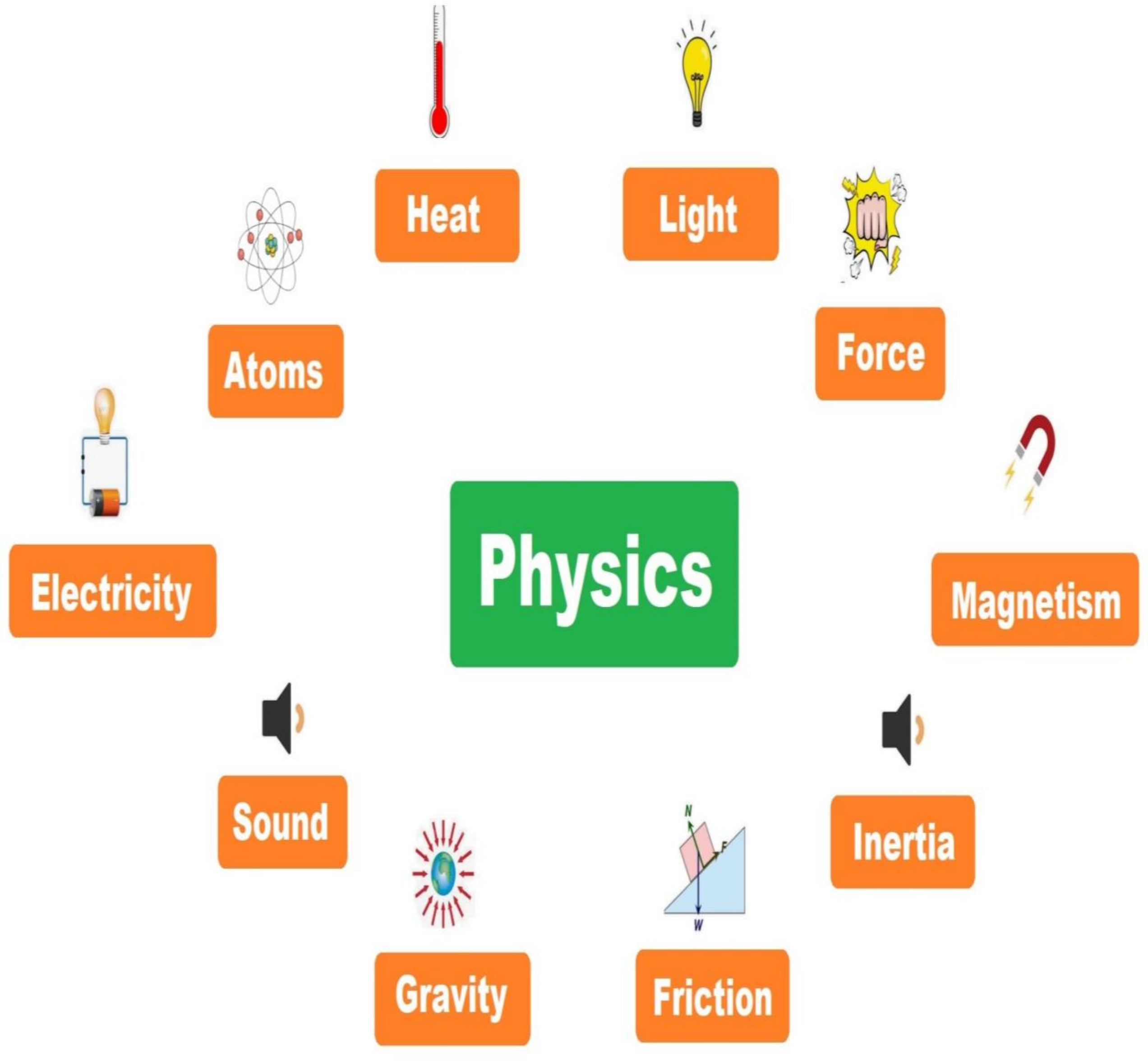
Md. Hasibur Rahman

Lecturer

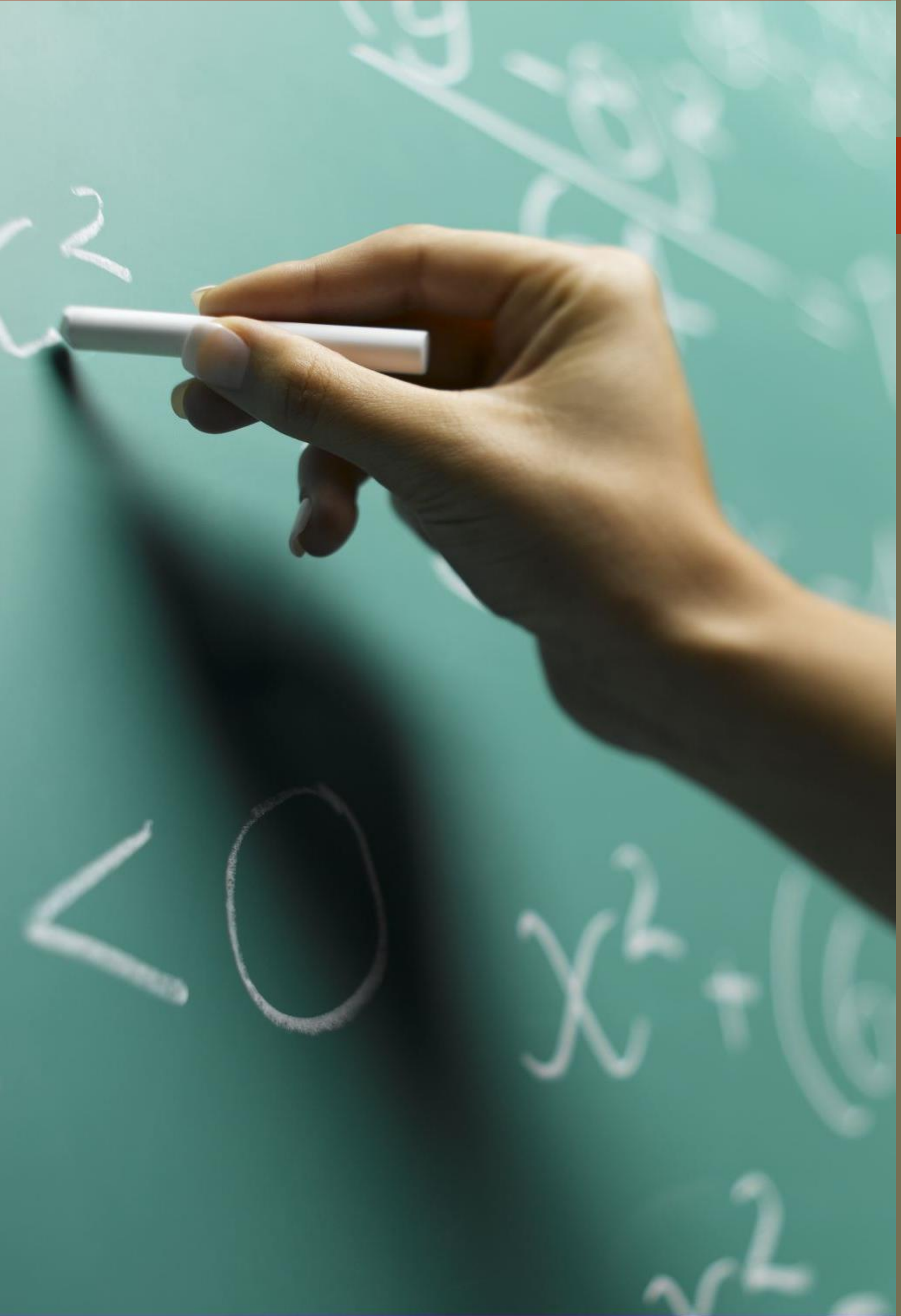
Department of Physics & Astronomy,

University of Global Village, Barishal

Course Title: Physics-II Optics, Modern Physics, Thermodynamics



Rationale: The course provides a comprehensive exploration of light, contemporary physics, and the behavior of energy and heat. It connects foundational theories with practical applications, covering topics like wave optics, quantum mechanics, and thermodynamics. By combining theoretical knowledge with problem-solving skills, it prepares students for advanced studies and innovations in physical sciences.



Course Credit: 3

Course Code: PHY 0533-1201

Class: 17 Weeks (2 Lecture per week, Total = 34)

CIE Marks: 90

SEE Marks: 60

Total Marks: 150

Total: 26 weeks per semester

Exam/ Result: 06 weeks

Holiday/ Leave: 3 weeks

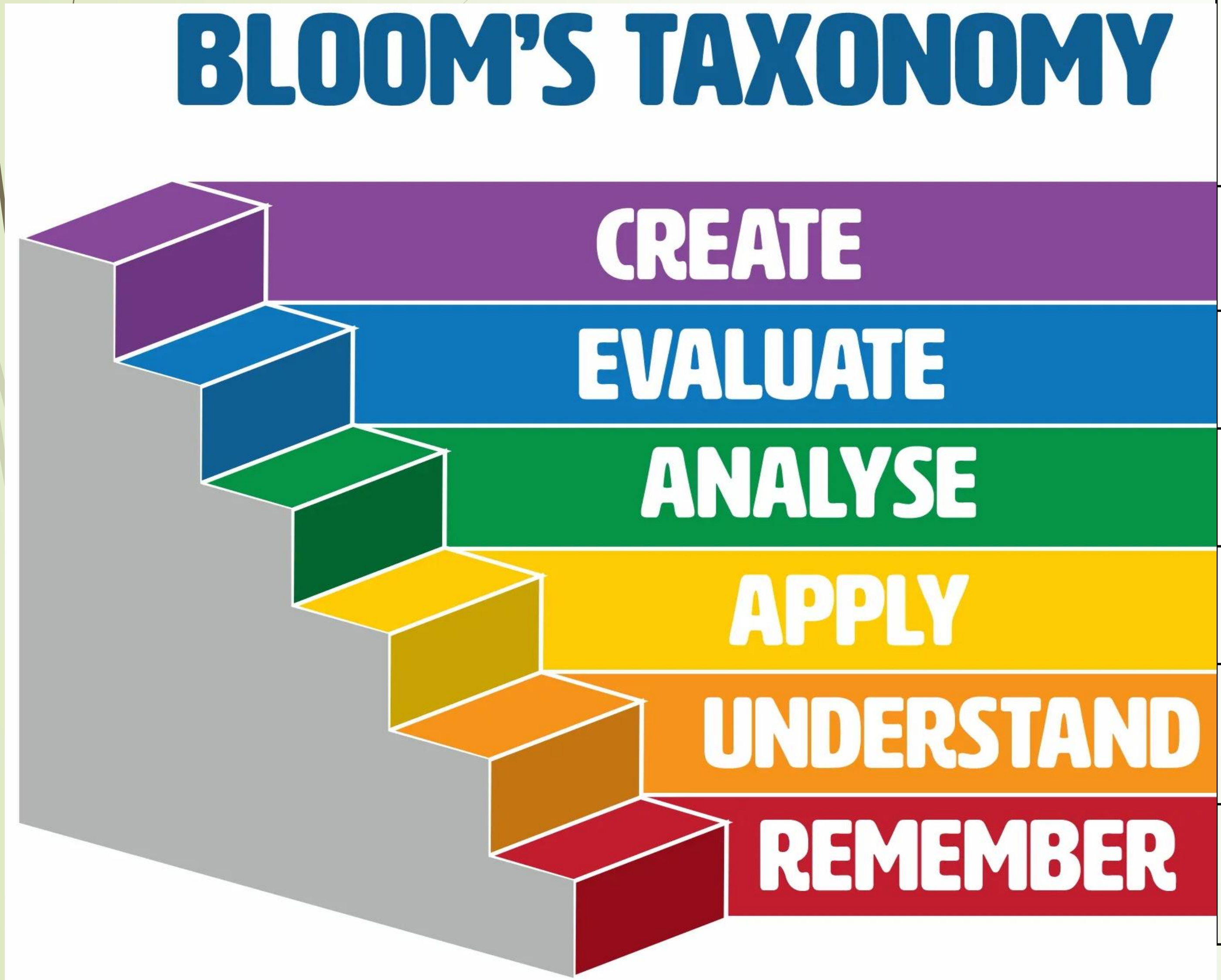
Assessment Pattern

Continuous Internal Evaluation (CIE 90 marks)

Blooms Category	Test (Out of 45)	Assignments (15)	Quiz (15)	Co-curricular Activities (15)
Remember	05		5	Attendance 15
Understand	05			
Apply	10			
Analysis	8	7	10	
Evaluate	7	8		
Create	10			

Assessment Pattern

Semester End Examination (SEE 60)



Test (Out of 60)
10
10
10
10
10
10

Grading System:

80% and above	A+	4.00
75% to less than 80%	A	3.75
70% to less than 75%	A-	3.50
65% to less than 70%	B+	3.25
60% to less than 65%	B	3.00
55% to less than 60%	B-	2.75
50% to less than 55%	C+	2.50
45% to less than 50%	C	2.25
40% to less than 45%	D	2.00
Less than 40%	F	0.00
	F* Failure I** Incomplete W*** Withdrawal R**** Repeat Y***** Audit	

Course learning outcomes (CLO): After successful completion of the course *Optics, Modern Physics, and Thermodynamics*, students will be able to

CLO1:

Demonstrate a clear understanding of the fundamental principles of optics, modern physics, and thermodynamics.

CLO2:

Analyze and interpret key theories and laws governing wave optics, quantum mechanics, and thermodynamic processes.

CLO3:

Apply mathematical and analytical skills to solve problems related to optical phenomena, modern physics, and energy systems.

CLO4:

Investigate and evaluate the performance of optical instruments, quantum systems, and thermodynamic devices using theoretical and practical approaches.

SL	Content of Courses	Hrs	CLO's
1	Optics, Nature Of light, Explanation of the Electromagnetic Wave, Law of Reflection, Total internal Reflection, Huygens Principle, Optics, Nature Of light, Explanation of the Electromagnetic Wave, Law of Reflection, Nature Of light, The Standard Model of Particle Physics: Unifying Fundamental Forces, Dark matter and Dark Energy, Topic Related Problems.	8	CLO1, CLO3
2	Explanation of the Electromagnetic Wave, Law of Reflection, Total internal Reflection, Huygens Principle, Brewster's Law, Snell's law, Malus law, LASER, Classical Mechanics, Quantum Mechanics, Properties of quantum mechanics, Topic Related Math's	10	CLO2, CLO3
3	Thermodynamics, laws of thermodynamics, The Energy Transfer Mechanics in Thermal process, Thermal Expansion of solid and liquid, Conduction, Convection, Radiation, Stefan's law, Refrigerator, Thermoelectricity, order, Disorder, Entropy, Topic Related Problems	8	CLO3, CLO4
4	Total internal Reflection, Huygens Principle, Optics, Boltzmann law, Black body, Heat Engine, Carnot Engine, Refrigerator, Thermoelectricity, order, Disorder, Entropy, Superconductivity, Topic Related Problems	8	CLO3, CLO4

OBE Based Curriculum

No.	Course Outcome
CLO1	Demonstrate a clear understanding of the fundamental principles of optics, modern physics, and thermodynamics
CLO2	Analyze and interpret key theories and laws governing wave optics, quantum mechanics, and thermodynamic processes.
CLO3	Apply mathematical and analytical skills to solve problems related to optical phenomena, modern physics, and energy systems.
CLO4	Investigate and evaluate the performance of optical instruments, quantum systems, and thermodynamic devices using theoretical and practical approaches.

Week	Topics	Teaching and Learning Strategy	Assignment Strategy	Corresponding CLOs
1	Optics, Nature Of light, Explanation of the Electromagnetic Wave, Law of Reflection,	Lecture, Oral Presentation, Video, presentation	Quiz, Assignment, and Written Exam, Presentation	CLO1, CLO3
2	Total internal Reflection, Huygens Principle, Refraction, Diffraction, Polarization,	Lecture, Oral Presentation,	Quiz, Assignment, and Written Exam	CLO1, CLO3
3	Interference of light, Newton's rings, Interferometers, Fresnel Bi-prism.	Lecture, Oral Presentation	Quiz, Assignment, Written Exam, and Discussion	CLO1, CLO2

Week	Topics	Teaching and Learning Strategy	Assignment Strategy	Corresponding CLOs
4	Malus law, Brewster's Law, Topic Related Math's	Lecture, Oral Presentation, Video presentation.	Quiz, Assignment, and Written Exam,	CLO1, CLO3
5	Snell's law, LASER, Topic Related Mathematics	Lecture, Oral Presentation,	Quiz, Assignment, and Written Exam	CLO2, CLO3
6	Classical Mechanics, Quantum Mechanics, Properties of quantum mechanics	Lecture, Oral Presentation	Quiz, Assignment, Written Exam, and Discussion	CLO3, CLO4

Week	Topics	Teaching and Learning Strategy	Assignment Strategy	Corresponding CLOs
7	Wave-particle duality, Theory of Relativity, Michel Morley Experiment	Lecture, Oral Presentation,	Quiz, and Written Exam,	CLO1, CLO3
8	Explain Time Dilation, Length Contraction, Increase of Mass according to the theory of relativity	Lecture, Oral Presentation,	Quiz, Assignment, and Written Exam	CLO2, CLO3
9	Four types of fundamental Forces Mass-Energy Equivalence Law	Lecture, Oral Presentation	Quiz, and Written Exam	CLO1, CLO2
10	Photoelectric Effect, Compton effect, Problem-Solving	Lecture, Oral Presentation and Video presentation	Quiz, and Written Exam	CLO1, CLO2

Week	Topics	Teaching and Learning Strategy	Assignment Strategy	Corresponding CLOs
11	Atomic Decay, De Broglie Wave Topic Related Problems	Lecture, Oral Presentation, Video presentation.	Quiz, Assignment, and Written Exam,	CLO3, CLO4
12	Thermodynamics, laws of thermodynamics, The Energy Transfer Mechanics in Thermal process	Lecture, Oral Presentation,	Quiz, and Written Exam	CLO2, CLO3
13	Thermal Expansion of solid and liquid, Newtons law of cooling , Topic Related Problems	Lecture, Oral Presentation	Quiz, and Written Exam	
14	Stefan’s law, Boltzmann law, Black body, Heat Engine, Carnot Engine Topic Related Problems	Lecture, Oral Presentation and video presentation	Quiz, and Written Exam	CLO1, CLO2

Week	Topics	Teaching and Learning Strategy	Assignment Strategy	Corresponding CLOs
15	Refrigerator, Thermoelectricity, order, Disorder, Entropy, Topic Related Problems	Lecture, Oral Presentation, Video presentation.	Quiz, Assignment, and Written Exam,	CLO1, CLO3
16	Review and discussion class	Lecture, Oral Presentation,	Quiz, Assignment, and Written Exam,	CLO3, CLO4
17	Review and discussion class	Lecture, Oral Presentation,	Quiz	CLO3

❖ Reference Books For Optics

1. Physics Vol.-02 by David Halliday, Jearl Walker, and Robert Resnick
2. Fundamentals of Optics By F.A Jenkin and H, E White
3. Optics By A. Ghatak

❖ Reference Books For Heat and Thermodynamics

1. Heat and Thermodynamics by Brijlal and Subramanyam
2. Heat and Thermodynamics By Zemansky
3. Fundamentals of Thermodynamics By Miah, W

❖ Reference Books For Modern Physics

1. Concept of Modern Physics By Beiser, Arthur
2. Modern Physics by kenneth S. Krane
3. A Brief History of Time By Stephen Hawking.

1st Week

Topic: Optics-

Nature Of light, Explanation of the Electromagnetic Wave, Law of Reflection.

Topic Related Math

Page: 15- 28


Optics

- **What is Optics**

Optics is the branch of physics that studies the behavior and properties of light, including its interactions with matter and the construction of instruments that use or detect it.

- **Write short notes about the Nature of Light**:

1. Light is an **electromagnetic wave** that the human eye can observe.

2. Early experiments on **diffraction** and **interference** provided evidence for its wave-like behavior.

3. Like all electromagnetic waves, light can **travel through a vacuum**.

4. Light show the nature of wave particle duality.

5. Source of Light:

Light can be produced in two ways:

- ✓ **Incandescence**: Emission from "hot" matter (with temperatures above 800 K).
- ✓ **Luminescence**: Emission when excited electrons return to lower energy levels (whether the matter is "hot" or not).

➢Types of luminescence include:

- **Fluorescence**: Emission within 10 ns of excitation due to allowed transitions.
- **Phosphorescence**: Delayed emission (more than 10 ns) from forbidden transitions.
- **Electroluminescence**: Emission caused by an electric field.
- **Radioluminescence**: Emission due to x-rays or radioactive radiation.
- **Chemiluminescence**: Emission from chemical reactions.
- **Bioluminescence**: Occurs in living organisms (think fireflies!)

❖ **Dual Nature of Light**

•Light exhibits both wave and particle nature.

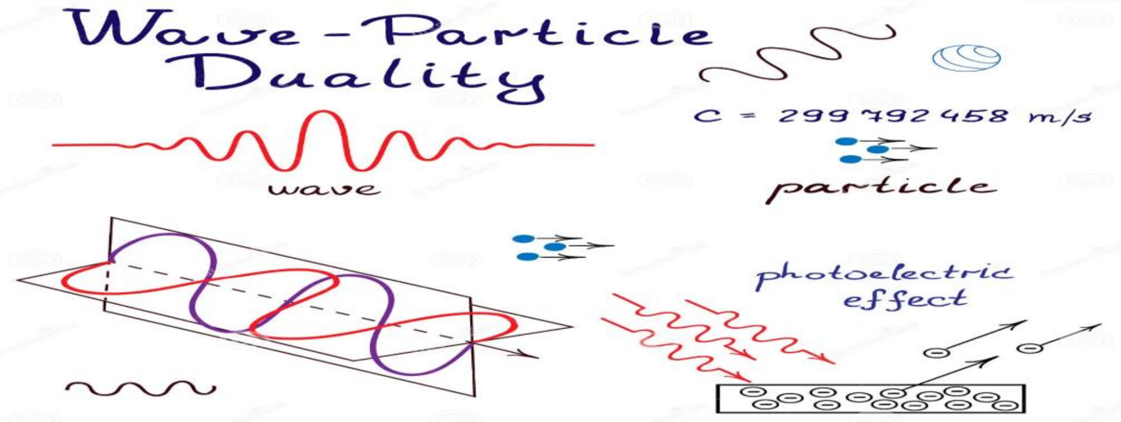
•This surprising wave-particle duality is shared by other fundamental particles (e.g., electrons).

- Particle Nature of Light:

Evidence for light's particle nature came from the photoelectric effect:

- When light shines on a metal surface, it can cause the emission of free electrons.
- This led to the conclusion that light consists of packets or quanta of energy.
- These energy packets are called photons.

- Wave Nature of Light:
  - Light is an electromagnetic wave that the human eye can observe.
  - Early experiments on diffraction and interference provided evidence for its wave-like behavior.
  - Like all electromagnetic waves, light can travel through a vacuum



What is Light

- The behavior of light remained mysterious about the decades
- Newton proposed the simplest model of light which is known as the corpuscular model of light
- According to this theory, a luminous body continuously emits tiny light and elastic particles called corpuscles in all directions.
- These particles or corpuscles are so small that they can readily travel through the interstices of the particles of matter with the velocity of light and they possess the property of reflection from a polished surface or transmission through a transparent medium.
- Phenomenon of reflection and refraction of light can be explained by using this model

Speed of Light

Light travels incredibly fast through a vacuum, moving at a constant speed of 3×10^8 ms^{-1} .This speed is a universal constant, and nothing with mass can travel at or exceed this velocity.

What is light Year?

The distance traveled by light in one year is called light year.

1 year = 365 days

= (365×24) hours = (365×24×60) min = (365×24×60×60) sec

Now, in 1 sec light travels 3×10^8 m distance

∴ In (365×24×60×60) sec light travels (365×24×60×60) × (3×10^8) m distance

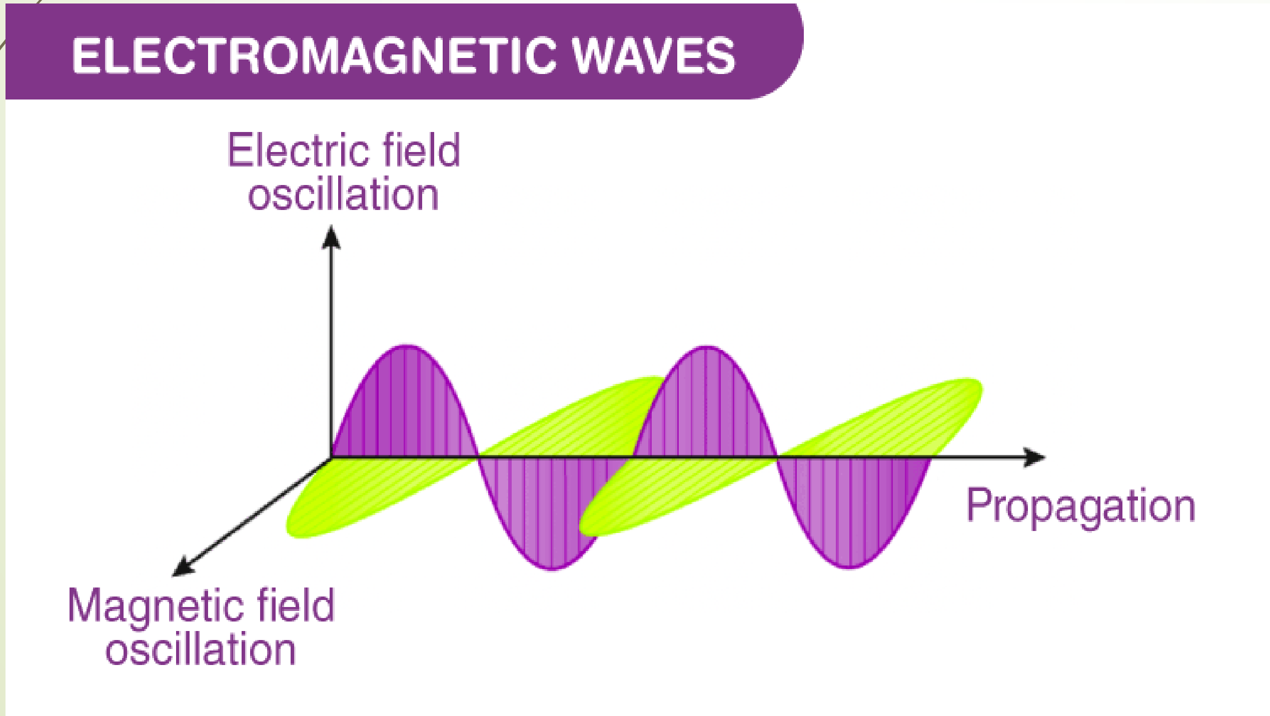
∴ 1 Light year = 9.46×10^{15} m

1 Light year = 9.46×10^{12} km

❖ **What is the Electromagnetic Wave?**

Electromagnetic waves are the composition of oscillating electric and magnetic fields. Electromagnetic waves are solutions of Maxwell's equations, which are the fundamental equations of electrodynamics.

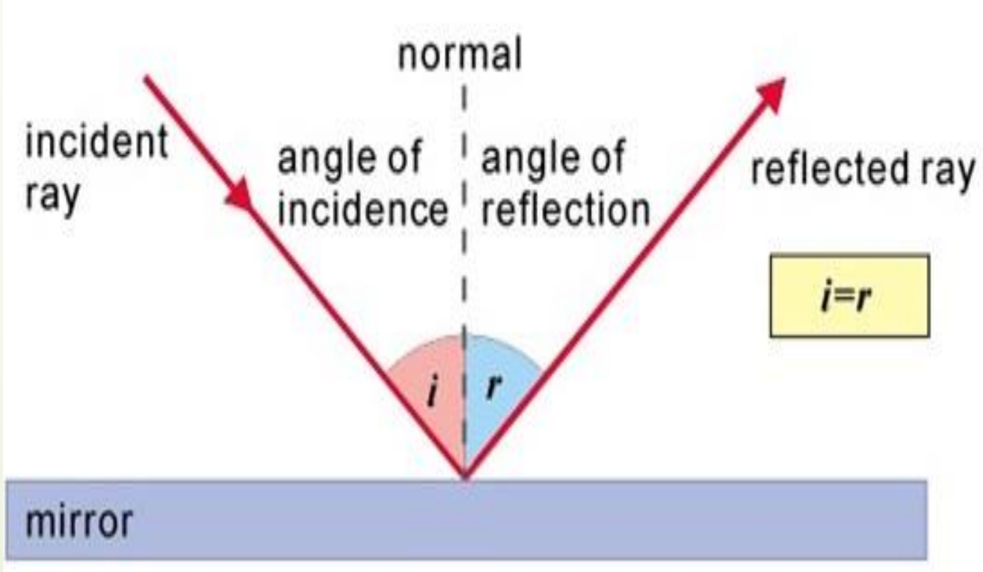
The electromagnetic spectrum is the range of all electromagnetic radiation in terms of its wavelengths and frequencies.

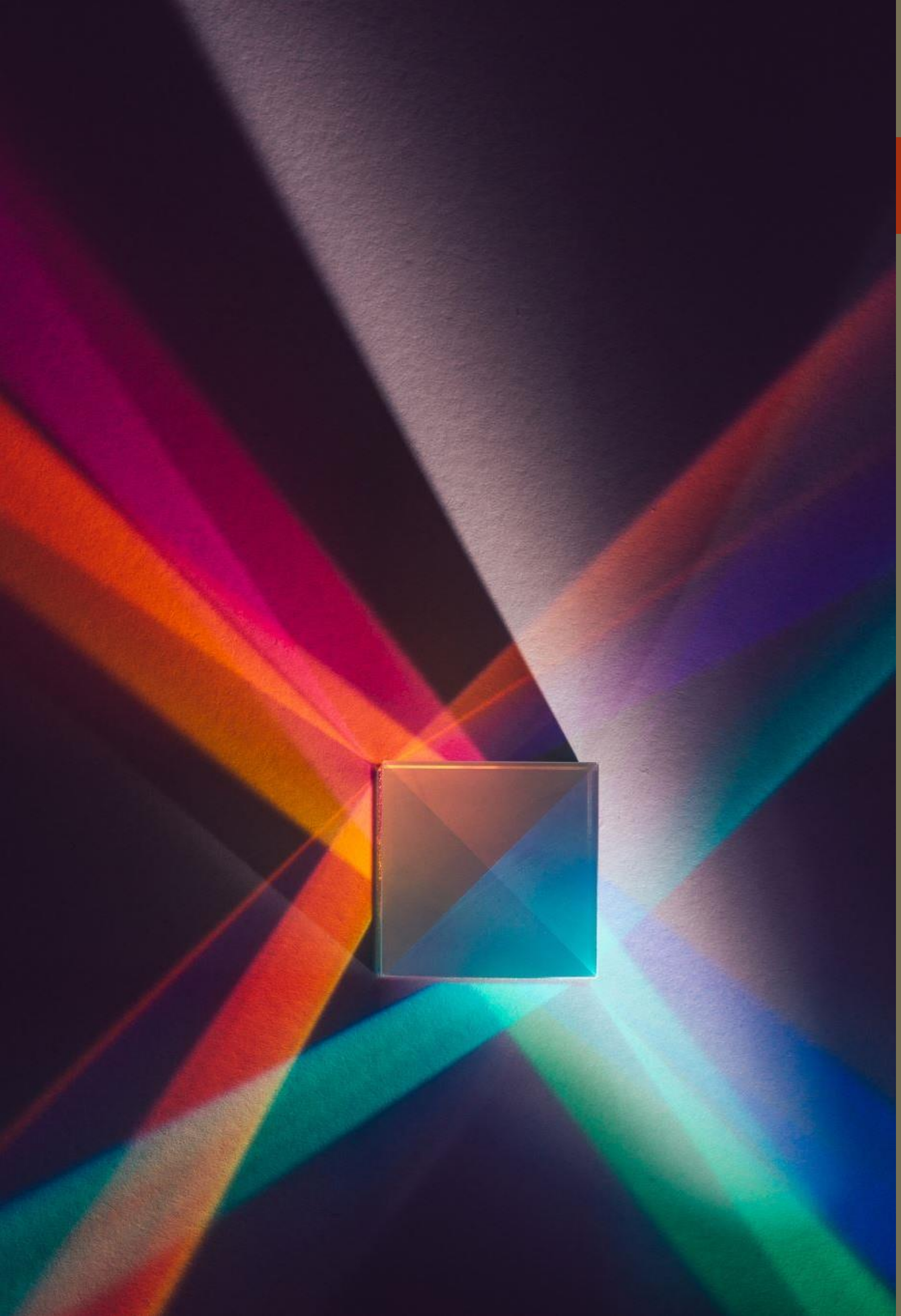


What is the Nature of Light

Reflection of light

When the light falling on a surface turn back into the same medium, it means it is reflected. The angle made by the incident ray with the normal to the reflecting or refracting surface is called the angle of incidence, and the angle made by the reflected or refracted ray with normal is called the angle of reflection or refraction.





Terms used in refraction

Refracted ray is the bent ray as a result of passing from one optical medium to another.

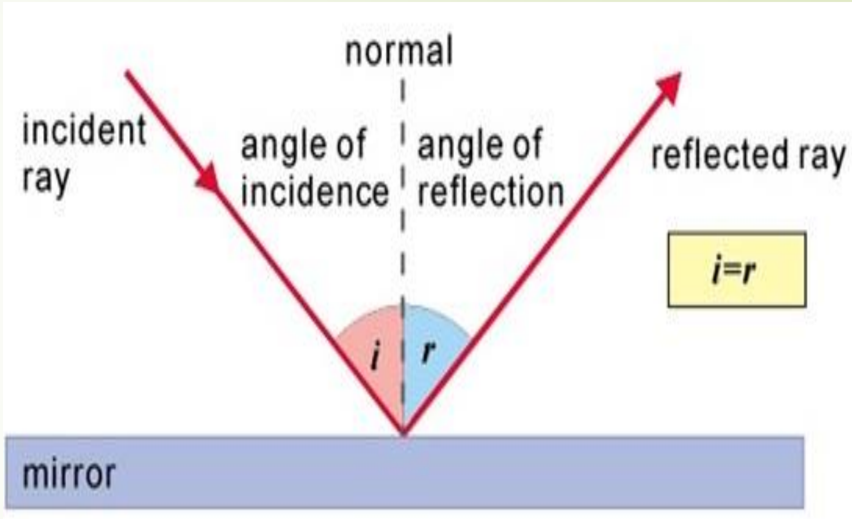
Normal is an imaginary line perpendicular to the interface of media where the refraction occur.

