Unit - 18

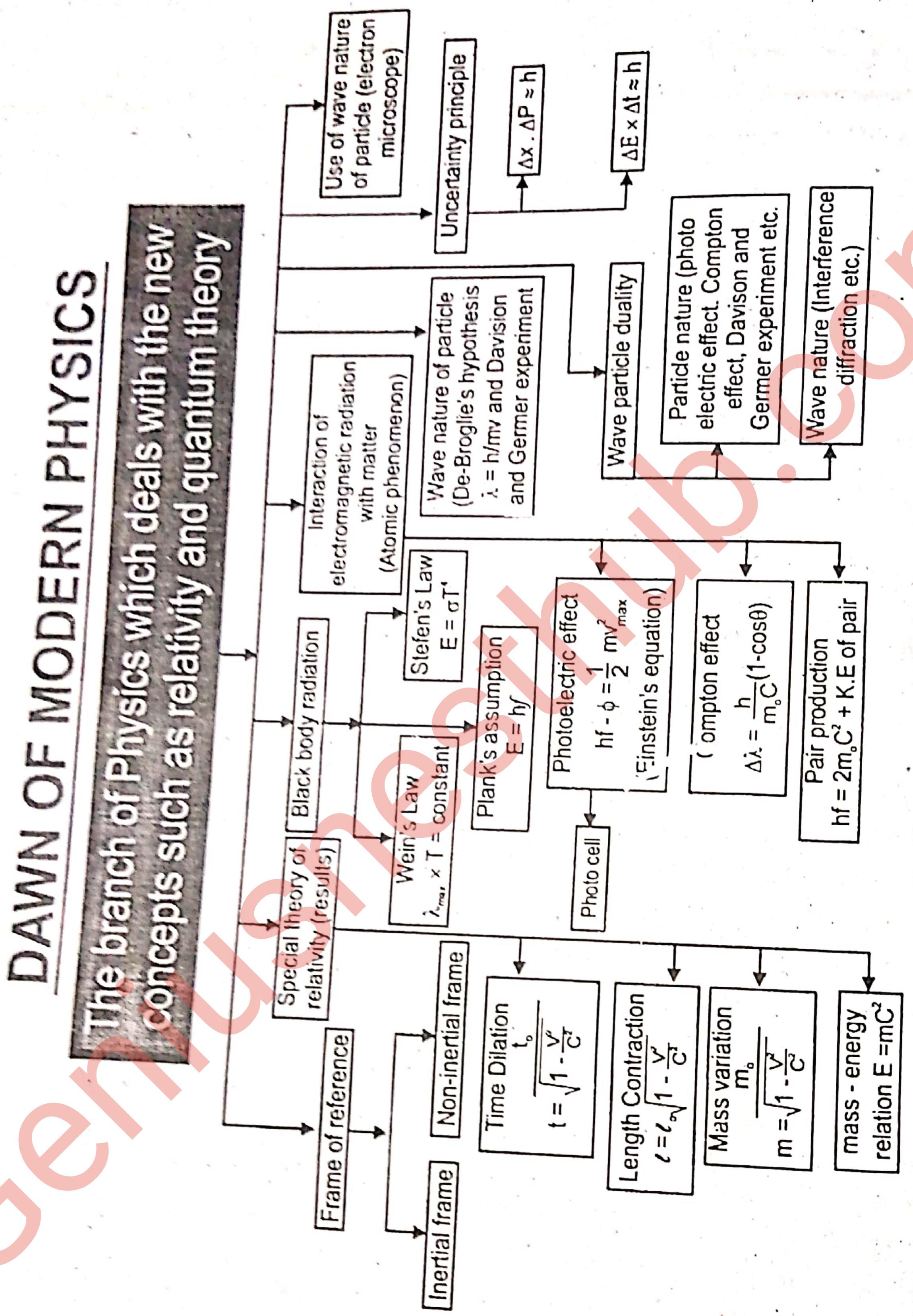
DAWN OF THE MODERN PHYSICS

Learning Objectives

After studying this chapter the students will be able to

- Distinguish between inertial and non-inertial frames of reference.
- Describe the significance of Einstein's assumption of the constancy of the speed of light.
- Identify that if *c* is constant then space and time become relative.
- Explain qualitatively and quantitatively the consequence of special relativity in relation.
  - the relativity of simultaneity
  - the equivalence between mass and energy
  - length contraction
  - time dilation
  - mass increase
- Explain the implications of mass increase, time dilation and length contraction for space travel.
- Describe the concept of black body radiation.
- Describe how energy is distributed over the wavelength range for several values of source temperature.
- Describe the Planck's hypothesis that radiation emitted and absorbed by the walls of black body cavity is quantized.
- Elaborate the particle nature of electromagnetic radiation.
- Describe the phenomenon of photoelectric effect.
- Solve problems and analyze information using $E = hf$ and $c = f\lambda$.
- Identify data sources, gather, process and present information to summarize the use of the photoelectric effect in solar cells & photocells.
- Describe the confirmation of de Broglie's proposal by Davisson and Germer experiment in which the diffraction of electrons by the surface layers of a crystal lattice was observed.
- Describe the impact of the Broglie's proposal that any kind of particle has both wave and particle properties.
- Explain the particle model of light in terms of photons with particular energy and frequency.
- Describe Compton effect qualitatively.
- Explain the phenomena of pair production and pair annihilation.
- Electrons and magnetic fields to focus them, allows electron microscope to describe uncertainty principle.
- Describe uncertainty principle.

CONCEPT MAP


DAWN OF MODERN PHYSICS
The branch of Physics which deals with the new concepts such as relativity and quantum theory
Frame of reference
Inertial frame
Non-inertial frame
Special theory of relativity (results)
Time Dilation $t = \frac{t_o}{\sqrt{1-\frac{v^2}{c^2}}}$
Length Contraction $\ell = \ell_o\sqrt{1-\frac{v^2}{c^2}}$
Mass variation $m = \frac{m_o}{\sqrt{1-\frac{v^2}{c^2}}}$
mass - energy relation $E = mC^2$
Black body radiation
Wein's Law $\lambda_{max} \times T = constant$
Plank's assumption $E = hf$
Stefen's Law $E = \sigma T^4$
Interaction of electromagnetic radiation with matter (Atomic phenomenon)
Photoelectric effect $hf - \phi = \frac{1}{2} mv^2_{max}$ (Einstein's equation)
Photo cell
Compton effect $\Delta\lambda = \frac{h}{m_oC}(1-\cos\theta)$
Pair production $hf = 2m_oC^2 + K.E$ of pair
Wave nature of particle (De-Broglie's hypothesis $\lambda = h/mv$ and Davision and Germer experiment
Wave particle duality
Particle nature (photo electric effect, Compton effect, Davison and Germer experiment etc.
Wave nature (Interference diffraction etc.)
Uncertainty principle
$\Delta x . \Delta P \approx h$
$\Delta E \times \Delta t \approx h$
Use of wave nature of particle (electron microscope)

CLASSICAL PHYSICS:

The branch of physics which is based on Newton's Laws and Maxwell's electromagnetic equations is called Classical Physics.

1. **Newton's Law:** Using Newton's Laws we can explain falling bodies, Projectiles, Earth satellites, the motion of planets and the motion of other macroscopic bodies. Newtonian mechanics gives us the laws of conservation of energy, momentum and angular momentum. Newton's law combined with molecular theory of matter provides kinetic theory of heat.
2. **Maxwell's Equations:** Maxwell's equation unify the subjects of electricity and magnetism to electromagnetism. Moreover, these equation predict the existence of electromagnetic waves and explain that light waves are electromagnetic in nature.

