CHAPTER 8

OSCILLATIONS, WAVES AND OPTICS

OSCILLATIONS, WAVES AND OPTICS

Contents

OSCILLATIONS, WAVES AND OPTICS

Introduction

- An oscillation is a disturbance in a physical system that is repetitive in time.
- In general, an oscillation involves a continuous back and forth flow of energy between two different energy types: e.g., kinetic and potential energy, in the case of a pendulum.
- A wave is a disturbance in an extended physical system that is both repetitive in ime and periodic in space.
- Waves are responsible for basically every form of communication we use. Whether you're talking out loud, texting on your phone or waving to someone in a crowd there's going to be a wave transmitting information.
- A wave involves similar repetitive energy flows to an oscillation, but, in addition, is capable of transmitting energy and information from place to place.

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5.1 Simple Harmonic Motion

Periodic and Oscillatory Motion

- When a body repeats its path of motion back and forth about the equilibrium or mean position, the motion is said to be periodic.
- The periodic motion in which there is existence of a restoring force and the body moves along the same path to and fro about a definite point, equilibrium position, is called oscillatory motion.
- All periodic motions need not be back and forth like the motion of the earth about the sun, which is periodic but not vibratory in nature
- In all types of oscillatory motion restoring force that increases with increase in displacement from mean position.

Types of oscillatory motion:

There are two types of oscillatory motion: *linear oscillation* and *circular oscillation.*

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- Continued

- Example of *linear oscillation*:-Oscillation of mass spring system, Oscillation of fluid column in a U-tube, Oscillation of floating cylinder, Oscillation of body dropped in a tunnel along earth diameter, Oscillation of strings of musical instruments.
- Example of *circular oscillation*:-Oscillation of simple pendulum, Oscillation of solid sphere in a cylinder (If solid sphere rolls without slipping), Oscillation of a circular ring suspended on a nail, Oscillation of balance wheel of a clock, Rotation of the earth around the sun.

Oscillatory system:

- Oscillators are the basic building blocks of waves. Oscillatory systems are of two types: *mechanical* and *non- mechanical systems*.

Mechanical oscillatory system: In this type of system a body itself changes its position. For mechanical oscillation two things are especially responsible, *inertia* and *restoring force*.

Non-mechanical oscillatory system: In this type of system the body itself doesn‘t change its position but its physical property varies periodically.

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Terminologies of oscillation

i. AMPLITUDE (A): is the maximum displacement of the oscillator from the equilibrium position.

ii. PERIOD (T): is the time required to complete one full cycle of vibration or oscillation.

ii. FREQUENCY (*f*): The frequency is the number of complete oscillations or cycles per unit time. The frequency of wave is given by:

$$f = \frac{1}{T}$$

iii. Angular frequency $\omega = \frac{2\pi}{T} = 2\pi f$

Example: 1. On average a human heart is found to beat 75 times in a minute. Calculate its frequency and period. Determine the frequency, period angular frequency of human heart.

{Ans: f=1.25Hz ; T= 0.8sec and ω=7.85rad/s}

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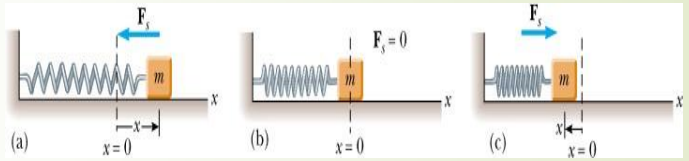
Simple Harmonic Motion (SHM)

- SHM acceleration (a) is always directly proportional in size but opposite in direction to its displacement (x).

$$a \propto -x = a = -cx$$



Where c=constant=ω^2more on this later

Eg: A block, of mass m, attached to one end

of a spring, of constant k, and oscillating in a horizontal frictionless floor is one example of a SHM. For this kind of SHM c=ω^2=K/m (show!)