Angle of incidence is the angle between incident ray and the normal.

Angle of refraction is the angle between refracted ray and the normal.

Laws of Reflection

The laws of reflection describe how **light behaves** when it encounters a **reflecting surface**, such as a **mirror or a smooth shiny surface**



1st law

When the **incident ray**, the **reflected ray** and the normal to the reflecting surface at the point of **incidence lie** in the same plane, it is called the plane of incidence.

2nd Law

The **angle of incidence** is equal to the **angle of reflection**. That means,

<i = <r

2nd Week

Topic: Optics-

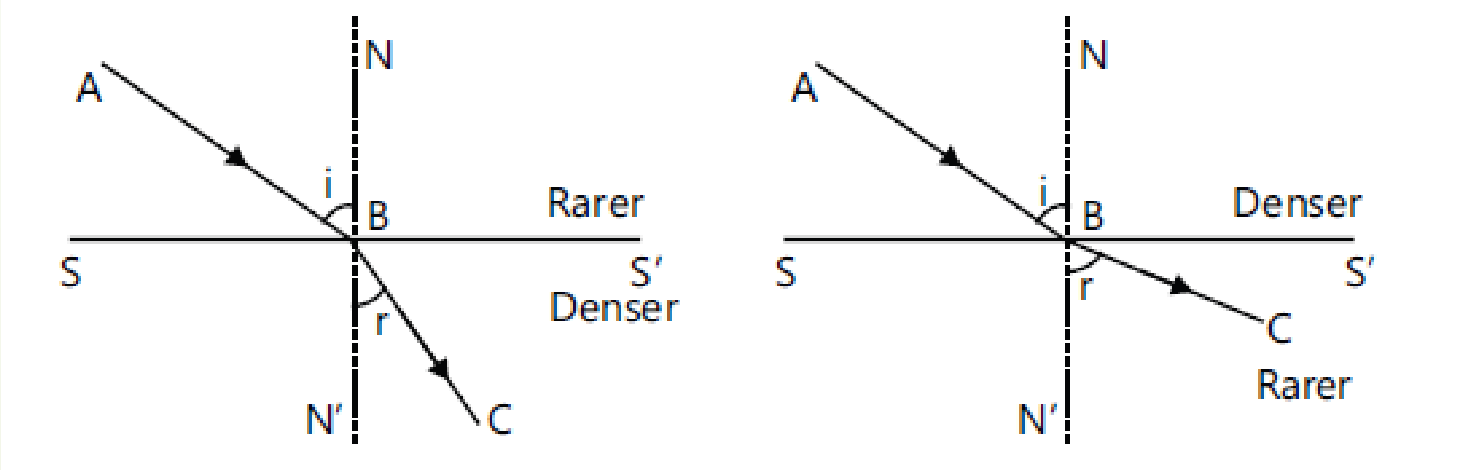
Total internal Reflection, Huygens Principle, Refraction, Diffraction, Polarization,

Topic Related Math

Page: 29-57

Refraction of light(cont.)

- **The deviation or bending of light rays from their original path while traveling from one medium to another is called refraction.**
- If the refracted ray bends away from the **normal**, then the second medium is said to be **RARER** as compared to the first medium, and the **speed increases**.
- **Refraction** of light is the change in direction (bending of light rays) when it passes from one optically transparent medium to another. If the refracted ray bends toward the normal, then the second medium is said to be DENSER compared to the first, and the speed decreases.



Laws of Refraction

- The laws of refraction, describe how light behaves when it passes from one medium into another, where its speed changes. These laws are essential in understanding how light bends as it enters or exits substances with different optical densities
- First law of refraction

The incident ray, the refracted ray and the normal to the interface all lie in the same plane

- Second law of refraction

When light travel one transparent medium to another transparent medium in a certain angle then, the ratio of sine of angle of incidence to the sine of angle of refraction is a constant, for the light of a given color and for the given pair of media. This constant could be represented by μ or n.

$$\frac{\sin i}{\sin r} = \mu$$

μ is the refractive index of the medium

Refractive index

- Refractive index:

Refractive index is a physical property of a material that describes how light propagates through it. It is defined as the ratio of the speed of light in a vacuum to the speed of light in the material. In other words, it is a measure of how much a material slows down the speed of light as it passes through it.

$$\mu = \frac{\text{Velocity of light in Vacuum}}{\text{Velocity of light in that medium}} = \frac{v_0}{v_m}$$

If the transparent media are a and b, the refractive index of the medium b with respect to the medium a is

$$a^{\mu_b} = \frac{\text{Velocity of light in medium ,a}}{\text{Velocity of light in that medium ,b}} = \frac{v_a}{v_b}$$

Or, $a^{\mu_b} = \frac{v_a}{v_b}$

Refractive index(Cont.)

Kinds of refractive index

Refractive index is of two types, viz-

(1) Absolute refractive index and

(2) Relative refractive index

Absolute refractive index: If a ray of light coming from vacuum or air, is refracted into another transparent medium, the ratio of the sine of angle of incidence to the sine of angle of refraction is called the absolute refractive index (or simply refractive index) of the second medium with respect to vacuum. In short, the refractive index of a transparent medium with respect to that of vacuum is called the absolute refractive index of that medium.

Refractive index(Cont.)

Of course, absolute refractive index is also considered with respect to air, since refractive index of air = 1-00029 ≈ 1.

During refraction of a ray of light from vacuum to a transparent medium b, if the angle of incidence is i and the angle of refraction is r, then the absolute refractive index of the medium b is

$$o\mu_{\mathrm{b}} = \frac{\sin i}{\sin r}$$

While writing absolute refractive index, it is not needed to write 0.

Refractive index(Cont.)

Relative refractive index: If a ray of light is refracted from a transparent medium to another transparent medium, the ratio of the sine of the angle of incidence to the sine of the angle of refraction is called relative refractive index of the second medium with respect to the first medium. That means, the refractive index of a transparent medium with respect to another transparent medium is called relative refractive index of the medium with respect to the first medium.

If a ray of light is refracted from a transparent medium 'a' to medium 'b', this constant is called the refractive index of medium b with respect to the medium a.

Refractive index(Cont.)

It is denoted by. So, during refraction from medium a to medium b, if the angle of incidence is i and the angle of refraction is r then

$$a^{\mu_b} = \frac{\sin i}{\sin r}$$

If it is said that the refractive index of glass is 1'5 with respect to air, it is understood that if a ray of light is refracted from air to glass, then the ratio of the sine of the angle of incidence to the sine of the angle of refraction is 1'5.

Refractive index(Cont.)

Relative refractive index explains how much denser a transparent medium is compared to another transparent medium. Points to be noted:

(1) The value of μ does not depend on the angle of incidence; it depends on the nature of the two transparent media and the color of the rays of light. The refractive index of a medium is higher for red rays than that for violet rays.

(2) Between two transparent media, the medium having higher refractive index is denser than the other one. Optical density and physical density are not same.

The Wave Model

- Large number of experimental observations like diffraction, interference, polarization which could not be explained on the basis of corpuscular model.
- Huygens proposed a wave model in 1678.
- A satisfactory explanation of the diffraction phenomenon can only be given if one assumes a wave model of light.
- Wave model was not very popular before young interference experiment.

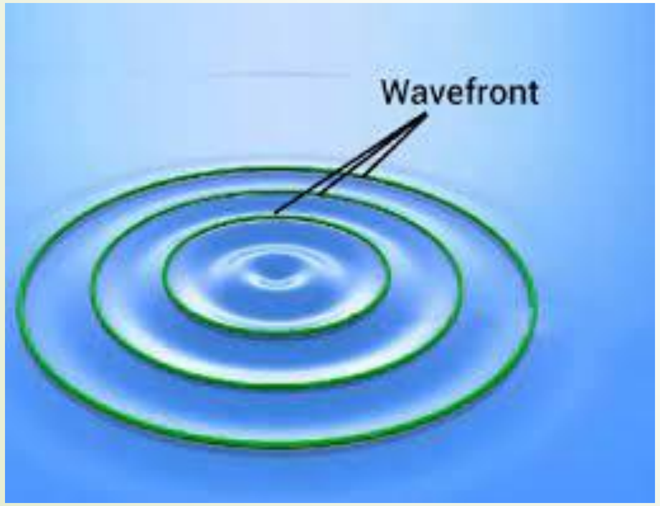
The Wave Model

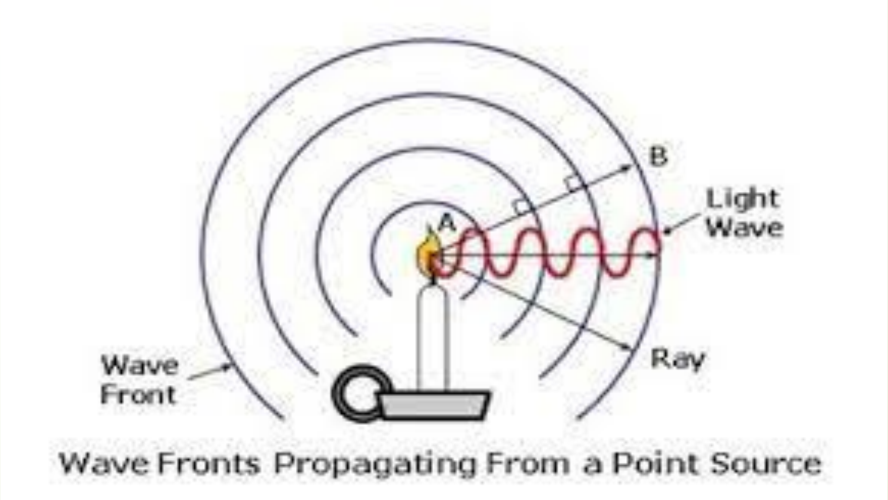
- Young interference experiment could not only be explained on the basis of wave theory.
- In 1802, young gave a satisfactory explanation of the formation of Newton's ring.
- Also in 1808, malus observed the polarization of light.
- In 1816, a satisfactory explanation of the diffraction phenomena was provided by Fresnel.

Concept of Wavefront

A wave front is the locus of the points which are in same Phase.

Example: If we drop a small stone in a calm pool of water, circular ripples spreads out from the point of impact, each point on the circumference on the circle (Whose Centre is at the point of impact) oscillates with the same amplitude and same phase and thus we have a circular wavefront.



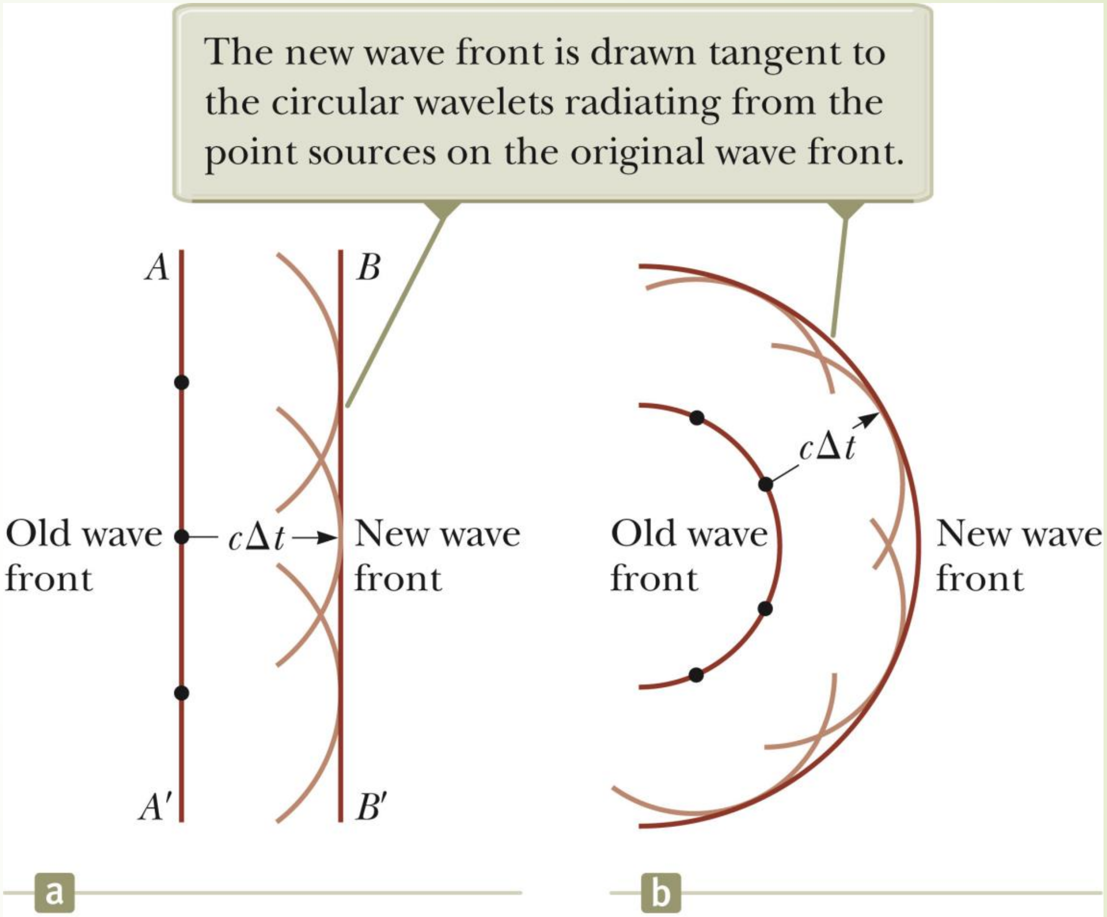


Huygens Principle

- Huygens theory is essentially based on geometrical Constructions which allow us to determine the shape of the wavefront at any time.
- According to Huygens principle, each point of a wavefront is a source of secondary disturbance and the wavelets emanating from these points spread out in all directions with the speed of wave, through a hypothetical medium called ether.
- The envelope of these wavelets gives the shape of the new wavefront.

Huygens Principle (Cont.)

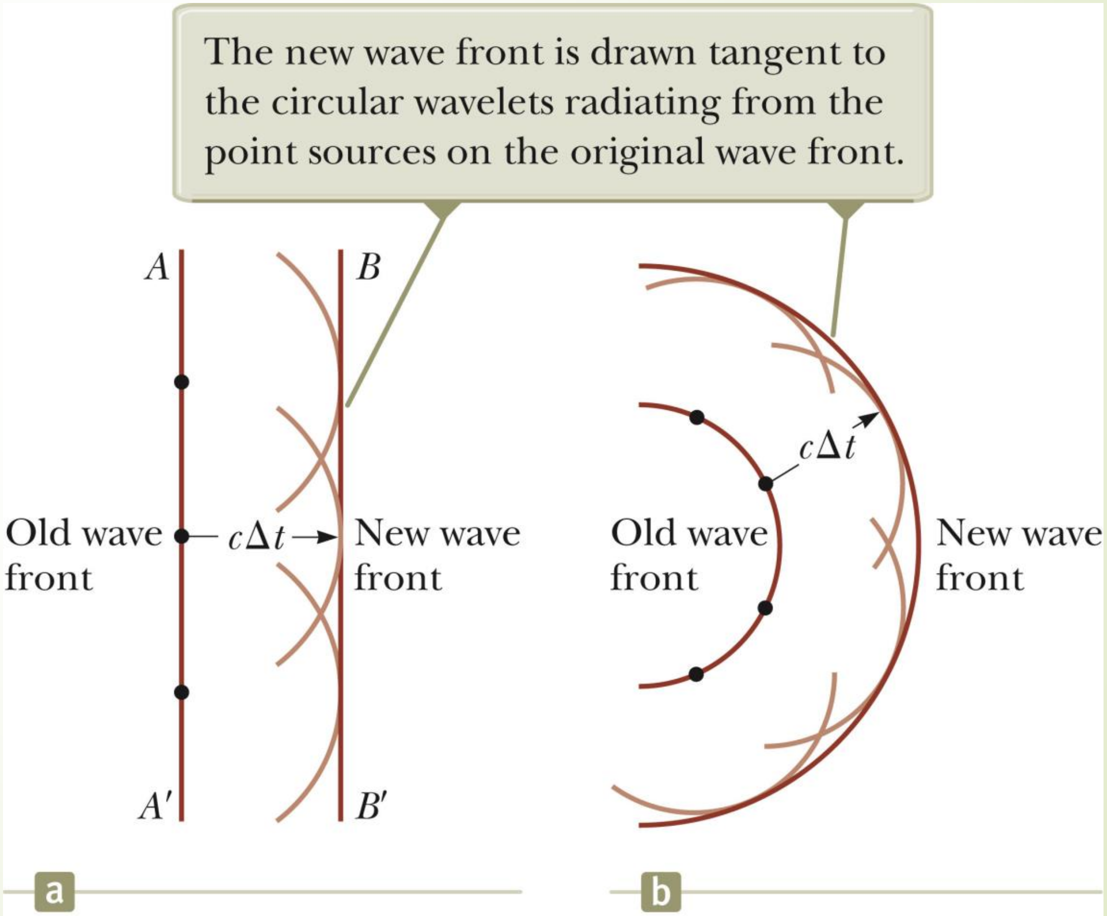
- All points on a given wave front are taken as point sources for the production of spherical secondary waves, called wavelets, which propagate outward through a medium with speeds characteristic of waves in that medium.



Huygens Principle (Cont.)

- After some time has passed, the new position of the wave front is the surface tangent to the wavelets.
- At t = 0, the wave front is indicated by the plane *AA*.’
- The points are representative sources for the wavelets.

After the wavelets have moved a distance *c*Δ*t*, a new plane *BB*’ can be drawn tangent to the wavefronts.



Huygens Principle(Cont.)

This theory is successful in explaining the phenomenon of reflection, refraction, interference.

❖Advantages and Disadvantages of Huygens Principle

➢Advantages:

Huygens's concept proved the reflection and refraction of light.

The concepts like diffraction of light, as well as interference of light, were proved by Huygens.

➢Disadvantage:

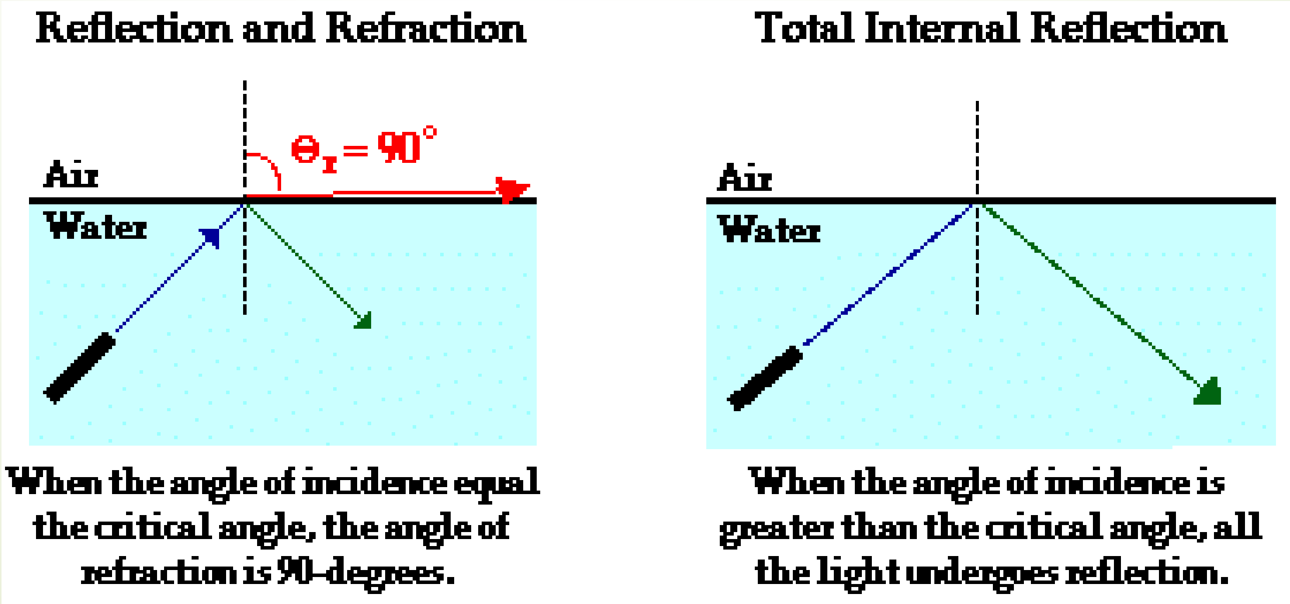
Concepts like emission of light, absorption of light and polarisation of light were not explained by Huygens principle.

Huygens principle failed to explain the photoelectric effect.

A serious drawback is that the theory proposes an all-pervading medium required to propagate light called luminiferous ether. This was proved to be false in the 20th century

Total Internal Reflection

Total internal reflection (TIR) is an optical phenomenon that occurs when light traveling from a medium with a higher refractive index to a medium with a lower refractive index strikes the interface between the two media at an angle of incidence greater than a specific angle called the critical angle. When the angle of incidence exceeds this critical angle, instead of refracting (bending) as it would under normal circumstances, the light is entirely reflected back into the higher refractive index medium

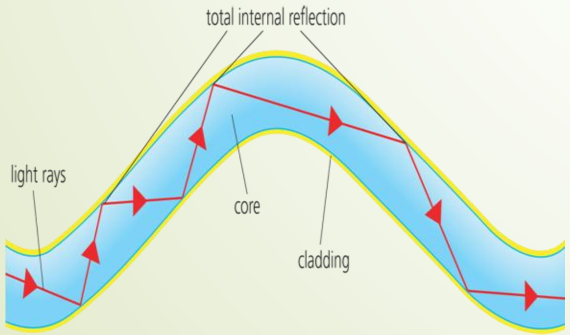


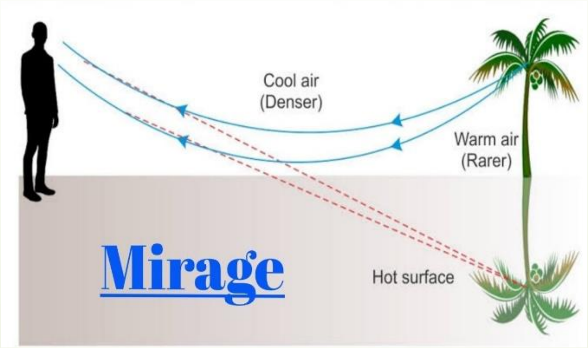
Total Internal Reflection(Cont.)

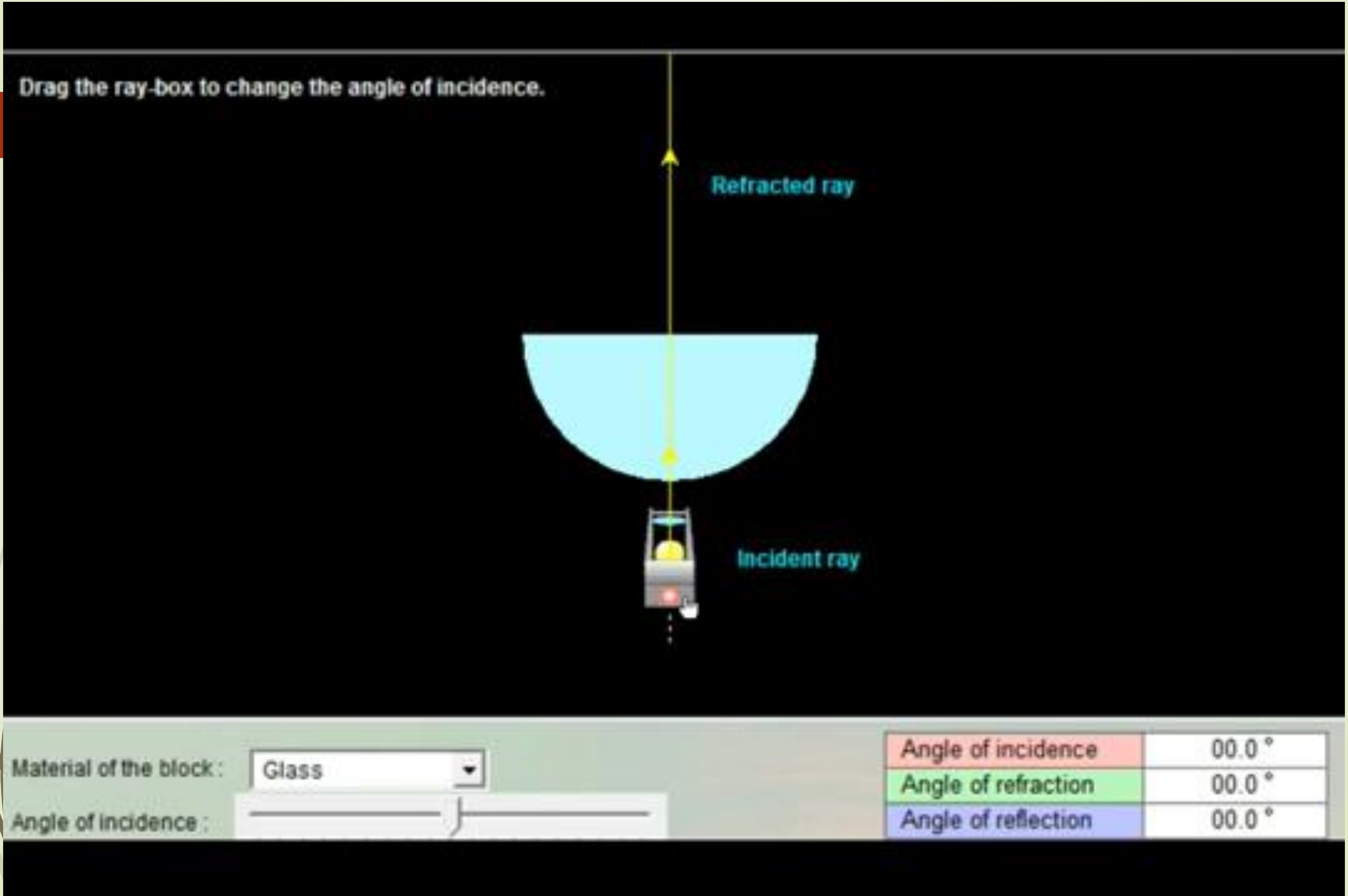
Condition for total internal reflection

- Light ray travel from an optically denser medium to a less dense medium.
- The angle of incidence must be greater than the critical angle.

Application of total internal reflection







Drag the ray-box to change the angle of incidence.
Refracted ray
Incident ray
Material of the block :
Glass
Angle of incidence :
Angle of incidence
00.0 °
Angle of refraction
00.0 °
Angle of reflection
00.0 °

Relation between critical angle and refractive index

Let a ray passes from denser medium to lighter medium. If angle of incidence is r and angle of refraction is r, then according to Snells law

$$\frac{\sin i}{\sin r} = \frac{\mu_r}{\mu_i}$$

$$\frac{\sin r}{\sin i} = \frac{\mu_i}{\mu_r} = a^{\mu_b}$$

Now, if i=θ_c , meaning if angle of incidence equals to critical angle then r=90

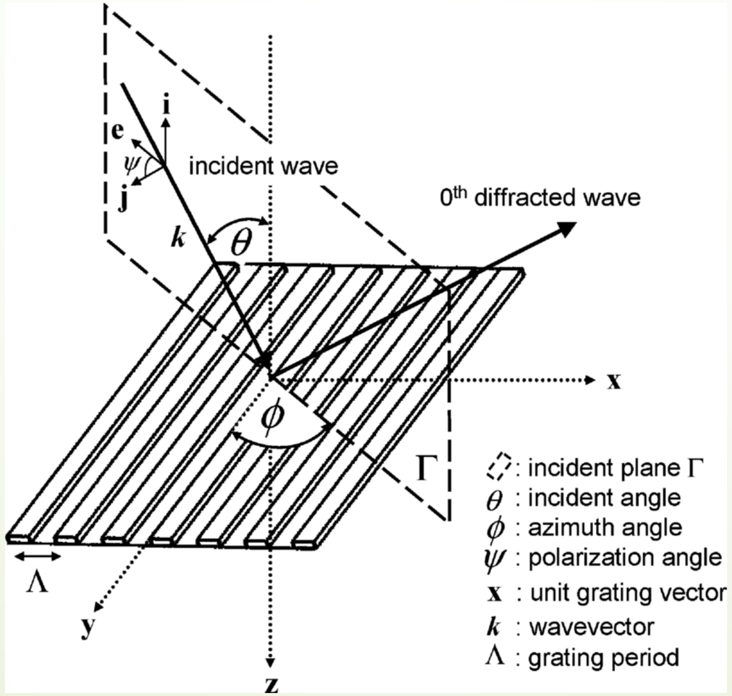
$$\text{So } \frac{\sin 90}{\sin \theta_c} = a^{\mu_b}$$

$$\frac{1}{\sin \theta_c} = a^{\mu_b}$$

$$\theta_c = sin^{-1}(\frac{1}{a^{\mu_b}})$$

❖ **Diffraction:**

Diffraction is the bending or spreading out of light waves as they encounter an obstacle or pass through an aperture (a narrow opening). It occurs when the size of the obstacle or aperture is comparable to or smaller than the wavelength of light. Diffraction can be observed when light waves encounter edges, corners, or small slits, and it causes the light to spread out into a pattern of bright and dark regions. Diffraction is a crucial phenomenon in fields such as optics, radio waves, and X-ray crystallography, where it is used to study the structure of materials and waves

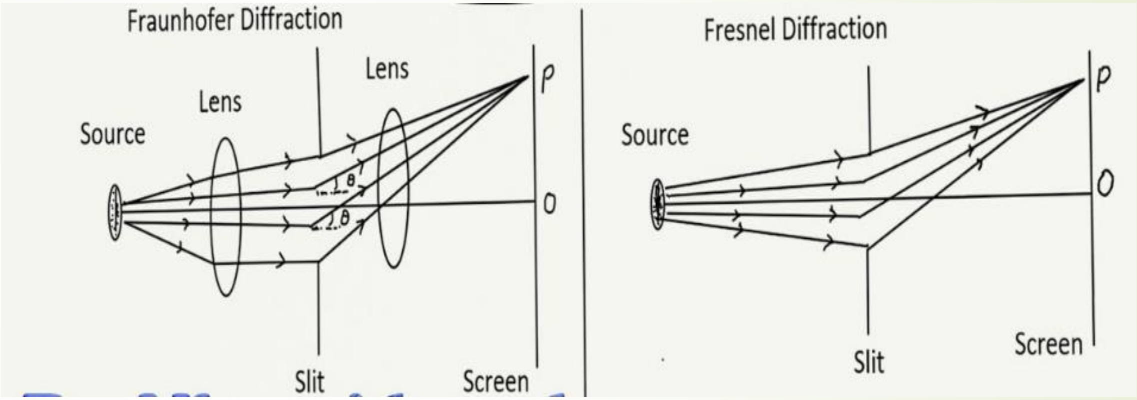


❖ Types of Diffraction

There are two types of diffraction

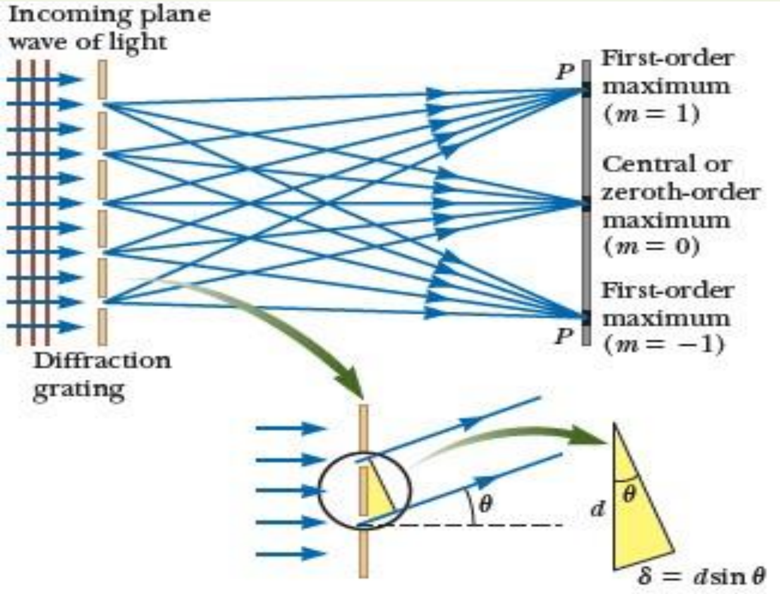
1. **Fresnel Diffraction:** Fresnel diffraction occurs when light from a point source meets an obstacle. The waves are spherical and the pattern observed is a fringed image of the object.

2. Fraunhofer Diffraction: Fraunhofer diffraction occurs with plane wave-fronts with the object situated at infinity. The pattern observed is a fringed image of the source and in a particular direction.



❖ The Diffraction Grating

- The **diffraction grating,** a useful device for analyzing light sources, consists of a large number of equally spaced parallel slits. The spaces between the grooves are transparent to the light and hence act as separate slits. Current technology can produce gratings that have very small slit spacings. For example, a typical grating ruled with 5 000 grooves/cm has a slit spacing $d = (1/5\,000)\ \text{cm} = 2.00 \times 10^{-4} cm$
- **The formula for diffraction grating is** $n\lambda = d \sin(\theta)$ where n = 1, 2, 3, …



Problem 08

At what angle will 638-nm light produce a second-order maximum when passing through a grating of 900 lines/cm?