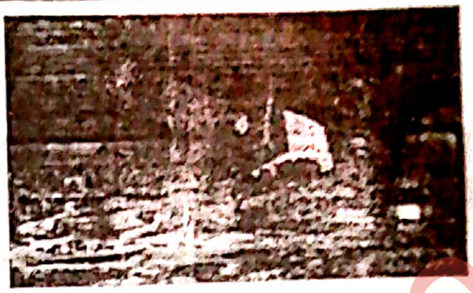
MODERN PHYSICS:

The branch of physics Based on theory of relativity and quantum mechanics is known as modern physics.

Modern physics came with 20th century and took over where Newtonian physics had fallen short. At the beginning of 20th century, a series of experimental results were observed which could not be explained on the basis of the existing laws of physics. There experimental results were concerned with extremely small objects and high velocities. After tremendous hard work and thinking a new mechanics called quantum mechanics was established. Quantum mechanics is more basic and more general then Newtonian mechanics

Therefore relativity and quantum mechanics are the two great theories of modern physics which help us in understanding atomic and nuclear phenomenon. Some of the experimental result which could not be experiment (the constancy of the velocity of light in free space), photoelectric effect, Compton Effect, stable atomic structure, line spectra of atomic radiation, black body radiation spectrum and radioactivity.

For your Information



A GPS satellite is a satellite used by the NAVSTAR Global Positioning System (GPS) (Navigation System using Timing And Ranging). The Global Positioning System (GPS) is a space-based satellite navigation system that provides location and time information in all weather conditions, anywhere on or near the Earth. According to relativity theory, a moving clock appears to run slow with respect to a similar clock that is at rest. The satellites are constantly moving relative to observers on the Earth which causes them to run at a slightly faster rate than do clocks on the Earth's surface. A calculation using General Relativity predicts that the clocks in each GPS satellite should get ahead of ground-based clocks by 45 microseconds per day. So the role of special theory of relativity is important in Global poisoning system.

Reference Frames

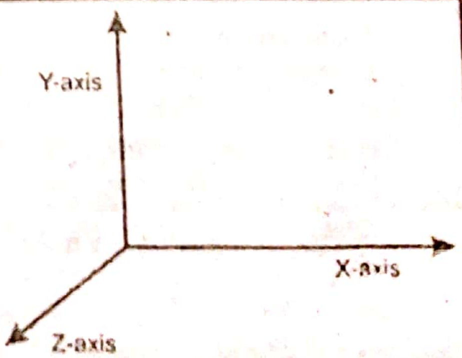
Q.1 Define and Explain the Frame of Reference. Also Discuss Inertial and Non-Inertial Frame of Reference.

Frame of Reference

Any coordinate system relative to which the measurements are taken is called frame of reterance.

For example

- The position of the table in a room can be located relative to the walls of the room. The room is then frame of reference.
- For measurements taken in the college laboratory, the laboratory is the reference frame.
- If the experiment is performed in moving train, the train is the frame of reference.
- The position of spaceship can be described by the reference of the position of distant start. The coordinate system based on these stars is then frame of reference.



Coordinate axis

Inertial Frame of Reference

The frame which is at rest or moving with uniform velocity ($a = 0$) is called inertial frame of reference or non-accelerated frame of reference.

For such a frame, the law of inertia must hold. According to which, a body remains at rest or moving with uniform velocity unless an unbalanced force produces the acceleration in it. Any frame of reference which is moving with uniform velocity relative to an inertial frame is also an inertial frame.

Examples

- Earth may be considered as an inertial frame of reference.
- A body places in a car moving with uniform velocity with respect to earth also remains at rest, that car is also an inertial frame of reference.

Non-Inertial Frame of Reference:

A frame of reference moving with variable velocity is called non-inertial frame of reference. ***[or]***
An accelerated frame of reference is called non-inertial or accelerated frame of reference.

Examples

- When a car is moving and suddenly the brakes are applied. Then the body placed in it no longer remains at rest. So due to acceleration car is an accelerated frame of reference.
- Earth is rotating and revolving and hence *strictly speaking, the earth is not an inertial frame.* But it can often be treated an inertial frame without serious error because of very small acceleration.

▶ **Any reference frame that moves with constant velocity with respect to an inertial frame is itself inertial;** if the acceleration of a body in one inertial frame is zero, its acceleration in any of the other inertial frames is also zero.

Q.2 What is Special Theory of Relativity and discuss its Results.

Special theory of Relativity

In 1905 Einstein presented his famous special theory of relativity in his research paper entitled, "On the electro-dynamics of moving body", which is defined as: The part of relativistic mechanics which deals with uniform motion of object is called special theory of relativity. The special theory of relativity is based on the following two postulates.

> **Check Point**
>
> **Q. What happens to the density of an object as its speed increases?**
>
> **Ans:** The density of an objects increases, because to special theory of relativity, mass of an object increases while length of an object decreases when its speed increases as a result volume (L^3) decreases.
>
> $\rho = \frac{m}{V} = \frac{m}{L^3}$ ∴ density increases

1. Principle of equivalence:

The laws of physics are the same in all inertial frame of references.

They may be expressed in the same set of equations in all inertial frame of reference.

Explanation: The principle of relativity was first of all detected by Galileo which states that, it is not possible to detect uniform motion by performing an experiment in an inertial frame of reference. For example, if you are moving in a spacecraft far away from any planet, star or any other planet, then you cannot detect that you are moving. The only way to detect the motion of inertial frame of reference it is necessary to refer to n other frame of reference by considering relative motion.

2. Principle of the constancy of the speed of light:

The speed of light "c" in vacuum is universal constant, the speed of light in vacuum is the same in all inertial frames and is independent of the motion of source and observe.

Explanation: This postulate stressing on the constancy of the speed of light in vacuum. Let you are sitting in a train facing forward and the train is moving with a speed of light. You hold a mirror in front of you at arm's length; will you be able to see your reflection in mirror? Yes the reflection will be seen, because there is no relative motion between you and the mirror. You and the mirror are both moving with the same constant speed C. It is not possible for any person to detect the uniform motion with which he or she is travelling in the same frame.

Q.3 What are consequences of the special theory of relativity.

(i) The relativity of simultaneity.

(ii) The Equivalence Between Mass and Energy.

The relativity of simultaneity

The two events occurring at different places in the observer frame of reference are observed simultaneously by the observer.

- But it will not be observed simultaneously by another observer in another frame of reference moving with relative motion.
- For examples consider a train fitted with light operated doors. The light source is in the center of the roof and is operated by an observer standing in the middle of the floor. When the train is moving with a speed of 0.5C, the observer turns ON the light to open the door. The light travels with the same speed in all directions. The observer sees that the front and back doors open **simultaneously.**
- But another observer standing outside the train on the road side watching this event, sees that the back door opens before the front door. This is because the back door is moving towards the light waves coming towards it while the front door is moving away from the light waves coming towards it.

The Equivalence Between Mass and Energy

The rest mass of an object is equivalent to certain quantity of energy.

Mass can be converted into energy under extraordinary circumstances and, conversely, energy can be converted into mass. For example, part of the mass is converted into energy in nuclear fission reactions. When particle and its anti-particle collide, the entire mass is converted into energy.

Einstein's famous equation expresses the equivalence between energy, E and mass, m :

$$E = mc^2$$

The amount of energy given off in a nuclear transmutation is related by this relation to the amount of mass lost. In special theory of relativity, the law of conservation of Energy and the law of conservation of mass have been replaced by the law of conservation of mass-Energy.

Check Point

- It is said that Einstein, asked the question, "What would I see in a mirror, is carried in my hand and at the speed of light"? How would you answer this question?
- Yes Einstein would see himself in the mirror because there is no relative motion between Einstein and the mirror in his hand.

Q. Explain Length Contraction, Time Dilation, Mass Dilation and Application of time dilation and length contraction for space travel.

