Physics Notes (Wave)

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11. Waves

11.1 Wave Motion

- **Definition:** A wave is a disturbance that transfers energy from one point to another without the net transfer of matter.
- **Medium:** The substance through which a wave travels (e.g., water, air, a string). Some waves (electromagnetic waves) do not require a medium.
- **Energy Transfer:** Waves carry energy, not matter. For example, in an ocean wave, the water oscillates up and down, but the wave itself travels forward.

11.2 Production of Mechanical Waves

- **Mechanical Waves:** Waves that require a medium for their propagation. They are produced by a vibrating source.
    - **Examples:** Sound waves, water waves, waves on a string.
- **Generation:** A disturbance creates vibrations in the particles of the medium, and these vibrations are passed on from particle to particle.

11.3 Transverse and Longitudinal Waves

- **Transverse Waves:** Waves in which the oscillations of the medium's particles are perpendicular to the direction of wave propagation.
    - **Examples:** Water waves, waves on a string, all electromagnetic waves (light, radio waves).
    - **Features:** Crests (highest points) and Troughs (lowest points).

- **Longitudinal Waves:** Waves in which the oscillations of the medium's particles are parallel to the direction of wave propagation.
    - **Examples:** Sound waves.
    - **Features:** Compressions (regions of high density and pressure) and Rarefactions (regions of low density and pressure).

11.4 Properties of Waves

- **Amplitude (A):** The maximum displacement of a particle from its equilibrium position. Relates to the energy carried by the wave.
- **Wavelength (\lambda):** The distance between two consecutive corresponding points on a wave (e.g., crest to crest, trough to trough, or compression to compression).
- **Frequency (f):** The number of complete oscillations or wave cycles passing a point per second.
    - **Unit:** Hertz (Hz).
- **Period (T):** The time taken for one complete oscillation or wave cycle.
    - **Relation:** T = 1/f
- **Wave Speed (v):** The speed at which the wave disturbance travels through the medium.

- Wave Equation: $v = f\lambda$

- **Wavefront:** An imaginary line or surface connecting points of the same phase on a wave.
- **Ray:** A line drawn perpendicular to the wavefronts, indicating the direction of wave propagation.

11.5 Summary

- Waves transfer energy without transferring matter.
- Mechanical waves need a medium, electromagnetic waves do not.
- Transverse waves have oscillations perpendicular to direction of travel; longitudinal waves have oscillations parallel.
- Key wave properties: amplitude, wavelength, frequency, period, and speed (v = fλ).

12. Reflection of Light Waves

12.1 Sources of Light

- **Luminous Objects:** Objects that produce their own light (e.g., sun, stars, light bulb, firefly).
- **Non-luminous Objects:** Objects that do not produce their own light but reflect light from luminous sources (e.g., moon, planets, most objects around us).

12.2 Transmission of Light

- **Transparent Materials:** Allow light to pass through them clearly, so objects can be seen distinctly through them (e.g., clear glass, air, water).
- **Translucent Materials:** Allow some light to pass through, but scatter it, so objects cannot be seen clearly through them (e.g., frosted glass, parchment paper).
- **Opaque Materials:** Do not allow light to pass through them at all (e.g., wood, metal, stone).

12.3 Rectilinear Propagation of Light

- **Principle:** Light travels in straight lines in a uniform medium.
- **Evidence/Applications:**
    - Formation of sharp shadows.
    - Pinhole camera: forms an inverted, real image.
    - Eclipses (solar and lunar).

12.4 Reflection of Light at Plane Surfaces

- **Reflection:** The bouncing back of light when it strikes a surface.
- **Plane Mirror:** A flat, smooth surface that reflects light regularly.
- **Laws of Reflection:**
    1. **Incident Ray, Reflected Ray, Normal:** The incident ray, the reflected ray, and the normal (an imaginary line perpendicular to the surface at the point of incidence) all lie in the same plane.
    2. **Angle of Incidence equals Angle of Reflection:** The angle of incidence (Øi) is equal to the angle of reflection (Ør). (Øi = Ør)
- **Image Formation by Plane Mirror:**
    - **Virtual:** Image cannot be formed on a screen.
    - **Upright (Erect):** Same orientation as the object.
    - **Laterally Inverted:** Left and right are reversed.
    - **Same Size:** Image is the same size as the object.
    - **Same Distance:** Image is as far behind the mirror as the object is in front.