Solution

$\lambda = 638 \text{ nm} = 6.38 \times 10^{-7} \text{ m}$ $\qquad d = \dfrac{1}{900 \text{ lines/cm}} = 1.11 \times 10^{-3} \text{ cm} = 1.11 \times 10^{-5} \text{ m}$

$m = 2$ $\qquad \theta = ?$

$$\sin\theta_m = \frac{m\lambda}{d} \quad \text{(for bright maxima)}$$

$$\sin\theta_2 = \frac{2(6.38 \times 10^{-7} \text{ m})}{1.11 \times 10^{-5} \text{ m}}$$

$$\sin\theta_2 = 1.15 \times 10^{-1}$$

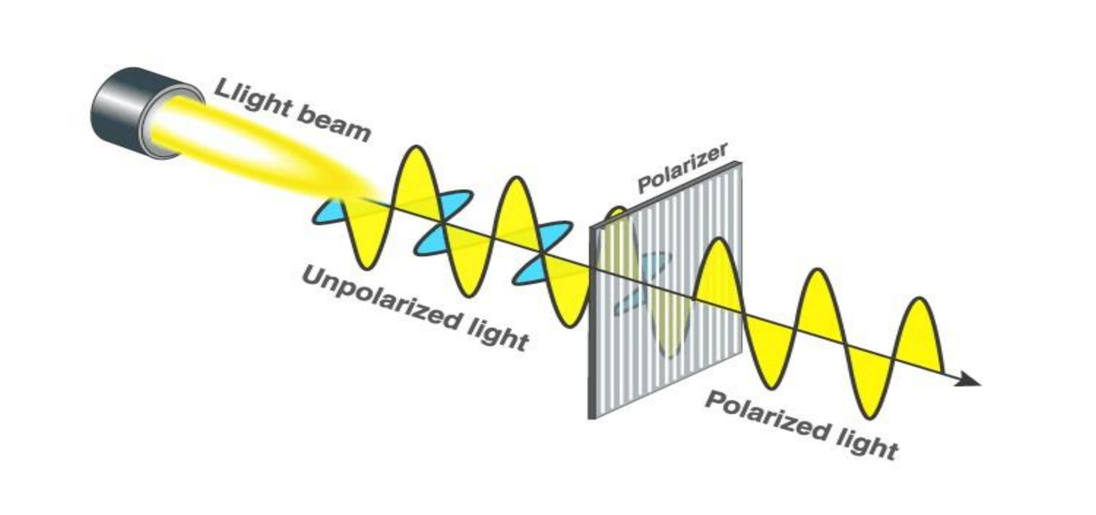
$$\theta_2 = 6.60°$$

The angle to the second maximum is 6.60°.

Polarization of Light Waves

❖ **Definition of Polarization**

The light wave in which the particles vibrate in all various planes is known as unpolarized light. Polarized light waves are light waves in which the vibrations occur in a single plane. Polarization is the process of converting non-polarized light into polarized light.



Unpolarized light

The light beam which has vibrations in more than one plane is called unpolarized light.

Polarization of Light Waves

Polarizer:

- A polarizer is device that transforms unpolarized light into polarized light.

Analyzer:

- An analyzer is a device which is used to identify the direction of vibration of linearly polarized light.

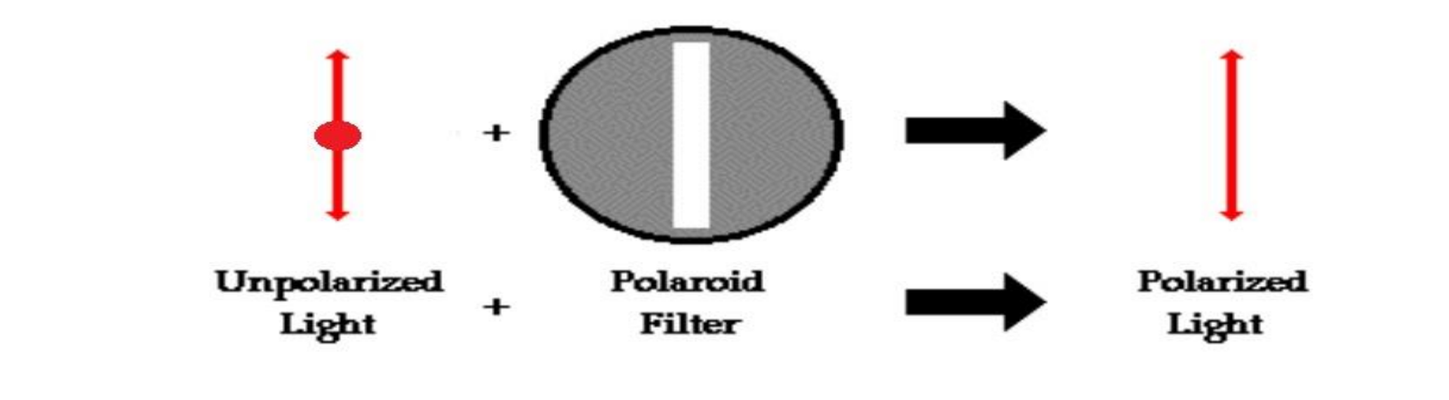
- Linear polarizers are prepared using birefringent crystals or dichroic crystals out of these Nicol crystal is widely used for linear polarizer.
- Polarizer sheets made using dichroism are known as polarized sheets.

Methods Used in the Polarization of Light

1. Polarization by Transmission (**Polarization by Use of a Polaroid Filter)**
2. Polarization by Reflection
3. Polarization by Refraction
4. Polarization by Scattering

1. Polarization by Transmission :

The most common method of polarization involves the use of a **Polaroid filter.** Polaroid filters are made of a special material that is capable of blocking one of the two planes of vibration of an electromagnetic wave.



2. Polarization by Reflection:

Unpolarized light can also undergo polarization by reflection off of nonmetallic surfaces. When an unpolarized light beam is reflected from a surface, the reflected light can be

- Completely polarized
- Partially polarized
- Unpolarized

It depends on the angle of incidence θ :

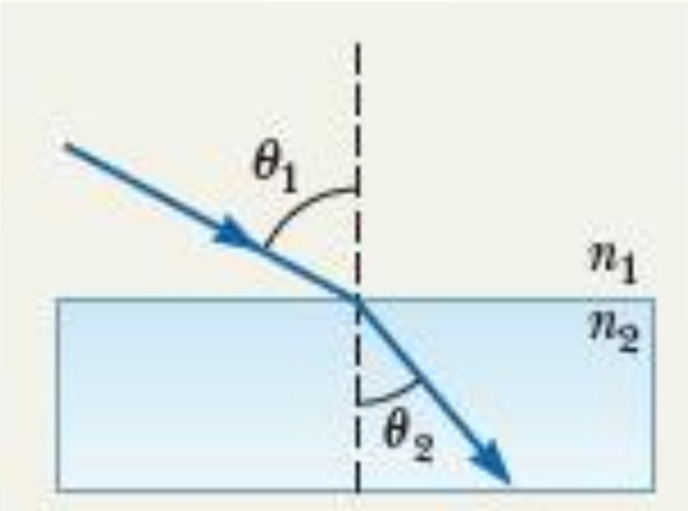
If $\theta = 0^\circ$, the reflected beam is unpolarized

For $0^\circ < \theta < 90^\circ$, there is some degree of polarization.

For one particular angle, the beam is completely polarized!

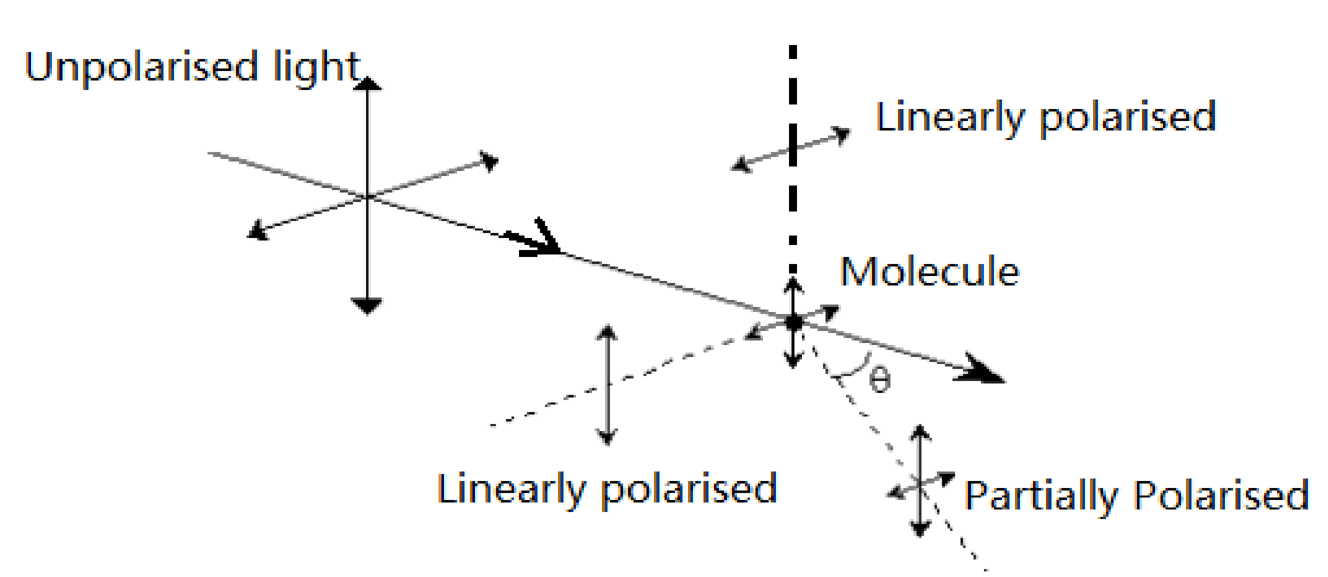
3. Polarization by Refraction:

Refraction is the bending of light as it passes from one transparent medium to another with a different optical density. This bending occurs because the speed of light changes when it moves from one medium to another, causing the light rays to change direction. The amount of bending depends on the angle of incidence and the refractive indices of the two materials involved. When light passes through a lens, for example, refraction is used to focus or diverge the light, enabling us to correct vision problems and create various optical instruments. In this process, the refracted beam attains some degree of polarization



4. Polarization by Scattering

When light travels through a medium, atoms of the medium vibrate and produce electromagnetic waves. These waves are radiated outwards and thus the light is scattered. In this entire process, absorption and remission of light waves occur throughout the material. The scattered light is also known as partially polarized. Transmission of these partially polarized lights causes glare.



Polarisation by Scattering

3^{rd} Week

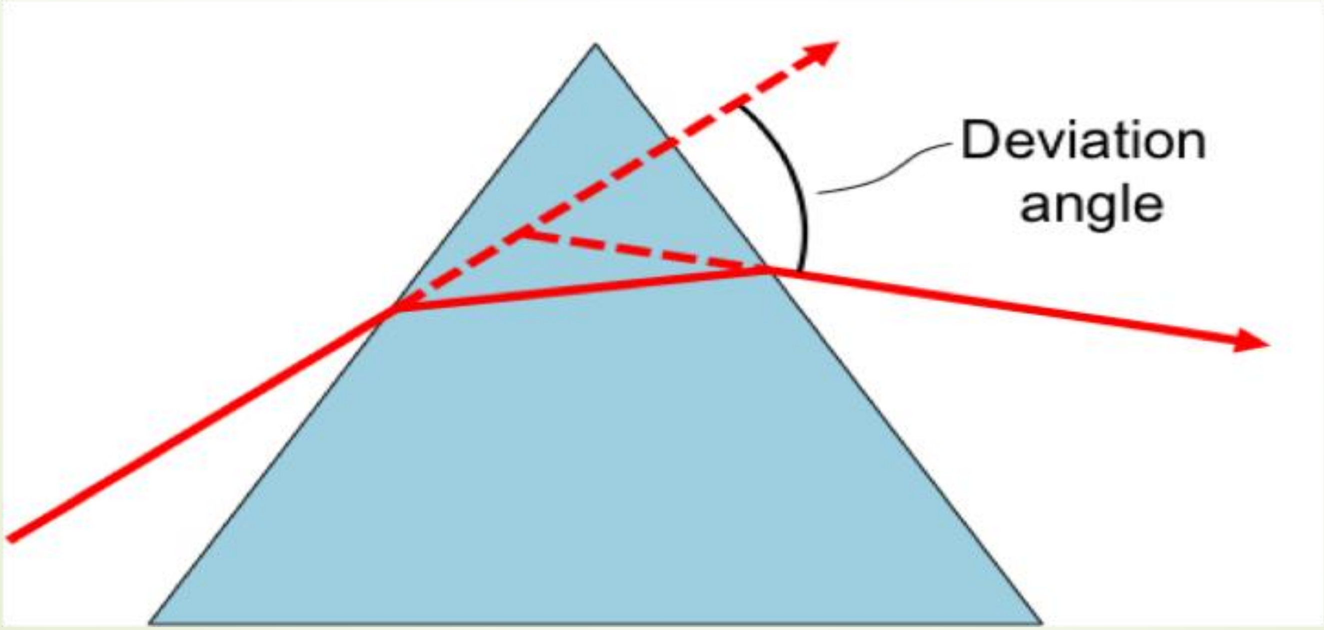
Topic: Optics- Interference of light, Newton's rings, Interferometers, Fresnel Bi-prism,

Topic Related Math

Page: 58- 95

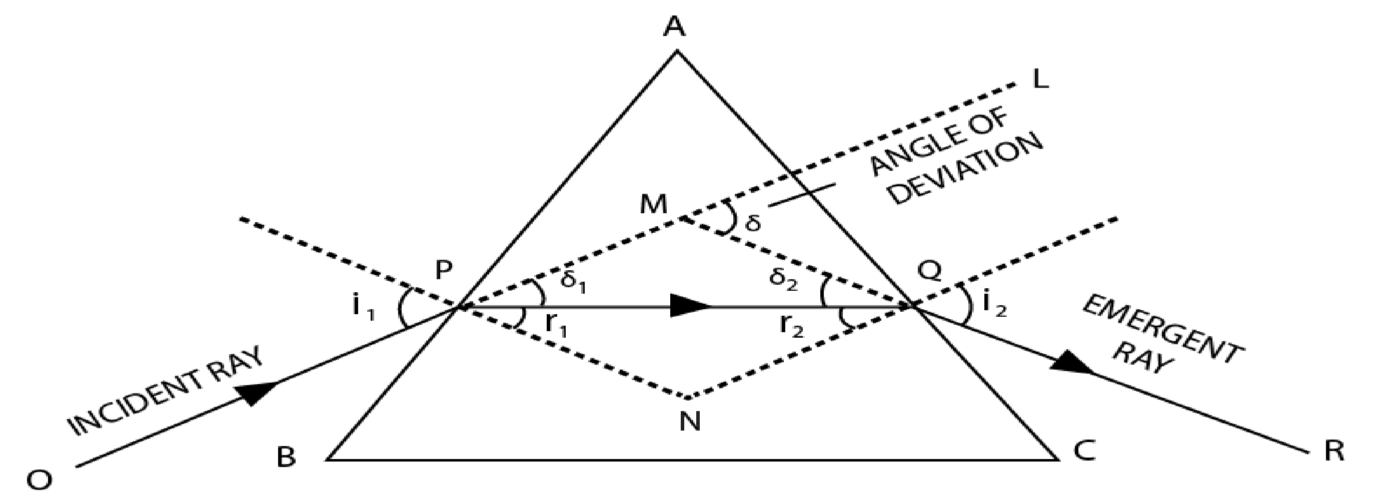
Angle of Deviation

The angle of deviation through a triangular prism is defined as the angle between the incident ray and the emerging ray (angle δ). When the angle of incidence (i) is equal to the angle of refraction (r) for the emerging ray, the angle of deviation is at a minimum.



Determination of angle of deviation

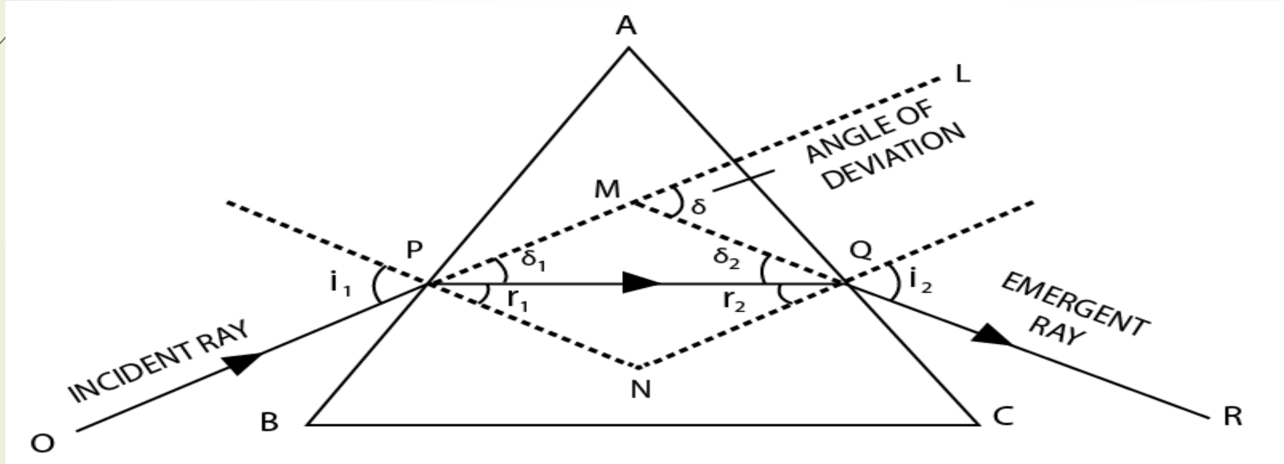
Let, principle of a prism the ABC, Refracting surfaces are AB &AC, base BC, Prism angle $\angle A$ and surrounding is air. Again, let OP ray incident on AB at P point and bends towards PN and exists on PQ path. PQ ray will hit AC on Q point and exit the prism while bending a way from QN in QR path. So, OPQR is the total path. Here, OP Incident ray, PQ refracted ray and QR exiting ray.



Determination of angle of deviation

Fig shows that, while exiting the prism, the ray bends towards base BC- in an angle. This angle is called Angle of deviation, Angle of deviation is denoted by δ or D.

Let, in AB plane, OP makes incident angle i_1 & refracting angle r_1, and in AC plane incident angle r_2 & refracting angle or exiting angle i_2. If OP is increased forward and QR is increased backwards then ∠LMR is created. So, ∠LMR= angle of deviation δ



So δ= ∠MPQ+∠MQP = $(i_1 - r_1) + (i_2 - r_2)$

So δ= $(i_1 - r_1) + (i_2 - r_2)$

$\delta = (i_1 + i_2) - (r_1 + r_2)$ ………. (1)

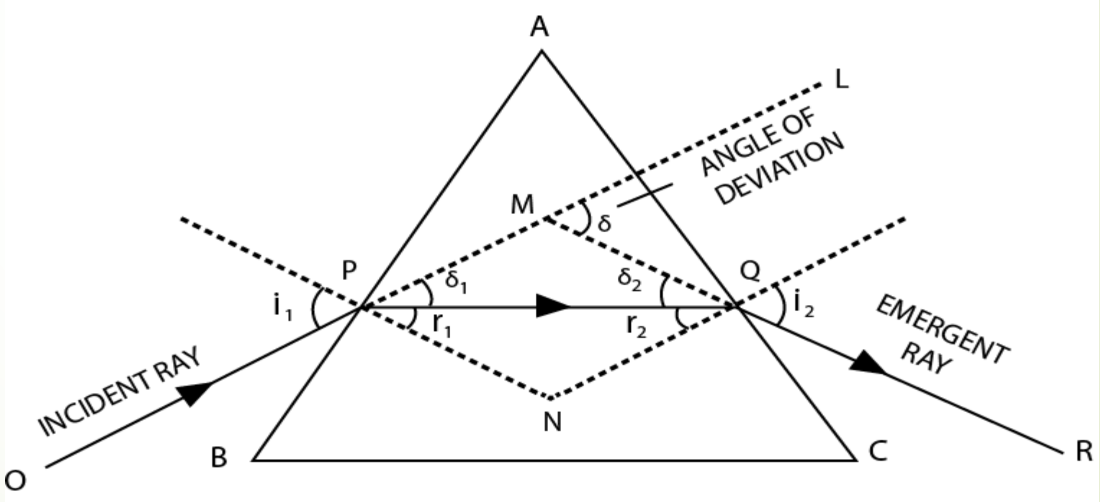
Determination of angle of deviation

We know, total of 4 angles of a rectangle is equal to 360° ,So APNQ,

$\angle A + \angle N + \angle APN + \angle NQA = 360°$

But, ∠APN and ∠NQA are right angle So, ∠APN+ ∠NQA=180°

∴ ∠A+∠N=180°………………. (2)



Again, from Triangle, ΔPQN

∠N+r_1+∠ r_2 =180°

∠N+ r_1+∠ r_2 =∠A+∠N

∠A=∠ r_1+∠ r_2

A = r_1+ r_2 ………………. (3)

Putting this value in Eq.1 we have

δ = (i_1+ i_2) - A …………………. (4)

This is the required expression for the Total angle of deviation

Minimum deviation

As a ray of light enters the transparent material, the ray's direction is deflected, based on both the entrance angle (typically measured relative to the perpendicular to the surface) and the material's refractive index, and according to Snell's Law. A beam passing through an object like a prism or water drop is deflected twice: once entering, and again when exiting. The sum of these two deflections is called the deviation angle. There is an angle of incidence at which the sum of the two deflections is a minimum. The deviation angle at this point is called the "minimum deviation" angle, or "angle of minimum deviation".

Refractive index of a prism for minimum deviation

Now applying the laws of refraction in the prism,

$$\mu = \frac{\sin i_1}{\sin r_1} \;\ldots\ldots\ldots\ldots\ldots\ldots\; (5)$$

For the angle of minimum deviation, $\delta = \delta_m; i_1 = i_2$ and $r_1 = r_2$

Putting, $r_1 = r_2$ in eq. (3) we can write,

$$A = r_1 + r_1$$

$$\therefore\; r_1 = \frac{A}{2}$$

Putting, $i_1 = i_2$ in eq. (4) we can write,

$$\Rightarrow \delta_m = (i_1 + i_1) - A$$

$$\Rightarrow \delta_m = 2i_1 - A$$

$$\therefore\; i_1 = \frac{\delta_m + A}{2}$$

Putting the value of i_1 and r_1 in eq. (5) we have,

$$\mu = \frac{\sin\frac{\delta_m + A}{2}}{\sin\frac{A}{2}}$$

This is the required expression for the refractive index of the prism.

Problem 01

The refractive index of an equilateral prism is $\sqrt{2}$. What is its angle of minimum deviation if the refracting angle of a prism is 58°.

Problem:02

Refractive index of glass is 1.5. If the speed of light in vacuum is 3×10^8 m/s, find velocity of light in medium.

Solution: Refractive index, $\mu = \frac{c}{v}$

$$\mu = \frac{\text{Velocity of light in vacuum}}{\text{Velocity of light in medium}}$$

$$\mu = \frac{c}{v}$$

$$\mu = \frac{3\times10^8}{1.5}$$

$$= 2 \times 10^8 \text{ m/s. (Ans.)}$$

Problem:03

If active index of water is 4/3 and that of glass is 3/2. Find the refractive index of glass with respect to water.

Solution: $\mu_w = 4/3, \quad \mu_g = 3/2$

Refractive index of glass w.r.t. water (${}^{w}\mu_g$) = $\frac{{}^{a}\mu_g}{{}^{a}\mu_w}$

$$= \frac{3/2}{4/3}$$

$$= 3/2 \times 3/4$$

$$= 9/8 \quad \text{(Ans.)}$$

Problem:04

Refracting angle of a prism is 58°,minimum angle of deviation 38°. What will be the refractive index of prism?

Solution: We know, refractive index

$$\mu = \frac{\sin\frac{\delta m + A}{2}}{\sin\frac{A}{2}} = \frac{Sin(\frac{58° + 38°}{2})}{Sin(\frac{58°}{2})} = \frac{Sin\ 48°}{Sin\ 29°} = \frac{0.743145}{0.484810} = 1.53$$

What will be the angle of refraction if ray incidences from water to diamond at 60° ?

Refractive index for water and Dimond are 1.34 and 2.4 respectively.

Problem:05

What will be the angle of refraction if ray incidences from water to diamond at 60° ? Refractive index for water and Dimond are 1.34 and 2.4 respectively.

$\Rightarrow \mu_w \text{Sin}\theta_w = \mu_d Sin\ \theta_d$

$\Rightarrow 1.34\ \text{Sin}60 = 2.4\ Sin\ \theta_d$

$\Rightarrow Sin\ \theta_d = \frac{1.34 \times 0.866}{2.4}$

$\Rightarrow\ \theta_d = \text{Sin}^{-1}(0.4835) = 28.91°$

Problem 06

The refractive angle of a prism is 60°. The refractive index is $\sqrt{2.2}$. What is its angle of minimum deviation?

Problem 07

A ray of light is incident on a medium of refractive index μ= 1.6 with an angle of incidence 45°. With what angle will it enter into the second medium?

Interference of Waves

What Is Interference Of Light?

Interference is a phenomenon that occurs when two or more waves meet or overlap in space and combine their amplitudes (peak heights) to create a new resultant wave. This interaction leads to constructive or destructive interference, depending on the phase relationship between the waves.

The phenomenon of two light waves superposing to create a new wave with a larger, smaller or the same amplitude is known as **interference of light** waves. Thomas Young discovered the phenomena of light interference in 1801 AD.

When two or more light rays of the same frequency, wavelength and amplitude collide in a medium, the effect is cancelled or enhanced. This is referred to as **interference of light** waves."

The concept of interference between two waves is quite straightforward. Furthermore, it is significantly simpler to calculate. To obtain the resultant wave, combine each point that appears in the same location on each wave. Interference effects are observed for many waves, including light, gravity waves, sound, matter and surface water waves.

Superposition of Wave

What happens when two or more light waves overlap in some region of space?

$$\frac{\partial^2\Psi}{\partial x^2} = \frac{1}{v^2}\frac{\partial^2\Psi}{\partial t^2}$$

Suppose ψ_i are the individual solutions of this wave equation, any linear combination of them will be a solution. Thus

$$\psi(\vec{r},t) = \sum_{i=1}^{n} C_i\psi_i\,(\vec{r},t)$$

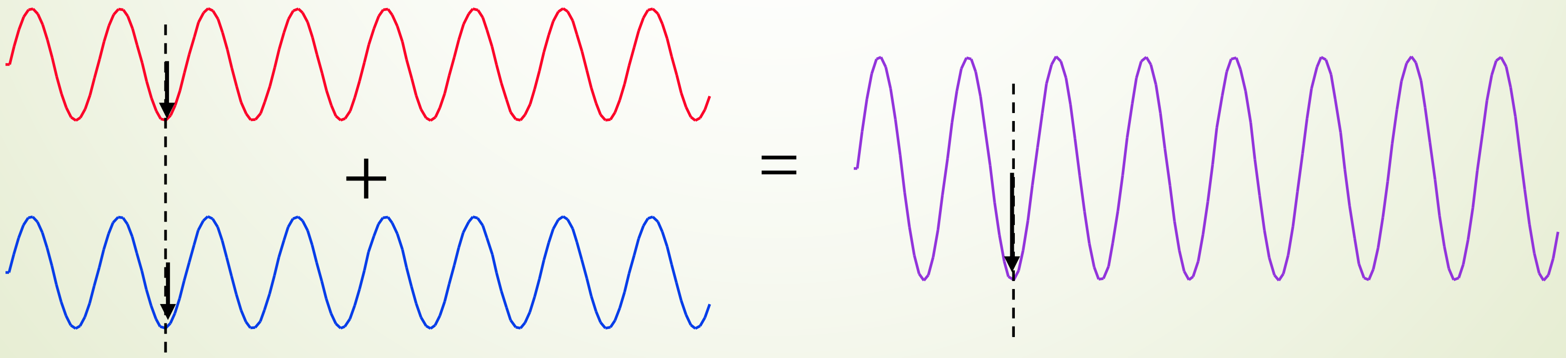
Satisfies the wave equation.

This property suggests that the resultant disturbance at any point in a medium is the algebraic sum of the separate constituent waves. This is the principle of superposition

Superposition of Wave

In general, when we combine two waves to form a composite wave, the composite wave is the algebraic sum of the two original waves, point by point in space [Superposition Principle].

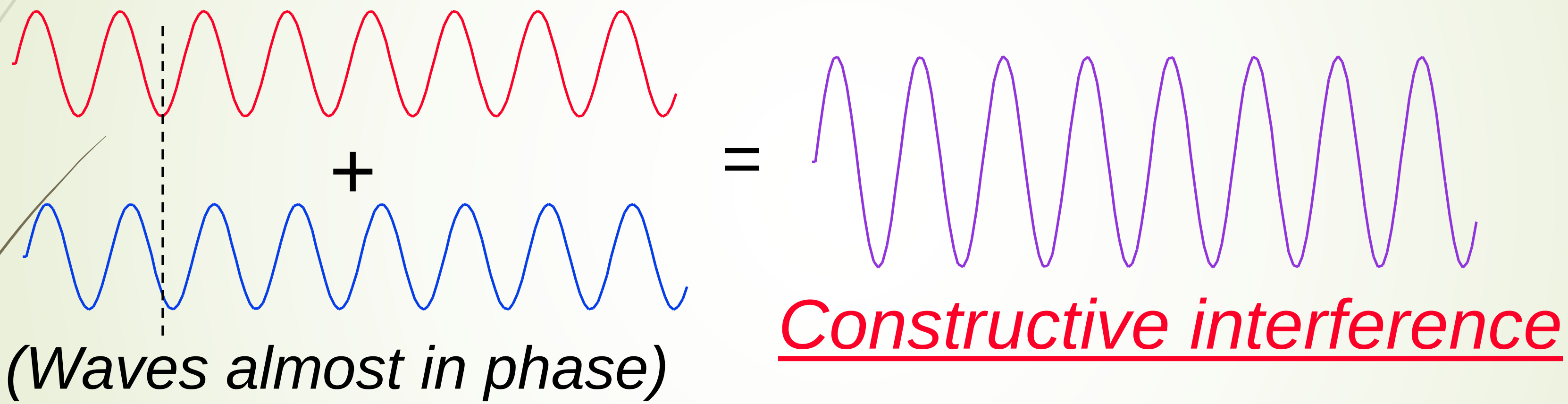
When we add the two waves we need to take into account their: Direction, Amplitude, Phase



Superposition of Wave

The combining of two waves to form a composite wave is called:

Interference

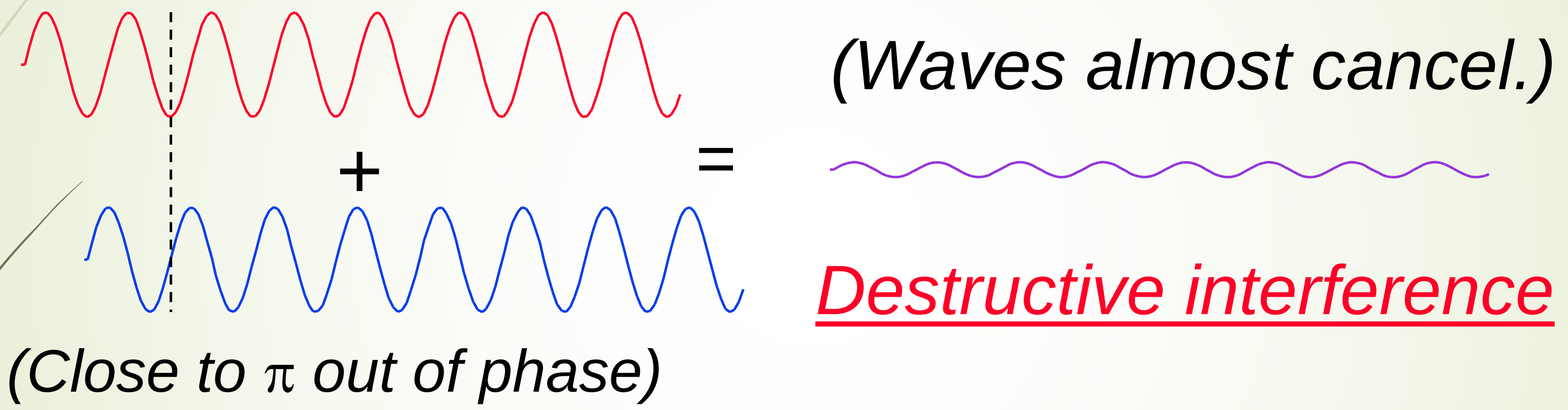


The interference is constructive
if the waves reinforce each other.

Superposition of Wave

The combining of two waves to form a composite wave is called:

Interference



Destructive interference

The interference is destructive
if the waves tend to cancel each other.

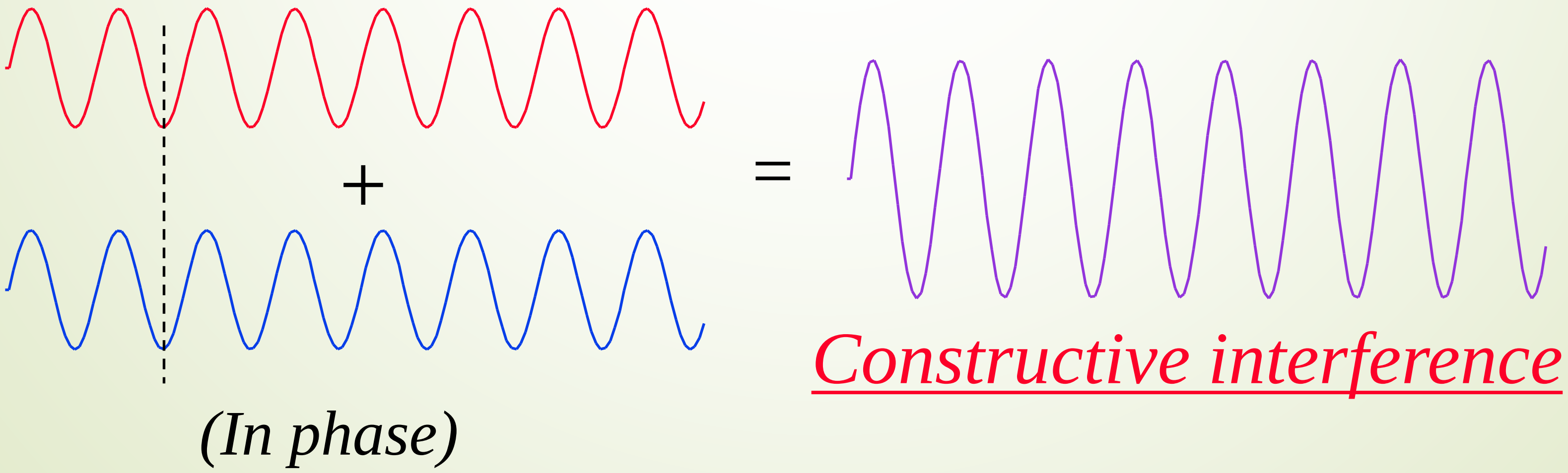
Types of Interference

1.Constructive Interference

This happens when two waves of light superpose on top of each other. When this happens, one wave's peak falls on the crest of another wave and the trough of another wave falls on its trough. This makes the resultant wave have more amplitude and intensity. This is referred to as constructive interference. **Constructive interference** occurs when the two waves are in phase, corresponding to $\phi = 0, 2\pi, 4\pi, \quad ...$ rad

Some of its consequences include:

- Two light waves reinforce one another in constructive interference.
- A bright fringe can be seen on the screen due to constructive interference.