Length Contraction

- The length of an object measured within its rest frame is called **proper length (L_o).**
- Observers in different reference frames in relative motion will always measure the length (L) to be shorter.

$$L = L_o\sqrt{1-\frac{v^2}{c^2}} \quad \ldots (1)$$

Where v = Relativistic velocity
c = speed of light in free space

- Let a train that is measured to be 100 meters long when at rest, travels at 80% of the speed of light (0.8c). A person inside the train will measure the length of the train to be 100m. a person standing by the side of the track will observe the train to be just 60 meters long.
- This effect of relativity i.e., **shortening of length in direction of motion** is called length contraction.
- **No such contraction would be observed perpendicular to the direction of motion.**

Time Dilation

- The time taken for an event to occur within its rest frame is called **proper time (t_o).**
- Observers in different reference frames in a relative motion will always judge the time taken (t) to be longer.

$$t = \frac{t_o}{\sqrt{1-\frac{v^2}{c^2}}} \quad \ldots (2)$$

Where v = Relativistic velocity
c = speed of light in free space

For Example: A traveler on a train with a speed of 0.8c picks up and open a newspaper. The event takes 1.0 s as measured by the train traveler. As observed by a person standing by the side of the track the event takes 1.7 s.

Increase in Mass

Another consequence of the special theory of relativity is that the mass of a **moving objects increases as its velocity increases.** It is another expression of the mass energy equivalence and is represented mathematically as:

$$m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}} \quad \dots (3)$$

The orbital speed of earth is 30 km/s

Where m = relativistic mass of particle.
m_0 = rest mass of particle
v = Relativistic velocity of the particle relative to a stationary observer.
c = speed of light

This effect is noticeable only at relativistic speed. As an object is accelerated close to the speed of light its mass increases. The more massive it become, the more energy that has to be used to give it the same acceleration, making further acceleration more and more difficult. The energy that is put into attempted acceleration is instead converted into mass. The total energy of an object is then its K.E plus the energy embodied in its mass.

Check Point

- Since mass is a form of energy, can we conclude that a compressed spring has more mass than the same spring when it is not.
- *Yes*, the compressed spring will have more mass than uncompressed spring.
  Explanation
- The work done in compressing the spring converted into energy.
- According to Einstein mass energy relation, ($\Delta E = \Delta mc^2$)
- This increase in energy increases the mass as
- $$\Delta m = \frac{\Delta E}{c^2}$$
- As ΔE is very small, therefore Δm is in too small to be measured.

Can a material object move with speed of light?

The increase in mass shows the increase in inertia at high speeds.

As
$$m = \frac{m_o}{\sqrt{1 - \frac{v^2}{c^2}}}$$

If speed of the material object is equal to the speed of light (i.e., $v = c$) then

$$m = \frac{m_o}{\sqrt{1 - \frac{c^2}{c^2}}}$$

$$m = \frac{m_o}{\sqrt{1 - 1}}$$

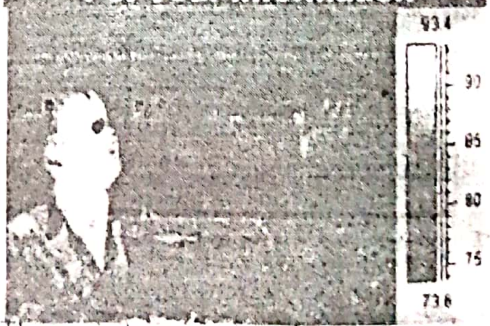
$$m = \frac{m_o}{0} = \infty$$

As **infinite mass requires an infinite force** to accelerate it. As the infinite force is not available.

- So an object cannot be accelerated to the speed of light in free space.

To accelerate even the smallest body to the speed of light would require an infinite amount of energy. Thus material object are limited to speed less then the speed of light.

For your Information



The radiation represents a conversion of a body's thermal energy into electromagnetic energy, and is therefore called thermal radiation. Person's energy is radiated away in the form of infrared energy.

Application of time dilation and length contraction for space travel

Let a spaceship is traveling to a star at a half of the speed of light. Let it take eight years to reach to the star. from the point of view of the observers on Earth. From the Earth's point of view the **clocks on the spaceship are moving slowly**, so that less time passes on the spaceship compared to the Earth.

From the point of view of the spaceship" occupants, the length of the journey has **contracted to a significantly shorter distance**, which they cover in less time. Hence the occupants of the spaceship recorded seven years to reach to their destination, rather than eight years. Hence the current maximum velocities do not allow for viable interstellar travel because the travel times are prohibitively long.

MCQ's From Past Board Papers

1. Which of following is the waves Earth's orbital speed
   (A) 10 km/s (B) 20 km/s (C) 30 km/s (D) 40 km/s
2. Using relativistic effects the location of an air craft after an hr flight can be predicted
   (A) 20 m (B) 50 m (C) 760 m (D) 780 m
3. Inertial frame is a frame in which
   (A) 1st law holds (B) 2nd law holds (C) 3rd law holds (D) Kelvin's law
4. Which of following waves do not travel at speed of light?
   (A) Radio-waves (B) Hear waves (C) X-rays (D) Sound waves
5. The speed of light (3×10^8 m/sec) in free space is
   (A) Variable (B) Less than that in air (C) Unpredictable (D) Constant
6. The special theory of relativity is applicable to the object moving with maximum velocity equal to:
   (A) speed of light (B) more than speed of light (C) less than speed of light (D) double the speed of light
7. At what speed would the mass of an electron become double of its rest mass? **(Fed 2011)**
   (A) 0.5c (B) 0.707c (C) 0.866c (D) 0.99c
8. 0.1 kg is equivalent to the energy of
   (A) 5×10^8 J (B) 6×10^{16} J (C) 9×10^{16} J (D) 9×10^{15} J
9. The coordinate system in which law of inertia is valid is called:
   (A) Special frame of reference (B) inertial frame of reference
   (C) non-inertial frame of reference (D) Standard frame of reference.
10. In 1905, the special theory of relativity was proposed by:
    (A) Maxwell (B) de–Broglie (C) Bohr (D) Einstein
11. By using NAVSTAR speed of an object can now be determined to an accuracy of:
    (A) 20 cm/sec (B) 760 cm/sec (C) 50 cm/sec (D) 2 cm/sec
12. If ah object moves with speed of light, its mass will be:
    (A) Zero (B) Maximum (C) Infinity (D) Minimum
13. All motions are:
    (A) Absolute (B) Uniform (C) Relative (D) Variable
14. Two Photons approach each other, their relative speed will be:-
    (A) 2 C (B) Zero (C) Less than C (D) C
15. At which relativistic velocity the mass of a body become double than its rest mass
    (A) $\frac{\sqrt{3}}{2}$ C (B) $\frac{2}{\sqrt{3}}$ C (C) $\frac{\sqrt{3}}{2}$ (D) C
16. The special theory of relativity based on
    (A) One postulate (B) Two postulates (C) Three postulates (D) Four postulates
17. The mass of object will be double at speed.
    (A) $2.5 \times 10^8 \frac{m}{s}$ (B) $1.6 \times 10^8 \frac{m}{s}$ (C) $3.6 \times 10^8 \frac{m}{s}$ (D) $0.6 \times 10^8 \frac{m}{s}$

Answers Key

1. C	2. B	3. A	4. D	5. D	6. C	7. C	8. D	9. B	10. D	11. D	12. C
13. C	14. D	15. A	16. B	17. A							

Q.4 What is black Body Radiation? Discuss the Energy Distribution graphs.

Black Body Radiation

Radiation: The continuous emission of energy from a body is called radiation

Thermal Radiation

When the body is heated, it emits radiation called thermal radiation.

The nature of radiation depends upon the temperature. All the bodies not only emit radiations but also absorb radiations from their surroundings.

