SIZE OF PARTICLE - KSCISOP

SIZE OF PARTICLE

1. Key Concepts

- Wave nature of light
- Interference
- Diffraction
- Quantum phenomenon of EM radiation
- Heisenberg uncertainty principle

2. Introduction

The behaviour of light, for example interference, diffraction can be understood when light is studies as a wave phenomenon. Interaction of waves interact with matter results in either transmission, reflection, absorption and diffraction of the wave. When the size of matter is comparable to the wavelength of wave that it interacts with, a phenomenon called diffraction occurs. Diffraction of light due to particles is a function of the size of the particle and the wavelength of the light incident. It is possible to measure the size of a particle by studying the diffraction patterns created by it.

3. Objective

To measure the width/thickness of the given samples by analysing the diffraction pattern.

4. Theory

When a beam of light strikes an obstacle, whose dimensions is comparable to its wavelength, then some of the light is diffracted, some reflected, some of it refracted, absorbed and re-radiated.

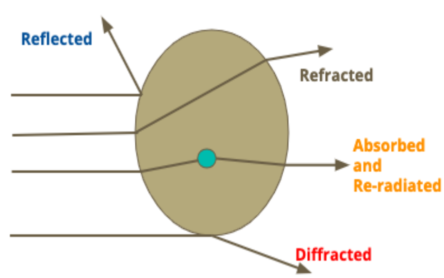

Fig 1: Interaction of wave with a particle

Diffraction is a phenomenon of bending of waves when it encounters obstacles or narrow opening (slits). Diffraction is a universal phenomenon in waves.

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Christian Huygen's proposed a theory to explain the phenomena of diffraction. It is called the **Huygen's principle,** in whichhe used wavefront model to explain diffraction. To make it easier to visualise wavefront, when a stone is dropped in water, the stone disturbs the water and causes a number of circular ripples that travel outward. As time progresses the radius of the ripples increase. They start out small and become big.

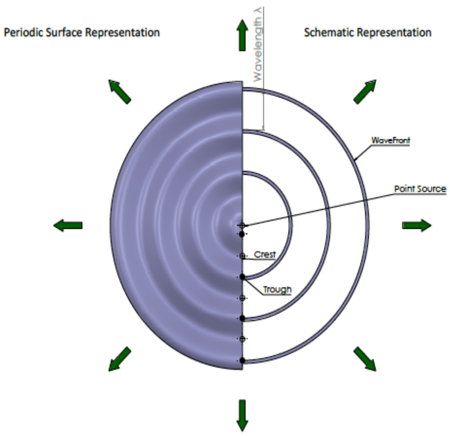


Fig 2: periodic surface wave

Consider a ripple of radius r form the point source, here along this circle of radius r, the points are in some phase of oscillation. This is referred to as **wavefront.** In a wavefront all the points have the same phase of oscillation.

The radius of the wavefront increase as it travels outwards from the coherent point source. The circular wavefronts can be approximated as nearly straight wavefronts known as plane wavefronts. According to Huygen's principle, any wavefront can be thought to be composed of a collection of coherent point sources emanation in all directions (figure 3). Each such point source has emits circular waves called as ***wavelets.***

Figure 2 depicts how the wavefronts are always perpendicular to the direction of propagation of the wave and the separation between the two wave fronts is same as the wavelength (λ) of the wave

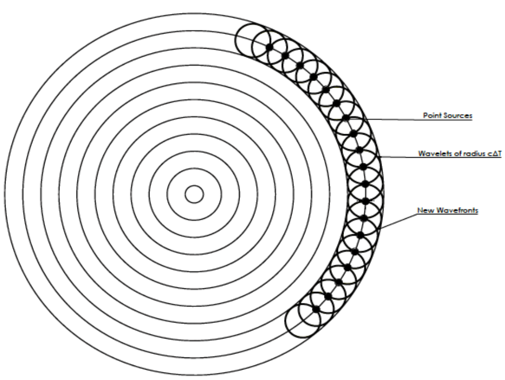
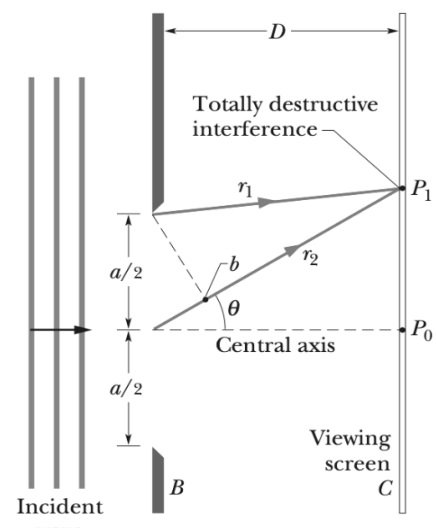