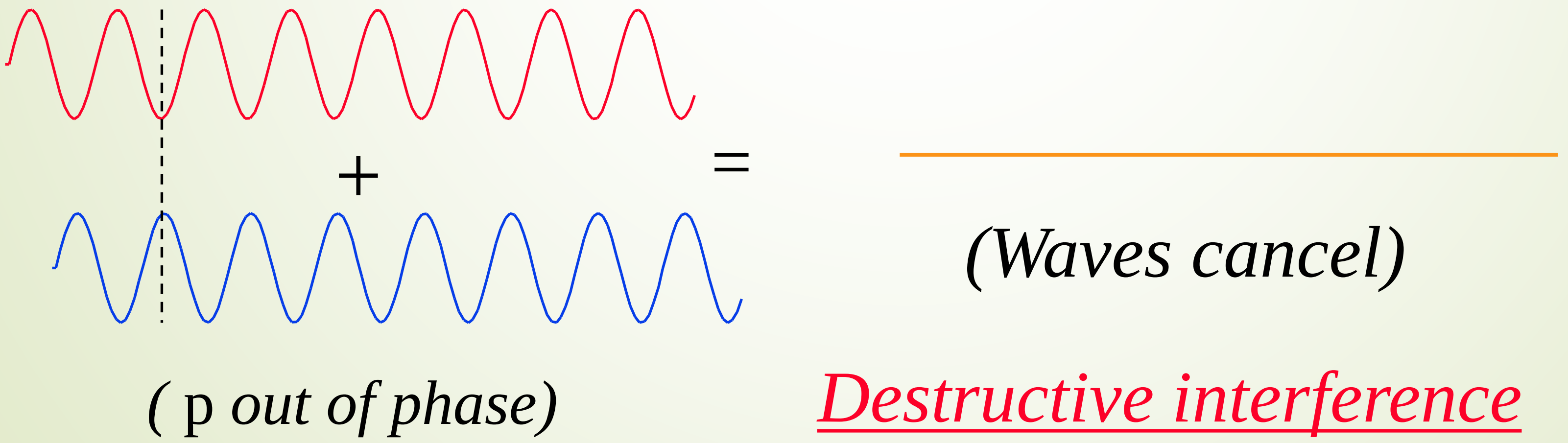
2.Destructive Interference

In case of destructive interference, whenever two light waves are superimposed so that their crests and troughs coincide, the resultant wave's amplitude and intensity is zero. **Destructive interference** occurs when the two waves are 180° out of phase, corresponding to $\phi = \pi, 3\pi, 5\pi, ...$ rad

Several of its consequences include the following:

•Two waves cancel out each other's effects.

•A dark fringe appears on the screen as a result of this



Destructive interference

❖ **Conditions for the interference of light waves:**

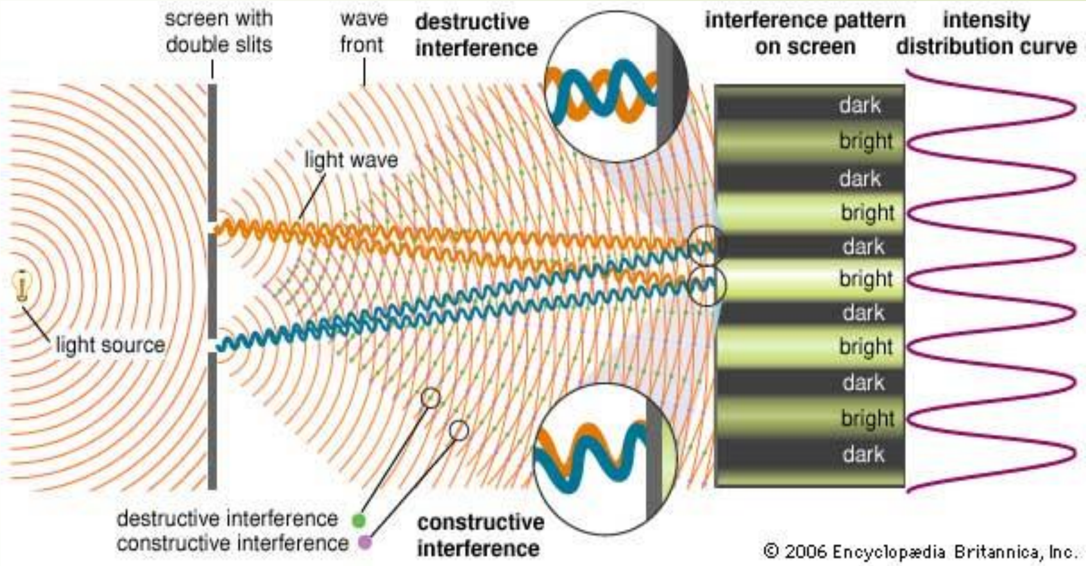
1. **Coherent Sources**:
    1. For sustained interference, the two sources of light must be coherent.
    2. Coherent sources emit waves with the same frequency and a constant phase difference.
2. **Nearly Equal Amplitudes and Intensities:**

    The amplitudes of the two waves should be equal or nearly equal..
3. **Small Sources:**
    1. The two sources should be very fine and small.
    2. Small sources help create well-defined interference patterns.
4. **Near Sources**:

The two sources should be close to each other.

5. Monochromatic Sources:

1. The waves should be monochromatic, meaning they have a single wavelength.



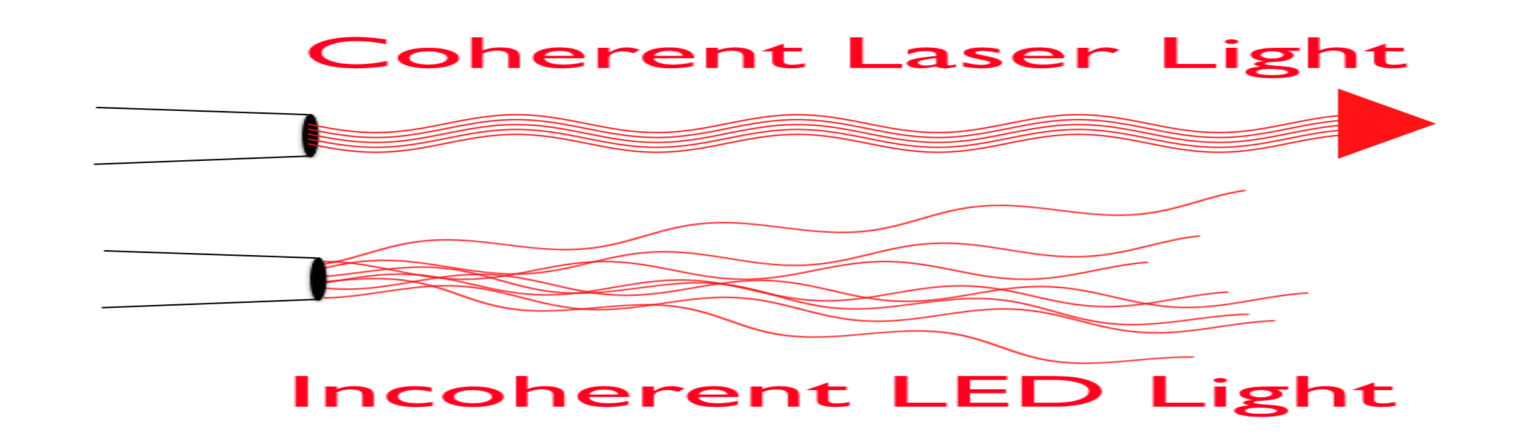
Coherent Source:

Two sources are said to be coherent if they have exactly **same frequency**, and have zero or constant phase difference.

In physics, two wave sources are perfectly coherent if they have a **constant phase** difference and the same frequency, and the same waveform.

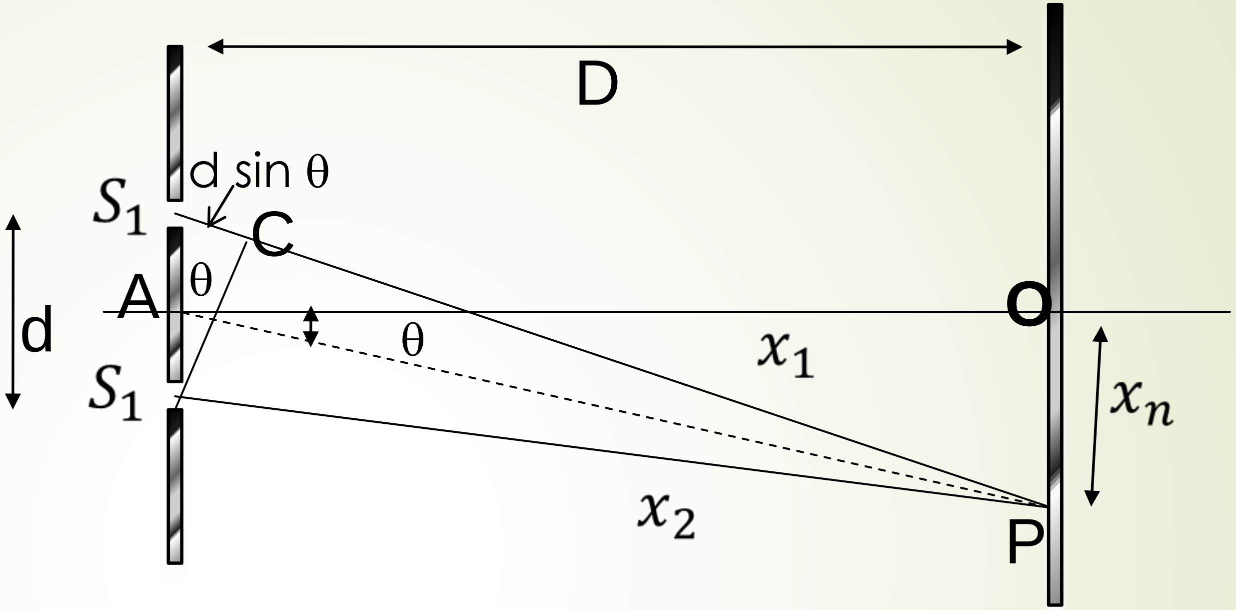
If two (or more) waves maintain a **constant phase difference over a long distance and time, then they are said to be coherent.**

Most of the light sources around us - lamp, sun, candle etc. are combination of multitude of incoherent sources of light. Laser is a coherent source i.e. constituent multiple sources inside the laser are phase-locked.



Interference of Waves (Young's Double- Slit Experiment)

Consider two progressive waves of amplitude *a* and wavelength λ travelling at same velocity *v* in same direction and after some time they meet at same point. If the displacement of two waves after time *t* become y_1 and y_2, then



$$y_1 = a sin \frac{2\pi}{\lambda}(vt - x_1)$$

$$y_2 = a sin \frac{2\pi}{\lambda}(vt - x_2)$$

Here the distance travelled by two waves are x_1 and x_2. After superposition, consider the resultant displacement become *y*, so we get

Interference of Waves (Young's Double-Slit Experiment)

$$y = y_1 + y_2 = a sin\frac{2\pi}{\lambda}(vt - x_1) + a sin\frac{2\pi}{\lambda}(vt - x_2)$$

$$= a\left[sin\frac{2\pi}{\lambda}(vt - x_1) + sin\frac{2\pi}{\lambda}(vt - x_2)\right]$$

$$= 2a\left[sin\frac{2\pi}{\lambda}\left(\frac{vt - x_1 + vt - x_2}{2}\right).cos\frac{2\pi}{\lambda}\left(\frac{vt - x_1 - vt + x_2}{2}\right)\right]$$

$$= 2a cos\frac{2\pi}{\lambda}\left(\frac{x_2 - x_1}{2}\right) sin\frac{2\pi}{\lambda}\left(vt - \frac{x_1 + x_2}{2}\right)$$

$$\mathrm{Y} = A sin\frac{2\pi}{\lambda}\left(vt - \frac{x_1 + x_2}{2}\right)$$

Consider amplitude of two interfered waves is: $A = 2a cos\frac{2\pi}{\lambda}\left(\frac{x_2 - x_1}{2}\right)$

Relation between phase difference and path difference

$$y_1 = a\sin\frac{2\pi}{\lambda}(vt - x_1) \;\&\; y_2 = a\sin\frac{2\pi}{\lambda}(vt - x_2)$$

Phase angle at P for $S_1 and\ S_2$ are $\frac{2\pi}{\lambda}(vt - x_1)$ and $\frac{2\pi}{\lambda}(vt - x_2)$ Respectively.

At point P phase difference $\delta = \frac{2\pi}{\lambda}(vt - x_1) - \frac{2\pi}{\lambda}(vt - x_2)$

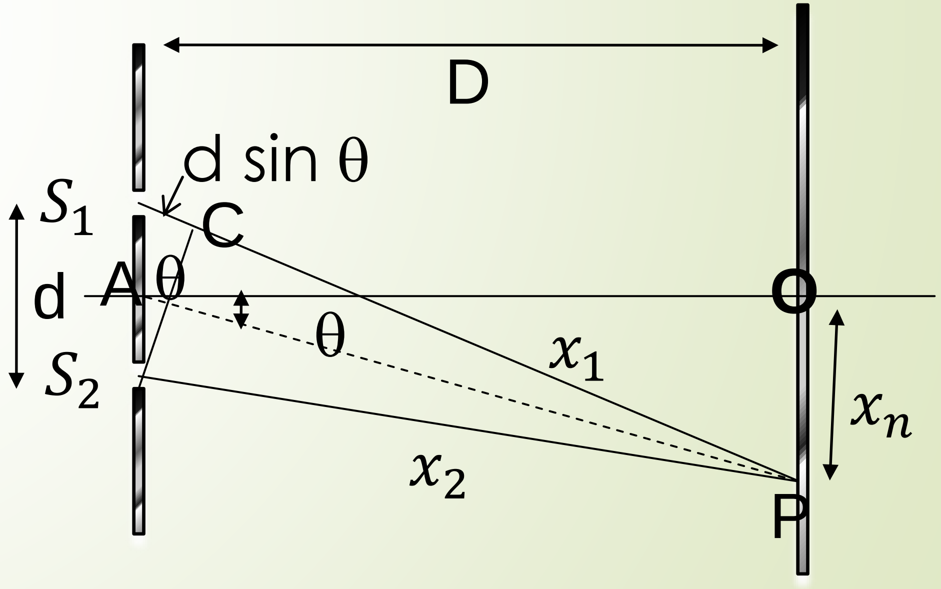
$\Rightarrow \delta = \frac{2\pi}{\lambda}(x_1 - x_2)$

$\Rightarrow \delta = \frac{2\pi}{\lambda}(S_1P - S_2P)$

$\Rightarrow \delta = \frac{2\pi}{\lambda} \times$ Path difference

Therefore, The phase difference $\Rightarrow \delta = \frac{2\pi}{\lambda} \times$ Path difference

$$\therefore \delta = \frac{2\pi}{\lambda} \times \Delta x$$



Interference of Waves(Cont.)

Condition for constructive interference:

$$cos\frac{2\pi}{\lambda}\left(\frac{x_2 - x_1}{2}\right) = \pm 1$$

$$or, \frac{\pi}{\lambda}(x_2 - x_1) = 0, \pi, 2\pi, 4\pi \ldots\ldots\ldots\ldots\ldots n\pi;$$

$$where\ n = 0, 1, 2, 3 \ldots\ldots\ is\ even\ and\ integer$$

$$or, (x_2 - x_1) = 0, \lambda, 2\lambda, 3\lambda \ldots\ldots\ldots\ldots n\lambda$$

$$or, (x_2 - x_1) = 0, \frac{2\lambda}{2}, \frac{4\lambda}{2}, \frac{6\lambda}{2} \ldots\ldots\ldots\ldots 2n\frac{\lambda}{2}$$

When the path difference become even multiplication of $\frac{\lambda}{2}$ then at these points the interference may constructive.

Interference of Waves(Cont.)

Condition for destructive interference:

$$cos\frac{2\pi}{\lambda}\left(\frac{x_2 - x_1}{2}\right) = 0$$

$$or, \frac{\pi}{\lambda}(x_2 - x_1) \quad = \quad \frac{\pi}{2}, \frac{3\pi}{2}, \frac{5\pi}{2} \dots \dots \dots \dots \dots \dots;$$

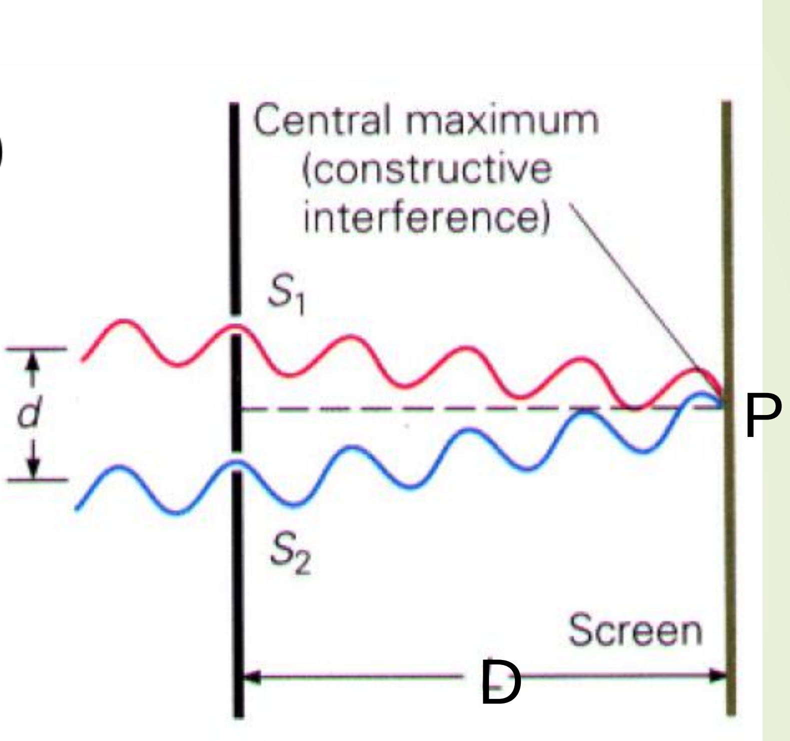
$$where\ n = 0, 1, 2, 3 \dots \dots\ is\ odd\ and\ integer$$

$$or, (x_2 - x_1) \quad = \quad \frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2} \dots \dots \dots \dots \dots \dots (2n+1)\frac{\lambda}{2}$$

When the path difference become odd multiplication of $\frac{\lambda}{2}$ then at these points the interference may destructive.

Interference of Waves(Cont.)

Path difference for central maxima is $(S_1P - S_2P) = n\lambda = 0$ i.e. $(S_1P = S_2P)$ $= 0 \times \lambda$ (n = 0)

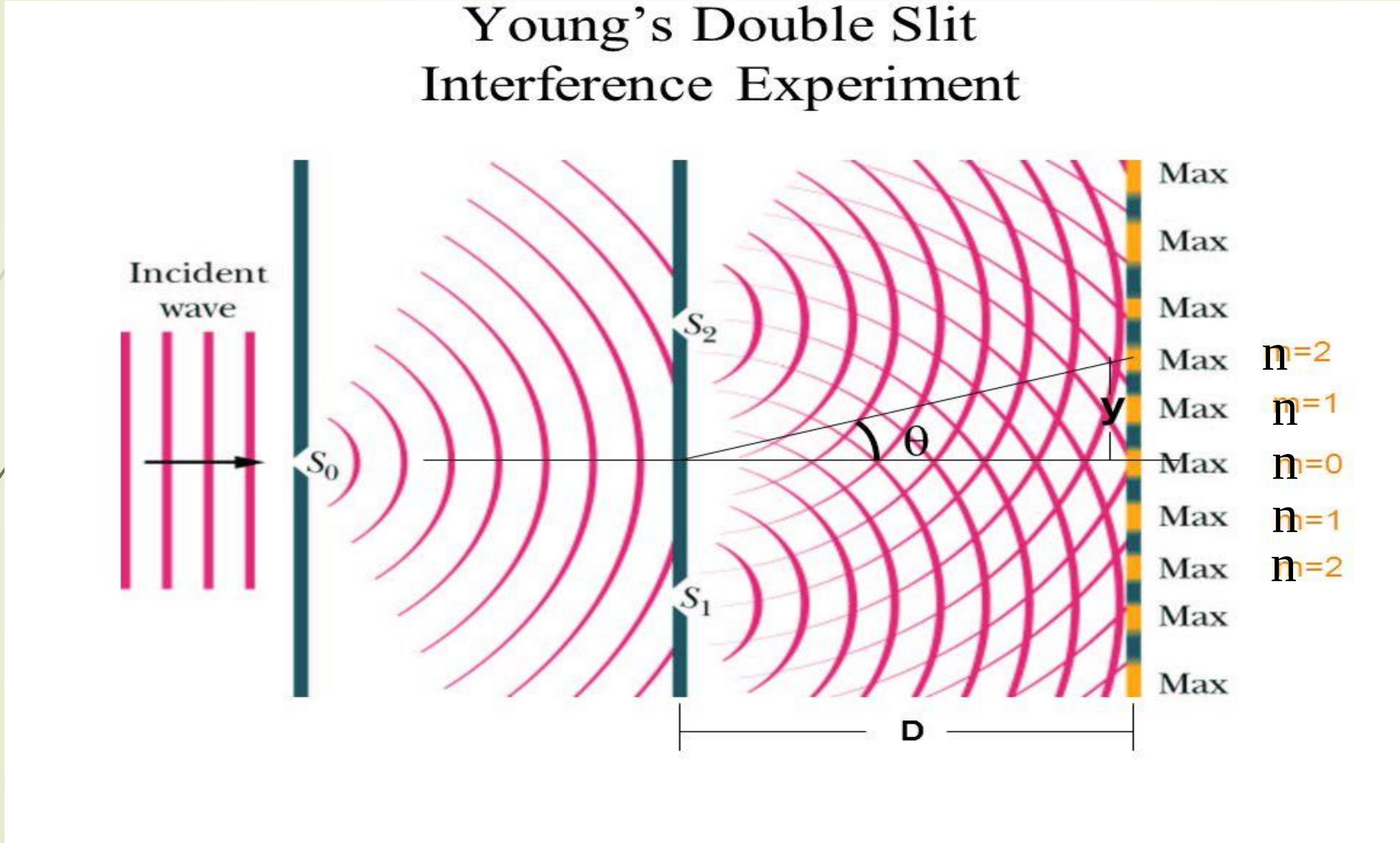


If two waves go through the slit and then proceed straight ahead to the screen, they both cover the SAME DISTANCE and thus will have constructive interference. Their amplitudes will build and leave a very bright intense spot on the screen. We call this the **CENTRAL MAXIMUM**.

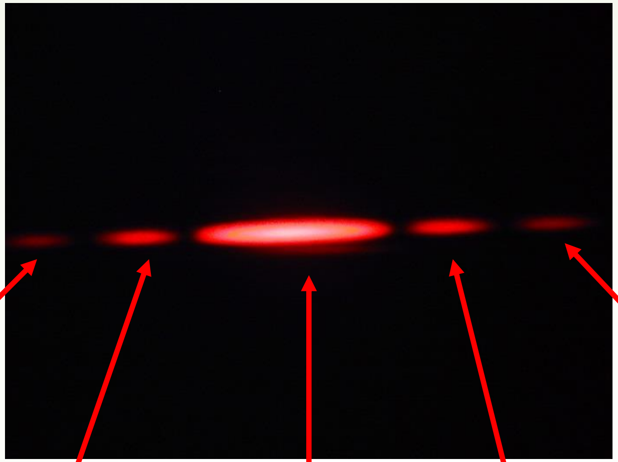
So for Bright fringe path difference is dsinθ =n λ

And for dark fringe path difference is dsinθ $= (2n + 1)\frac{\lambda}{2}$

Young's Double-Slit Experiment



Bright fringes



We use the letter, **n**, to represent the ORDER of the fringe from the bright central.

Second Order Bright Fringe n = 2

First Order Bright Fringe n = 1

Central Maximum

First Order Bright Fringe n = 1

Second Order Bright Fringe n = 2

It is important to understand that we see these bright fringes as a result of CONSTRUCTIVE INTERFERENCE.

Dark Fringes

First Order Dark Fringe n = 1

ZERO Order Dark Fringe n = 0

Central Maximum

ZERO Order Dark Fringe n = 0

First Order Dark Fringe n = 1

It is important to understand that we see these dark fringes as a result of DESTRUCTIVE INTERFERENCE.

Fringe separation and fringe width

Fringe separation means the distance between two consecutive bright or dark stripes on a screen. Now we will determine the fringe separation produced due to interference. Suppose, S_1 and S_2 are two coherent sources of the same colour. The distance between them is d. Again suppose, the distance of the screen from S_1 and S_2 is D. The point O on the screen is equidistant from S_1 and S_2 As the path difference from the sources to point O is zero so the intensity of resultant wave at point O will be maximum. This is called the central maxima or central extreme point.

The distance S_1C = S_1P- S_2P= Path Difference

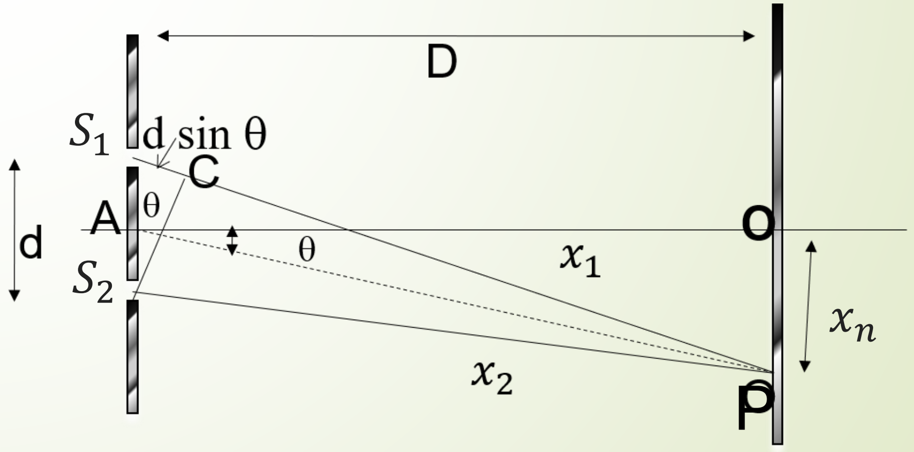
The distance from O to nth numbers of fringe at P is x_n .

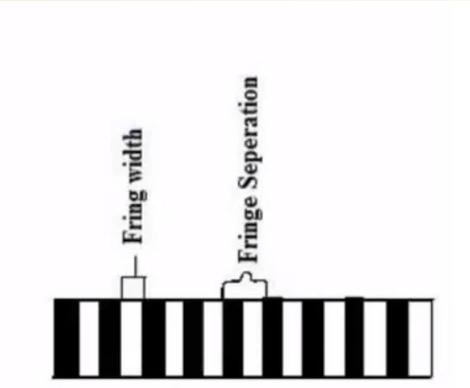
Thus path difference $\boldsymbol{S_1}$**C = n$\boldsymbol{\lambda}$**

i.e. For constructive interference

And $\boldsymbol{S_1}$**C = (2n+1)$\boldsymbol{\frac{\lambda}{2}}$**

i.e. For destructive interference





Now for the triangle of $\Delta S_1 S_2 C$

$$\sin\theta = \frac{S_1C}{S_1S_2} = \frac{S_1C}{d}$$

$\therefore S_1C = d\sin\theta$ ————————(1)

For constructive interference at point P path difference = **n𝝀**

Therefore $d\sin\theta$ = **n𝝀-------(2)**

n= 0,1,2….

Again for the triangle of ΔPAO

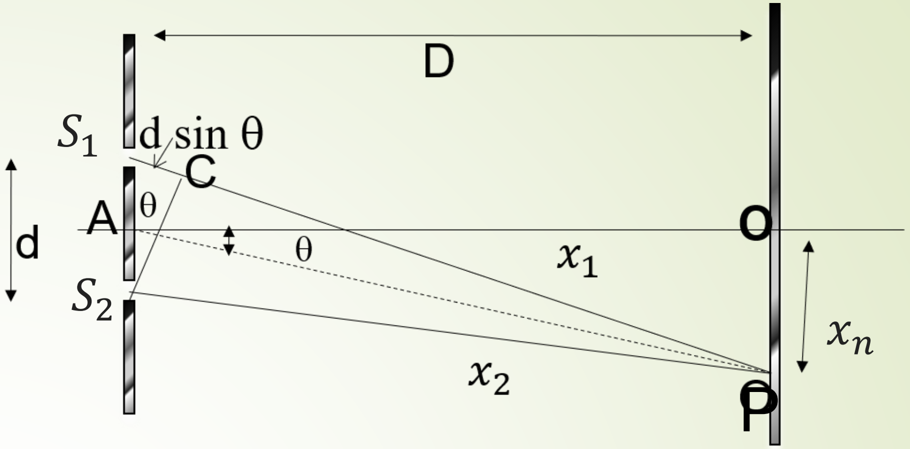
$\therefore \tan\theta = \frac{OP}{OA} = \frac{x_n}{D}$ **----------(3)**

For small angle of θ , tanθ = sinθ

Then we can write from equation(2) &(3)

$$\therefore n\lambda = \frac{dx_n}{D}$$

Therefore, $x_n = \frac{n\lambda D}{d}$



Again The distance from O to (n-1)th numbers of fringe is x_{n-1}

x_{n-1} = **(n-1)** $\frac{\lambda D}{d}$.

Then the separation of two bright fringe is

$\beta = x_n - x_{n-1}$

$\Rightarrow \beta = n\frac{\lambda D}{d}$ - **(n-1)** $\frac{\lambda D}{d}$ = (n-n-1) $\frac{\lambda D}{d}$

$$\therefore \beta = \frac{\lambda D}{d}$$

Fringe width, can be calculated as-

$$\therefore \Delta\beta = \frac{\lambda D}{2d}$$

Problem -01

In young's experiment. The two slits are 0.04 mm a part, and the screen is located 2 m away from the slits. The third bright fringes from the center is displaced 8.3 cm from the center fringes.

A) Determine the wavelength of the incident light

Solution

a) For the third fringes n =3 ,d = 0.04mm D = 2m, x_n = 8.3 cm

$$x_n = n\frac{\lambda D}{d}$$

$$l = \frac{x_n\, d}{nD} = \frac{8.3 \text{ x } 10^{-2} \text{x } 4 \text{ x} 10^{-5}}{3 \times 2}$$

l =5.53 x 10^{-7} m = 553 nm

Problem 02:

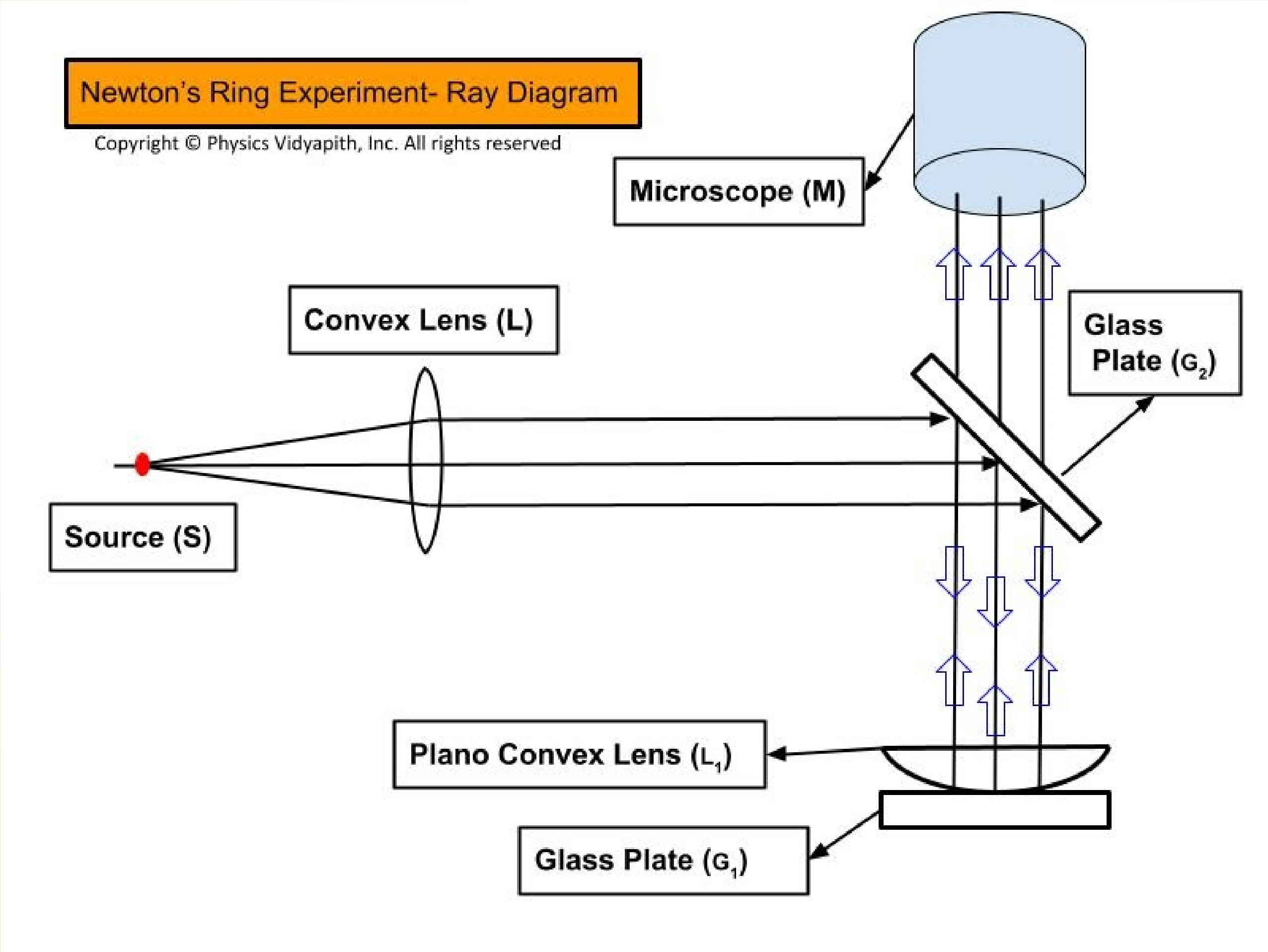
In Young double slit experiment the distance between two slits is 2 mm. The separation between two fringes at a distance 1 m from the slit is found to be 0.295 mm. Find the wavelength of light.

