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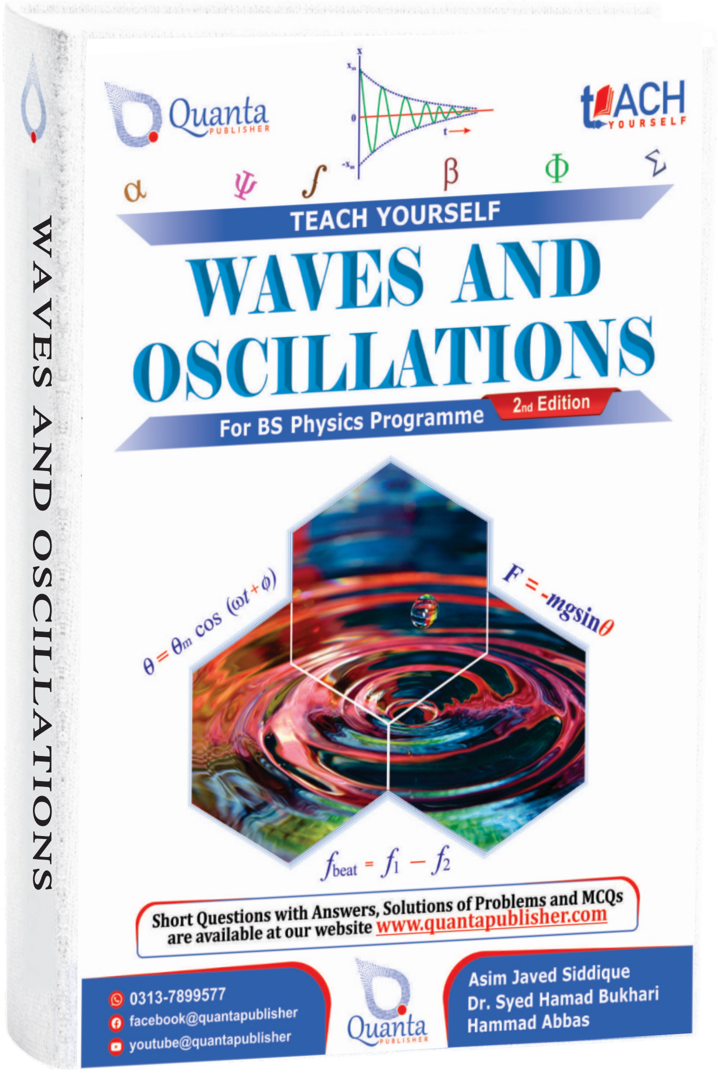

TEACH YOURSELF

WAVES & OSCILLATIONS

2nd Edition

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

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Quanta Publisher, Raza Abad, Shah Shamas, Multan. 03137899577

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Chapter 1

Harmonic Motion

EACH day we encounter many kinds of oscillatory motion. Common examples include the swinging pendulum of a clock and vibrating guitar string. Examples on the microscopic scale are vibrating atoms in quartz crystal of a wristwatch and vibrating molecules of air that transmit sound waves. The above cases are **mechanical oscillations**.

We are also familiar with **electromagnetic oscillations**, such as electrons moving back and forth in circuits that are responsible for transmitting and receiving radio or TV signals. One common feature of all these systems is the mathematical formulation used to describe their oscillations. In all cases, the oscillating quantity, whether it is the displacement of a particle or the magnitude of an electric field, can be described in terms of sine or cosine functions. In this chapter, we concentrate on mechanical oscillations with their description and applications.

1.1 Simple Harmonic Motion (SHM)

The repetitive motion of a body in a specific interval of time about its mean position is called SHM.

"To and fro motion of a body in which acceleration is directly proportional to the displacement and always directed towards the mean position is called simple harmonic motion".

The body executing simple harmonic motion is called simple harmonic oscillator.

Motion of simple pendulum and motion of spring mass system are the examples of SHM.

Conditions of SHM

Restoring Force: Necessary to move the object towards mean position. According to Hooks law, $F \propto -x$.

Inertia: To move the object away from the mean position to extreme position.