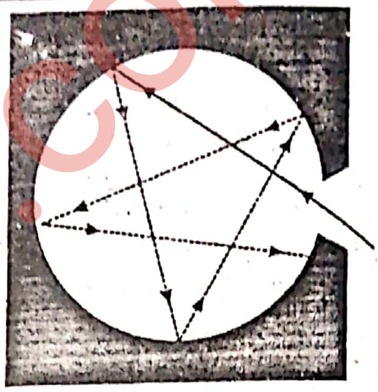
- If a body is hotter than its surrounding it emits more radiation than it absorbs and tend to cool.
- At low temperature, a body emits radiations of longer wavelengths in invisible infrared region.

- At high temperature, the proportion of shorter wavelength radiation increases.
- As the temperature of the object is increased, it eventually begins to glow red. At sufficiently high temperatures, it appears to be white, as the glow of the hot tungsten filament of a light bulb.
- A careful study of thermal radiation shows that it consists of a continuous distribution of wavelengths from the infrared, visible, and ultraviolet portions of the spectrum.
- A perfectly black body is defined as "An ideal substance which is capable of absorbing radiation of all wavelengths falling on it is called Black Body.
- The absorption power of a perfect black body is equal to unity".

A good experimental approximation to black body is provided by a cavity of iron or copper whose interior walls are maintained at uniform temperature and which can communicate with outside by means of a narrow opening. Any radiation entering the cavity is partly absorbed and partly reflected, a large number of times at the interior walls. A negligible part of radiations find its way out of the opening. The radiations emitted by the interior walls are similarly absorbed and reflected a large number of times. The interior walls of the cavity are painted with lamp black.

By definition a black body is an ideal system that absorbs all radiation incident on it.

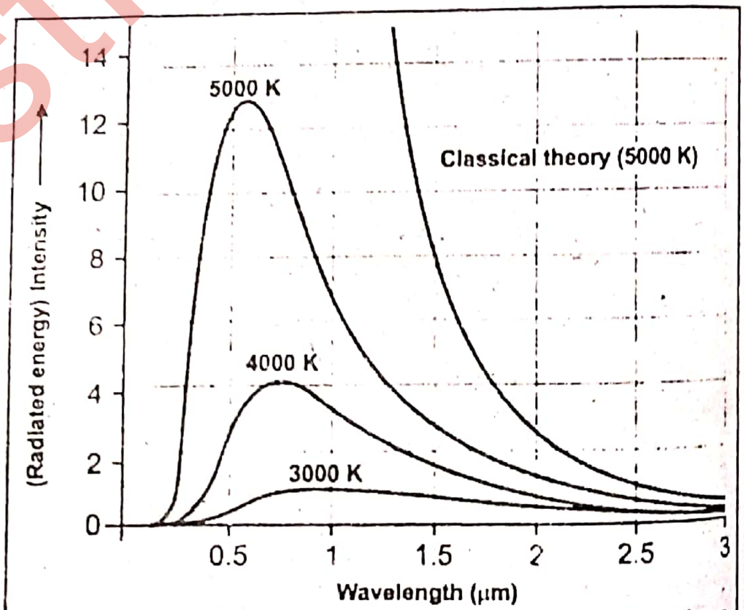
A good approximation to a black body is the inside of a hollow object, as shown in fig 18.2. The nature of the radiation emitted through a small hole leading to the cavity depends only on the temperature of the cavity walls. Experimental data for the distribution of energy for black body radiation at three different temperatures are shown in fig 18.3.



Black Body

BLACK BODY RADIATION AND INTENSITY DISTRIBUTION DIAGRAM

The radiations emitted by a black body are known as black body radiation or temperature radiation. Because the energy associated with the radiations depends upon the temperature of the black body. When a black body such as a cavity radiator is heated, it emits radiations of all possible wave lengths. Lummer and Pringshelm measure the intensity of the emitted radiation with wave length, from a black body at different temperature by the apparatus as shown in figure. The amount of radiation emitted with different wavelengths is shown in the form of energy distribution curve from each temperature as shown. We note the following characteristics from the above plots.



Intensity of black body radiation versus wavelength at three different temperature.

i. The monochromatic emissive power or intensity of the radiation varies with the wavelength for each temperature.
ii. The wavelength distribution is a function of temperature of the black body. All the curves have similar shape.
iii. At a given temperature T the emitted energy has a maximum value for a certain wavelength λ_m.
iv. The position of the peak maximum shifts towards the shorter wavelength with increasing the temperature. The shift obeys wine's displacement law which states "The maximum wavelength λ_m is inversely proportional to the absolute temperature of the radiator".

$$\lambda_m \propto \frac{1}{T}$$

$$\lambda_m = \frac{1}{T} \times \text{constant}$$

$$\lambda_m T = \text{constant} \text{ ------- (1)}$$

Where constant = 2.9×10^{-3}mK. This agrees with fact that a white hot incandescent is hotter than a red hot one

v. The total energy E radiation per second per unit area increases rapidly with temperature.

This is called Stefan's Boltzmann Law, which states that E is directly proportional to forth power of absolute temperature (T^4).

$E \propto T^4$

$E = \delta T^4$ ------- (2)

Where δ is called Boltzman constant. Its value is 5.67×10^{-8} w/m^2.K^4.

BLACK BODY RADIATION SPECTRUM

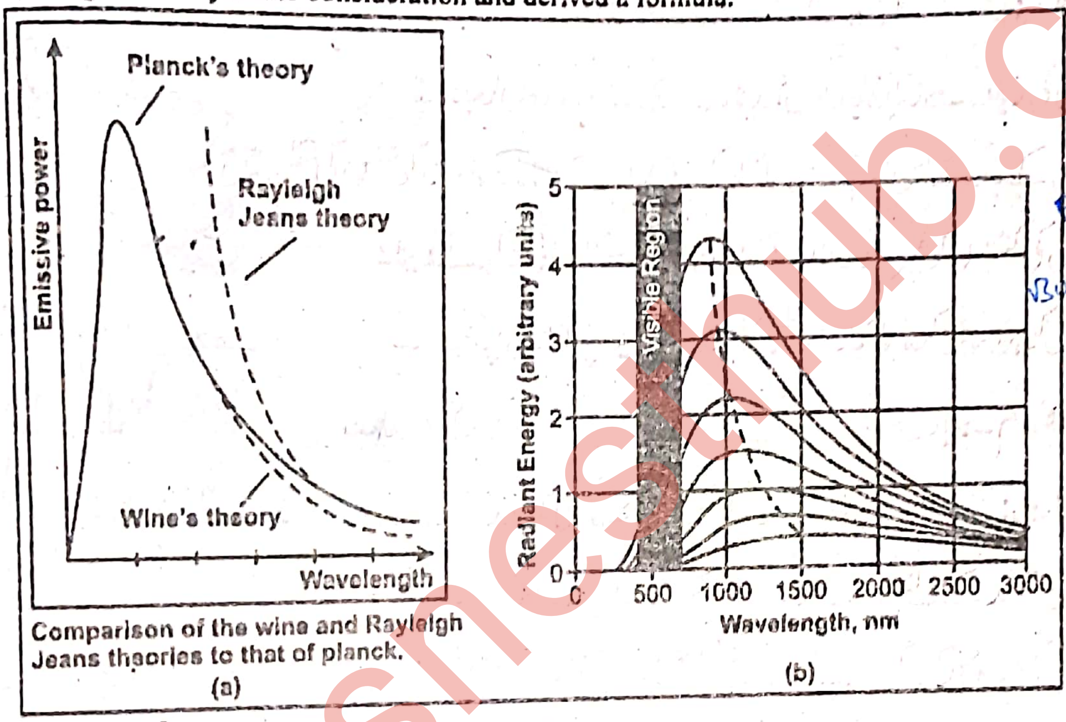
A series of attempts were made to explain the black body radiation spectrum.

(i) **Rayleigh-Jean Law:** Rayleigh-Jean advanced a theory and argued the black body radiation inside a cavity is reflected back and forth form the walls to form a system of standing waves. Rayleigh-Jean used kinetic theory of gases and got a relation called Rayleigh-Jean Law which is given by

$$E_\lambda = \frac{8\pi KT}{\lambda^4}$$

When we compare this theory with experimental data, we see that the agreement between theory and experiment is good for long wavelength but failed completely at short wavelength. At short wavelength it leads to infinity.