Problem 03:

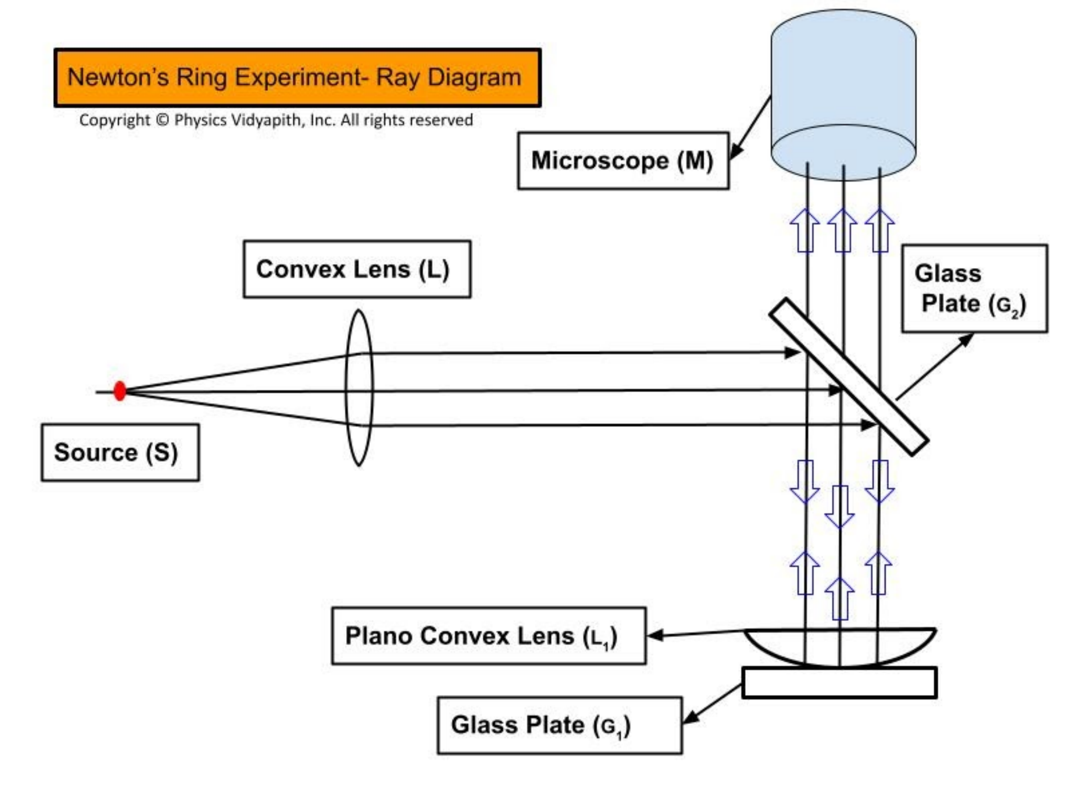
Interference fringes are produced on a screen kept at 1m away from two slits 0.4 mm apart. The wavelength of the light used is 5000×10^{-10}m. Find the fringe width of a dark fringe.

❖ Newton's Rings

Newton's Rings refer to a fascinating interference phenomenon created by the reflection of light between two surfaces: typically a spherical surface (such as a convex lens) and an adjacent flat surface. Let's explore the intriguing details:



❖Formation of Newton's Rings:



When a beam of monochromatic light (light of a single color or wavelength) is directed onto the thin air wedge between the lens and the flat surface, some of the light is reflected back and some passes through. The light waves reflect off both the top and bottom surfaces of the air wedge and interfere with each other. The interference between the reflected waves produces a series of bright and dark concentric rings. The center of the rings corresponds to the point of contact between the lens and the flat surface. For constructive interference (bright rings), the condition is that the extra path traveled by the reflected light (due to the air wedge) is an integral multiple of the wavelength of light. For destructive interference (dark rings), the extra path is a half-integral multiple of the wavelength.

4^{th} Week

Topic: Optics- Brewster's Law, Malus law, Topic Related Math’s

Topic Related Math

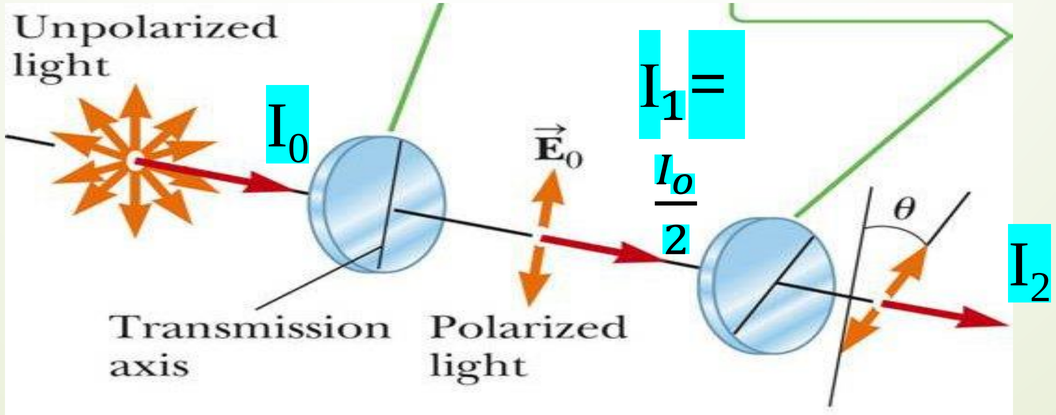
Page: 95- 106

Malus's law

When natural (unpolarized) light is incident on a polarizer, the transmitted light is linearly polarized. If this light further passes through an analyzer, the intensity varies with the angle between the transmission axes of the polarizer and analyzer.

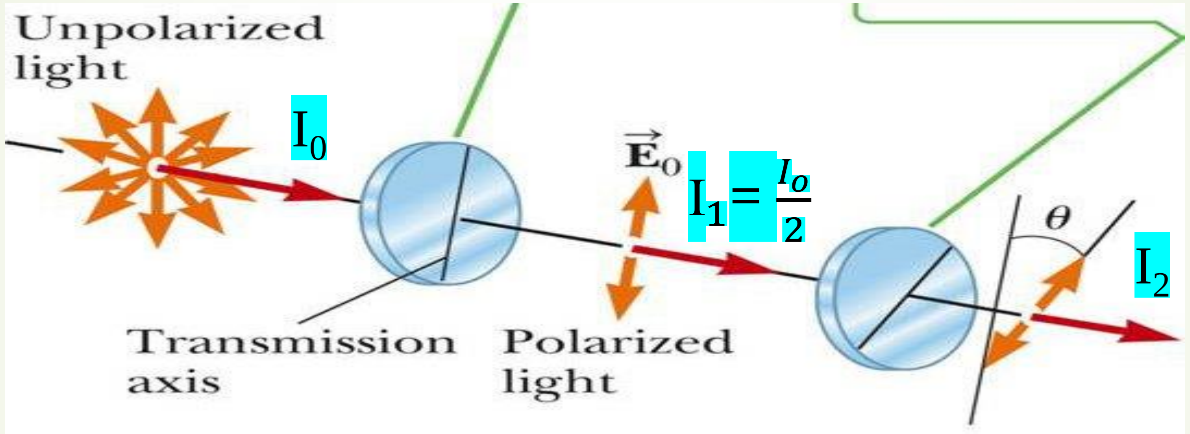
According to Malus, when completely plane polarized light is incident on the analyzer, the intensity I_2 of the light transmitted by the analyzer is directly proportional to the square of the cosine of angle between the polarizer and the analyzer

$$I_2 \propto \cos^2\theta$$



Malus's law

Suppose the angle between the transmission axes of the analyzer and the polarizer is θ. The completely plane polarized light form the polarizer is incident on the analyzer.



If unpolarized light of intensity I_0 is incident on a polarization, plane polarized light of intensity $\frac{I_0}{2}$ is transmitted by it. Let us denote $\frac{I_0}{2}$ by I_1. E_o is the amplitude of the electric vector transmitted by the polarizer, then intensity I_1 of the light incident on the analyzer is,

$I_1 \infty E_o^2$

$$I_1 = K E_o^2 \quad \ldots\ldots\ldots\ldots\ldots(1)$$

Malus's law (Cont.)

The electric field vector E_0 can be resolved into two rectangular components i.e $E_o \cos\theta$ and $E_o \sin\theta$. The analyzer will transmit only the component (i.e $E_o \cos\theta$) which is parallel to its transmission axis. However, the component $E_o\sin\theta$ will be absorbed by the analyzer.

Therefore, the intensity I_2 of light transmitted by the analyzer is,

$I_2 \propto (E_o \cos\theta)^2$ or, $I_2 = K (E_o \cos\theta)^2$ …………..(2)

Now from eq.(1) and eq.(2) we get

$I_2 / I_1 = K (E_o \cos\theta)^2 / K E_o^2$

$I_2 = I_1 \cos^2\theta$, Therefore we can write $I_2 = \frac{I_0}{2} \cos^2\theta$

$I_2 \propto \cos^2\theta$

This equation is known as Malus's law.

Malus’s law (Cont.)

Case I: When $\theta = 0°$ (or 180°), $I_2 = I_1 \cos^2 0° = I_1$

That is the intensity of light transmitted by the analyzer is maximum when the transmission axes of the analyzer and the polarizer are parallel.

Case II: When $\theta = 90°$, $I_2 = I_1 \cos^2 90° = 0$

That is the intensity of light transmitted by the analyzer is minimum when the transmission axes of the analyzer and polarizer are perpendicular to each other.

❖ What is Bragg's Law?

Brag's Law states the following:

When the X-ray is incident onto a crystal surface, its angle of incidence, θ, will reflect with the same angle of scattering, θ. And, when the path difference, d is equal to a whole number, n, of wavelength, λ,

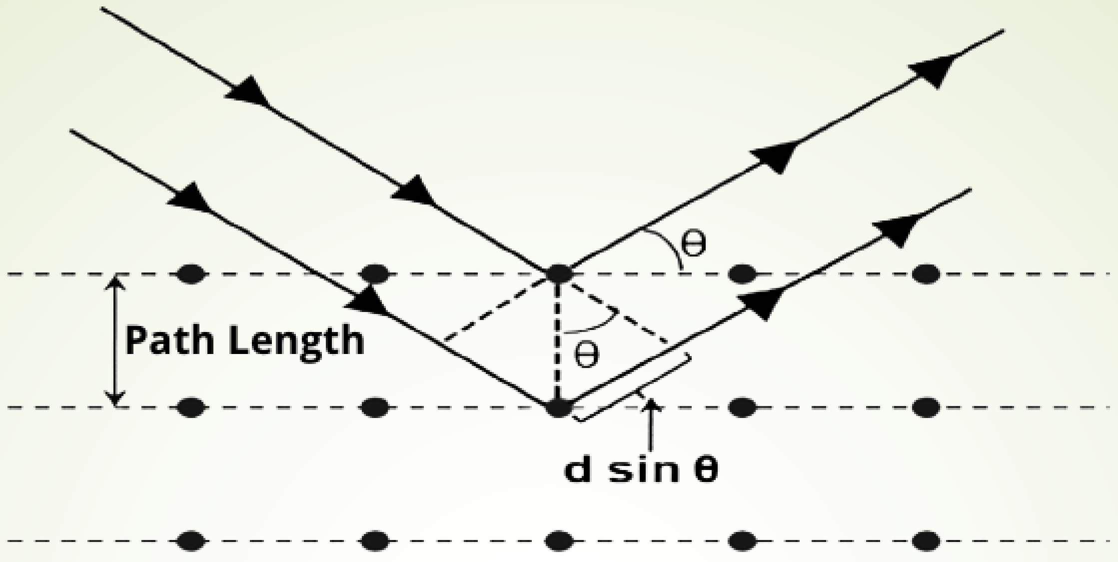
$$n\lambda = 2d\sin\theta$$

Also, constructive interference occurs under the condition that the path difference is equal to the whole number n of the wavelength.

❖ Bragg's Law Derivation

Consider a crystal that has parallel planes of ions that are spaced at a distance d apart. The conditions for a sharp peak in the intensity of the scattered radiations are as follows:

- The x-rays should be reflected by the ions in any one of the planes.
- The reflected rays that come out from the crystal's successive planes should interfere constructively



- ➢ The path difference is the phase shift. The constructive interference occurs when: $\Delta = n\lambda$

From the diagram, we can write sinθ = xd and

x=dsinθ

These criteria give the condition for constructive interference.

That is $n\lambda = 2dsin\theta$ is the expression for Bragg's law.

Bragg's law tells the angle at which the maximum diffraction intensity can occur.

❖ Brewster's Law:

The angle of incidence for which the reflected beam is completely polarized is called the *polarizing angle*, θ_p

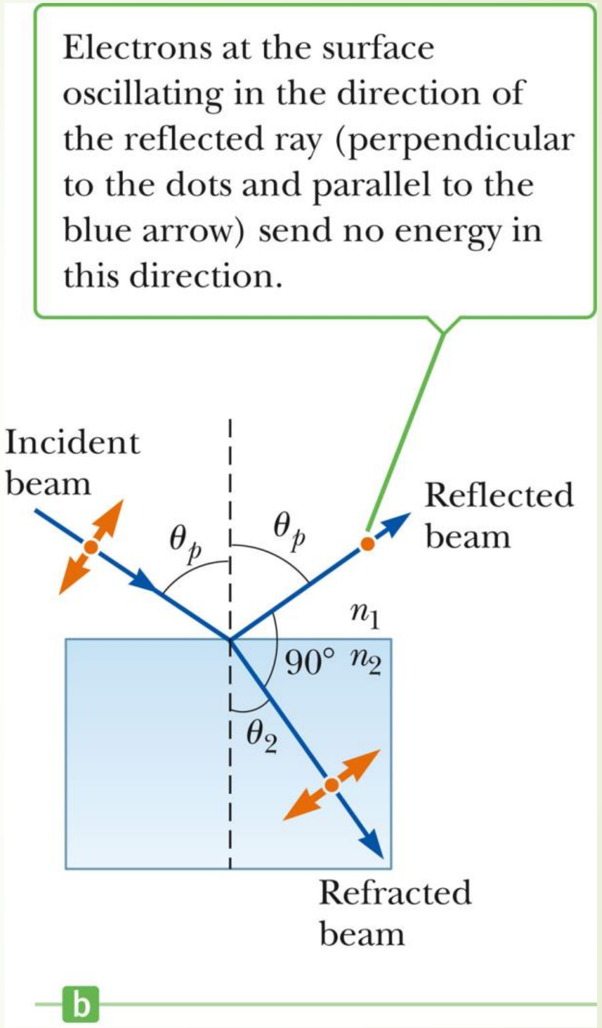
The polarizing angle θ_p is when the reflected and refracted rays are 90° from each other, i.e. when $\theta_p + \theta_2 = 90°$.

Or, $\theta_2 = 90° - \theta_p$

According to the law of refraction,

$$\mu = \frac{\sin\theta_p}{\sin\theta_2}$$

$$or, \qquad \mu = \frac{\sin\theta_p}{\sin(90° - \theta_p)}$$



$$\mu = \frac{\text{Sin } \theta_p}{\sin\,(90^\circ - \theta_p)}$$

$$or, \qquad \mu = \frac{\sin\theta_p}{\cos\theta_p}$$

$$\therefore\ \mu = \tan\theta_p$$

This equation is known as Brewster's Law

Problem 08:

Example: A beam of light strikes the surface of a plate of glass with a refractive index of √3 at the polarizing angle. What will be the ray's angle of refraction?

Solution:

The angle of incidence is considered to be the polarizing angle,

Refractive Index, $\mu = \tan i_P = \sqrt{3}$

$i_P = 60°$

The angle of refraction,

$r = 90° - i_P$

$\Rightarrow r = 90° - 60°$

$\Rightarrow r = 30°$

Hence, the angle of refraction is 30°.

Problem 09:

A light ray with 60° angle is incident on the reflection plane of diamond and the refraction angle in diamond is found to be 12°. Determine the polarization angle of diamond.

Answer:

Angle of incident , i = 60°

Angle of refraction , r = 12°

Polarizing angle of diamond , θ_p = ?

Therefore , Refractive index of diamond,

$$\mu = \frac{\text{Sin i}}{\text{Sin r}} = \frac{\text{Sin } 60^\circ}{\text{Sin} 12^\circ} = 4.165$$

Again

$$\mu = tan\,\theta_p$$

$$\theta_p = tan^{-1}(\mu) = tan^{-1}(4.165) = 76.5^\circ$$

Problem 10: A beam of polarized light is incident on a polarizing sheet. The light is initially linearly polarized in a vertical direction, and the polarizing sheet is oriented at an angle of 30 degrees to the vertical. Calculate the intensity of the light transmitted through the polarizing sheet.

Problem 11: A beam of linearly polarized light is incident on a polarizing sheet. The initial intensity of the light is I_0. If the polarizing sheet is oriented at an angle of 45 degrees to the vertical, calculate the intensity of the light transmitted through the sheet.

Ans: $I_0/2$

Problem 12: A beam of linearly polarized light is incident on a polarizing sheet with an intensity of 100 mW/cm^2. The polarizing sheet is oriented at an angle of 60 degrees to the direction of polarization of the light. Calculate the intensity of the light transmitted through the sheet

Problem 13: A ray of light is incident on a glass surface at an angle of 45 degrees with the normal to the surface. The refractive index of glass is 1.5. Calculate the Brewster's angle for this situation and determine the polarization of the reflected light

5^{th} Week

Topic: Optics- Snell law, LASER, Topic Related Mathematics

Topic Related Math

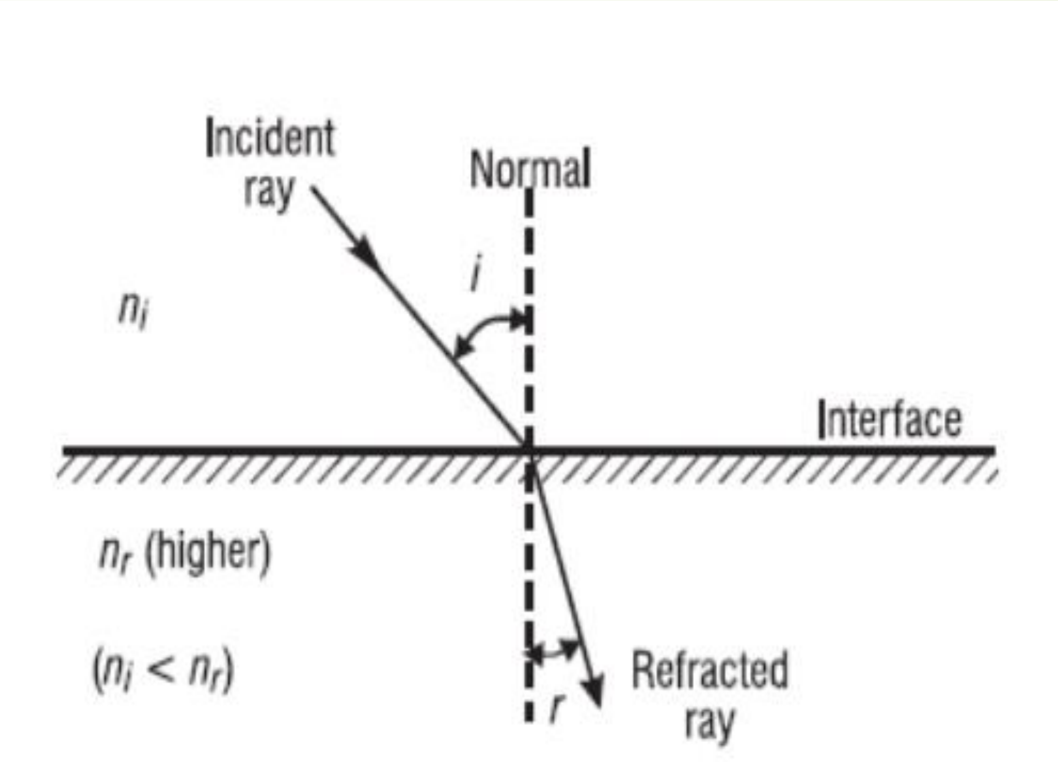
Page: 107- 116

Snell's law

The Snell's Law, also known as the law of refraction, describes how light changes direction when it passes from one medium into another with a different refractive index

For two given media, the ratio between sin i and sin r is constant.

$$\frac{\sin i}{\sin r} = \frac{\mu_r}{\mu_i} = constant$$



where i is the angle of incidence

R is the angle of refraction

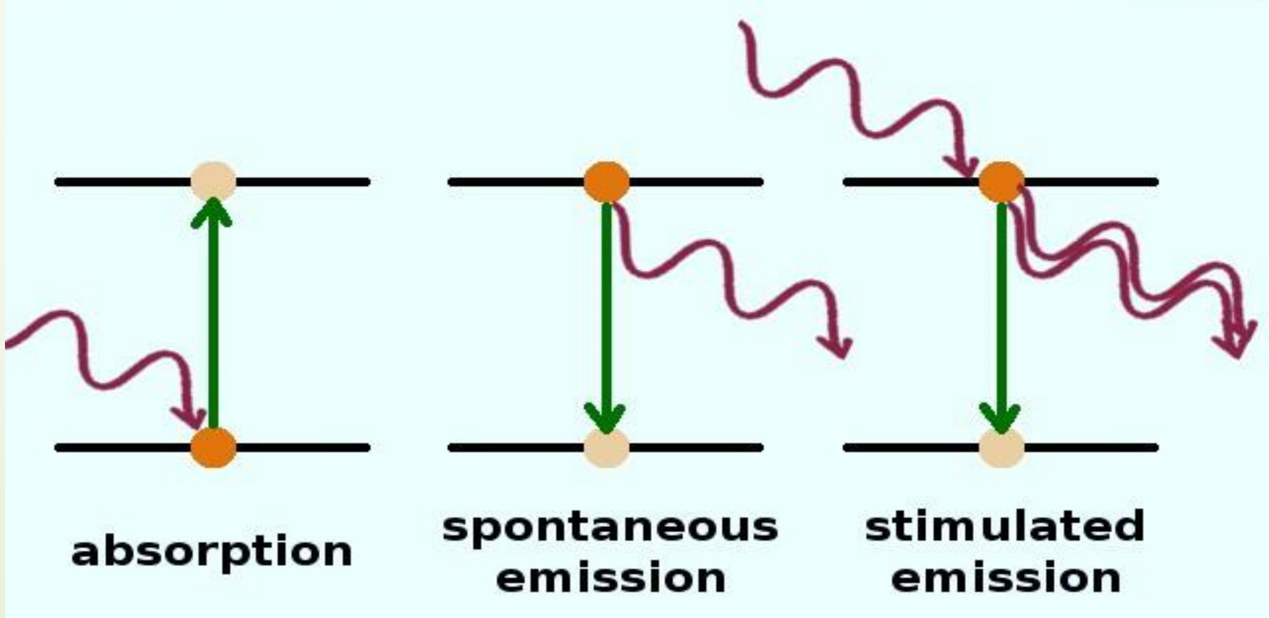
μ_i is the index in the incident medium

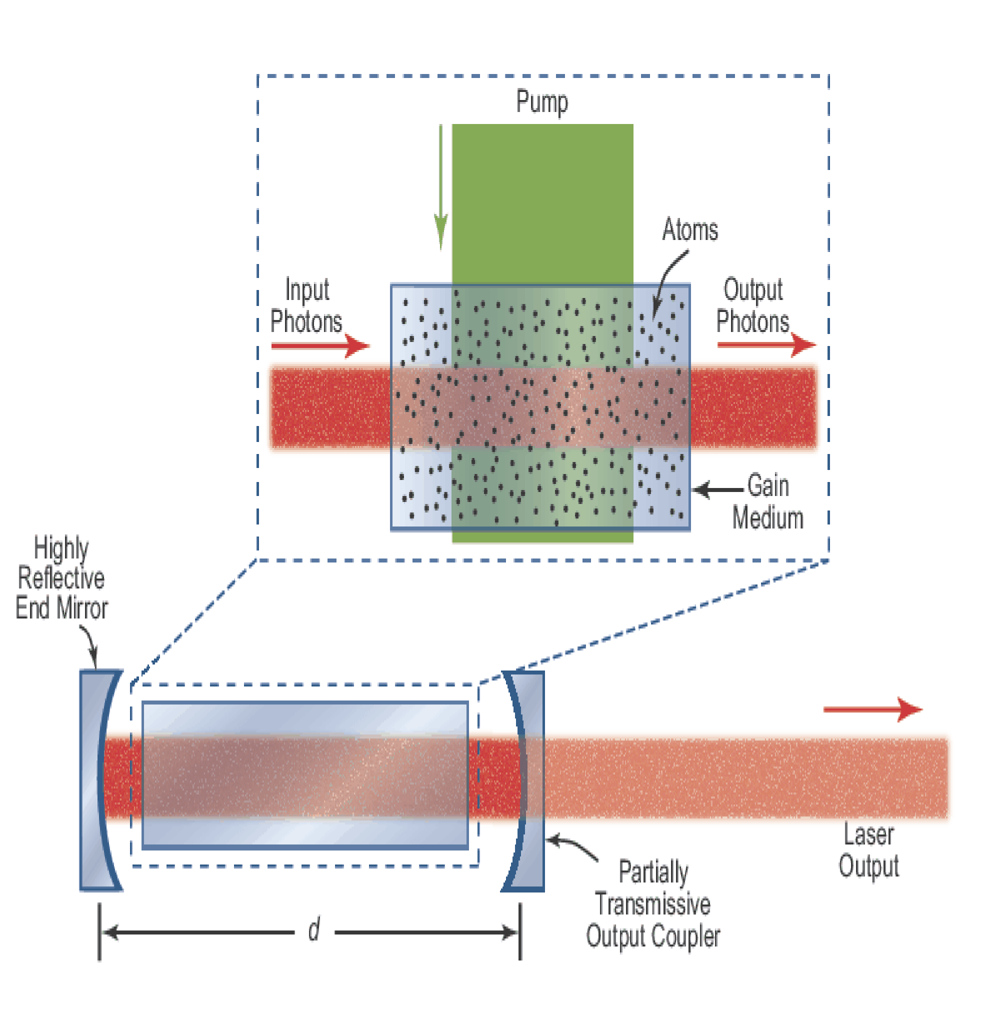
μ_r is the index in the refracting

❖ Absorption & Spontaneous Emission

When appropriate energy is supplied to the atom, electrons can jump from low-energy orbitals (ground state) to high-energy orbitals, leading to atomic excitation by the process of energy **absorption**.

If an electron is in the excited state with the energy E_2 it may spontaneously decay to the ground state, with energy E_1, releasing the difference in energy between the two states as a photon with random phase and direction. This process is called **spontaneous emission**.





- **Stimulated Emission**

The emitted photon (by spontaneous emission) can collide with one of the mirrors in the resonating cavity and reflect back into the lasing medium causing further collision with some of the already excited atoms. If an excited atom is struck, it can be stimulated to decay back to the ground state, releasing two photons identical in direction, phase, polarization, and energy (wavelength). This process is termed **stimulated emission**.

- **Population Inversion**

If the higher energy state has a greater population than the lower energy state, then the light in the system undergoes a net increase in intensity. And this is called population inversion.

❖ What is LASER?

A laser is a device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation.

The term "laser" originated as an acronym for "light amplification by stimulated emission of radiation“

❖ Properties of laser light

Unlike other forms of light, laser light has special properties which make it significantly more effective and dangerous than conventional light of the same power. The laser light particles (photons) are usually:

1.Monochromatic:

consisting of a single wavelength or colour

2. Coherent:

photons are in phase

3.Collimated:

photons are almost in parallel (aligned), with little divergence from the point of origin

❖ Components of a laser

A laser consists of three basic components:

1. A lasing medium or "gain medium":

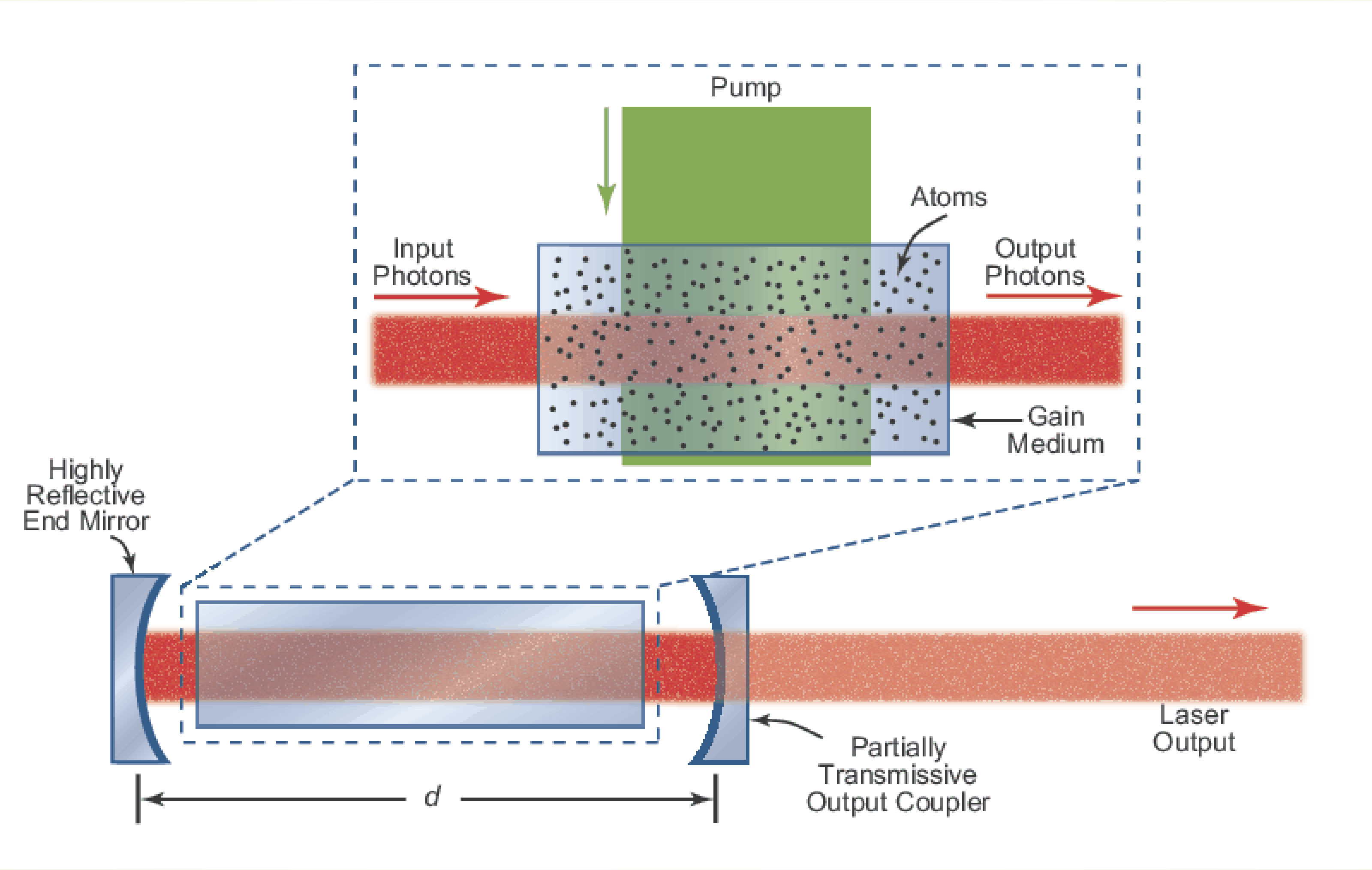
May be a solid (crystals, glasses), liquid (dyes or organic solvents), gas (helium, CO_2), or semiconductor

2. An energy source or "pump":

May be a high-voltage discharge, a chemical reaction, a diode, a flash lamp, or another laser

3. An optical resonator or "optical cavity":

Consists of a cavity containing the lasing medium, with two parallel mirrors on either side. One mirror is highly reflective and the other mirror is partially reflective, allowing some of the light to leave the cavity to produce the laser's output beam – this is called the output coupler



Pump
Atoms
Input Photons
Output Photons
Gain Medium
Highly Reflective End Mirror
d
Partially Transmissive Output Coupler
Laser Output

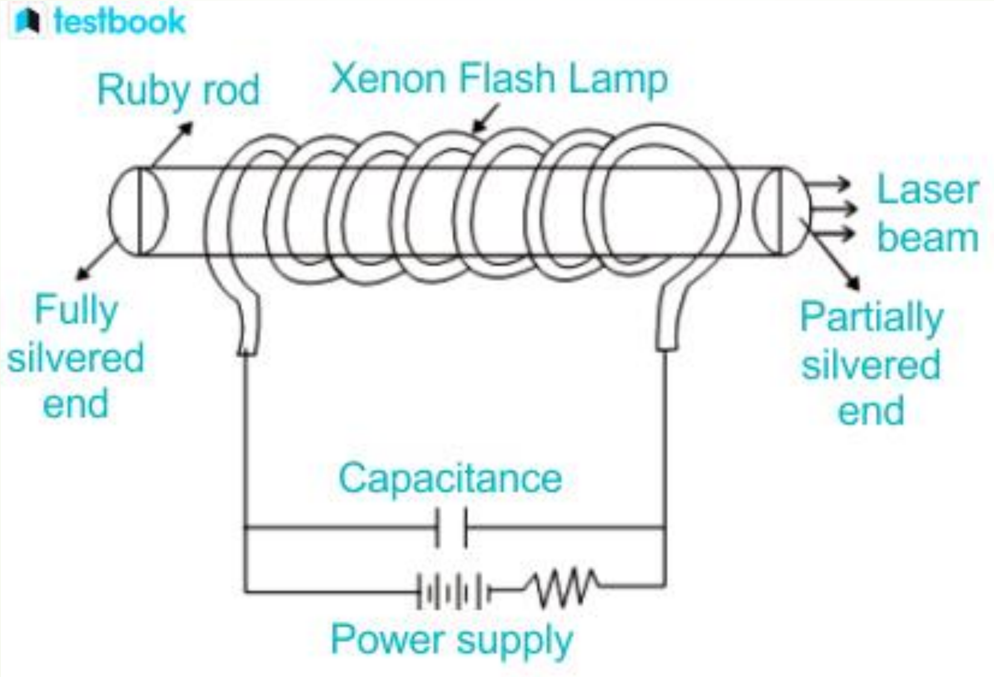
❖ Components of a laser

A laser consists of three basic components:

Gain Medium	Acts as medium for population inversion. Determines laser emission properties	Atomic or molecular gases (Ne, Ar, CO_2) Ions in crystals or glasses (Nd, Er, Yb, Cr) Semiconductors (GaAs, InGaAsP)
Pump Source	Serves as energy source for inverting population	Electric discharge Flashlamp or arc lamp Other laser Electric current
Resonator	Provides feedback mechanism for amplification. Selects spectral and spatial properties of light	Bulk mirrors in solid-state laser Cleaved or coated facets in laser diode Bragg reflectors in fiber laser

❖ Working of a Laser

The ruby laser consists of a ruby crystal medium, a set of mirrors on either end, and a flash tube stimulant. When a current is run through a ruby crystal, electrons are excited, and the excited electrons excite other electrons, resulting in a collective electron state. When an electron reaches its ground state energy, it emits photons, which are collected to produce a powerful beam of light known as a laser.