12.5 Reflection of Light by Curved Surfaces

- **Spherical Mirrors:** Mirrors that are part of a sphere.
    - **Concave Mirror (Converging Mirror):** Reflecting surface curves inward, like a spoon.
        - Can form both real and virtual images, magnified or diminished, depending on object position.
        - **Uses:** Shaving mirrors, dentist's mirrors, solar furnaces, car headlights (as reflectors).
    - **Convex Mirror (Diverging Mirror):** Reflecting surface curves outward.
        - Always forms virtual, upright, and diminished images.
        - **Uses:** Rear-view mirrors in vehicles, security mirrors in shops (provide wider field of view).
- **Key Terms for Spherical Mirrors:**
    - **Pole (P):** The center of the mirror's surface.
    - **Centre of Curvature (C):** The center of the sphere from which the mirror is a part.
    - **Radius of Curvature (R):** The distance from the pole to the centre of curvature (R = 2f).
    - **Principal Axis:** A straight line passing through the pole and the centre of curvature.
    - **Principal Focus (F) / Focal Point:** The point on the principal axis where parallel rays converge (concave) or appear to diverge from (convex) after reflection.
    - **Focal Length (f):** The distance from the pole to the principal focus. (f = R/2).

12.6 Summary

- Light originates from luminous sources and travels in straight lines.
- Reflection is the bouncing of light, governed by two laws.
- Plane mirrors form virtual, erect, laterally inverted images.
- Concave mirrors can converge light, forming various images; convex mirrors diverge light, always forming virtual, diminished images.

13. Refraction of Light Waves

13.1 Introduction, Definitions

- **Refraction:** The bending of light as it passes from one transparent medium to another of different optical density.
- **Optical Density:** A measure of how much a medium slows down light. Denser media slow light more.
- **Terms:**
    - **Incident Ray:** The light ray approaching the interface.
    - **Refracted Ray:** The light ray after bending in the second medium.
    - **Normal:** A line perpendicular to the surface at the point of incidence.
    - **Angle of Incidence (Ø1):** Angle between incident ray and normal.
    - **Angle of Refraction (Ø2):** Angle between refracted ray and normal.
- **Behavior of Light:**
    - When light goes from less dense to more dense medium (e.g., air to glass), it bends *towards* the normal.
    - When light goes from more dense to less dense medium (e.g., glass to air), it bends *away* from the normal.
- **Cause of Refraction:** Change in the speed of light as it enters a different medium. Frequency remains constant, so wavelength changes ($v = f\lambda$).
- **Snell's Law:** Relates the angles of incidence and refraction to the refractive indices of the two media.

- **Formula:** $n_1 \sin\theta_1 = n_2 \sin\theta_2$
- **Refractive Index (n):** A dimensionless quantity that represents how much a medium bends light.
  - $$n = \frac{\text{speed of light in vacuum}}{\text{speed of light in medium}}$$
  - Also $n = \frac{\sin\theta_1}{\sin\theta_2}$ (when light goes from vacuum/air to medium).

13.2 Refraction Through Rectangular Glass Block

- Light enters from air to glass (bends towards normal).
- Light exits from glass to air (bends away from normal).
- The emergent ray is parallel to the incident ray, but laterally displaced (shifted).

13.3 Total Internal Reflection (TIR)

- **Conditions for TIR:**
  1. Light must travel from a denser optical medium to a less dense optical medium.
  2. The angle of incidence must be greater than the critical angle.
- **Critical Angle (Øc):** The angle of incidence in the denser medium for which the angle of refraction in the less dense medium is 90°.

- **Relation to Refractive Index:** $\sin\theta_c = \frac{1}{n}$

  (where n is the refractive index from less dense to denser medium).

- **Applications of TIR:**
  - Optical fibres (endoscopes, telecommunications).
  - Periscopes (using prisms).
  - Binoculars.
  - Sparkle of diamonds.

13.4 Refraction of Light Through Triangular Prism

- Light undergoes two refractions: once entering the prism and once exiting.
- The emergent ray is deviated from the original path.
- **Angle of Deviation (D):** The angle between the incident ray and the emergent ray.
- Prisms can be used to disperse white light (see next section).