(ii) **Wein's Formula (Law):** Wein's presented a theory and tied to explain the energy distribution in black body spectrum, using thermodynamic consideration and derived a formula.



Comparison of the wine and Rayleigh Jeans theories to that of planck.
(a) (b)

$$E_\lambda = \frac{C_1\lambda^{-5}}{e^{C_2/KT}} \text{ ------ (2)}$$

Where C_1 and C_2 are constant. Wein's theoretical curve coincides with the experimental curve for shorter wavelength. His formula is excellent for short wavelength but not for long wavelength, as shown

(iii) **Stefan-Boltzmann Law:** Boltzmann law states that the amount of energy of all wavelength radiate per second per unit surface area of a black body is directly proportional to the fourth power of its absolute temperature T.

$E \propto T^4$

$E = \sigma T^4$ ----- (3)

Where σ is a constant called Boltzmann constant. Its value is 5.67×10^{-8} w/m^2.k^4

(iv) **Planck's Quantum theory:** In 1900 Max Planck announced his quantum theory which explained the whole shape of the black body radiation spectrum for all wavelengths. He said that energy is emitted by a hot body in form of packet which he named quanta. The energy of each quantum is directly proportional to the frequency of the radiation. If f is the frequency of the radiation then the energy of each quanta is:

$E \propto f$

$E = hf$ ----- (4)

Where h is Planck constant and its value is 6.63×10^{-34} J.S. Hence Planck introduced quantum concept instead of classical theory of classical theory (continuity in energy). Planck carried out the following assumptions.

Momentum of Photon

According to Einstein

$$E = mc^2 \quad \text{———} (5)$$

And according to Planck's assumption,

$$E = hf \quad \text{———} (6)$$

Comparing equations (5) and (6)

$$mc^2 = hf$$

$$mc = \frac{hf}{c} \quad \text{———} (7)$$

As momentum of photon can be expressed as p = mc. So equation (3) becomes

$$p = \frac{hf}{c}$$

$$p = \frac{hc}{c\lambda} \qquad [\because f = \frac{c}{\lambda}]$$

Or $$p = \frac{h}{\lambda} \quad \text{———} (8)$$

> **For Your Information**
> As E = pc
> It infers that the energy and momentum of the photon are directly proportional, So the ratio of energies of two photons is same as the ratio of their momentum.

The energy and the momentum of photon can be related as

$$E = mc^2$$

$$E = (mc)\,c$$

$$E = pc$$

(i) Each atom of the walls of the cavity behave like a tiny electromagnetic oscillator. These oscillators can emit and absorb electromagnetic waves.

(ii) An oscillators can have energy given by

$$E_n = n\,h\,f$$

Where n is called quantum number and can have integral value.

(iii) An oscillators does not radiate energy continuously. It emits energy in the form of quanta, when an oscillator changes from one energy state to another.

(iv) An long as an oscillator remains in one of its quantized state its energy remains constant, using the above assumptions Planck derived formula for the energy distribution in black body radiation spectrum, which is given by

$$E_\lambda = \frac{8\pi}{\lambda^4}\frac{hf}{e^{hf/kt}} \text{ --------- } (5)$$

Planck's theoretical curve coincides with the experimental curve for both short and long wavelengths as shown.

Importance of Planck's Quantum Theory:

(i) Planck's quantum theory marked the birth of modern physics.
(ii) Einstein used Planck's quantum theory and in 1905 explained photoelectric effect.
(iii) Quantum theory was applied to explain the line spectrum of Hydrogen.
(iv) Quantum theory explains the Compton scattering of x-rays.
(v) Quantum theory gives the right explanation of Heisenberg uncertainty Principle In fact quantum theory brought a great change and developments in physics. In 1918 Max Planck received the Nobel Prize in physics for his introduction of the quantum concept and his explanation of the black body spectrum.

Q.6 State and explain the photo electric effect? Write down its experimental results and the failure of classical theory.

Photo Electric Effect

The emission of electrons from a metal surface when a light of suitable frequency is incident on it is called photo-electric effect.

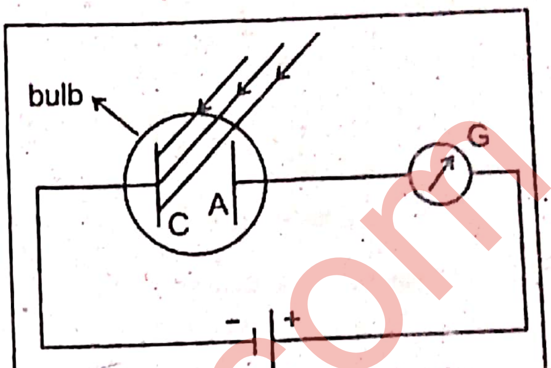
- *The emitted electrons are called photoelectrons.*
- The current flowing due to photoelectrons is called photoelectric current.

→ why mass decreas on final step?

The electrons are also emitted from the metal surface under the influence of electromagnetic radiation such as x-rays, ultraviolet..

This effect was first of all discovered by Hertz in 1887, when he was trying to confirm the existence of electromagnetic waves as predicted by Maxwell in 1884.

Experiment: The experimental arrangement used to study the different aspects of photoelectric effect as shown in the figure. It consists of an evacuated glass tube in which a metallic cathode C and a metal anode A acts is Collector, are enclosed. The cathode and anode are externally connected to a variable voltage source and galvanometer. The galvanometer gives zero deflection when no light falls on cathode C.



Circuit diagram for observing the photoelectric effect.

Working: When a monochromatic beam of light falls on a negatively charged plate C, through a quartz window, photoelectrons are emitted, which are attracted by positively charged plate A. this produces a current I_p, through the tube measured by the galvanometer. Increasing the voltage V by using rheostat R, the current I_p also increase, until a saturation stage is reached. At this stage all the ejected electrons are attracted by the collector and maximum current flows through the circuit. This photoelectric current depends upon the intensity of the incident beam of light.

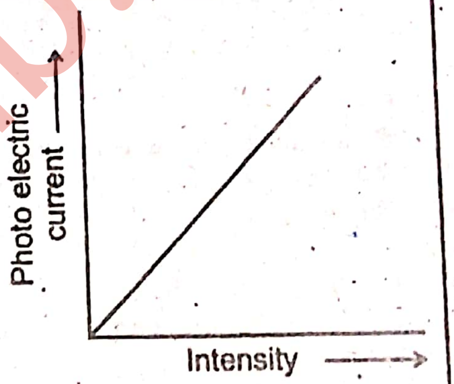
Maximum Kinetic Energy: The maximum kinetic energy of the photoelectrons can be determined by making the cathode C positive while collector A is made negative by the reversing switch. The electrons whose K.E is greater than eV will be able to reach A and will produce current. As A is made more and more negative, the current rapidly decrease and stops at some definite retarding voltage V_o which is known as stopping voltage, if "e" is the charge on an electron then relation between stopping voltage V_o and $(K.E)_{max}$ is given by

$$(K.E)_{max} = e\,V_o \quad \text{------ (1)}$$

$$(K.E)_{max} = \frac{1}{2} m V^2_{max} \quad \text{------ (2)}$$

$$\frac{1}{2} m v^2_{max} = e\,V_o \quad \text{------ (3)}$$

Where m is the mass and v_{max} is maximum velocity of the electron.



Variation of photoelectric current with intensity of incident radiation.