- Initially, an electric current is applied to switch on and off the flashlight, which excites the electrons in the ruby crystals.
- When these excited electrons in the high-energy state return to the ground state, they spontaneously generate a photon of light.
- These photons bounce off the reflectors and excite additional electrons into high-energy states as they pass through the medium. By increasing emission, this mechanism produces additional photons.
- Because there are now more excited electrons than ground electrons, a population inversion occurs.
- The photons continue to bounce back and forth between the medium’s two mirrors, but one of the mirrors is less reflective and lets some light through.
- Photons emitted by the mirror are condensed into a laser beam

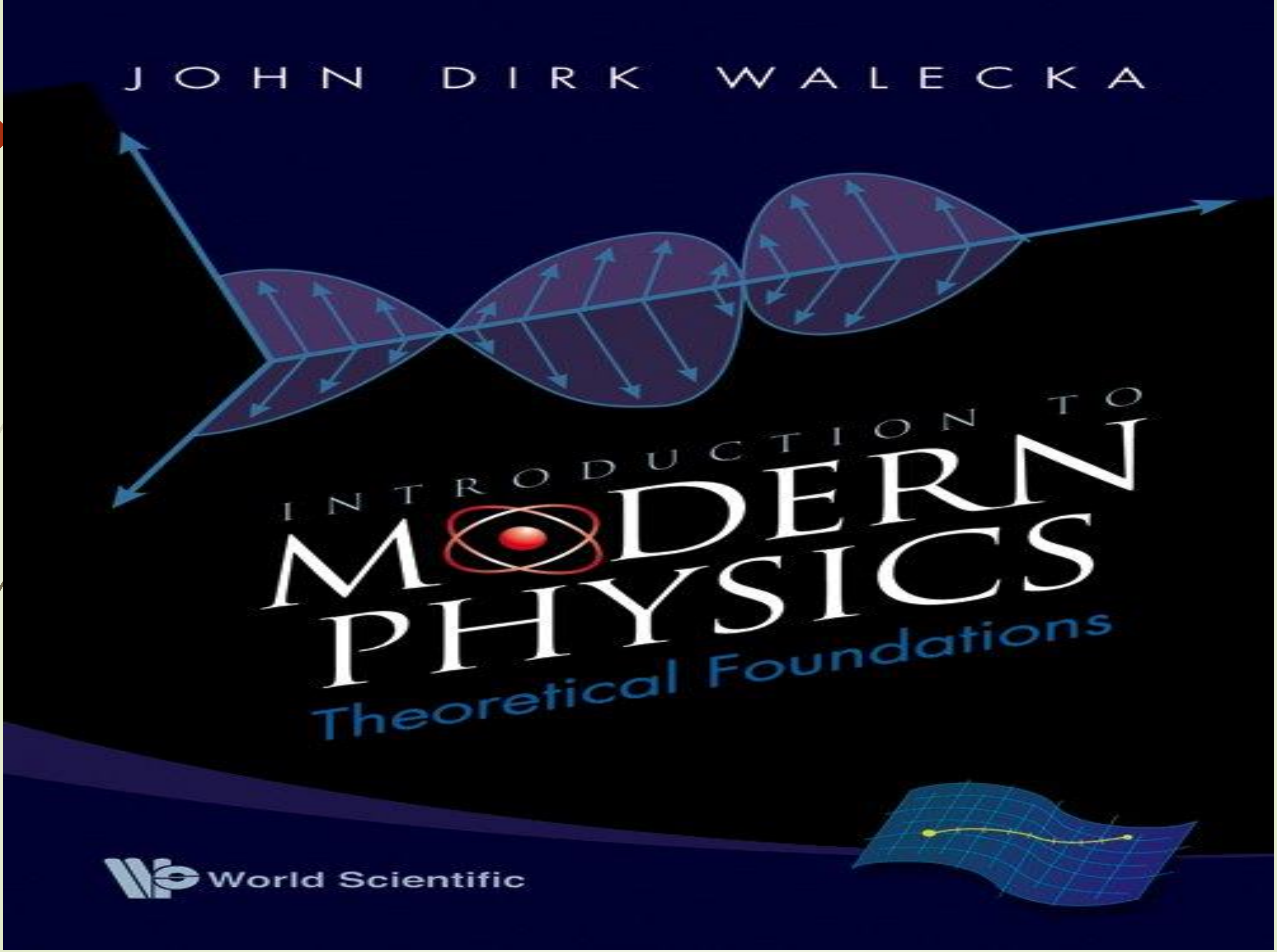
6^{th} Week

Topic: Modern Physics-

Classical Mechanics, Modern Mechanics

Topic Related Math

Page: 117- 127


JOHN DIRK WALECKA
INTRODUCTION TO
MODERN PHYSICS
Theoretical Foundations
World Scientific

Classical Mechanics :

Classical Mechanics refers to the foundational branch of physics that deals with the motion of objects based on Newton's law motion. It involves the study of finite-dimensional systems and has significant implications for the philosophy and foundation physics.

Key Principles

1.Newton's Laws of Motion:

1. **First Law (Inertia):** A body remains at rest or in uniform motion unless acted upon by an external force.
2. **Second Law (F=ma):** The rate of change of momentum of a body is proportional to the net force acting on it, expresse as $\vec{F}=m\vec{a}$.
3. **Third Law:** For every action, there is an equal and opposite reaction.

2.Conservation Laws:

1. **Conservation of Energy:** Total energy (kinetic + potential) in an isolated system remains constant.
2. **Conservation of Momentum:** The total momentum of an isolated system remains constant if no external forces act on
3. **Conservation of Angular Momentum:** Angular momentum remains constant in the absence of external torques.

❖ Applications of Classical Mechanics

Classical mechanics applies to systems ranging from everyday objects (cars, projectiles, and machinery) to large-scale celestial phenomena (planetary orbits, tides). While it breaks down at very small scales (quantum mechanics) or at very high speeds/strong gravitational fields (relativity), it remains an essential framework for engineering, astrophysics, and many other sciences.

❖ Quantum Mechanics

Quantum Mechanics is a fundamental branch of physics that describes the behavior of particles on extremely small scales, such as atoms and subatomic particles. It departs significantly from classical mechanics, introducing concepts such as wave-particle duality, quantization, and probabilistic outcomes

Fundamental Properties of Quantum Mechanics

- **Wave-Particle Duality:** Quantum entities, such as electrons and photons, exhibit dual behavior, acting as both particles and waves depending on the experimental conditions.
- **Quantization of Physical Quantities:** Certain properties, like energy, angular momentum, and charge, are quantized, meaning they take on discrete values rather than a continuous spectrum.
- **Superposition Principle:** A quantum system can exist simultaneously in multiple states until observed or measured, represented mathematically as a combination of wavefunctions.
- **Heisenberg's Uncertainty Principle:** It is impossible to precisely measure both the position and momentum (or energy and time) of a particle simultaneously. This uncertainty is intrinsic to quantum systems.

Fundamental Properties of Quantum Mechanics

- **Entanglement:** Two or more quantum particles can become entangled, meaning the state of one particle is directly correlated with the state of another, regardless of the distance separating them.
- **Wavefunction and Probabilities:** The state of a quantum system is described by a wavefunction, whose square gives the probability of finding a particle in a particular state or location.
- **Discrete Energy Levels:** Systems such as atoms have specific, quantized energy levels. Transitions between these levels involve the absorption or emission of energy in discrete packets called photons.
- **Wavefunction Collapse:** Upon measurement, a quantum system collapses from a superposition of states into one definitive state, determined probabilistically.

Core Topics in Quantum Mechanics

1. **The Schrödinger Equation**:
   - Governs the time evolution of quantum systems: $i\hbar\frac{\partial\psi}{\partial t} = \hat{H}\psi$
   - The wavefunction ψ encodes the probabilities of finding a particle in various states.
2. **Wavefunctions and Probability**:
   - The square of the wavefunction's magnitude, $|\psi|^2$, represents the probability density of a particle's location.
3. **Operators and Observables**:
   - Physical quantities (e.g., energy, momentum) are represented by operators that act on wavefunctions.
   - Measurement yields eigenvalues of these operators.

4. **Quantum States**:
    - Represented in Hilbert space, often using notations like Dirac's bra-ket formalism: $|\psi\rangle$
5. **Spin and Angular Momentum**:
    - Particles possess intrinsic angular momentum (spin) in discrete units.
    - Example: Electrons have a spin of $\pm\frac{1}{2}$.
6. **Quantum Tunneling**:
    - Particles can pass through potential barriers that they classically shouldn't have enough energy to cross.

Difference between Classical Mechanics and Quantum Mechanics

Classical Mechanics	Quantum Mechanics
Deals with macroscopic objects like planets, cars, and projectiles.	Deals with microscopic systems like atoms, electrons, and photons.
Assumes that objects have definite positions, velocities, and trajectories.	Describes systems probabilistically using wavefunctions.

2. Core Principles

Classical Mechanics	Quantum Mechanics
Deterministic: The future state of a system can be precisely predicted if initial conditions are known.	Probabilistic: Outcomes are described by probabilities; measurement collapses the wavefunction.
Continuous: Quantities like energy and momentum vary smoothly.	Discrete: Quantities like energy levels are quantized.
Follows Newton's laws of motion.	Governed by the Schrödinger equation and principles like superposition and entanglement.

3. Behavior of Particles

Classical Mechanics	Quantum Mechanics
Particles are distinct entities with well-defined properties like position and momentum.	Particles exhibit wave-particle duality, behaving as both waves and particles.
No interference or diffraction phenomena.	Demonstrates interference and diffraction, as in the double-slit experiment.

4. Mathematical Framework

Classical Mechanics	Quantum Mechanics
Uses equations like F=maF = maF=ma and conservation laws for energy and momentum.	Relies on wavefunctions, operators, and matrices.
Calculus-based, with clear physical interpretations.	Heavily reliant on linear algebra and probability theory, often abstract.

5. Key Concepts

Classical Mechanics	Quantum Mechanics
Time and space are absolute.	Time and space are not absolute, especially in relativistic quantum mechanics.
Energy is continuous and deterministic.	Energy is quantized; transitions occur in discrete steps.
Observables like position and momentum can be measured simultaneously with infinite precision.	Heisenberg's Uncertainty Principle limits the simultaneous precision of certain measurements.

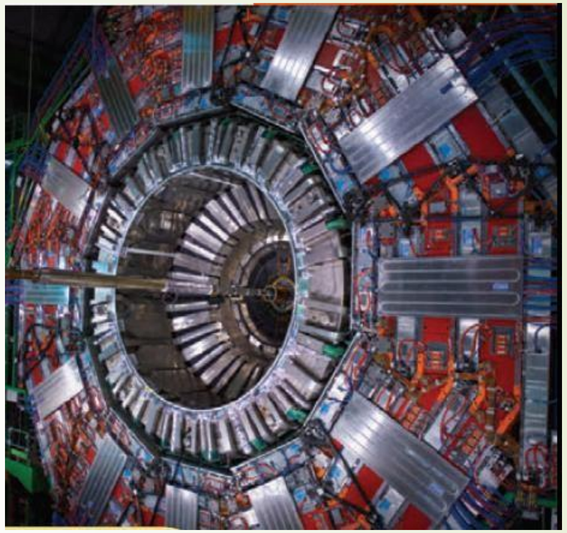
7^{th} Week

Topic: Modern Physics-

Theory of Relativity, Michel Morley Experiment, Topic Related Math

Page: 128- 135

At the end of the 19th century, many scientists believed they had learned most of what there was to know about physics. Newton's laws of motion and theory of universal gravitation, Maxwell's theoretical work in unifying electricity and magnetism, the laws of thermodynamics and kinetic theory, and the principles of optics were highly successful in explaining a variety of phenomena.



At the turn of the 20th century, however, a major revolution shook the world of physics. In 1900, Max Planck provided the basic ideas that led to the formulation of the quantum theory, and in 1905, Albert Einstein formulated his special theory of relativity. The excitement of the times is captured in Einstein's own words: "It was a marvelous time to be alive." Both theories were to have a profound effect on our understanding of nature.

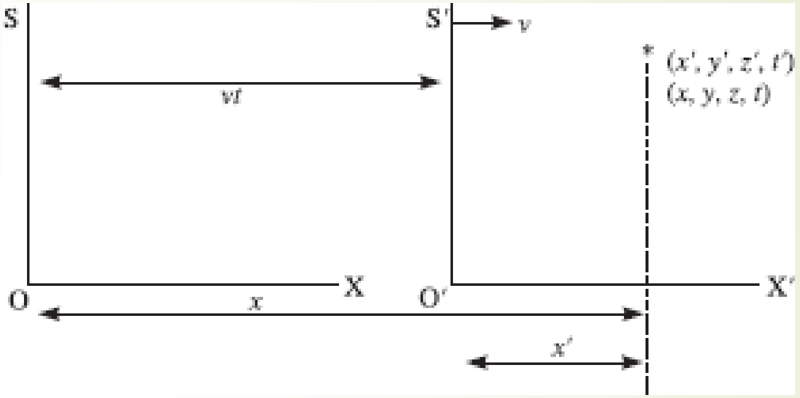
Relativity

Our everyday experiences and observations involve objects that move at speeds much less than the speed of light. Newtonian mechanics was formulated by observing and describing the motion of such objects, and this formalism is very successful in describing a wide range of phenomena that occur at low speeds. Nonetheless, it fails to describe properly the motion of objects whose speeds approach that of light.

Experimentally, it is possible to accelerate an electron to a speed of 0.99*c* (where *c* is the speed of light) by using a potential difference of several million volts. According to Newtonian mechanics, if the potential difference is increased by a factor of 4, the electron's kinetic energy is four times greater and its speed should double to 1.98*c*. Experiments show, however, that the speed of the electron—as well as the speed of any other object in the Universe—always remains less than the speed of light, regardless of the size of the accelerating voltage.

GALILEAN TRANSFORMATION EQUATIONS

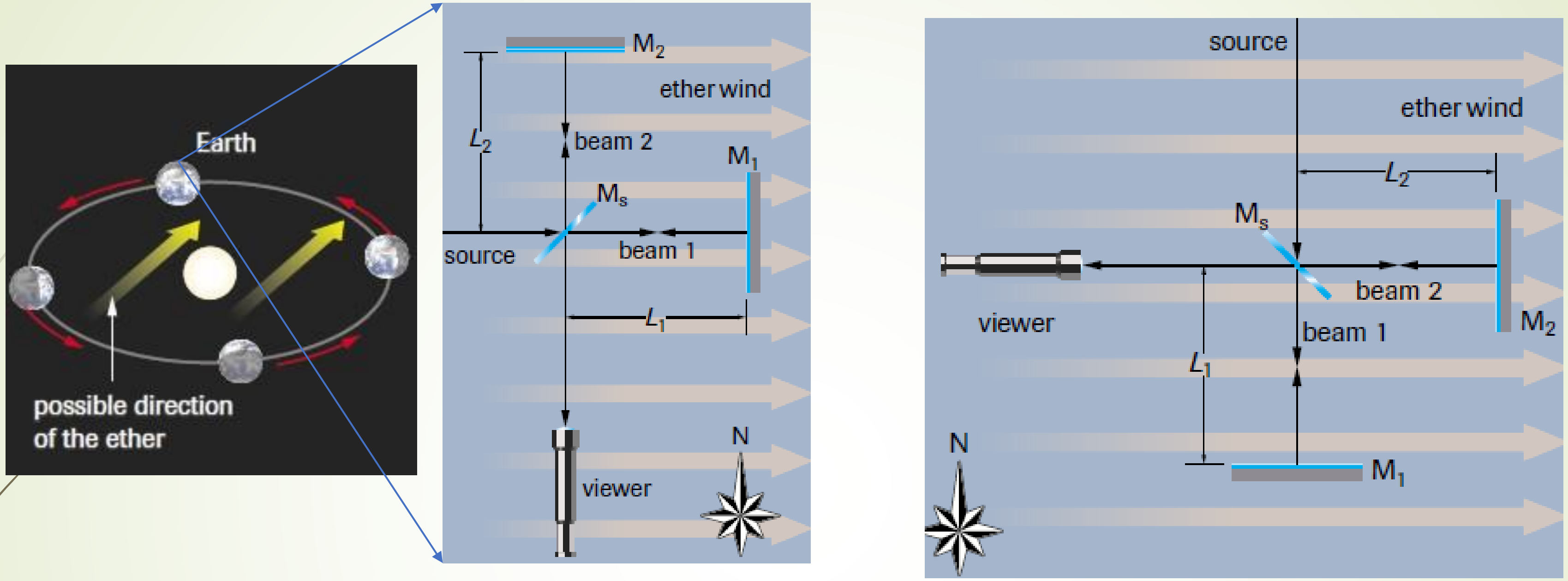
The Galilean transformation equations are a set of equations connecting the space-time coordinates of an event observed in two inertial frames, which are in relative motion. Consider two inertial frames S and S′ with their corresponding axes parallel; the frame S′ is moving along the common *x*-*x*′



direction with velocity *v* relative to the frame S. Assume that when the origin O of the frame S′ passes over the origin O of frame S, both observers set their clocks at zero *i.e.*, $t = t' = 0$. The event to be observed is the motion of a particle. At certain moment, the S-observer registers the space-time coordinates of the particle as (x, y, z, t) and S'- observer as (x', y', z', t'). The relationship,

$$x' = x - vt, y' = y, z' = z, t' = t.$$

A simplified view of Michelson–Morley experiment place in the hypothetical ether wind.



Would the speed of light, like the speed of a ball rolling in a vehicle, depend on the frame of reference from which it is observed?

The speed of light was the same whether it travelled back and forth in the direction of the ether wind or at right angles to it.

Michelson–Morley experiment

$$\Delta t_{\text{arm } 1} = \frac{2L}{(c^2 - v^2)^{1/2}} = \frac{2L}{c}\left(1 - \frac{v^2}{c^2}\right)^{-1/2}$$

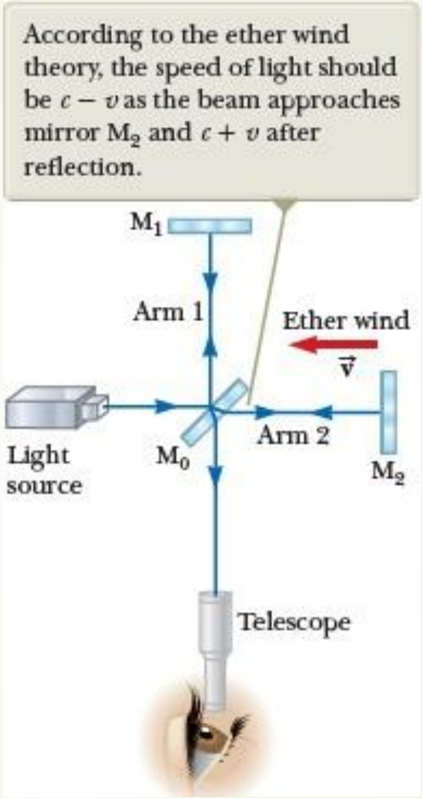
$$\Delta t_{\text{arm } 2} = \frac{L}{c+v} + \frac{L}{c-v} = \frac{2Lc}{c^2 - v^2} = \frac{2L}{c}\left(1 - \frac{v^2}{c^2}\right)^{-1}$$

$$\Delta t = \Delta t_{\text{arm } 2} - \Delta t_{\text{arm } 1} \approx \frac{Lv^2}{c^3} \qquad \Delta d = c(2\Delta t) = \frac{2Lv^2}{c^2}$$

Because a change in path length of one wavelength corresponds to a shift of one fringe, the corresponding fringe shift is equal to this path difference divided by the wavelength of the light: Th expected shift

$$\text{Shift} = \frac{2Lv^2}{\lambda c^2} = \frac{2(11\ \text{m})(3.0 \times 10^4\ \text{m/s})^2}{(5.0 \times 10^{-7}\ \text{m})(3.0 \times 10^8\ \text{m/s})^2} = 0.44$$

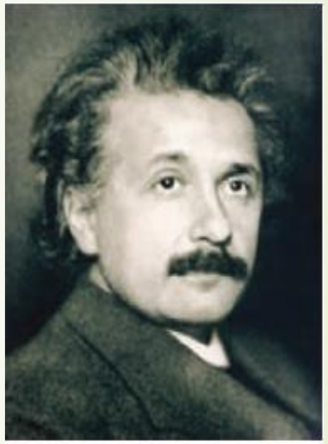
Th observed shift $= 0.01$.



Special Theory of Relativity

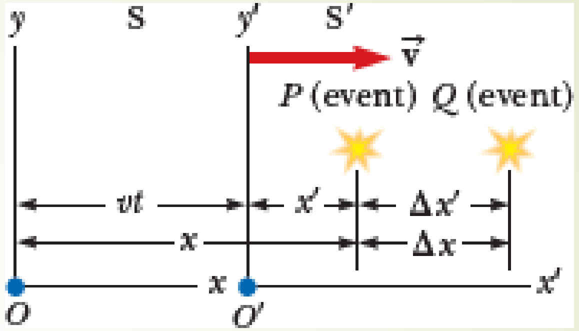
1. ***The relativity principle:*** all the laws of physics are valid in all inertial frames of reference.

2. ***The constancy of the speed of light:*** light travels through empty space with a speed of $c = 3.00 \times 10^8$ m/s, relative to all inertial frames of reference.



Albert Einstein
German-American Physicist
(1879–1955)

The Lorentz Transformation



Suppose two events occur at points *P* and *Q* and are reported by two observers, one at rest in a frame S and another in a frame S’ that is moving to the right with speed *v* as in Fig. The observer in S reports the events with space–time coordinates (*x*, *y*, *z*, *t*), and the observer in S’ reports the same events using the coordinates (*x* ‘, *y* ‘, *z* ‘, *t* ‘). The **Lorentz transformation equations** $\boldsymbol{S \rightarrow S'}$ **:**

$$x' = \gamma(x - vt) \qquad y' = y \qquad z' = z \qquad t' = \gamma\left(t - \frac{v}{c^2}x\right)$$

$$where, \qquad \gamma = \frac{1}{\sqrt{1 - v^2/c^2}}$$

Lorentz Velocity transformation for $S \rightarrow S'$:

$$u'_x = \frac{u_x - v}{1 - \frac{u_x v}{c^2}}$$

8th Week

Topic: Modern Physics-

Explain Time Dilation, Length Contraction, and Increase of Mass according to the theory of relativity

Topic Related Math

Page: 136- 141

Time Dilation: $\Delta t_m = \gamma \Delta t_S = \frac{\Delta t_S}{\sqrt{1 - v^2/c^2}}$

where Δt_s is the time interval for the observer stationary relative to the sequence of events and Δt_m is the time interval for an observer moving with a speed *v* relative to the sequence of events.

The Twin Paradox

One of Einstein's most famous thought experiments is the "twin paradox," which illustrates time dilation.

As the twins depart, they are the same age.

When the astronaut twin returns, he has aged less than the twin who stayed on Earth.

An example:

An astronaut whose pulse frequency remains constant at 72 beats/min is sent on a voyage. What would her pulse beat be, relative to Earth, when the ship is moving relative to Earth at (a) 0.10*c* and (b) 0.90*c*?

Solution $$\Delta t_s = \frac{1}{72\ \text{beats/min}} = 0.014\ min$$

(a) At $v = 0.10c$,

$$\Delta t_m = \frac{\Delta t_s}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$= \frac{0.014\ \text{min}}{\sqrt{1 - \frac{(0.10c)^2}{c^2}}}$$

$$= \frac{0.014\ \text{min}}{0.995}$$

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

$$= \frac{1}{0.014\ \text{min}}$$

$$f = 72\ \text{beats/min}$$

(b) At $v = 0.90c$,

$$\Delta t_m = \frac{0.014\ \text{min}}{\sqrt{1 - \frac{(0.90c)^2}{c^2}}}$$

$$= \frac{0.014\ \text{min}}{0.436}$$

$$\Delta t_m = 0.032\ \text{min}$$

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

$$= \frac{1}{0.032\ \text{min}}$$

$$f = 31\ \text{beats/min}$$

Length Contraction:

$$L_m = \frac{L_s}{\gamma} = L_s\sqrt{1 - v^2/c^2}$$

The shortening of distances in a system, as seen by an observer in motion relative to that system.

Observer	Distance	Time
stationary observer	L_s	Δt_m
spacecraft observer	L_m	Δt_s

An example:

A spaceship travelling past Earth with a speed of 0.87*c*, relative to Earth, is measured to be 48.0 m long by observers on Earth. What is the proper length of the spaceship?

Solution

Since the spaceship is moving relative to the observers on Earth, 48.0 m represents *L*m.

$$v = 0.87c$$
$$L_m = 48.0\text{ m}$$
$$L_s = ?$$

$$L_m = L_s\sqrt{1 - \frac{v^2}{c^2}}$$

$$L_s = \frac{L_m}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$= \frac{48.0\text{ m}}{\sqrt{1 - \frac{(0.87c)^2}{c^2}}}$$

$$L_s = 97.35\text{ m, or } 97.4\text{ m}$$

The proper length of the spaceship is 97.4 m.

Relativistic Linear Momentum

$$\vec{\mathbf{p}} \equiv \frac{m\vec{\mathbf{u}}}{\sqrt{1-\frac{u^2}{c^2}}} = \gamma m\vec{\mathbf{u}}$$

where *m* is the mass of the particle and $\vec{\boldsymbol{u}}$ is the velocity of the particle. When u is much less than *c*, $\gamma = (1 - u^2/c^2)^{-1/2}$ approaches unity and $\vec{\boldsymbol{p}}$ approaches $m\vec{u}$.

9TH WEEK

TOPIC: MODERN PHYSICS-

FOUR TYPES OF FUNDAMENTAL FORCES

MASS-ENERGY EQUIVALENCE LAW

, TOPIC RELATED MATH

PAGE: 142- 147

Mass and Energy: $E = mc^2$

Einstein suggested that the total (relativistic) energy associated with an object of rest mass *m*, moving at speed *v* relative to an inertial frame is

$$E_{\text{total}} = \frac{mc^2}{\sqrt{1 - \frac{v^2}{c^2}}}$$

If the object happens to be at rest in this inertial frame, then *v* is zero and the total (relativistic) energy is simply

$$E_{\text{rest}} = mc^2$$

Problem m-01:

If the 0.50 kg mass of a ball at rest were converted to another form of energy. What would the energy output be ?

Solution

$\Delta m = 0.50$ kg

$\Delta E = ?$

$$\Delta E = (\Delta m)c^2$$
$$= (0.50 \text{ kg})(3.00 \times 10^8 \text{ m/s})^2$$
$$\Delta E = 4.5 \times 10^{16} \text{ J}$$

The energy equivalent is 4.5×10^{16} J, or approximately half the energy emitted by the Sun every second.

The total annual energy consumption of Canada is about 9.80×10^{18} J. How much mass would have to be totally converted to energy to meet this need?

The four fundamental forces

The four fundamental forces of nature govern all interactions in the universe. Each force operates over specific ranges and has unique characteristics. Here's an overview

1. Gravitational Force

Description: The attractive force between objects with mass.

Key Characteristics:

- Weakest of the four forces but acts over infinite range.
- Governs large-scale structures like planets, stars, and galaxies.

Equation:

$$F_g = G\frac{m_1 m_2}{R^2}$$

Mediating Particle: Hypothetical **graviton** (not yet observed)

2. Electromagnetic Force

Description: The force between charged particles.

Key Characteristics:

Acts over infinite range.

Can be attractive or repulsive (opposite charges attract, like charges repel).

Much stronger than gravity.

Responsible for electricity, magnetism, and light.

Equation

$$F = \frac{1}{4\pi\varepsilon_\circ}\frac{q_1 q_2}{d^2}$$

Mediating Particle: **Photon**.

3. Strong Nuclear Force

Description: The force that binds protons and neutrons together in atomic nuclei.

Key Characteristics:

- Strongest of the four forces.
- Acts only over very short ranges ($\sim 10^{-15}$ meters, the size of an atomic nucleus).
- Overcomes the electromagnetic repulsion between positively charged protons.

Mediating Particle: **Gluon**

4. Weak Nuclear Force

Description: Responsible for processes like radioactive decay and nuclear fusion in stars.

Key Characteristics:

- Weak compared to the electromagnetic and strong forces.
- Acts over very short ranges $\sim 10^{-18}$ meters).
- Crucial for changing one type of particle into another (e.g., a neutron into a proton in beta decay).

Mediating Particles: **W and Z bosons**.

10^{th} Week

Topic: Modern Physics-

Photoelectric Effect, Compton effect, Problem-Solving

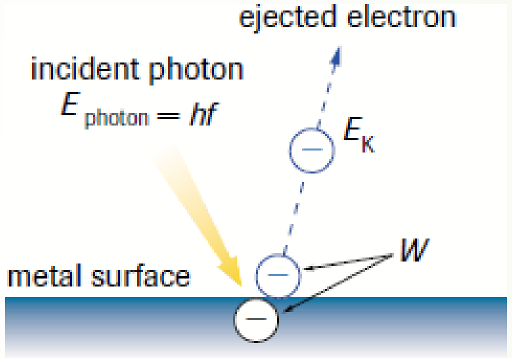
Page: 148- 154

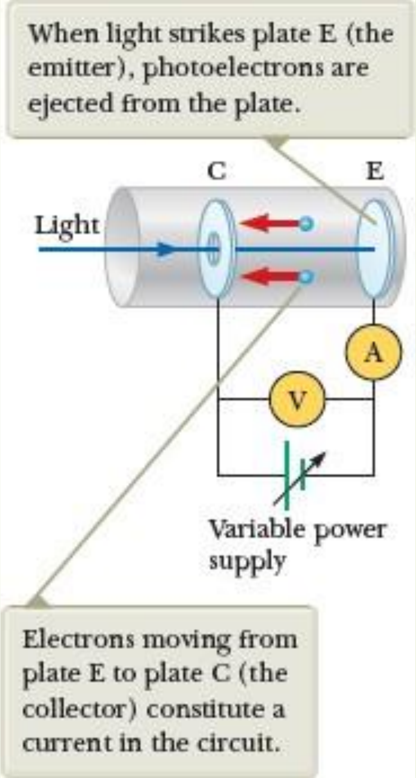
❖ The Photoelectric Effect:

Light incident on certain metallic surfaces causes electrons to be emitted from those surfaces. This phenomenon is known as the **photoelectric effect,** and the emitted electrons are called **photoelectrons.**

Einstein's photoelectric equation:

$$E_K = hf - W$$





The value *W*(the energy needed to release an electron from an illuminated metal) is called the work function of the metal.Part of the energy of the incident photon goes to releasing the surface electron. (*W* is the energy binding the electron to the surface.) The remainder provides the kinetic energy of the ejected electron.

Problem-PE-01:

Orange light with a wavelength of 6.00×10^2 nm is directed at a metallic surface with a work function of 1.60 eV. Calculate (a) the maximum kinetic energy, in joules, of the emitted electrons (b) their maximum speed

Solution

(a) $\lambda = 6.00 \times 10^2\ \text{nm} = 6.00 \times 10^{-7}\ \text{m}$

$h = 6.63 \times 10^{-34}\ \text{J·s}$

$E_K = ?$

$W = 1.60\ \text{eV}$

$= (1.60\ \text{eV})(1.60 \times 10^{-19}\ \text{J/eV})$

$W = 2.56 \times 10^{-19}\ \text{J}$

$$E_{K,max} = \frac{hc}{\lambda} - W$$

$$= \frac{(6.63 \times 10^{-34}\ \text{J·s})(3.00 \times 10^8\ \text{m/s})}{6.00 \times 10^{-7}\ \text{m}} - 2.56 \times 10^{-19}\ \text{J}$$

$E_{K,max} = 7.55 \times 10^{-20}\ \text{J}$

(b) $v = ?$

$m_e = 9.11 \times 10^{-31}\ \text{kg}$ (from Ap

$$E_K = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2E_K}{m}}$$

$$= \sqrt{\frac{2(7.55 \times 10^{-20}\ \text{J})}{9.11 \times 10^{-31}\ \text{kg}}}$$

$v = 4.07 \times 10^5\ \text{m/s}$

Problem –DB01:

What is the magnitude of the momentum of a photon with a wavelength of 1.2×10^{-12} m?

