t = 1$ second then;

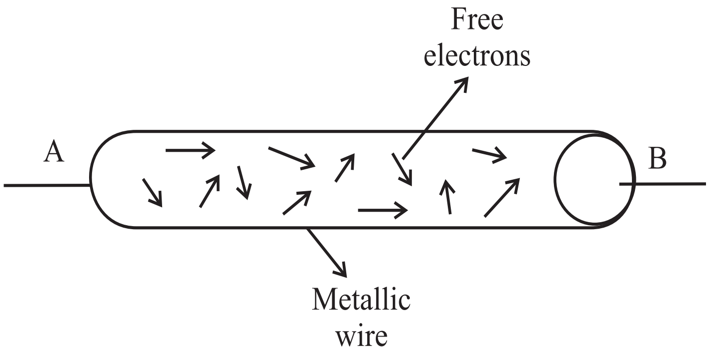

Fig. 7.1. schematic picture of flow of current in metallic wire.

$$I = 1A$$

Thus a wire is said to carry a current of the one ampere when charge flows through it at the rate of one coulomb per second. When an electric potential difference is applied across the metallic wire, the loosely attached free electrons start moving towards the positive terminal of the cell shown in the Fig.(7.1). The continuous flow of electrons constitutes the electric current. The flow of current in the wire is from the negative terminal of the cell to the positive terminal through the extended circuit.

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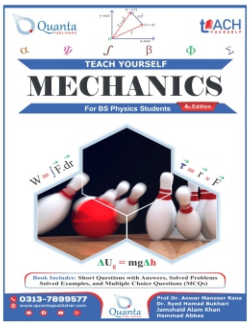