13.5 Dispersion of White Light

- **Definition:** The splitting of white light into its constituent colours (spectrum: Red, Orange, Yellow, Green, Blue, Indigo, Violet - ROYGBIV) when it passes through a prism or other transparent medium.
- **Cause:** Different colours (wavelengths) of light travel at slightly different speeds in a medium (other than vacuum), thus having different refractive indices. Violet light bends the most, Red light bends the least.

13.6 Refraction of Light Through Lenses

- **Lens:** A transparent optical device that refracts light to converge or diverge it.
- **Types of Lenses:**
  - **Convex Lens (Converging Lens):** Thicker in the middle, converges parallel rays of light to a real focus.
    - Can form both real and virtual images, magnified or diminished, depending on object position.
    - **Uses:** Magnifying glasses, cameras, projectors, eyeglasses for hyperopia (long-sightedness).
  - **Concave Lens (Diverging Lens):** Thinner in the middle, diverges parallel rays of light from a virtual focus.
    - Always forms virtual, upright, and diminished images.
    - **Uses:** Eyeglasses for myopia (short-sightedness), peepholes in doors.

- **Lens Formula:** $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ (where f is focal length, u is object distance, v is image distance).
- **Magnification (M):** $M = \frac{\text{Image height}}{\text{Object height}} = \frac{v}{u}$ (for real images, v is positive; for virtual images, v is negative, same for f).

13.7 Summary

- Refraction is the bending of light due to a change in speed when entering a new medium.
- Snell's Law (n_1 \sin \theta_1 = n_2 \sin \theta_2) describes refraction.
- Total Internal Reflection occurs when light goes from dense to less dense medium at an angle greater than the critical angle.
- Prisms disperse white light into its spectrum.
- Lenses (convex and concave) use refraction to form images, crucial for optical instruments.

14. Application of Light Waves

14.1 Simple Lens Camera and Projector

- **Simple Lens Camera:**
  - Uses a **converging (convex) lens** to form a **real, inverted, and diminished image** on a film or sensor.
  - Light enters through the aperture, lens focuses it, shutter controls exposure time.
- **Projector:**
  - Also uses a **converging (convex) lens**.
  - The object (slide/film) is placed between f and 2f of the lens to produce a **real, inverted, and magnified image** on a distant screen.

14.2 The Human Eye

- **Components:**
  - **Cornea:** Transparent outer layer, does most of the light bending (refraction).
  - **Pupil:** Adjustable opening that controls the amount of light entering the eye.
  - **Iris:** Colored part that controls pupil size.
  - **Lens:** A flexible converging lens that changes shape (accommodation) to fine-tune focusing for different distances.

    - **Retina:** Light-sensitive layer at the back of the eye, containing rods (for dim light) and cones (for color vision), where the **real, inverted, and diminished image** is formed.
    - **Optic Nerve:** Transmits electrical signals from the retina to the brain.
- **Common Eye Defects:**
    - **Myopia (Short-sightedness):** Cannot see distant objects clearly. Image forms in front of the retina. Corrected by a **concave (diverging) lens**.
    - **Hyperopia (Long-sightedness):** Cannot see near objects clearly. Image forms behind the retina. Corrected by a **convex (converging) lens**.
    - **Presbyopia:** Age-related loss of accommodation, similar to hyperopia.
    - **Astigmatism:** Irregular curvature of cornea or lens, causing blurred vision at all distances. Corrected by cylindrical lenses.

14.3 Microscopes and Telescopes

- **Compound Microscope:**
    - Uses **two converging lenses**: an **objective lens** (short focal length) and an **eyepiece lens** (longer focal length).
    - The objective forms a real, inverted, magnified image of the object.
    - The eyepiece then acts as a magnifying glass to produce a final virtual, magnified image.
    - Used to view very small objects.
- **Astronomical Telescope:**
    - Also uses **two converging lenses**: a large **objective lens** (long focal length) and an **eyepiece lens** (short focal length).
    - The objective forms a real, inverted, diminished image of a distant object.
    - The eyepiece then acts as a magnifying glass to produce a final virtual, magnified image.
    - Used to view distant astronomical objects.
- **Galilean Telescope:** Uses a convex objective and a concave eyepiece, producing an upright image.