EXPERIMENTAL RESULTS

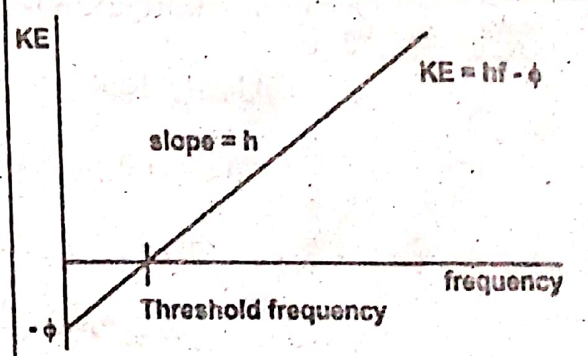
Some important experimental results of photoelectric effect are given below

i. **Dependence on light intensity:** When $f > f_o$ the number of photoelectrons is proportional to the intensity of incident light beam. Thus photoelectric current is directly proportional to the intensity of the incident beam of light as shown by graph. Hence brighter light causes an increase in photoelectric current.

ii. **Dependence on light frequency:** The K.E of photoelectrons depends upon the frequency of the incident light beam. The kinetic energy of photoelectrons is independent of the intensity of the incident beam of light used. Thus light is low intensity but high frequency will eject high K.E electrons

iii. **Instantaneous effect:** If the frequency f of the incident beam is greater than the threshold frequency ($f > f_o$), photoelectrons are emitted with in less than 10^{-9} seconds, just after the surface is illuminated by light.

iv. **Threshold frequency:** The minimum frequency required to eject the electrons from the metal surface, is called threshold frequency of that surface, denoted by f_o. Its value is of few electron volts. The emission of photoelectrons takes place only if the frequency of incident radiation id equal to or greater than

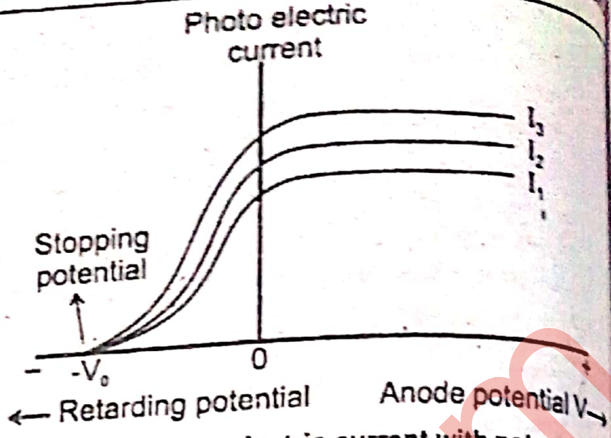


Variation of stopping potential with frequency of incident radiation.

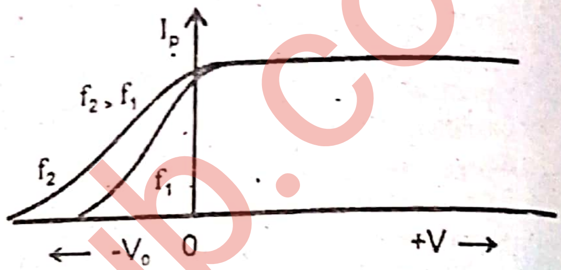
the threshold frequency $f \geq f_o$. Threshold frequency varies from metal to metal. The value of threshold frequency depends upon the nature of metal surface used as a cathode and its value is different for different metals.

a. **Dependence of current on light intensity:** If the above experiment is repeated for light beams of three different intensities I_1, I_2 & I_3 such that $I_3 > I_2 > I_1$, the amount of current I_P increase with increasing the intensity, but stopping voltage V_o is the same.

b. **Dependence of stopping voltage on frequency:** IF the intensity is kept constant and the experiment is performed with different frequencies f_1, f_2 such that $f_2 > f_1$ we obtain the curves as shown in the figure. In this case the current is same but shopping voltage is different for each frequency of incident light.
   - This indicates the maximum kinetic energy of electrons depends on frequency of incident light f.
   - This also indicates that the current I_P is independent on the frequency f o light.



Variation of photoelectric current with potential difference.



Characteristic curves of photocurrent VS. applied voltage for light of different frequencies.

Einstein Photoelectric Effect On The Basis Of Quantum Theory

Einstein explains the photoelectric effect on the basis of Planck's photon theory. He used the idea of quantization of energy as purposed by Max Planck. He assumed that light emitted or absorbed in quanta known as photon. Whose energy can be expressed as,

$$E = hf \qquad \text{where } h = 6.63 \times 10^{-34} \text{ J-s}$$

Work Function: *The minimum energy required to eject the electrons from metal surface, is called work function* $\varphi = hf_o$

- ▶ When the light falls on the metal surface then a photon of light transfer all its energy to one electron.
- ▶ If the incident photon has sufficient energy to escape the electron from surface of metal then a part of energy (called work function) is used by electron to break away the metal and rest of energy appears as the kinetic energy of the electrons.

Einstein Photoelectric Equation

Energy of incident photon = work function + Max K.E of electrons

$$\text{Or} \quad hf = \varphi + K.E_{max}$$

$$\text{Or} \quad hf = \varphi + \frac{1}{2} mv^2_{max}$$

$$\text{Or} \quad hf - \varphi = \frac{1}{2} mv^2_{max}$$

$$hf - hf_o = K.E_{max}$$

This is known a Einstein Photoelectric Equation.

> **For Your Information**
> Cesium has the least work function. Work function can be further decreased by oxidize coating of a substance.

Special Case

▶ If frequency f of light is equal to threshold frequency f_o then $K.E_{max}$ of photoelectron is zero,

So,

$$hf_o - \varphi = 0$$

Also

$$\phi = \frac{hc}{\lambda_c}$$

$$\lambda_c = \frac{hc}{\phi} = \frac{(6.63 \times 10^{-34} \text{ J.s})(3 \times 10^8 \text{m/s})}{3.94 \times 10^{-19} \text{ j}}$$

$$\lambda_c = 5.05 \times 10^{-7} \text{ m} = 505 \text{ nm}$$

This wavelength is in the green region of the visible spectrum.

Why do all the emitted electrons not possess the K.E of maximum value?

Because, some electrons come straight out of metal surface and some lose energy in atomic collision before coming out.

Thus photoelectric effect cannot be explained if we assume that light consists of waves and energy is uniformly distributed over its wave front. It can only be explained by assuming light consists of corpuscles of energy known as photons. Thus **photoelectric effect shows the particle nature of light.**

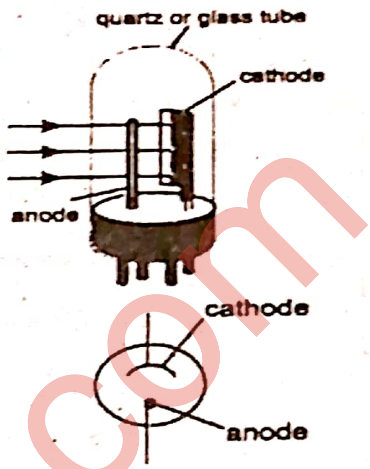
Nobel Prize

Einstein was awarded noble prize in **1921** for his explanation of photoelectric effect

Q.8 Write down a note on construction, working and uses of a Photo Cell.

Photo Cell

It is a device whose electrical properties are affected by light.



Simple photo - emissive cell.

Principle

The working of photocell is based upon the **photoelectric effect.**

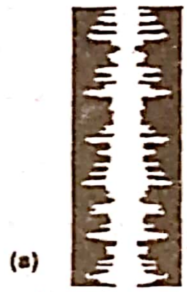
Construction

It consists of;

- An evacuated **glass tube** with two electrodes.
- A **Cathode,** which is in the form of con cave shaped plate to
- receive the incident radiation. Its material should be selected
- in accordance to frequency of incident light.
- An **anode,** which is in the form of thin straight rod so as not
- to block the cathode from the incident light. e.g.