Fig 3: wavefronts can be regarded to be composed of a collection of closely spaced, coherent point sources



Consider a beam of light propagating to the right, composed of planar wavefronts (figure 4) encounters an obstacle of width ***a***.

A basic set up to observe diffraction is shown in figure 4. It consists a slit B, screen at places at a distance of D from the slit. The wavefronts are partially obstructed by the slit B. The wavelets originating from the unobstructed part of the wave interfere on the screen resulting in diffraction pattern on the screen. **Fig 4:** Plane wave propagating to the right

The intensity distribution of the diffractionpattern is shown in figure 5. We can see that the intensity distribution is symmetric along about the central axis. The primary peak is called the central maxima. The corresponding peaks are called secondary, tertiary maxima.

Mathematically, the relation between the slit width (a), and the wave wavelength (λ) of the diffracted wave is given as follows.

$$d\text{x } \sin\vartheta = m\lambda$$

wheremistheorderofdiffraction,disthegratingconstant(distancebetweenthegratinglines).Thegratingconstantiscalculatedusingtheformula*d*= *1/N* Where,Nisthe numberoflinesinthediffractiongratingandθistheanglebetweentheincidentwavedirectionandthediffractedwavedirection

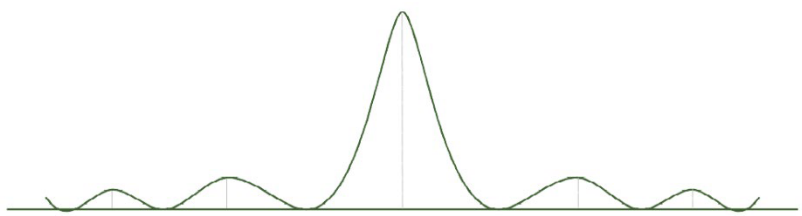
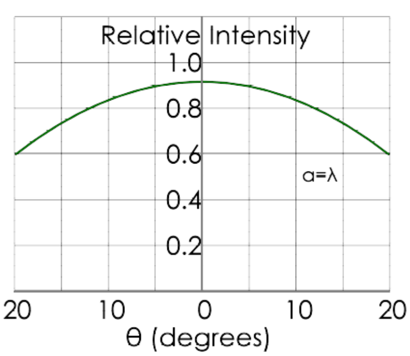


Fig 5: Intensity distribution of the diffracted light

The intensity distributions are governed by the relative wavelength difference between the two interfering waves.

Effect of the width of the slit/obstacle on the diffraction pattern.

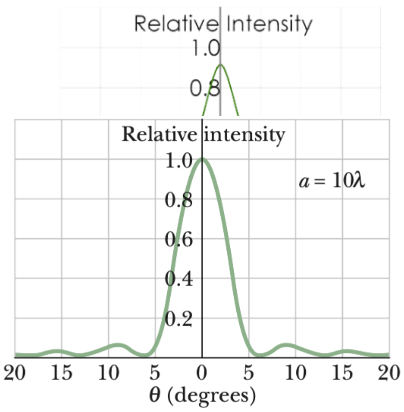


bstacle equal to the wavelength of the light. $a = \lambda$

Here, we can see the width of the central maxima is very large and the intensity variation is small across a the angular region. And the secondary maxima are not observable.

Case 2: The width of the slit/ obstacle is $a = 5\lambda$

Here, we can see that the central maxima has a much smaller width and the intensity variation is much greater across the angular region. And the secondary maxima are observable.



Case 3: The width of the slit/ obstacle is $a = 10\lambda$

Here, we can see that the central maxima has a much smaller width and the intensity variation is much greater across the angular region. And the secondary maxima, tertiary maxima are also observable.

This is the same principle that is in use to find the size of the particle. When a beam of laser encounters small particles/obstacle, the laser beam undergoes diffraction. The beam gets diffracted by different angles based on the size of the particles (figure 6).