14.4 Summary

- Cameras and projectors use lenses to form real images.
- The human eye is a complex optical system, corrected by lenses for common defects.
- Microscopes magnify small objects using two converging lenses.
- Telescopes magnify distant objects using two lenses (or mirrors).

15. Sound Waves

15.1 Production and Transmission of Sound

- **Production:** Sound is produced by **vibrations**. When an object vibrates, it causes the surrounding medium (usually air) to vibrate, creating a sound wave.
    - **Examples:** Vibrating vocal cords, guitar strings, drum skins.
- **Transmission:** Sound waves are **mechanical waves**, meaning they require a medium (solid, liquid, or gas) to travel. They cannot travel through a vacuum.
    - They are **longitudinal waves**, consisting of compressions and rarefactions that propagate through the medium.
- **Speed of Sound:** Varies with the medium and temperature.
    - Fastest in solids (e.g., steel: ~5000 m/s)
    - Slower in liquids (e.g., water: ~1500 m/s)

    - Slowest in gases (e.g., air at 20°C: ~343 m/s)
    - Generally, speed increases with temperature.

15.2 Characteristics of Sound

- **Loudness (Intensity):** Determined by the **amplitude** of the sound wave. Larger amplitude means louder sound. Measured in decibels (dB).
- **Pitch:** Determined by the **frequency** of the sound wave. Higher frequency means higher pitch (more shrill sound).
    - **Audible Range:** Humans can typically hear sounds between 20 Hz and 20,000 Hz.
    - **Infrasound:** Frequencies below 20 Hz.
    - **Ultrasound:** Frequencies above 20,000 Hz.
- **Quality (Timbre):** The characteristic that distinguishes different sound sources even if they produce the same pitch and loudness. Determined by the mixture of overtones (harmonics) present in the sound.
- **Echo:** The reflection of sound waves off a hard surface. Used in sonar and medical imaging.
- **Reverberation:** Multiple reflections of sound waves in an enclosed space, leading to a prolongation of sound.

15.3 Forced Vibrations

- **Definition:** When an object is made to vibrate at the frequency of an external driving force.
- **Resonance:** A special case of forced vibration where the frequency of the driving force matches the natural frequency of the object, leading to a large increase in amplitude.
    - **Examples:** A bridge vibrating due to rhythmic marching, shattering a glass with sound.

15.4 Vibrations in Strings and Pipes

- **Strings:** When a string vibrates, it produces standing waves.
    - **Fundamental Frequency (First Harmonic):** The lowest natural frequency, where the string vibrates as a single loop (one antinode, two nodes at ends).
    - **Overtones/Harmonics:** Higher natural frequencies that are integer multiples of the fundamental frequency.
    - Factors affecting string frequency: length (shorter = higher f), tension (tighter = higher f), mass per unit length (thinner/lighter = higher f).
- **Pipes (Air Columns):** Air inside pipes can vibrate to produce sound.
    - **Open Pipes:** Open at both ends. Produce all harmonics (fundamental, 2nd, 3rd, etc.).
    - **Closed Pipes:** Open at one end, closed at the other. Produce only odd harmonics (fundamental, 3rd, 5th, etc.).

15.5 Application of Sound Waves in Musical Instruments

- **String Instruments:** Guitar, violin, piano. Sound produced by vibrating strings. Pitch varied by changing string length (fingering), tension, or thickness.
- **Wind Instruments:** Flute, clarinet, trumpet, organ. Sound produced by vibrating air columns inside pipes. Pitch varied by changing length of air column (valves, holes) or blowing technique.
- **Percussion Instruments:** Drums, cymbals, xylophone. Sound produced by vibrating membranes or solid bodies.

15.6 Hearing Aids

- **Function:** Electronic devices that amplify sound for people with hearing loss.

- **How they work:** Contain a microphone to pick up sound, an amplifier to increase the sound intensity, and a speaker (receiver) to deliver the amplified sound into the ear canal.

15.7 Summary

- Sound is produced by vibrations and travels as longitudinal mechanical waves.
- Loudness (amplitude), pitch (frequency), and quality (overtones) are characteristics of sound.
- Forced vibrations and resonance are important phenomena for sound.
- Vibrations in strings and pipes produce musical notes based on harmonics.
- Musical instruments utilize these principles, and hearing aids assist with sound perception.