Solution

$\lambda = 1.2 \times 10^{-12}$ m

$h = 6.63 \times 10^{-34}$ J·s

$p = ?$

$$p = \frac{h}{\lambda}$$

$$= \frac{6.63 \times 10^{-34} \text{ J·s}}{1.2 \times 10^{-12} \text{ m}}$$

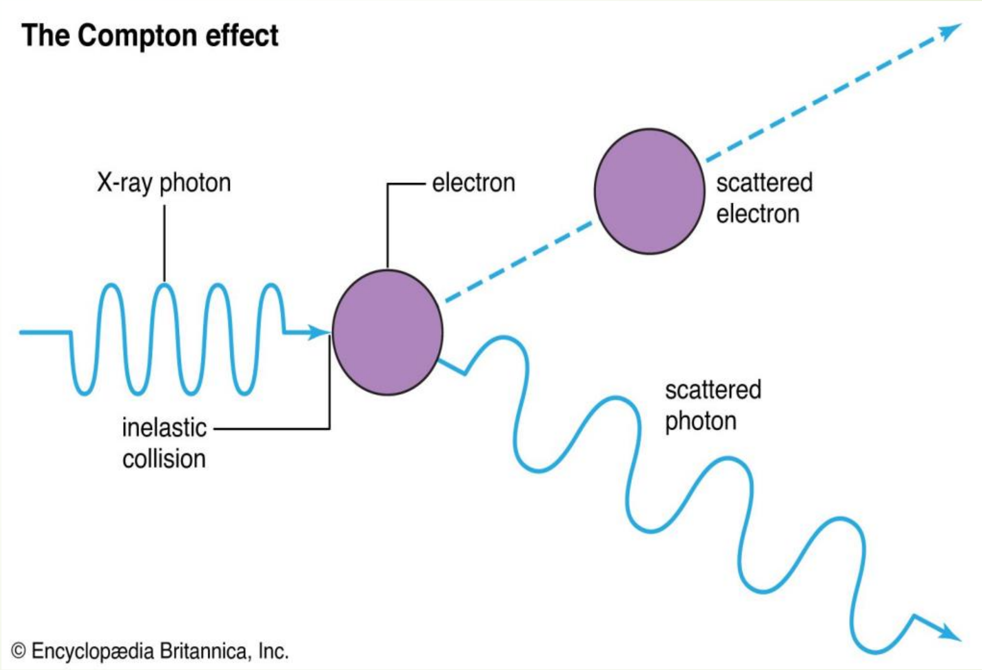
$$p = 5.5 \times 10^{-22} \text{ kg·m/s}$$

The magnitude of the momentum of the photon is 5.5×10^{-22} kg·m/s.

❖ Compton effect :

The Compton effect, also known as Compton scattering, refers to the phenomenon where X-ray or gamma-ray photons collide with electrons and scatter, resulting in a decrease in energy (increase in wavelength) of the photons. This effect is a key piece of evidence for the particle-like behavior of light and supports the quantum theory of electromagnetism. The change in the photon's energy is observed as a change in its wavelength. The formula describing this shift in wavelength ($\Delta\lambda$) is given by:

$$\Delta\lambda = \lambda' - \lambda = \frac{h}{m_e c}$$



where:

- λ is the initial wavelength of the photon,
- λ' is the wavelength after scattering,
- h is Planck's constant,
- me is the rest mass of the electron,
- c is the speed of light,
- θ is the angle at which the photon scatters.

❖ De Broglie Wave

The de Broglie wave refers to the wave-like behavior of particles, a concept introduced by French physicist Louis de Broglie in 1924. This concept is a cornerstone of quantum mechanics and embodies the principle of wave-particle duality, which states that all matter exhibits both particle and wave characteristics.

De Broglie Wavelength:

$\lambda = p/h$

where:

- λ is the de Broglie wavelength,
- h is Planck's constant (6.626×10−34 Js),
- p is the momentum of the particle

(momentum p is the product of mass m and velocity v: $p=mv$).

Problem-DB02:

What de Broglie wavelength is associated with a 0.10 kg ball moving at 19.0 m/s?

Solution

$m = 0.10$ kg

$v = 19.0$ m/s

$\lambda = ?$

$$\lambda = \frac{h}{mv}$$

$$= \frac{6.63 \times 10^{-34} \text{ J·s}}{(0.10 \text{ kg})(19.0 \text{ m/s})}$$

$$\lambda = 3.5 \times 10^{-34} \text{ m}$$

The de Broglie wavelength of the ball is 3.5×10^{-34} m.

Problem –DB03:

Calculate the de Broglie wavelength associated with an artillery shell having a mass of 0.50 kg and a speed of 5.00×10^2 m/s.

11th Week

Topic: Modern Physics-

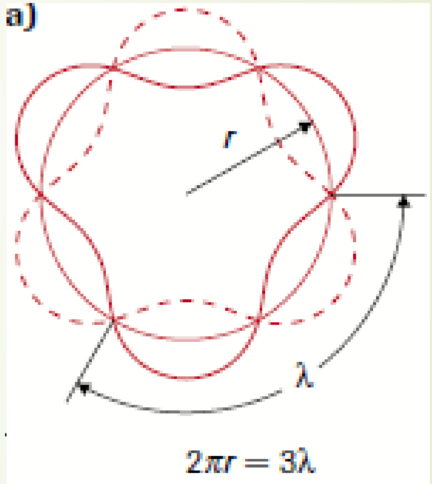
Atomic Decay, De Broglie Wave

Related Math

Page: 155- 160

The Bohr Model of the Atom

To summarize: Bohr's idea was that atoms only exist in certain stationary states characterized by certain allowed orbits for their electrons, which move in these orbits with only certain amounts of total energy, the so-called energy levels of the atom. If the orbits are essentially circular, and if the first allowed orbit has a radius r_1 and is occupied by an electron moving with a speed v_1, the length of the orbital path will be



one wavelength: $2\pi r_1 = \lambda$ *and* $2\pi r_1 = \frac{h}{mv_1}$

Similarly, for the second allowed orbit, $2\pi r_2 = 2\lambda$.

More generally, for the nth allowed orbit,

$$2\pi r_n = n\lambda = n\left(\frac{h}{mv_n}\right)$$

Thus, according to Bohr, the allowed orbits are those determined by the relationship: $mv_n r_n = n\left(\frac{h}{2\pi}\right) \quad (n = 1,2,\ldots)$.

Radioactive Decay:

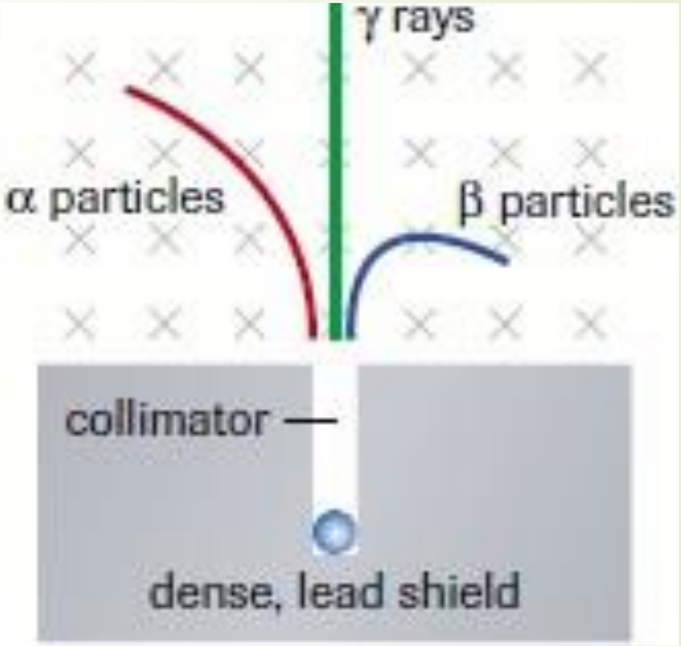
Alpha decay occurs when an unstable nucleus emits a particle, often denoted as $_2He^4$.

nucleus is of a different element and has two protons and two neutrons fewer

than the parent nucleus is of a different element and has two protons and two neutrons fewer than the parent.

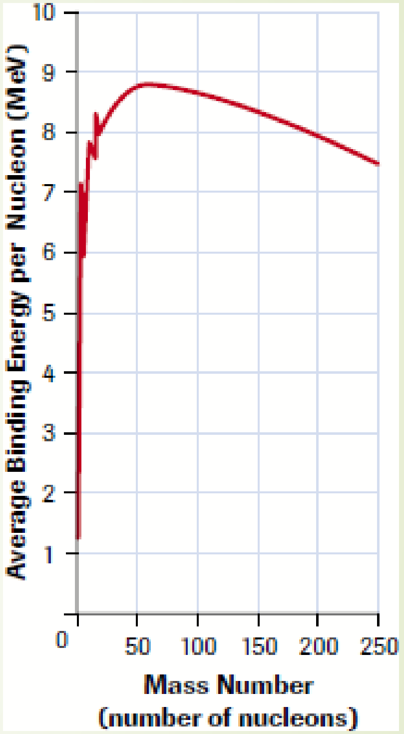
- Beta decay assumes two forms. In β^- decay, a neutron is replaced with a proton and a β^- particle (a high-speed electron). In β^+ decay, a proton is replaced with a neutron and a β^+ particle (a high-speed positron).

- Gamma decay is the result of an excited nucleus that has emitted a photon and dropped to a lower state.



Binding energy: the energy required to break up the nucleus into protons and neutrons. The average binding energy per nucleon is a maximum when the mass number is 56 (which is the case for iron) and decreases steadily afterward.

As we move in the periodic table toward iron, we find the nuclei have more nucleons, all pulling inward on each other. The binding energy therefore rises. As we move farther away from the middle elements, we have still more nucleons. Now, however, some pairs of nucleons are so widely separated that they can no longer experience the mutual attraction due to the (short-range) strong nuclear force. The proton pairs among these nucleon pairs continue to feel the repulsion of the infinite-range electromagnetic force. For the really massive elements, for example, radium, polonium, and uranium, the binding energy is so low that the nucleus is not stable at all.



Half-Life

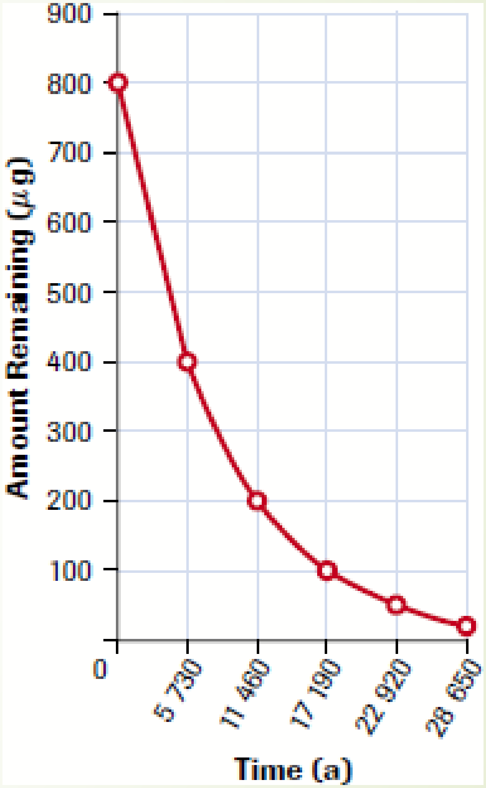
half-life a measure of the radioactivity of an isotope; the time $t_{1/2}$ needed for half the atoms in any sample of that

isotope, prepared at any instant, to decay

The amount of radioactive substance *N* left after some time *t* is given by

$$N = N_0 \left(\frac{1}{2}\right)^{\frac{t}{t_{1/2}}}$$

Where $N_0$is the initial quantity and t1/2 is the half-life.



The half-life for carbon-14 is 5730 a. A specimen of peat from an ancient bog presently contains 800 μg of carbon-14.

(a) What will be the amount of carbon-14 remaining after 10 000 a?

(b) At what time will the amount remaining be 300 μg?

Solution

(a) $N_0 = 800.0\ \mu g \qquad t = 10\ 000\ a$

$t_{1/2} = 5730\ a \qquad N = ?$

$$N = N_0\left(\frac{1}{2}\right)^{\frac{t}{t_{1/2}}}$$

$$= 800\left(\frac{1}{2}\right)^{\frac{10\,000}{5730}}$$

$$N = 240$$

(b) $N_0 = 400\ \mu g \qquad t_{1/2} = 5730\ a$

$N = 300\ \mu g \qquad t = ?$

$$N = N_0\left(\frac{1}{2}\right)^{\frac{t}{t_{1/2}}}$$

$$300 = 800.0\left(\frac{1}{2}\right)^{\frac{t}{5730}}$$

$$\frac{3}{8} = \left(\frac{1}{2}\right)^{\frac{t}{5730}}$$

$$\log\left(\frac{3}{8}\right) = \log\left(\frac{1}{2}\right)^{\frac{t}{5730}}$$

$$\log\left(\frac{3}{8}\right) = \frac{t}{5730}\log\left(\frac{1}{2}\right)$$

$$t = 5730\,\frac{\log\left(\frac{3}{8}\right)}{\log\left(\frac{1}{2}\right)}$$

$$t = 8100\ a$$

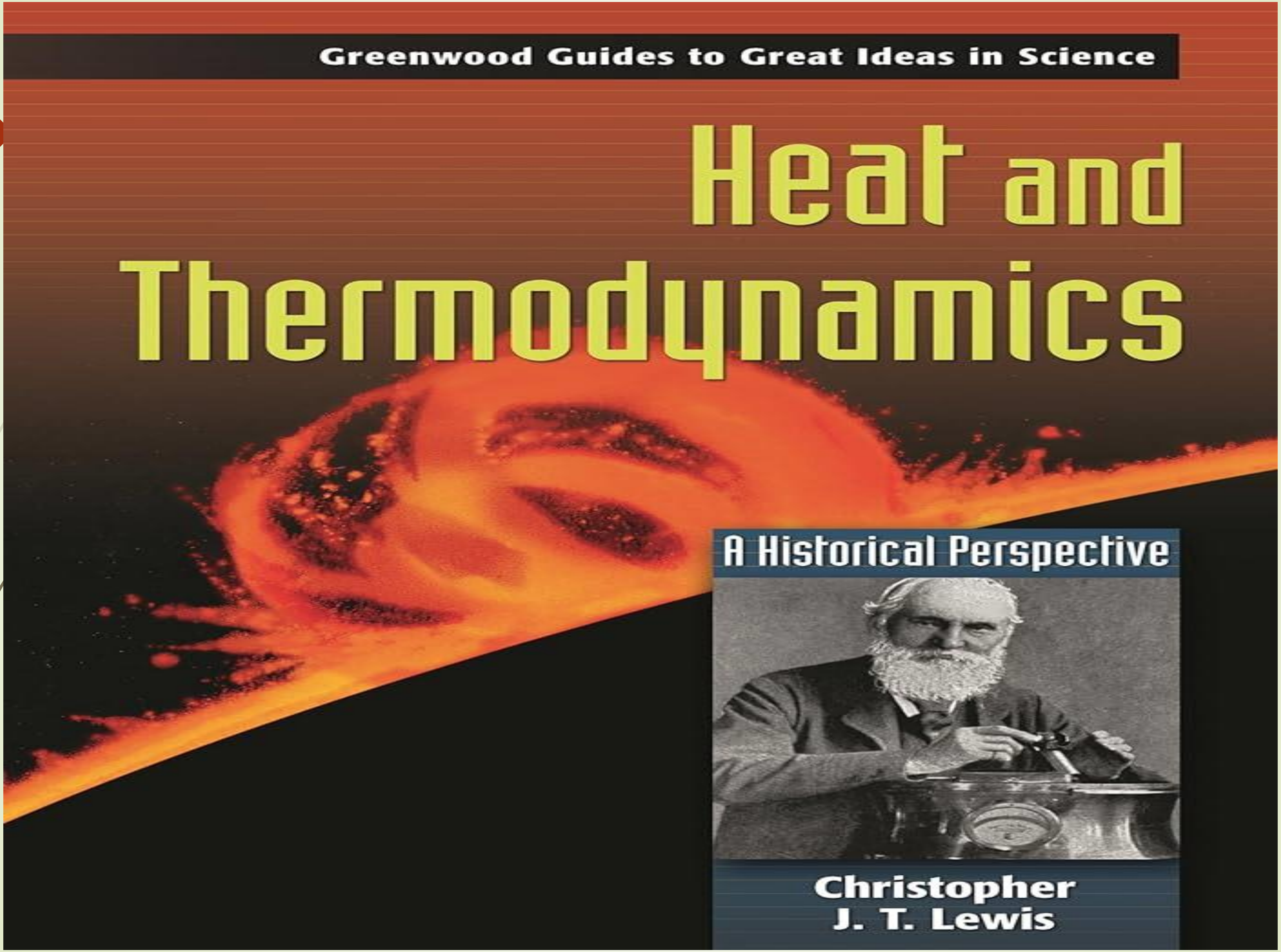
12th Week

Topic: Heat and thermodynamics-

Thermodynamics, laws of thermodynamics, The Energy Transfer Mechanics in Thermal process

Related Math

Page: 161- 186


Greenwood Guides to Great Ideas in Science
Heat and Thermodynamics
A Historical Perspective
Christopher J. T. Lewis

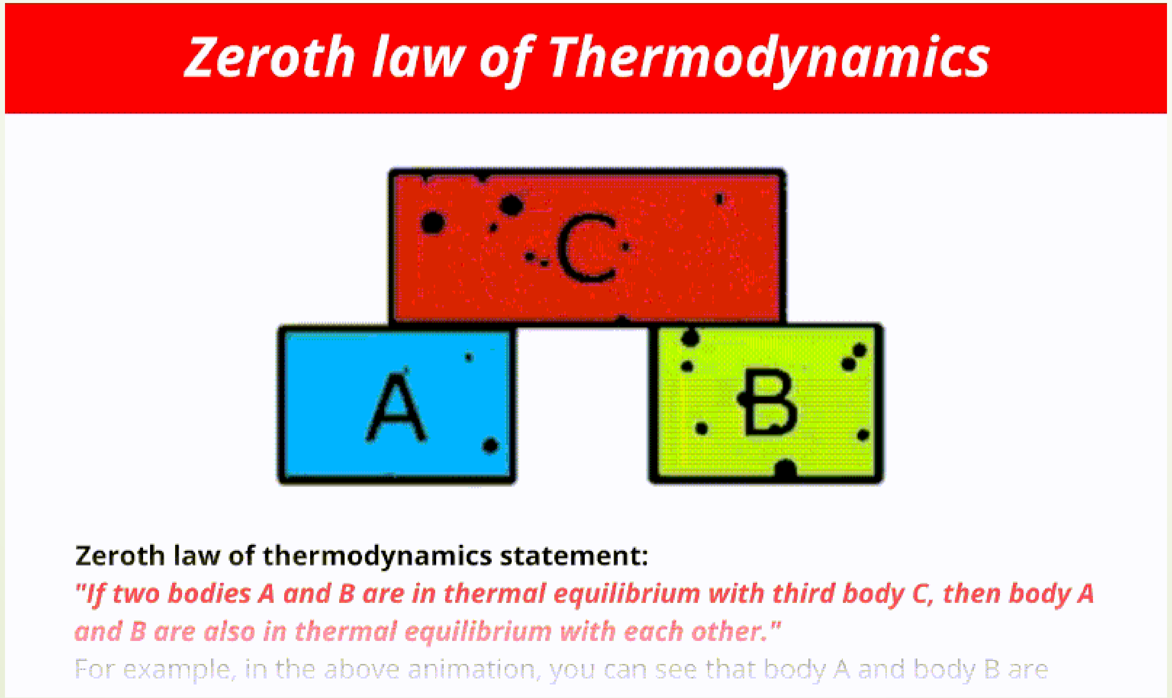
❖ What is Thermodynamics?

Thermodynamics in physics is a branch that deals with heat, work and temperature, and their relation to energy, radiation and physical properties of matter.

To be specific, it explains how thermal energy is converted to or from other forms of energy and how matter is affected by this process. Thermal energy is the energy that comes from heat. This heat is generated by the movement of tiny particles within an object, and the faster these particles move, the more heat is generated.

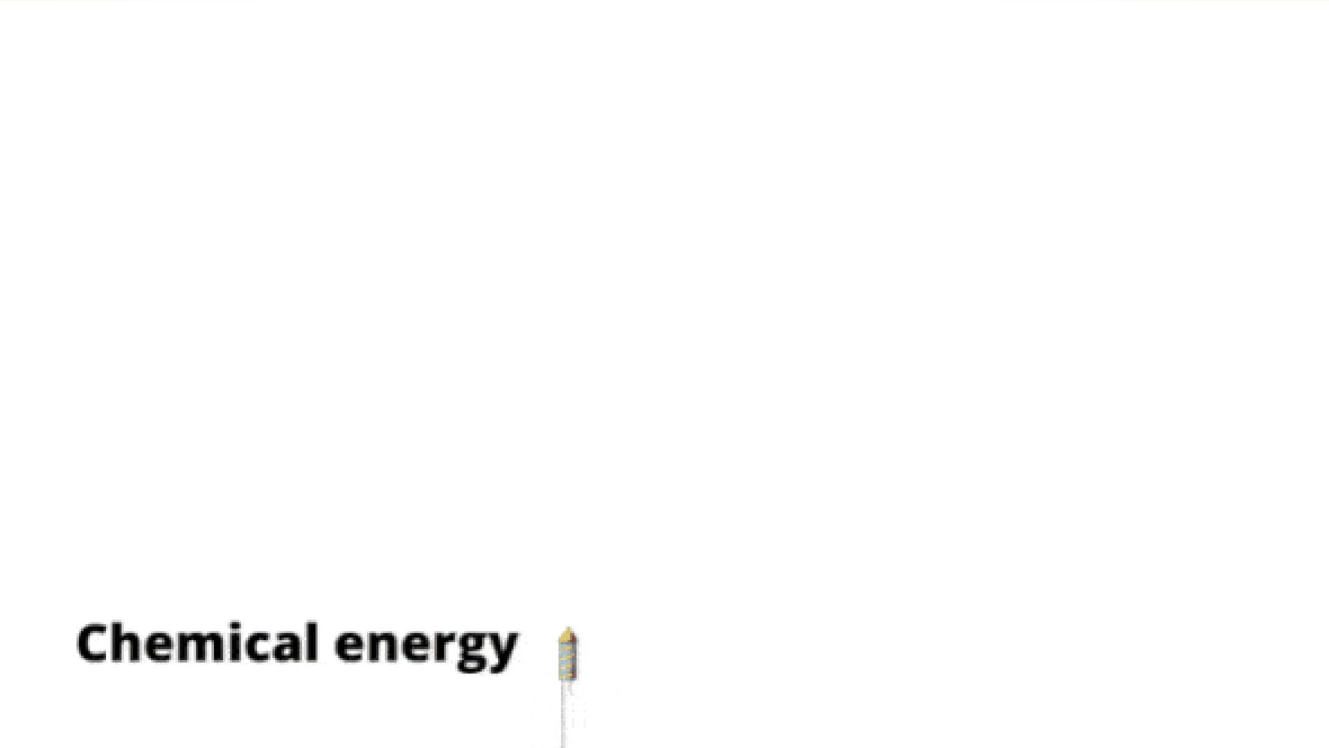
❖ The Zeroth Law of Thermodynamics

The Zeroth Law of Thermodynamics states that if two systems are in thermodynamic equilibrium with a third system, the two original systems are in thermal equilibrium with each other. If system A is in thermal equilibrium with system C and system B is also in thermal equilibrium with system C, system A, and system B are in thermal equilibrium with each other.



❖ 1st Law of Thermodynamics

The First Law of Thermodynamics states that energy can be converted from one form to another with the interaction of heat, work, and internal energy, but it cannot be created nor destroyed, under any circumstances.



❖ 2nd Law of Thermodynamics

The Second Law of Thermodynamics states that the state of entropy of the entire universe, as an isolated system, will always increase over time. The second law also states that the changes in the entropy in the universe can never be negative.

dQ=dU+dW

dq=Heat, dU= Internal Energy, dW = Work done

❖ 3rd Law of Thermodynamics

The 3rd law of thermodynamics will essentially allow us to quantify the absolute amplitude of entropies. It says that when we are considering a perfect (100% pure) crystalline structure, at absolute zero (0 Kelvin), it will have no entropy (S). Note that if the structure in question were not crystalline, then although it would only have an extremely small disorder (entropy) in space, we could not precisely say it had no entropy.

Temperature

- **Zeroth law of thermodynamics** enables us to define temperature:

• Temperature is the property that determines whether an object is in thermal equilibrium with another object.

• **Two objects in thermal equilibrium with each other are at the same temperature.**

• Conversely, if two objects have different temperatures, then they are not in thermal equilibrium with each

Heat and Internal Energy

- From the zeroth law: If there is a temperature difference there will be transfer of energy between them.

• **Heat**: ***Heat is the energy that is transferred across the boundary of a system due to a temperature difference between the system and its surroundings*** (i.e. between two objects).

Internal Energy

<u>Internal Energy</u>: ***Internal energy is all the energy of a system that is associated with its microscopic components—atoms and molecules***

- Bulk kinetic energy of the system due to its motion through space is not included in internal energy.
- The energy that are parts of internal energy are:

A. Kinetic energy of random translational, rotational, and vibrational motion of molecules.

B. Potential energy within molecules.

C. Potential energy between molecules.

Internal energy = Thermal (kinetic) energy + Potential

Heat	Temperature
Heat is a form of thermal energy	Temperature is the thermal state
Heat flows from hotter object to cooler object.	Temperature rises when heated and falls when cooled.
In the transmission of heat total amount of heat remain unchanged	In the transmission of heat temperature does not remain same.
Heat has the ability to do work.	Temperature can only be used to measure the intensity of heat.
S.I. unit is Joule (J)	S.I. unit is Kelvin (K)
Heat can be measured by Calorimeter	Temperature can be measured by Thermometer
Denoted by ‘Q’	Denoted by ‘T’

Types of thermometer

The following thermometers are usually recommended for measuring temperature.

1. Liquid thermometer
2. Gas thermometer
3. Resistance thermometer
4. Vapor-Pressure thermometer
5. Magnetic thermometer

Different scale of temperature

- To measure temperature with the help of a thermometer it is necessary to select scales of temperature. To select a scale two easily reproducible temperature are chosen. Which are called fixed points.

Lower Fixed Point

- At standard pressure the temperature at which pure ice beings to melt is known as lower fixed point or ice point.

Upper Fixed point

- At standard pressure the temperature at which pure water beings to become water vapor is known as upper fixed point or steam point.

- Consider the ice and steam point of a thermometer are θ_{ice} and θ_{steam} respectively and at that temperature the value may be X_{ice} and X_{steam}. If the other temperature being θ and the value at that property is X_θ then the temperature being

$$\frac{\theta - \theta_{ice}}{\theta_{steam} - \theta_{ice}} = \frac{X - X_{ice}}{X_{steam} - X_{ice}}$$

Fahrenheit Scale

The scale was introduced by Gabriel Daniel Fahrenheit in 1714

The scale in which **ice point** and **steam point** are taken as 32°F and 212°F respectively and the **fundamental interval** is equally divided into 180 divisions is called the Fahrenheit scale.

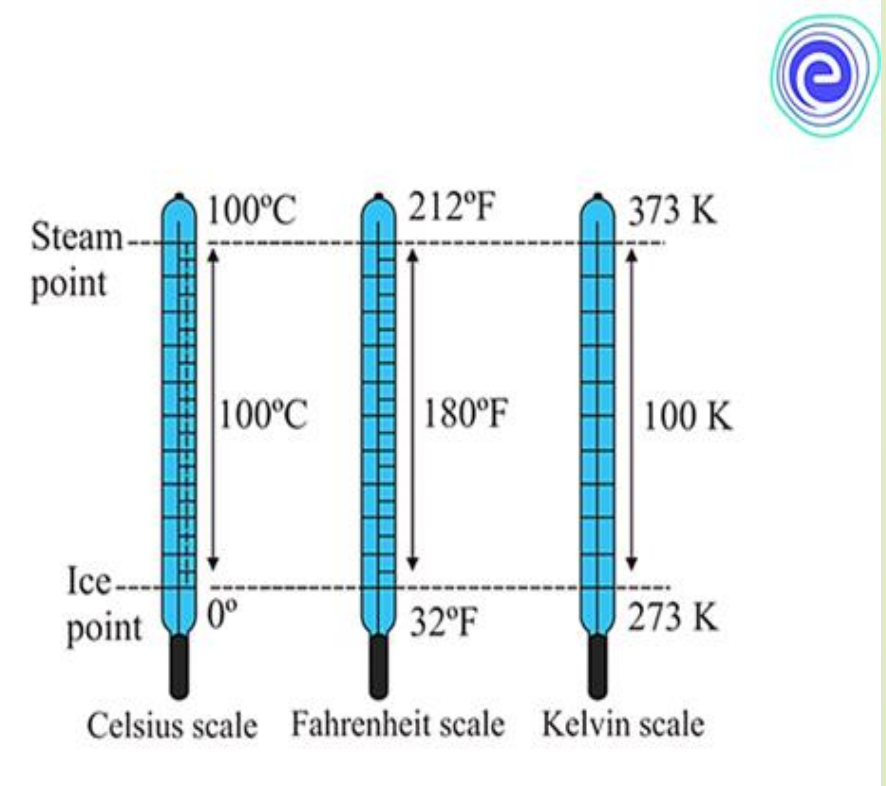
$$\frac{\theta - 32}{212 - 32} = \frac{X - X_{ice}}{X_{steam} - X_{ice}}$$

$$or, \theta = \frac{X - X_{ice}}{X_{steam} - X_{ice}} \times 180 + 32\ °F$$

Transformation Relation among Different Temperature Scales

They are many Temperature Conversion methods. Among them Kelvin, Celsius and Fahrenheit are the most commonly used methods.

According to Kelvin scale, the freezing point of water is 273.15K and the boiling point is 373.15K. According to Fahrenheit scale, the freezing point of water is 32^{o}F and the boiling point is 212^{o}F. According to Celsius scale, the freezing point of water is 0^{o}C and the boiling point is 100^{o}C.



Transformation Relation among Different Temperature Scales(Cont.)

So, the relationship may be stated as

$$\frac{S-M}{B-M}=\frac{C-0}{100-0}=\frac{F-32}{212-32}=\frac{K-273}{373-273}$$

$$or, \frac{C}{100}=\frac{F-32}{180}=\frac{K-273}{100}$$

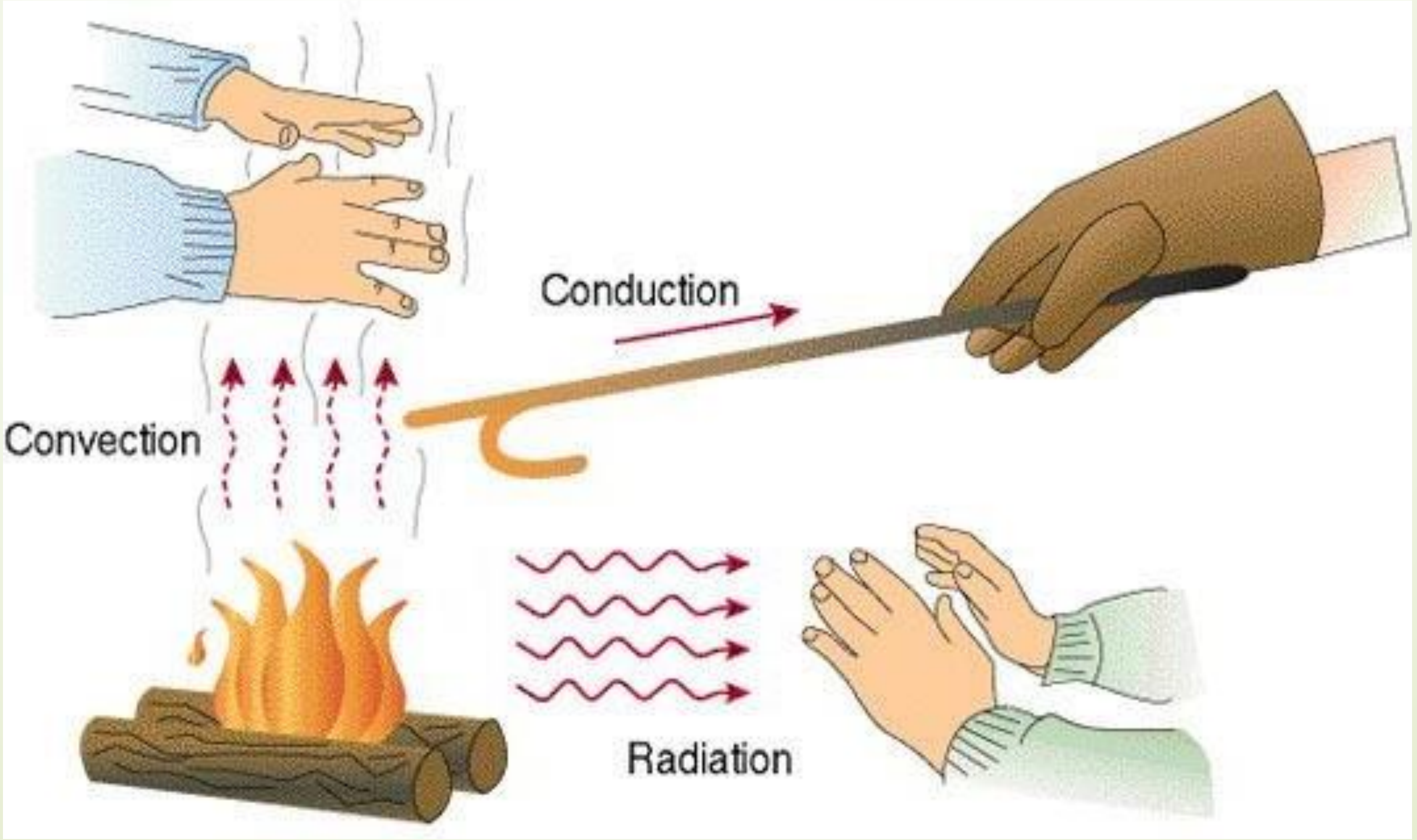
$$or, \frac{\boldsymbol{C}}{\mathbf{5}}=\frac{\boldsymbol{F}-\mathbf{32}}{\mathbf{9}}=\frac{\boldsymbol{K}-\mathbf{273}}{\mathbf{5}}$$

Problems

1. The boiling point of water is 100°C. What temperature does water boil at in the Fahrenheit scale?
2. Water freezes at 32°F. On the Celsius scale, what temperature is this?
3. At which temperature, Celsius and Fahrenheit thermometer show same measurement?