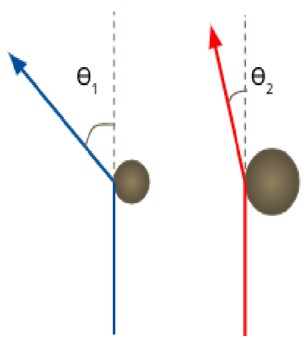


Fig 6: angle of diffraction

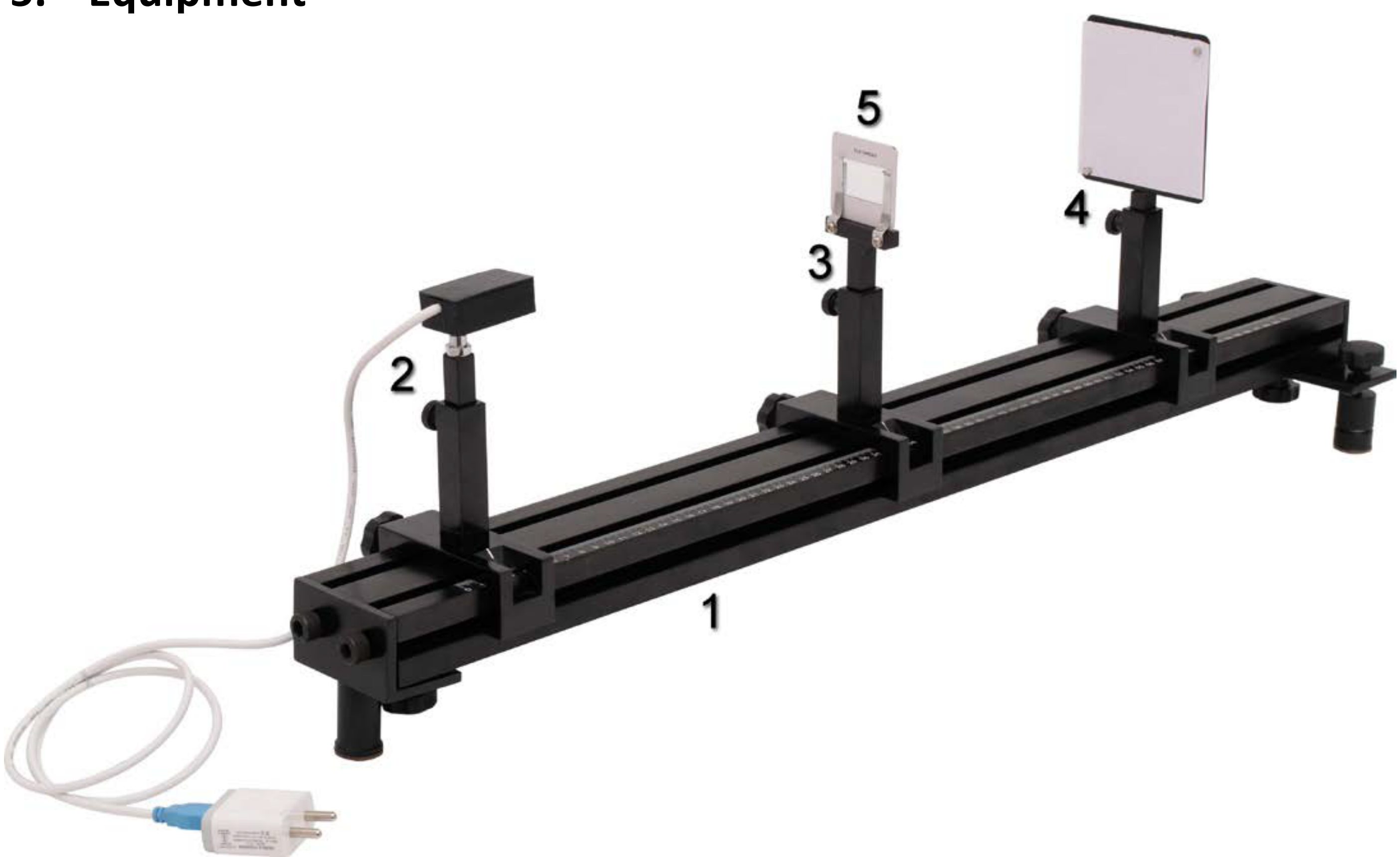
The angle of diffractionfor small particles (θ_1) is bigger than the diffraction angle of bigger particles (θ_2).