- The displacement of an oscillator in SHM follows sinusoidal wave patern.(see Fig. 10.2)

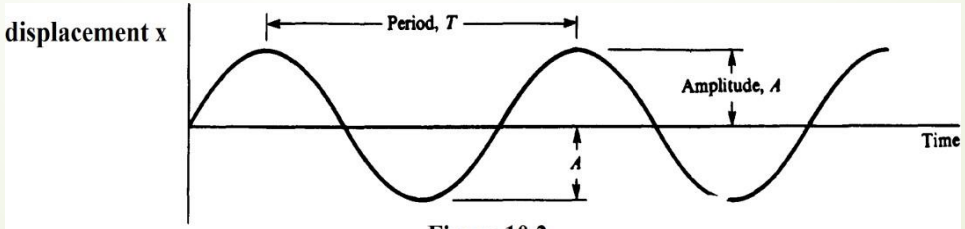


Figure 10.2

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Equation of SHM: Displacement, Velocity, Acceleration and Energy Oscillator in a SHM

- **Displacement:** $x = A\sin(\omega t)$; (if the oscillator starts from the equilibrium position).
- **Velocity:** $V = \omega A\cos(\omega t)$
- **Acceleration:** $a = -\omega^2 A\sin(\omega t) = -\omega^2 x$
- **Energy** : kinetic energy (E_k), Potential energy(U) and total energy of SHM oscillator

$$E_k = \frac{1}{2}m\omega^2(x^2 - x^2) = \frac{1}{2}K(A^2 - x^2)$$

$$U = \frac{1}{2}m\omega^2 x^2 = \frac{1}{2}Kx^2$$

$$E = \frac{1}{2}m\omega^2 A^2$$

- Energy of SHM is constant and proportional to the square of amplitude

$$E \propto A^2$$

- This relation ship is very important for analyzing resonance.

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Resonance

- Resonance is the increase in amplitude of oscillation of an electric or mechanical system exposed to a periodic force whose frequency is equal or very close to the natural undamped frequency of the system.

Resonance is a phenomenon in which an external force or a vibrating system forces another system around it to vibrate with greater amplitude at a specified frequency of operation. The frequency at which the second body starts oscillating or vibrating at higher amplitude is called the resonant frequency of the body. The best examples of resonance can be observed in various musical instruments around us. the increase in amplitude near $f = f_0$ is very large (and often dramatic). This effect is known as resonance. The natural frequency f_0 of a system is called it's resonant frequency

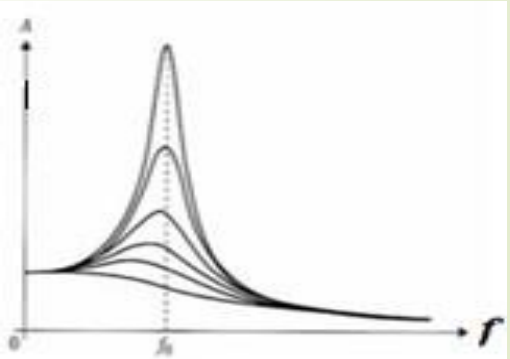

Figure 10.10

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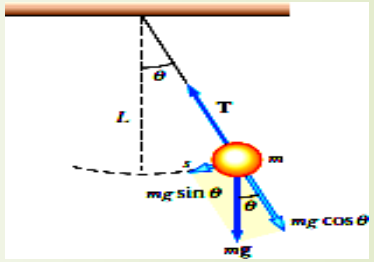
5.2 The simple Pendulum

- A simple pendulum is another mechanical system that exhibits periodic motion. It consists of a small bob of mass *m* suspended by a light string of length *L* fixed at its upper end, as in Figure below

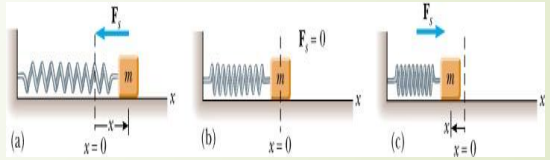


- The period of simple pendulum is given by the mathematical equation:

$$T = 2\pi\sqrt{\frac{l}{g}}$$

And $\omega^2=\frac{g}{l}$ (Show T and ω^2 are consistent by considering the figure above

- For **spring mass system the period** is:



$$T = 2\pi\sqrt{\frac{m}{K}}$$

And ω^2=K/m (Show T and ω^2 are consistent by considering the figure above)

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5.3.Wave and Its Characteristics

- The world is full of waves. Sound waves, waves on a string, seismic waves, and electromagnetic waves, are some of examples of a wave.
- **Wave** is a disturbance from normal or equilibrium condition that travels, or propagates, carrying energy and momentum through space without the transport of matter.
- **Pulse** is a single disturbance traveling into a medium. Wave supplies energy to the particles in a medium to set them in to motion.