Chapter 2

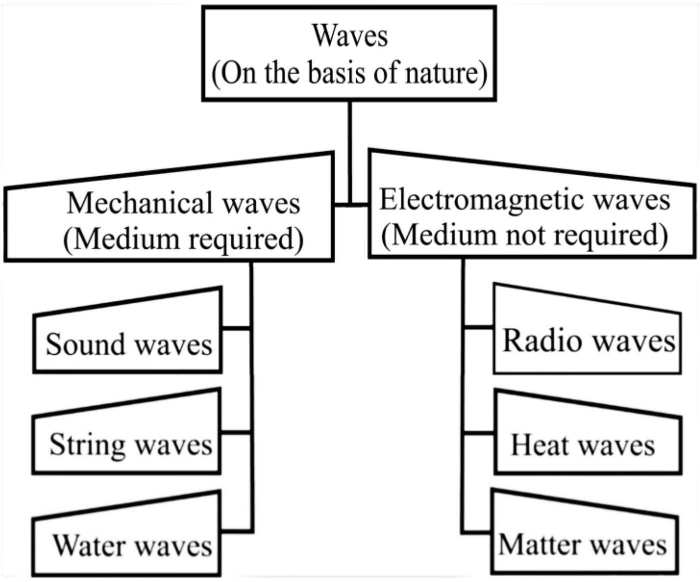
Wave in Physical Media

WAVE motion appears in almost every branch of Physics. Surface waves on bodies of water are commonly observed. Sound waves and light waves are essential to our perception of the environment, because we have evolved receptors (eyes and ears) capable of their detection. In the past century, we have learned how to produce and use radio waves. We can understand the structure of atoms and subatomic systems based on the wavelike properties of their constituent particles. The similarity of the physical and mathematical description of these different kinds of waves indicates that wave motion is one of the unifying themes of Physics.

2.1 Waves

A traveling disturbance that carries energy through matter and space is called wave.

Wave transfer energy and momentum from one place to another place without transferring matter is called wave motion. e.g. sound energy and light energy.



Types of Wave

There are two types of wave.

1. Electromagnetic Waves
2. Mechanical Waves

Electromagnetic Waves

Electromagnetic waves are in which electric and magnetic fields oscillates during propagation and need no medium for its propagation. For example, radio waves, X-rays, etc.

Chapter 3

Beats and Polarization

3.1 Beats (Applications of Principle of Superposition)

The periodic alterations or variation in the intensity of sound waves between minimum (faintness) and maximum (loudness) are called beats.

The phenomenon of beats arises due to superposition of two sound waves of the same amplitude but slightly different frequencies. When two sound waves of same amplitude and having slightly different frequencies superimpose each other, they produce a resultant wave whose amplitude varies with time i.e., the amplitude rises and falls, periodically. These periodic changes in amplitudes produces rises and falls in the intensity of sound waves which is called **beats**.

1 beat = Loudness + Faintness.

Number of beats per second = Difference in frequency.

3.1.1 Analytical Treatment

The displacement due to the two harmonic oscillations that pass simultaneously through same point of space may be written as,

$$\psi_1 = A\cos\omega_1 t = A\cos 2\pi f_1 t \quad ; \quad \psi_2 = A\cos\omega_2 t = A\cos 2\pi f_2 t \tag{3.1}$$

(the amplitudes are assumed to be equal and the same or constant phase, which we take equal to zero). By the principle of superposition, the resultant displacement is

$$\psi = \psi_1 + \psi_2 = A\cos\omega_1 t + A\cos\omega_2 t \tag{3.2}$$

since

$$\cos P + \cos Q = 2\cos\frac{P+Q}{2}\cos\frac{P-Q}{2} \tag{3.3}$$

this may be written as

$$\psi = 2A\cos\frac{(\omega_1-\omega_2)}{2}t\cos\frac{(\omega_1+\omega_2)}{2}t \tag{3.4}$$

Chapter 4

Coupled Oscillators and Normal Modes

THis chapter will describe how a single vibrating system will behave. Oscillators rarely exist in complete isolation; wave motion owes its existence to neighbor vibrating systems which are able to transmit their energy to each other. Such energy transfer takes place, in general, because two oscillators share a common component, capacitance or stiffness, inductance or mass, or resistance. Resistance coupling brings energy loss and a rapid decay in the vibration, but coupling by either of the other two parameters consumes no power, and continuous energy transfer over many oscillators is possible. This is the basis of wave motion. We shall investigate first a mechanical example of stiffness coupling between two pendulums. Two atoms set in a crystal lattice experience a mutual coupling force and would be responsive to a similar treatment. Then we investigate an example of mass, or inductive, coupling, and finally we consider the coupled motion of an extended array of oscillators which leads us naturally into a discussion on wave motion.