Light emitted by cathode

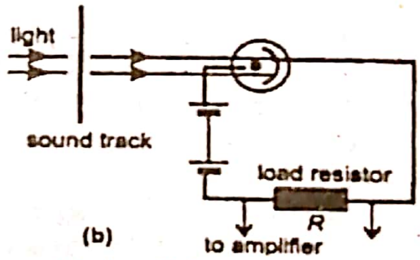
- Sodium and Potassium emits electrons for visible light.
- Cesium coated oxidized silver emits electrons for infrared light.
- Other metal responds to ultraviolet light.



Sound track on a film which varies the intensity of light reaching the photo cell.

Working

When light of suitable frequency is incident on the photo-emissive surface of cathode, electrons are emitted and current flows in the external circuit. The current varies directly with the intensity of incident light and it stops when light beam is cut off.



Photocell detection circuit for sound track of movies.

Uses

1) Automatic door system
2) Counting system
3) Security system
4) Exposure meter for photography (i.e. as light meter)
5) Sound track for movies
6) Automatic street lighting

Q. What are solar cell.

Solar Cell

Solar cell converts solar energy into electrical energy.

Principle: It works on principle of photoelectric emission.

A solar cell is a type of photo-cell whose aim is to obtain energy from solar radiation, either on the Earth's surface or in space. A recent method uses a bloomed resellers to focus the light from a large area into a cell. Even with simple silicon cells this technique can give effective efficiencies over 20%. The largest solar power station being built (2006) is in southern Portugal; designed to produce 11 Mw, it consists of 52000 photovoltaic panels steered always to point to the sun during day light. But trapping solar energy by direct absorption in solid and liquid materials is just as important in research area as those described; such cells are for cheaper than ones that use semi-conductors.

MCQ's From Past Board Papers

1. **In order to increase the K.E. of ejected photo electrons, there should be an increase in**
(A) Intensity Radiation (B) Wavelength of Radiation (C) Frequency of Radiation (D) Both as B and C
2. **Potassium cathode in photocell emit electrons for a light:**
(A) Visible (B) Infra-red (C) Ultra violet (D) X-rays
3. **Maximum kinetic energy of photoelectrons depends upon_______ of incident light.**
(A) Frequency (B) Intensity (C) Brightness (D) Power
4. **Number of electrons emitted in photoelectric effect depends upon:**
(A) Intensity of incident light (B) Frequency of incident-light (C) Energy of incident light (D) Wavelength of incident light
5. **In photoelectric effect, which factor increases by increasing the intensity of incident photon?**
(A) Kinetic energy of electrons (B) stopping potential (C) Work function (D) Number of emitted electrons
6. **Einstein was awarded Nobel Prize in Physics in:**
(A) 1905 (B) 1911 (C) 1918 (D) 1921
7. **Which is the most refined form of matter?**
(A) Smoke (B) fog (C) Light (D) electron
8. **Potassium cathode in photocell emit electrons for a light:**
(A) Visible (B) Infra-red (C) Ultra violet (D) X-rays
9. **When the K.E max of photoelectron is zero, the frequency of incident photon is ____ that of threshold frequency:-**
(A)Less than (B)Greater than (C)Much greater (D) Equal to
10. **Who explained the photo electric effect?**
(A)Max plank (B)Einstein (C)Henry (D) Rutherford

Answers Key

1. C	2. A	3. A	4. A	5. D	6. D	7. C	8. A	9. D	10. B

Q.9 Define and explain the Compton Effect.

Compton's Effect

The phenomenon in which a photon of high frequency such as X-ray is scattered by an electron so that the frequency of photon is decreased or wavelength is increased, is called Compton Effect.

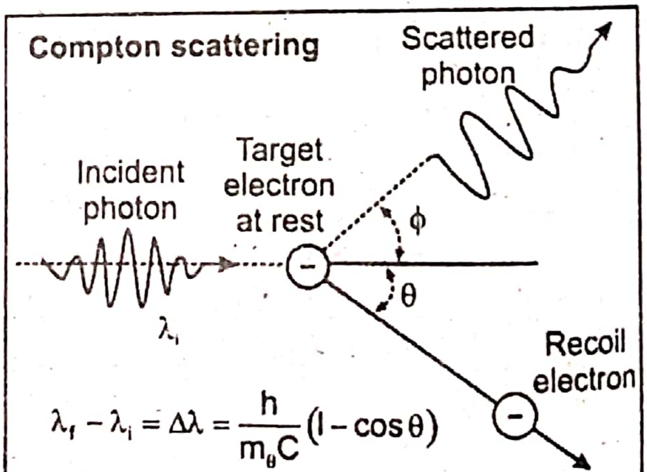
In 1923 Campton performed an experiment and directed a beam of X-rays at a block of graphite and measured the wavelength of the scattered beam at various angles to the direction of incident beam.

He observed two type of radiation scattering.

a. One had the same wavelength λ as the incident beam.

b. The other had slightly longer wavelength λ' as shown.

The wavelength shift or [Compton sift] $\Delta\lambda = \lambda' - \lambda$ was found to become larger and larger as the scattering angle was increased.



Incident photon collision with electron

Expression: To derive an expression for the wavelength shift or change in frequency, consider an elastic collision between x-ray photon and stationary free electron. When a photon of energy hf strikes a stationary and free electron, it gives a part of its energy to electron and is scattered with less energy say hf′.

- So the frequency of photon after collision is decreased or its wavelength is increased. This change in frequency or wavelength is called Compton Effect.
- Let the initial energy of photon is hf and momentum is hf/c. The initial rest energy of electron in m_oc^2 and momentum is zero.
- After collision the photon is scattered with less energy hf′ and momentum hf′/c, making angle θ with its original direction, as shown, while the electron is recoiled with some kinetic energy making an angle ϕ with original direction of photon as shown in fig.

The final rest mass energy of electron = mc^2

Final momentum of electron = mv

Where v is the speed of the recoil electron and m is its mass in motion.

Law of conservation of energy: Applying the law of conservation of energy

$$hf + m_oc^2 = hf' + m_oc^2$$

$$hf - hf' = mc^2 - m_oc^2 \text{ ----- (1)}$$

$$h(f - f') = (m - m_o)c^2$$

Conservation of momentum:

a. Applying the law of conservation of momentum along x-axis we have

$$\frac{hf}{c} + 0 = \frac{hf'}{c}\cos\theta + mv\cos\phi$$

$$\frac{hf}{c} = \frac{hf'}{c}\cos\theta + mv\cos\phi \text{ ----- (2)}$$

$$\frac{h}{\lambda} = \frac{h}{\lambda'}\cos\theta + P_e\cos\phi$$

b. Applying the law of conservation of momentum along y-axis.

$$0 + 0 = \frac{hf'}{c}\sin\theta - mv\sin\phi$$

$$0 = \frac{hf'}{c}\sin\theta - mv\sin\phi \text{ ----- (3)}$$

$$0 = \frac{h}{\lambda'}\sin\theta - P_e\sin\phi$$

Solving the above equation (1), (2) & (3) we get

$$\frac{1}{f'} = \frac{1}{f} + \frac{h}{m_oc^2}(1 - \cos\theta)$$

$$\frac{1}{f'} - \frac{1}{f} = \frac{h}{m_oc^2}(1 - \cos\theta)$$

Multiplying both sides by c

$$\frac{c}{f'} - \frac{c}{f} = \frac{h}{m_oc}(1 - \cos\theta)$$

$$\lambda' - \lambda = \frac{h}{m_oc}(1 - \cos\theta) \text{ ----- (5)}$$

Let $\lambda' - \lambda = \Delta\lambda$[Compton shift]

$$\Delta\lambda = \frac{h}{m_oc}(1 - \cos\theta) \text{ ----- (6)}$$

Thus the wavelength shift $\Delta\lambda$ depends upon the angleθ. If θ=90° then equation (8) becomes

$$\Delta\lambda = \frac{h}{m_oc}(1 - \cos 90^\circ)$$

$$\Delta\lambda = \frac{h}{m_oc} \text{ ----- (7)}$$

$$\Delta\lambda = \frac{h}{m_oc} = \frac{6.63 \times 10^{-34}}{9.10 \times 10^{-31} \times 3 \times 10^8} = 2.42 \times 10^{-12}\,m$$

If $\theta = 0$ then, $\Delta\lambda = \frac{h}{m_oc}(1 - \cos 0^\circ) = 0$

Hence, the wavelength shift varies between zero and $\frac{h}{m_oc}$. The factor $\frac{h}{m_oc}$ is called Compton wavelength.