Mode of transmission of heat

There are three distinct modes by which heat may be transferred or propagate from one place to another place. These are i) Conduction ii) Convection and iii) Radiation

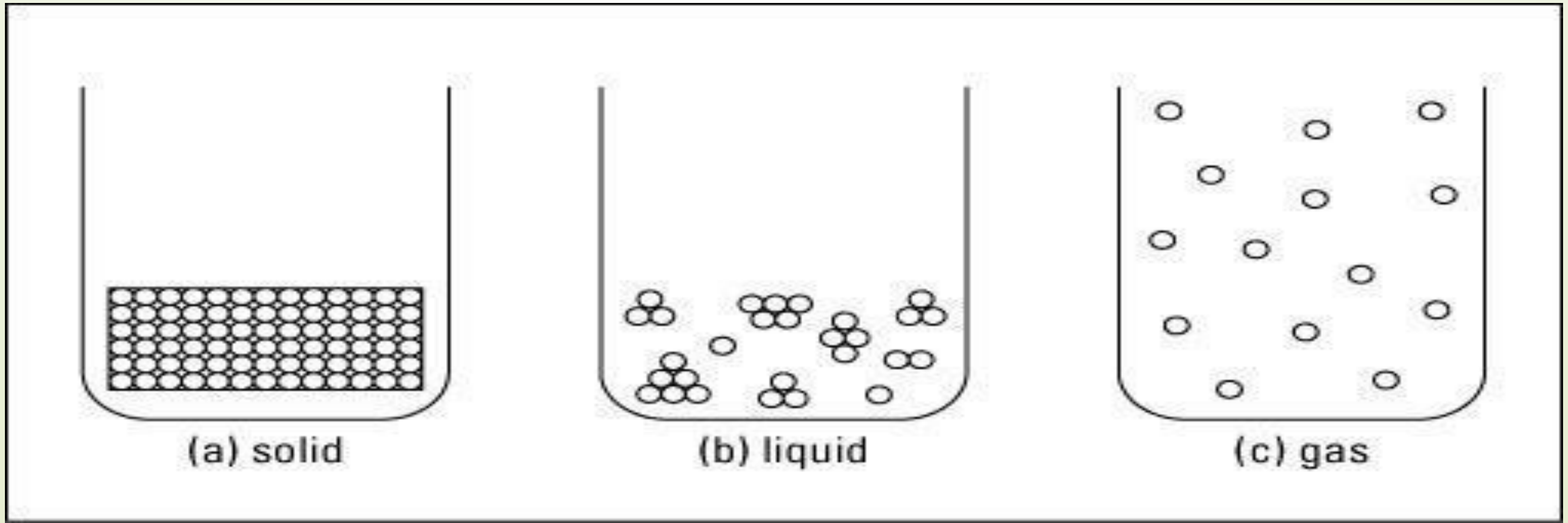


Conduction

- ***Thus conduction may be defined as the mode of transfer of heat in which heat energy travels from particles to particles in the direction of decreasing temperature without any bodily movement of the material particles from their normal positions.***
- Particles in contact with heat vibrate, pass energy through vibration to other particles

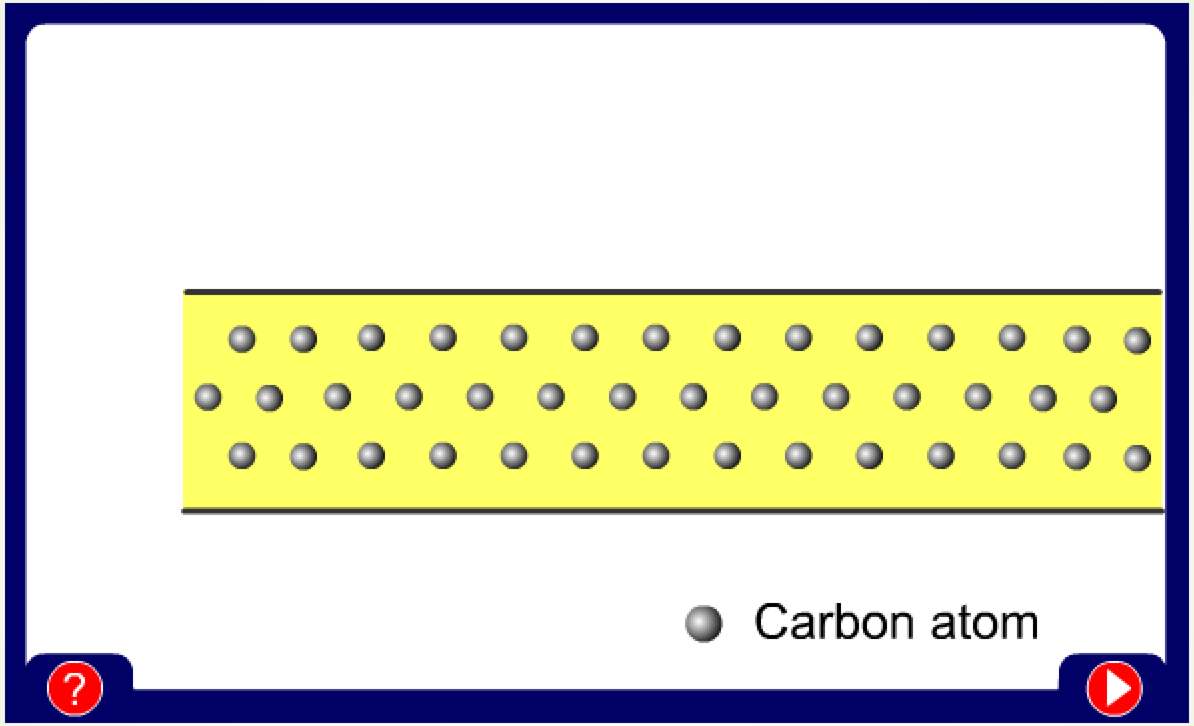
Why does conduction work BEST in solids?

- Conduction works best (most efficiently) when particles are in contact with each other
- Since in solids particles are touching, transfer is quicker; in liquids and gases, particles are further apart so transfer by conduction is more difficult



Conduction

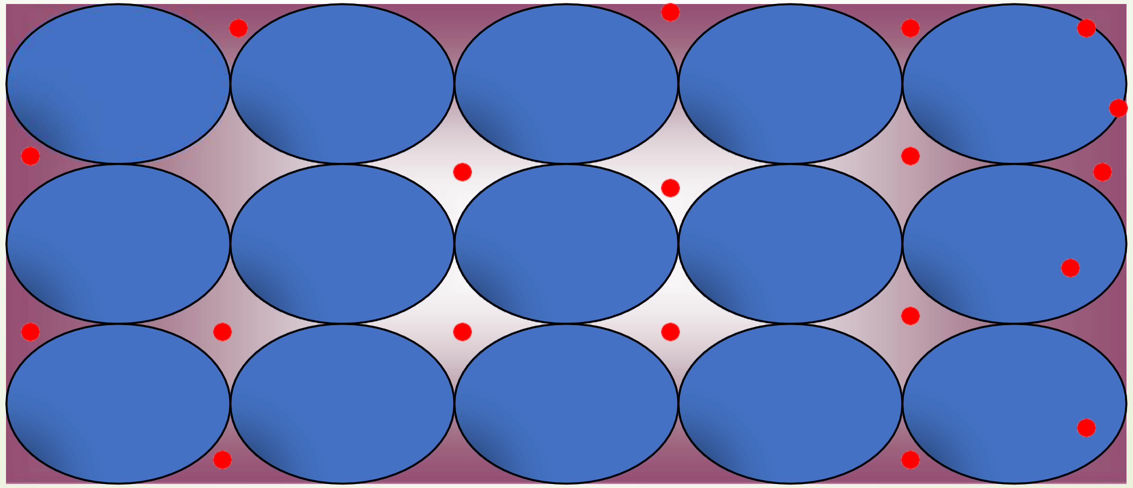
When you heat a metal strip at one end, the heat travels to the other end.



As you heat the metal, the particles vibrate, these vibrations make the adjacent particles vibrate, and so on and so on, the vibrations are passed along the metal and so is the heat. We call this? Conduction

Metals are different

The outer electrins of metal atoms drift, and are free to move. When the metal is heated, this ‘sea of electrons’ gain kinetic energy and transfer it throughout the metal.Insulators, such as wood and plastic, do not have this ‘sea of electrons’ which is why they do not conduct heat as well as metals.



Convection

- Heat transfer that occurs due to the **MOVEMENT** of particles
- Since **particles MUST move** for convection to take place, convection **DOES NOT OCCUR** in solids; it does occur in both **liquids and gases**
- As **energy increases**, particles move **further apart**, making the **substance less dense**
- ***<u>Convection</u>* is the mode of heat transfer in which the material particles conveying the heat are themselves carried from one place to another place until the whole mass of the substance becomes uniformly heated. Transmission of heat in liquids and gases take place in this manner by actual motion of the heated particles**

Transfer of heat by Radiation

- Transfer of heat energy by **electromagnetic waves**
- EM waves carry the thermal energy AWAY from the object with the higher energy (i.e. warmer object) to the object with lower energy (i.e. colder object)
- Can transfer heat through a medium OR through space
- Transmission of heat either by conduction or convection requires a material medium but there is yet another mode of transference of heat in which no material medium is needed.
- ***Radiation*** in the mode of transmission of heat in which the heat energy travels from the source of it to the recipient without any material medium taking part in it

The mechanism of heat flow by radiation

The mechanism of heat flow by radiation consists three distinct phases:

1. **Conversion of thermal energy of the hot source into electromagnetic waves.**

- Photons are propagated through the space as rays.

2. **Passage of wave motion through intervening space**

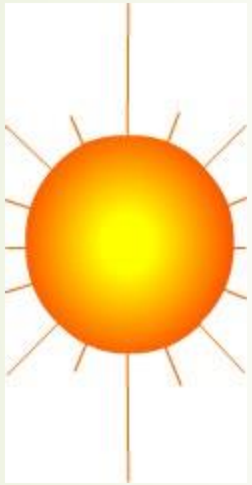
- Photons travel with unchanged frequency in straight paths with speed equal to that of light.

3. **Transformation of waves into heat.**

- Reconversion of wave motion into energy occurs in the receiving surface which may partly absorbed, reflected or transmitted through.

The third method of heat transfer

How does heat energy get from the Sun to the Earth?



?

There are no particles between the Sun and the Earth so it CANNOT travel by conduction or by convection.

RADIATION

Review-Mode of transmission of heat

Conduction	Convection	Radiation
In conduction, the heat transfer occurs in solid object.	In convection, the heat transfer occurs in fluid such as air and water	In radiation, the heat transfer occurs through electromagnetic waves.
In conduction, molecules of the medium do not leave their mean position.	In convection, molecules of the medium leave their mean position.	No medium is required.
The heat transfer takes place due to the difference in temperature.	The heat transfer occurs due to the difference density.	Radiation occurs in all object with temperature greater than 0 K.
The heat transfer in conduction is slow	The heat transfer in convection is faster than conduction.	The heat transfer in radiation is fastest.
It does not follow the law of reflection and refraction.	It does not follow the law of reflection and refraction.	It follows the law of reflection and refraction.

13th Week

Topic: Heat and thermodynamics-

Thermal Expansion of solid and liquid, Newton's law of cooling, Topic Related Problems

Page: 187- 200

Newton’s law of cooling

When a body is at high temperature than its surroundings it will go losing their until its temperature becomes equals to that of its surroundings. This loss of heat from the body is due to the process of conduction, Convection, and radiation. If conduction can be neglected by thermally lagging the body by an enclosed air layer or nonconducting materials like wood, cork etc., then cooling process will be partly due to the convection and partly due to radiation.

Newton’s law of cooling(Cont.)

The rate of loss of heat depends upon the following factors

i. The difference in the temperature of the body and that of the surroundings medium

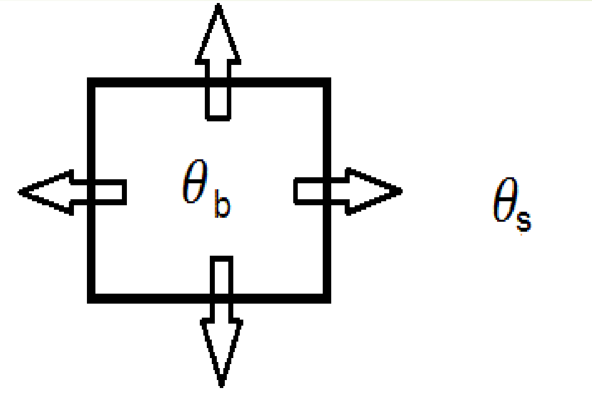
ii. The area of the surface exposed to the medium (the largest the area exposed to the air, more Rapid is the cooling)

iii. The nature of the expose surface or its emissive power (Emissive power is defined as a quantity of heat radiated from the surface per second per unit area per unit temperature difference with the surroundings

Newton's law of cooling(Cont.)

The rate of fall of heat of a body is directly proportional to the temperature difference between the body and its surroundings

$$-\frac{dQ}{dt} \propto (\theta_b - \theta_s)$$



$$\Rightarrow -\frac{dQ}{dt} = k(\theta_b - \theta_s)\text{-------(1),)}$$

K is proportionality constant and depends only upon the area and nature of the surface exposed.

We know that, $dQ = ms\ d\theta_b$ ------------(2)

Now combining (1) and (2) , We get

$$\Rightarrow -\frac{ms\ d\theta_b}{dt} = k(\theta_b - \theta_s$$

Newton's law of cooling(Cont.)

$$\Rightarrow \frac{d\theta_b}{dt} = -\frac{k}{ms}(\theta_b - \theta_s)$$

$$\Rightarrow \frac{d\theta_b}{(\theta_b - \theta_s)} = -\frac{k}{ms}dt$$

$$\Rightarrow \frac{d\theta_b}{(\theta_b - \theta_s)} = -c\ dt$$

Integrating both side we get, $\int \frac{d\theta_b}{(\theta_b - \theta_s)} = \int -c\ dt$

$$\Rightarrow \ln(\theta_b - \theta_s) = -ct + \mathrm{k}$$

$$\Rightarrow (\theta_b - \theta_s) = e^{-ct+k}$$

$$\Rightarrow (\theta_b - \theta_s) = e^{-ct}e^{k}$$

Newton's law of cooling(Cont.)

$$\Rightarrow (\theta_b - \theta_s) = De^{-ct} \quad (e^k = D)$$

$$\Rightarrow \theta_b\ (t) = \theta_s + De^{-ct} \ \ldots\ldots\ldots(3)$$

Now at the initial point, t = 0

Then, $\theta_b(0) = \theta_0$ and from equation (3)

$$\therefore (\theta_0 - \theta_s) = D$$

Putting the value of D in eq.(3) We get,

$$\therefore\ \theta_b\ (\mathrm{t}) = \theta_s + (\theta_0 - \theta_s)\ e^{-ct}$$

Newton's law of cooling(Cont.)

Where

t = time,

θ_b (t) = temperature of the given body at time t,

θ_s = surrounding temperature,

θ_0= initial temperature of the body,

k = constant.

Problem 01

A Liquid takes 5 minutes to cool from 80 ° C to 50° C. How much time will it take to cool from 60 ° C to 30 ° C ?The temperature surroundings is 20° C

Integrating $\frac{d\theta_b}{(\theta_b - \theta_s)} = -c\,dt$ between proper limit we have

$$\Rightarrow \int_{\theta_1}^{\theta_2} \frac{d\theta_b}{(\theta_b - \theta_s)} = \int_0^t -c\,dt$$

In the first case , θ_1= 80 ° C , θ_2 =50° C, θ= 20° C and t=5 minutes

$$\Rightarrow \int_{80}^{50} \frac{d\theta_b}{(\theta_b - \theta_s)} = -5c$$

$$\Rightarrow \ln(\theta_b - \theta_s)_{80}^{50} = -5c$$

$$\Rightarrow \ln(50 - 20) - \ln(80 - 20) = -5c$$

$$\therefore \ln\left(\frac{50-20}{80-20}\right) = \ln\left(\frac{30}{60}\right) = \ln\left(\frac{60}{30}\right) = \ln(2) = 5c \text{ ----------(i)}$$

In the 2nd case , θ_1= 60 ° C , θ_2 =30° C, θ= 20° C and t= ?

$$\Rightarrow \int_{60}^{30} \frac{d\theta_b}{(\theta_b - \theta_s)} = -tc$$

$$\Rightarrow \ln\,(\theta_b - \theta_s)_{60}^{30} = -tc$$

$$\Rightarrow \ln\,(30-20) - \ln\,(60-20) = -tc$$

$$\therefore \ln\left(\frac{30-20}{60-20}\right) = \ln\left(\frac{10}{40}\right) = \ln\left(\frac{40}{10}\right) = \ln(4) = tc \text{ ----------(ii)}$$

Dividing (ii) by (i), We get

$$\Rightarrow \frac{t}{5} = \frac{\ln(4)}{\ln(2)} = 2$$

$\therefore$t= 5×2 = 10 minutes

Problem 02: A Liquid takes 4 minutes to cool from 65°C to 50°C.What will be temperature after the next 10 minutes. The temperature of the surroundings is 35 °C .Assume that Newton's law of cooling hoods good throughout the process

Answer: 37.65 °C

Problem 03: A body initially at 80 °C cools to 64 °C in 5 minutes and to 52 °C in 10 minutes. What will be its temperature after 15 minutes and what is the temperature of surroundings

Answer: 43 °C

Thermal Expansion of Solids and Liquids

When the temperature of an object is changed by an amount ΔT, its length changes by an amount ΔL that is proportional to ΔT and to its initial length L_i.

$$\Delta L \text{ a } L_i \Delta T$$

$$\Delta L = \alpha L_i \Delta T \quad \text{or} \quad \alpha = \frac{\Delta L}{L\ \Delta T}$$

Where the proportionality constant α is the **average coefficient of linear expansion** for a given material and has units of $(^{o}C)^{-1}$.

The change in volume is proportional to the initial volume $V_i$and to the change in temperature according to the relationship

$$\Delta V = \beta V_i \Delta T$$

where the **average coefficient of volume expansion** Q for a solid is approximately equal to 3α.

To prove: $\beta = 3\alpha$:

$$V_i + \Delta V = (\ell + \Delta\ell)(w + \Delta w)(h + \Delta h)$$
$$= (\ell + \alpha\ell\,\Delta T)(w + \alpha w\,\Delta T)(h + \alpha h\,\Delta T)$$
$$= \ell w h(1 + \alpha\,\Delta T)^3$$
$$= V_i[1 + 3\alpha\,\Delta T + 3(\alpha\,\Delta T)^2 + (\alpha\,\Delta T)^3]$$

Dividing both sides by V_i and isolating the term $\Delta V/V_i$, we obtain the fractional change in volume:

$$\frac{\Delta V}{V_i} = 3\alpha\,\Delta T + 3(\alpha\,\Delta T)^2 + (\alpha\,\Delta T)^3$$

Because $\alpha\,\Delta T << 1$ for typical values of ΔT ($< \sim 100°C$), we can neglect the terms $3(\alpha\,\Delta T)^2$ and $(\alpha\,\Delta T)^3$. Upon making this approximation, we see that

$$\frac{\Delta V}{V_i} = 3\alpha\,\Delta T \quad \rightarrow \quad \Delta V = (3\alpha)V_i\,\Delta T$$

Comparing this expression to $\Delta V = \beta V_i \Delta T$ shows that $\beta = 3\alpha$

An Example:

A student eats a dinner rated at 2 000 Calories. He wishes to do an equivalent amount of work in the gymnasium by lifting a 50.0-kg barbell. How many times must he raise the barbell to expend this much energy? Assume he raises the barbell 2.00 m each time he lifts it and he regains no energy when he lowers the barbell.

(1) $\Delta U_{\text{total}} = W_{\text{total}}$

the change in gravitational potential energy $\Delta U = mgh$

barbell n times, (2) $\Delta U_{\text{total}} = nmgh$

$$nmgh = W_{\text{total}}$$

$$n = \frac{W_{\text{total}}}{mgh}$$

$$n = \frac{(2\ 000\ \text{Cal})}{(50.0\ \text{kg})(9.80\ \text{m/s}^2)(2.00\ \text{m})}\left(\frac{1.00 \times 10^3\ \text{cal}}{\text{Calorie}}\right)\left(\frac{4.186\ \text{J}}{1\ \text{cal}}\right)$$

$$= 8.54 \times 10^3\ \text{times}$$

Specific Heat

- The **heat capacity** *C* of a particular sample is defined as the amount of energy needed to raise the temperature of that sample by 1°C. From this definition, we see that if energy *Q* produces a change Δ*T* in the temperature of a sample, then

$$C = \frac{Q}{\Delta T}$$

- The **specific heat** *c* of a substance is the heat capacity per unit mass. Therefore, if energy *Q* transfers to a sample of a substance with mass *m* and the temperature of the sample changes by Δ*T*, the specific heat *c* of the substance is

$$c = \frac{Q}{m\Delta T} \qquad or \qquad Q = mc\Delta T$$

- For example, the energy required to raise the temperature of 0.500 kg of water by 3.00°C is $Q =$ (0.500 kg)(4 186 J/kg .°C)(3.00°C) = 6.28×10^3 J.

14^{th} Week

Topic: Heat and thermodynamics-

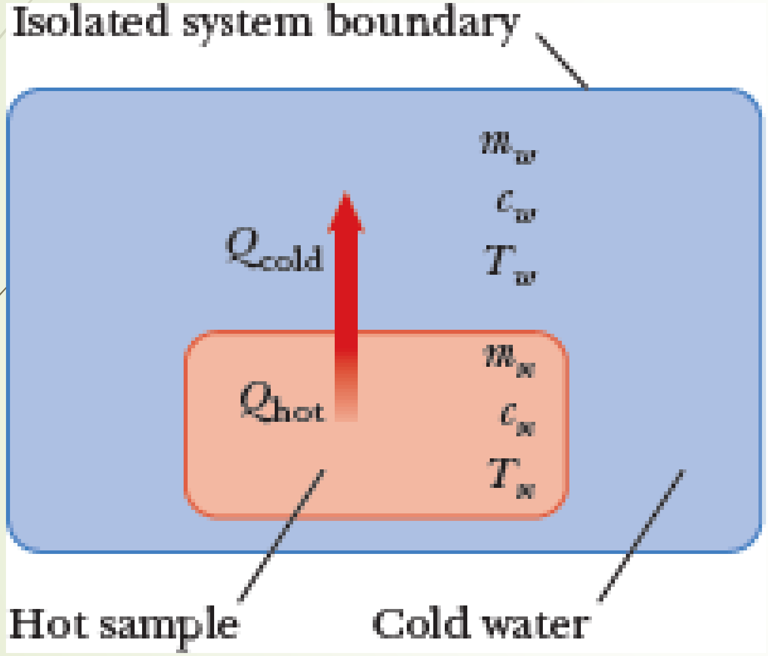
Stefan's law, Boltzmann's law, Black body, Heat Engine, Carnot Engine

Topic Related Problems

Page: 201- 209

❖ Calorimetry

Calorimetry is the branch of science concerned with the measurement of the amount of heat released or absorbed during chemical reactions, physical changes, or phase transitions.



One technique for measuring specific heat involves heating a sample to some known temperature T_x, placing it in a vessel containing water of known mass and temperature $T_w < T_x$, and measuring the temperature of the water after equilibrium has been reached. This technique is called **calorimetry,** and devices in which this energy transfer occurs are called **calorimeters.**

$$Q_{cold} = -Q_{hot} \quad or$$

$$m_w c_w (T_f - T_W) = -m_x c_x (T_f - T_x)$$

Example

A 0.0500 kg ingot of metal is heated to 200.0°C and then dropped into a calorimeter containing 0.400 kg of water initially at 20.0°C. The final equilibrium temperature of the mixed system is 22.4°C. Find the specific heat of the metal.

Solution:

$$m_w c_w (T_f - T_w) = -m_x c_x (T_f - T_x)$$

$$c_x = \frac{m_w c_w (T_f - T_w)}{m_x (T_x - T_f)}$$

$$c_x = \frac{(0.400 \text{ kg})(4\,186 \text{ J/kg} \cdot {}^\circ\text{C})(22.4^\circ\text{C} - 20.0^\circ\text{C})}{(0.050\,0 \text{ kg})(200.0^\circ\text{C} - 22.4^\circ\text{C})}$$

$$= 453 \text{ J/kg} \cdot {}^\circ\text{C}$$

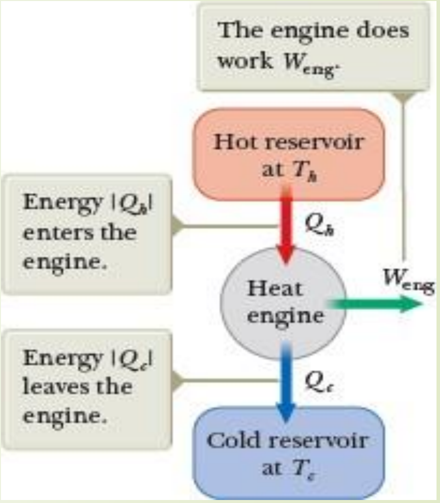
❖ Heat Engine:

A heat engine carries some working substance through a cyclic process during which

(1)the working substance absorbs energy by heat from a high- temperature energy reservoir,

(2) work is done by the engine, and

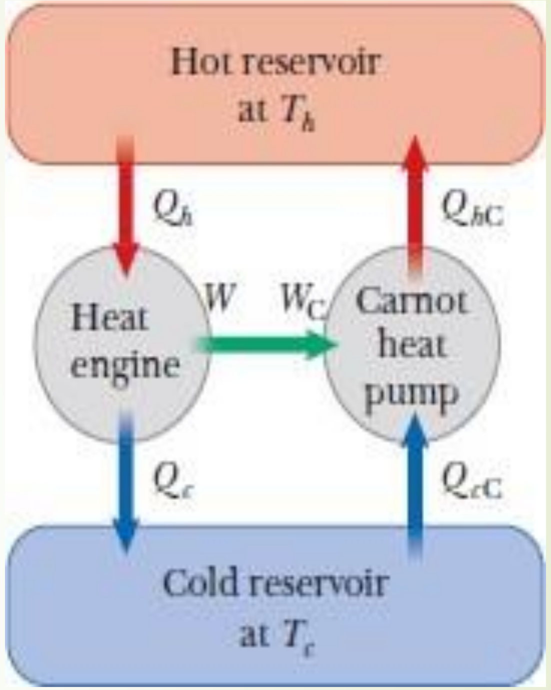
(3)energy is expelled by heat to a lower-temperature reservoir.



The engine absorbs a quantity of energy $|Q_h|$ from the hot reservoir. For the mathematical discussion of heat engines, we use absolute values to make all energy transfers by heat positive. The engine does work W_{eng} (so that *negative* work $W=-W_{eng}$ is done *on* the engine) and then gives up a quantity of energy $|Q_c|$ to the cold reservoir.

❖ The Carnot Engine (a theoretical engine)

A heat engine carries some working substance through a cyclic process during which the working substance absorbs energy by heat from a high- temperature energy reservoir, work is done by the engine, and energy is expelled by heat to a lower-temperature reservoir. A heat engine operating in an ideal, reversible cycle—called a Carnot cycle



In this cycle between two energy reservoirs is the most efficient engine possible. Such an ideal engine establishes an upper limiton the efficiencies of all other engines. Carnot's theorem can be stated as follows: No real heat engine operating between two energy reservoirs can be more efficient than a Carnot engine operating between the same two reservoirs. The thermal efficiency of a heat engine operating in the Carnot cycle is

Problem –HE-01:

2.00×10^3 J of energy from a hot reservoir during a cycle and transfers 1.50×10^3 J as exhaust to a cold reservoir.

(A) Find the efficiency of the engine. **(B)** How much work does this engine do in one cycle?

SOLUTION **(A)**

$$e = 1 - \frac{|Q_c|}{|Q_h|} = 1 - \frac{1.50 \times 10^3\ \text{J}}{2.00 \times 10^3\ \text{J}} = 0.250, \text{ or } 25.0\%$$

SOLUTION **(B)**

$$W_{\text{eng}} = |Q_h| - |Q_c| = 2.00 \times 10^3\ \text{J} - 1.50 \times 10^3\ \text{J}$$

$$= 5.0 \times 10^2\ \text{J}$$

Stefan's law,

The rate at which the surface of an object radiates energy is proportional to the fourth power of the absolute temperature of the surface. Known as **Stefan's law,** this behavior is expressed in equation form as

$$P = \sigma A e T^4$$

where P is the power in watts of electromagnetic waves radiated from the surface of the object, σ is a constant equal to $5.6696 \times 10^{-8} W/m^2 . K^4$, A is the surface area of the object in square meters, e is the **emissivity,** and T is the surface temperature in kelvins. The value of e can vary between zero and unity depending on the properties of the surface of the object.

The **Boltzmann Law**

The **Boltzmann Law** (or **Boltzmann Distribution Law**) is a fundamental principle in statistical mechanics that describes how particles in a system are distributed among available energy states at a given temperature.

Statement of Boltzmann Law

The probability of a particle being in a state with energy E is proportional to the Boltzmann factor:

$$P(E) \propto e^{-E/k_B T}$$

where:E: Energy of the state

B : Boltzmann constant (1.38×10−23 J/K1.38×10 −23 J/K).

T: Absolute temperature in kelvins. This law shows that higher-energy states are exponentially less likely to be occupied as their energy increases.

Applications of Boltzmann Law

1. **Maxwell-Boltzmann Distribution**:
   1. Describes the velocity distribution of particles in an ideal gas.
2. **Energy Distribution**:
   1. Explains how particles are distributed among different energy levels, such as in atoms or molecules.
3. **Thermal Radiation**:
   1. Forms the basis for the derivation of the Stefan-Boltzmann law and blackbody radiation.
4. **Chemical Reactions**:
   1. Helps calculate reaction rates by estimating how many molecules have sufficient energy to overcome activation barriers

14th Week

Topic: Heat and thermodynamics -

Refrigerator, Thermoelectricity, order, Disorder, Entropy, Topic Related Problems

Topic Related Problems

Page: 210- 215

Refrigerator

A **refrigerator** is a heat pump that transfers heat from a cooler region (inside the fridge) to a warmer region (the surrounding environment) by doing work on the system.

Working Principle:

Based on the **Second Law of Thermodynamics**, which states that heat naturally flows from hot to cold, but work can be used to reverse this.

Refrigerators use a **cyclic process** involving compression, condensation, expansion, and evaporation of a refrigerant.

Coefficient of Performance (COP):

$COP = Q_c/W$

where Q_c is the heat removed from the cold space and W is the work done

Thermoelectricity

Thermoelectricity involves the direct conversion between thermal energy and electrical energy through effects like:

•**Seebeck Effect**:

- A temperature difference between two dissimilar conductors generates a voltage.
- Used in thermoelectric generators.

•**Peltier Effect**:

- Passing an electric current through a junction of two materials either absorbs or releases heat, depending on the direction of the current.
- Used in thermoelectric coolers (TEC).

•**Thomson Effect**:

- Heat is absorbed or released along a conductor with a temperature gradient when a current flows.

•**Applications**:

- Power generation in space probes.
- Cooling systems in electronics.

- **Order and Disorder**:
  - Order represents a highly structured and predictable arrangement (e.g., crystals).
  - Disorder represents randomness or unpredictability (e.g., gases mixing).
- **Entropy (S)**:
  - A measure of disorder or randomness in a system.
  - **Second Law of Thermodynamics**: In an isolated system, entropy tends to increase, indicating that natural processes move toward greater disorder.
- **Mathematical Definition**:
  - For a reversible process:

$$\Delta S = \int \frac{\delta Q_{\text{rev}}}{T}$$

    where δQ_{rev} is the reversible heat transfer and T is the temperature.
- **Microscopic Interpretation**:
  - $S = k_B \ln \Omega$, where:
    - k_B: Boltzmann constant.
    - Ω: Number of microstates of the system.

1. **Refrigerator Efficiency**:

   - A refrigerator removes 300 J of heat from its interior while consuming 100 J of work. Calculate its COP.
     Solution:

$$\text{COP} = \frac{Q_c}{W} = \frac{300}{100} = 3$$

2. **Entropy Change in Mixing**:

   - Two gases, each 1 mole at T and P, are allowed to mix. Calculate the entropy change.
     Solution:

$$\Delta S = -nR(\ln x_1 + \ln x_2)$$

   where x_1, x_2 are mole fractions.

3. **Thermoelectric Peltier Effect**:

   - If a Peltier cooler requires 5 A of current and a voltage of 2 V to maintain a temperature difference of 40 K, calculate the power consumption.
     Solution:

$$P = IV = 5 \times 2 = 10\,\text{W}$$

4. **Entropy in Phase Change**:

   - Calculate the entropy change when 1 kg ice melts at 0°C. Latent heat of fusion of ice = 334,000 J/kg.

Difference between refrigerator and heat engine

Refrigerator	Heat engine
Heat extraction (transfers heat from a cold reservoir to a hot reservoir).	Heat conversion (converts heat energy from a hot reservoir into useful work).
Requires external work input (consumes energy).	Produces work output (generates energy).
Reversed thermodynamic cycle (e.g., reversed Carnot cycle or vapor-compression cycle).	Direct thermodynamic cycle (e.g., Carnot, Otto, Diesel cycle).
Requires work to transfer heat against the natural direction (cold to hot).	Cannot convert all heat into work; some heat must be rejected to the cold reservoir.
Refrigerators, air conditioners, heat pumps.	Internal combustion engines, steam turbines, jet engines.

16 &17 th Week

Topic:

Review the whole Topic of this Course


Any Question ?

The End


شكراً جزيلاً
ngiyabonga
рахмат
danke
謝謝
teşekkür ederim
Баярлалаа
mersi
kia ora
barka
welalin
tack
spas
mahalo
tapadh leat
спасибо
faafetai lava
vinaka
спасибі
blagodaram
dank je
misaotra
matondo
paldies
grazzi
gracias
thank you
kiitos
dankie
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dhanyavad
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