4.1 Two Coupled Oscillators

The oscillation in which no power consumes and continuous energy transfer from one oscillator to another oscillator is called **Coupled Oscillator**.

Fig.4.1 shows two identical pendulums, each having a mass m suspended on a light rigid rod of length . The masses are connected by a light spring of stiffness s whose natural length equals the distance between the masses when neither is displaced from equilibrium. The small oscillations are restricted to the plane of the paper. If x and y are the respective displacements of the masses, then the equations of motion are

$$m\ddot{x} = -kx - s(x-y) \qquad \because \quad k = -\frac{mg}{} \qquad \text{(Hooks law)}$$

Chapter 5

Interference and Diffraction

5.1 Interference

Superposition of two waves having same frequency, same wavelength and moving in the same direction will result in the phenomenon of interference. Interference is of two types.

1. Constructive Interference

If the two waves reach a point in phase i.e. crest of one wave falls on the crest of the other wave and trough of on wave falls on the trough of the other wave then the two waves reinforce each other and the net wave effect increases i.e. the net intensity is greater than the intensity of individual wave. Such interference is called constructive interference.

2. Destructive Interference

If the two waves reach a point out of phase i.e. crest of one wave falls on the trough of the other, then the two waves cancel each others effect and the net intensity is less than the intensity of individual wave. This type of interference is called destructive interference.

Coherence Source

Coherent source of light are those sources which emit a light wave having the same frequency, wavelength and in the same phase or they have a constant phase. difference. A coherent source forms sustained interference pattern when superposition of waves occur and the position of maximum and minimum are fixed.

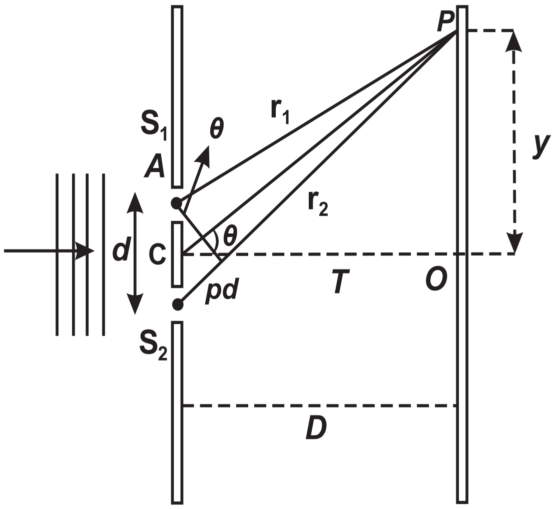


Fig. 5.1. Rays from S_1 and S_2 combine at P. Point a is the midpoint between the slits (point ***pd*** shows “path difference”).

Chapter 6

Multidimensional Waves and Wave Pulses

Note: This Chapter is only for the students of Ghazi University, D.G. Khan.

6.1 Sound Waves (Newton's Model)

According to Newton the velocity of sound waves in elastic medium is given by the relation,

$$v_\phi = \sqrt{\frac{E}{\rho}} \tag{6.1}$$

Where E =Modulus or Coefficient of elasticity and ρ =density of the medium under given conditions. He was the first to arrive at an expression predicting the velocity of sound wave in air. Newton's formula gives a velocity of about 280 m/sec which is not in agreement with its experimentally observed value of 322 m/sec at STP (Standard Temperature and Pressure), i.e. at one atmosphere pressure and 0°C (273 A). We discuss his derivation outlining the reason which led to wrong result as follows:

If a certain volume of air is enclosed in an air-tight container, it exerts an outward pressure on the walls of the container. Thus the enclosed air behaves like a compressed spring which would tend to extend itself. Suppose that the container is a long cylinder with one end closed by a wall and the other fitted with a movable massless piston. Then the enclosed air behaves like a compressed spring extending along the cylinder and tending to push the piston outward with a force of magnitude F.

At equilibrium, an external force of magnitude

$$F = PA$$

exerted by the outside atmosphere on the piston counter balances the force F of the enclosed air. Recall that P is the atmospheric pressure and A is the cross-sectional area of the piston or the inner cross-sectional area of the cylinder. For a spring of relaxed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