Terminologies in Wave

1. **Crests/Troughs**: are positions in a wave with maximum displacements above/below the equilibrium position
2. **Pulse** is a single disturbance traveling into a medium. Wave supplies energy to the particles in a medium to set them in to motion.

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3. **Amplitude (A):** is the maximum displacement from the equilibrium position.

4. **Displacement (y):** is position of a wave from equilibrium position at any time.

5. **Wave length (λ):** distance between any two consecutive points which are in phase.

6. **Period (T):** is the time taken by a wave to move one wave length.

7. **Frequency (*f*):** number of oscillations performed per unit time.

8. **Speed (v):** is constant in a medium provided the medium is homogeneous

$$v = \lambda f$$

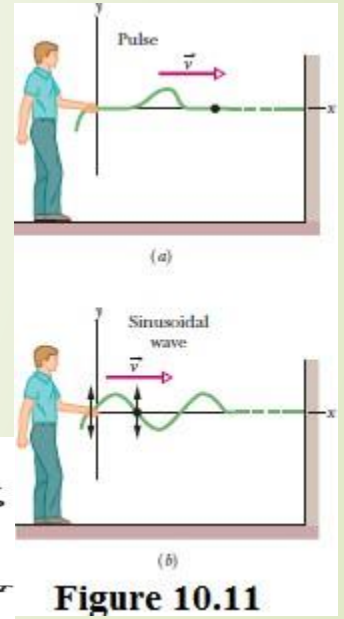

Figure 10.11

Types of waves

- Waves can be categorized as *Mechanical* and *Electromagnetic* waves based on the need of material medium for its propagation.

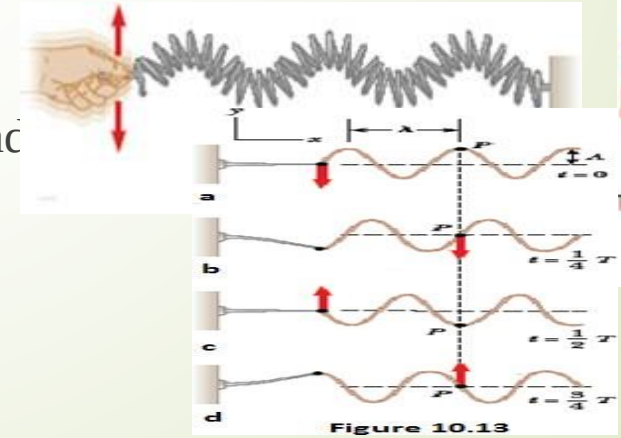

Figure 10.13

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Mechanical Waves - are waves produced by the oscillation of particles of a mechanical medium and need a medium for propagation. Examples are water waves, sound wave, waves in strings etc.

Electromagnetic (EM) waves-are produced by accelerated charged particles and can propagate through both material medium and vacuum. Examples are: Light, radio and television waves, micro waves, x-rays, etc. All EM waves in vacuum propagate with speed $c = 3.0 \times 10^8 m/s$.

- Waves can also be categorized as transverse and longitudinal waves based on the way they are propagating: **Transverse Wave and Longitudinal Wave.**

Transverse Wave- is a wave where particles of the disturbed medium oscillate perpendicular to the direction of wave motion. Examples are: water waves, waves on strings, and all EM waves. Sinusoidal graphs can represent this motion.