The geometry of the diffraction pattern is dependent on the shape of the diffracting object. If the diffracting particles are spherical the diffraction pattern will circular, if the diffracting particle is square them the diffraction pattern is like a cross etc.

Fig 7: Circular and Square diffraction patterns due to a spherical, square and cylindrical diffracting particle/slit respectively.

To calculate the size of the particle, the distance of the fringe from the centre of the central maxima has to be determined, the order to which that fringe belongs to has to noted and the distance between the screen and the sample has to be measured.

5. Equipment



S. No	Equipment	Item Code	Quantity
1	Optical Bench Set 0.8m	**KSCIOB1**	1
2	Laser Source holder	**KSCIHA003**	1
3	Grating Holder	**KSCIHA008**	1
4	Screen Holder	**KSCIHA024**	1
5	Laser Distance Meter	**KSCIAC010**	1

6. Safety Instructions

- Components like horizontal bench and power supply are heavy. Take adequate safety measures while handling them.
- Never look directly at the laser beam.

7. Experimental Setup

- Place the optical bench on a stable horizontal surface such as a sturdy table top and make sure the bench is parallel to the horizontal surface using the adjustable mounts.
- Mount the laser source securely on the upright, place the upright on the optical bench and lock the slide screw on the slider.
- In order to measure the wavelength of given laser source. Securely mount the diffraction grating on the upright.
- Mount the diffracting sample provided to you on an upright.
- During the experiment do not vary the distance between the sample mount and the screen.

8. Experiment

8.1 To find the wavelength of the laser

- Switch on the laser and beam and adjust it so that the laser bean fall on the diffraction grating.

- Fix the position of the diffraction grating on the optical bench so that the distance between the screen and the diffraction grating is constant.

- Once the diffraction pattern is obtained, measure and record the distance between the central maxima and secondary maxima on both sides of the diffraction pattern.

- The wave length of the laser light can be obtained from the following formula:

$$d sin(\theta) = m\lambda$$

where, *d*: is the grating constant, θ : angle between the central maxima and the maxima under consideration, m is the order of the maxima under consideration, and λ: is the wavelength of the laser.

8.2 Determination of the particle size

- Switch on the laser source and adjust the beam such that it falls on the diffracting sample and obtain a clear diffraction pattern.

- Keep the distance between the particle holder and the screen constant throughout the experiment.

- Once a clear diffraction pattern has been obtained, measure and record the distance between the central maxima and first minima on both sides of the pattern.

$$S = \frac{\lambda \times w}{D}$$

- The side of the particle can be calculated form the following formula.

  where, S: size of the particle, λ: is the wavelength of the laser, *D*: is the distance between the central maxima and the first minima under consideration, and w: is the distance between the screen and the particle holder.

- Repeat the process for other samples.

9. Tabulation

9.1 Wavelength of the laser

Diffraction grating constant (d) :___________________*d= 1/N* Where,Nisthe numberoflinesinthediffractiongrating

Order of the maxima (m): _______________

Wavelength of the laser __________________

9.2 Size of the particle

Diffracting Sample: ______________

Wavelength of the laser ___________

S.No	Order of minima (m)	Distance b/w Central maxima & first minima in cm	Distance b/w screen & wire in cm	Size of the particle S
1				
2				
3				
4				

10. Applications

Laser diffraction for particle sizing: Is extensively used in all branches of science and technology.

a. In medicine it its used to mechanical properties of the erythrocytes (RBC)

b. In ecology it is used to study the size and distribution of the particles in sediments, to study the size of pollutant particles in air and water.

c. In engineering it is used to study the size of the particles in cement. The distribution of the size of the particles has huge impact on the strength and bonding in cement.

d. In pharmaceutical industries, it is used to measure the size of the particles in aerosol sprays that are used to treat asthma.

11. References

1. Eugene Hetch, Optics (5th edition)

2. ISO 13320:2009, Particle size analysis - Laser diffraction methods

3. Merkus, H. (2009). Particle Size Measurements. Dordrecht: Springer Netherlands, 259-285.