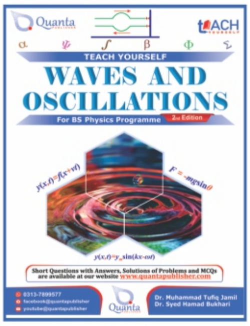

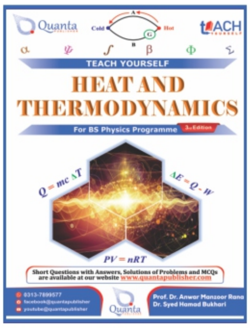

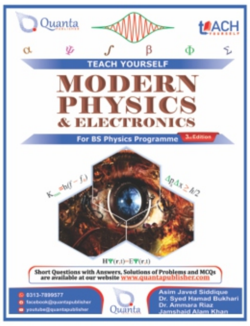

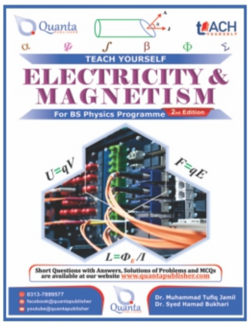

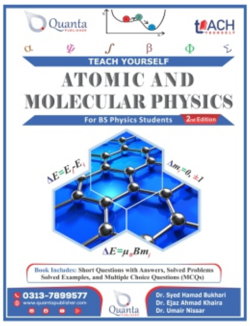

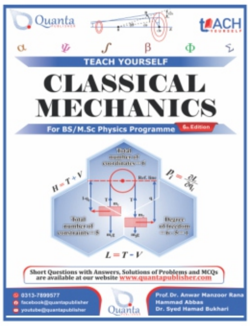

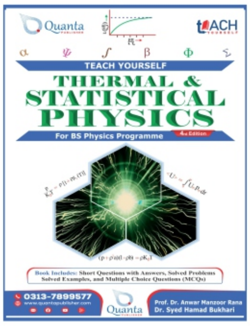

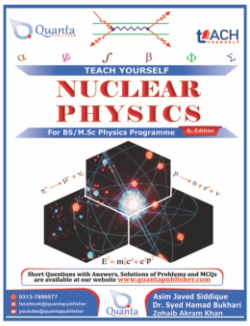

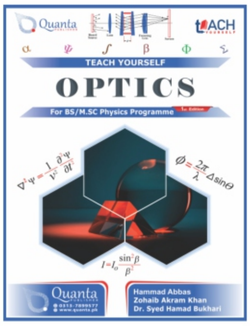

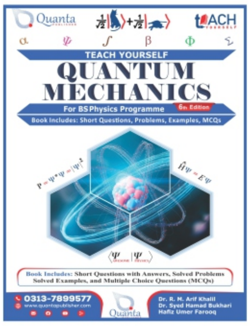

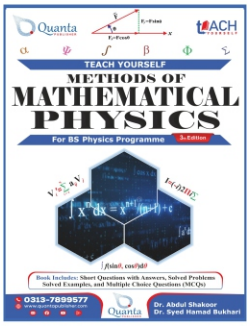

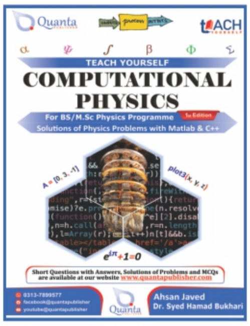

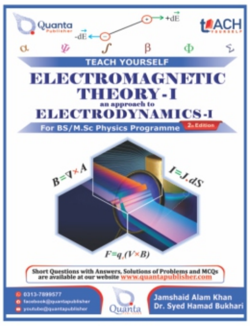

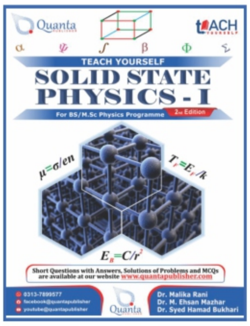

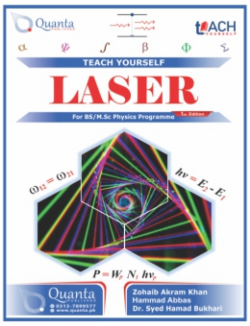

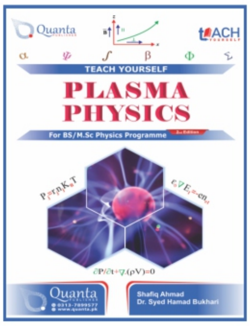

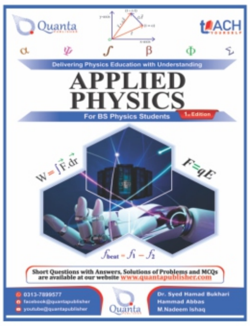

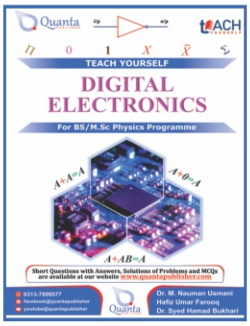

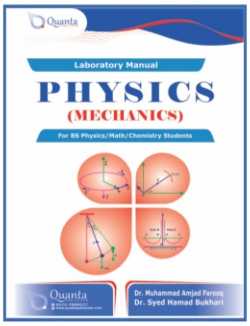

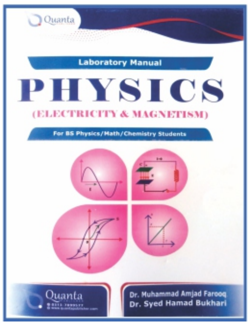

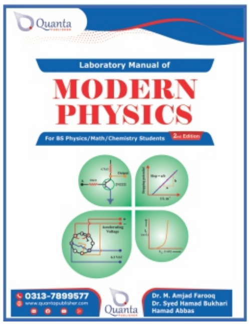

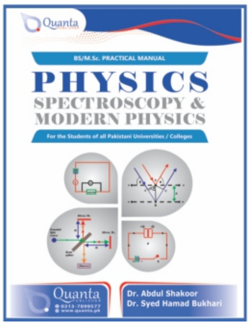

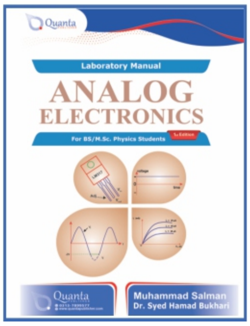

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