Longitudinal Wave- is a wave where particles of the disturbed medium oscillate parallel to the direction of wave motion. Example: sound wave

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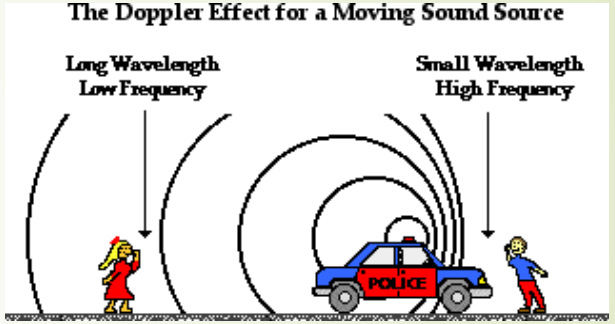
The Doppler Effect

- The Doppler Effect is observed whenever the source of waves is moving with respect to an observer.
- The Doppler Effect can be observed for any

type of wave; water wave, sound wave, light wave,

etc.



Let: f_o = frequency heard by the observer and f_s = frequency emitted by the source. Let: v_o, v, and v_s respectively be velocities of the observer, sound wave and the source.

- The observed frequency due to Doppler Effect is:

$$f_o = f_s\left(\frac{v \pm v_o}{v \mp v_s}\right)$$

Where: ‖*Upper*‖ *signs (i.e.,* $+ v_o$ *and* $- v_s$*) refer to*

motion of one towards the other and ‖*Lower*‖ *signs (i.e.,* $-v_o$ *and* $+ v_s$*) refer to motion of one away from the other.*

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Example

1. A police car moving at 20m/s with its horn blowing at 1200Hz is chasing a taxi moving at 15 m/s. what is the frequency heard by the taxi driver?{Take: Speed of sound =340m/s}{Ans: f_L =1219Hz}

2. An Ambulance sires at 600Hz and is moving at 15m/s towards a boy riding a bicycle at 6m/s towards the ambulance. What frequency is heard by the boy? Take: Speed of sound =340m/s} {Ans:$f_L = 639$}

Characteristics of Waves

- Following are some of the characteristics of waves:

Reflection: is phenomenon (rebounding of wave from a surface) is called reflection.

Refraction of wave: It is the change in direction of a wave passing from one medium to another caused by its change in speed.

Diffraction of wave: It is the spreading of waves around obstacles

Interference of wave: the effect is that of the addition of the amplitudes of the individual waves at each point affected by more than one wave.

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Chapter Summery

- ✓ Periodic motion is a motion of a body which repeats its path of motion back and forth about the equilibrium or mean position. There are two types of oscillatory motion: *linear oscillation* and *circular oscillation.* Oscillators are the basic building blocks of waves. Oscillatory systems are of two types, *mechanical* and *non-mechanical systems*.
- ✓ **Period** (T): is the time required to complete one full cycle of vibration or oscillation.
- ✓ **Frequency** (*f*): The frequency is the number of complete oscillations or cycles per unit time

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…Continued

- ✓ **Amplitude (A):** is the maximum displacement of the oscillator from the equilibrium
- ✓ Simple harmonic motion is a special type of oscillatory motion caused by a restoring force which obeys Hooke's law.
- ✓ **Displacement:** $x = A\sin(\omega t)$; (if the oscillator starts from the equilibrium position)
- ✓ **Velocity:** $V = \omega A\cos(\omega t)$
- ✓ **Acceleration:** $a = -\omega^2 A\sin(wt) = -\omega^2 x$
- ✓ The *potential energy* of SHM is given by: $= \frac{1}{2}Kx^2$
- ✓ Therefore the *total energy* of the oscillator performing SHM is: $E = \frac{1}{2}m\omega^2A^2$ $(\text{i. e}; E \propto A^2)$

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- **Wave** is a disturbance from normal or equilibrium condition that travels, or propagates, carrying energy and momentum through space without the transport of matter.
- Waves can be categorized as Mechanical and Electromagnetic waves based on the need of material medium for its propagation.
- Waves can also be categorized as transverse and longitudinal waves based on the way they are propagating.
- Resonance is the increase in amplitude of oscillation of an electric or mechanical system exposed to a periodic force whose frequency is equal or very close to the natural undammed frequency of the system.

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