If the scattering angle $\theta = 90^\circ$, then

$$\Delta\lambda = \frac{h}{m_oc}(1 - \cos 90^\circ)$$

$$\Delta\lambda = \frac{h}{m_oc}(1 - 0)$$

$$\Delta\lambda = \frac{h}{m_oc}$$

Compton shift = Compton wavelength $(\theta = 90^\circ)$

▶ If the scattering angle θ is 180°, then

$$\Delta\lambda = \frac{h}{m_o c}[1-\cos 180^\circ]$$

$$\Delta\lambda = \frac{h}{m_o c}[1-(-1)]$$

$$\Delta\lambda = 2[\frac{h}{m_o c}]$$

Compton shift =2 (Compton wavelength) $(\theta = 180^\circ)$

▶ **Compton shift is maximum at scattering angle 180^0**

Compton Effect again gives the direct confirmation of photon concept of radiation. The experiments carried by Compton to find Δλ were in agreement with the theoretical prediction. In 1927 Compton was awarded Nobel Prize in Physics for his discovery of the effect named after him.

Q.10 What do you know about Pair Production? Explain.

Pair Production

The phenomenon of conversion of energy of *γ.rays* in mass of electron and positron pair is called pair production. OR

The phenomenon in which a photon of energy greater than 1.02Mev disintegrates into an electron and positron pair in the vicinity of a nucleus is called pair production.

▶ It is also known as **the materialization of energy.**

When a photon of energy greater than 1.02 Mev strikes or passes in the vicinity of a heavy nucleus the photon disappears and in its place, an electron- position pair is formed.

▶ Positron is the anti-particle of electron. Its mass and charged are equal to the mass and charge of electron. But the charge of positron is positive (+e).

▶ In this process charge is conserved. Photon has no charge, electron has negative charge while positron has positive charge.

▶ Therefore, it is not possible to create a single electron only,or a single positron only.

In pair production, charge, momentum and energy and mass are conserved.

Charge of photon = charge of electron + charge of positron = 0

$$E_{Photon} = E_{elc} + E_{pos} \text{ ----- (1)}$$

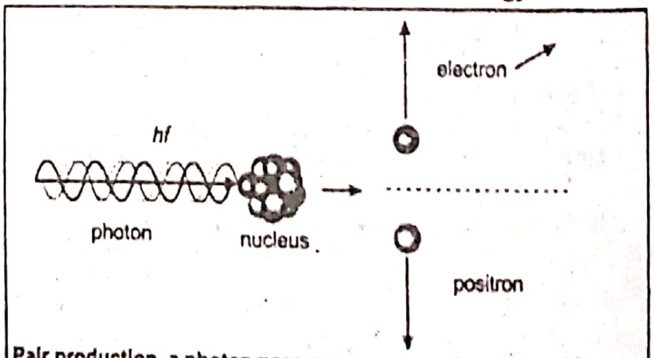
$$\frac{hc}{\lambda} = mv_{ele}' + mv_{posi} \text{ ----- (2)}$$

Pair production is an example of the conversion of electromagnetic energy intro rest mass energy.

▶ Furthermore this process confirms the result of special theory of relativity, that mass and energy are inter convertible.

$$E = mc^2$$

Pair production is shown in the diagram. When a photon of energy hf (greater than 1.02 Mev) disintegrates into an electron-positron pair, applying the law of conservation of energy.



Pair production, a photon passes near an atomic nucleus. After collision the photon vanishes by creating an electron - positron pair.

Energy of photon = energy required for pair production + K.E of electron+ K.E. of positron

$hf = m_o c^2 + m_o c^2 + K.E_{-e} + K.E_{+e}$

$hf = 2m_o c^2 + K.E_{-e} + K.E_{+e}$ ----- (3)

But $2m_o c^2 = 2 \times 0.51$ MeV = 1.02 MeV. Putting this value in equation (4) we get

$hf = 1.02 \text{ MeV} + K.E_{-e} + K.E_{+e}$ ----- (4)

Minimum energy of Photon: To find the minimum energy of photon required for pair production we have

$hf = 1.02 \text{ MeV} + K.E_{-e} + K.E_{+e}$

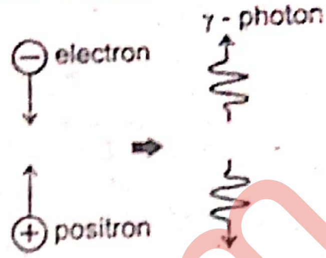
if $K.E_{-e} = K.E_{+e} = 0$, then we have $(hf)_{min} = 1.02$ MeV ----- (5)

Thus the minimum energy of photon for pair production is 1.02 MeV. In this process photon is totally absorbed.

NOTE: Pair Production cannot take place in vacuum: If pair production takes place in vacuum it will be the ***violation*** of law of conservation of momentum. So to conserve momentum, a heavy ***nucleus*** is needed

Q.11 What is Annihilation of Matter? Explain.

Annihilation of Matter



This process is reverse of pair production.

When an electron and a positron come close to each other then they annihilate each other and converted it into two photons in the range of γ-rays. This process is called annihilation of matter.

This process is experimental verification of Einstein's equation $E = mc^2$. It can be expressed as,

$$e^{+} + e^{-} \longrightarrow \gamma + \gamma$$

(i) Applying the law of Conservation of energy and neglecting K.E of electron and positron we have sum of the energies of electron and positron = Sum of energies of two photons

$$m_oc^2 + m_oc^2 = hf + hf \text{ ----- } (1)$$
$$2m_oc^2 = 2hf$$
$$m_oc^2 = hf$$
$$hf = m_oc^2 = 0.51 \text{ MeV}$$

(ii) According to the law of conservation of momentum

The net momentum of electron and positron is equal to zero due to their opposite motion. The photons also move in opposite direction in order to conserve the momentum.

$$\frac{hf}{c} - \frac{hf}{c} = 0$$
$$\frac{hf}{c} = \frac{hf}{c}$$

(iii) The net charge of electron and positron is zero and photons also have same zero charge, which is in accordance to law of conservation of charge.

Existence of positron

The existence of positron was predicted by Dirac in 1928 and Carl David Anderson, discovered the positron in the cosmic rays in 1932 and got the Noble Prize in 1936.

Particle and Antiparticle

It becomes clear that every particle has a corresponding antiparticle with the same mass and charge (if it is charged) but opposite sign (different quantum number). A particle and its antiparticle cannot exist together at one place, because when they meet and annihilate each other.

Proton and antiproton annihilation has also been observed at Lawrence Berkeley Laboratory.

MCQ's From Past Board Papers

1. The minimum energy required by photon to create an electron-positron pair
   (A) 0.52 MeV (B) 1.51 MeV (C) 1.02 MeV (D) 0.051 MeV
2. In compton scattering, the change in wavelength is maximum if:
   (A) $\theta = 90^\circ$ (B) $\theta = 180^\circ$ (C) $\theta = 0^\circ$ (D) $\theta = 45^\circ$
3. A positron is an anti-partcles of
   (A) Protron (B) Electron (C) Neutron (D) Photon
4. In Compton scattering the Compton shift $\Delta\lambda$, will be equal to Compton wavelength, if the scattering angle is:
   (A) Zero (B) 45° (C) 60° (D) 90°
5. Every particle has corresponding antiparticle with:
   (A) Same mass (B) Different mass (C) Opposite charge (D) Same mass and opposite charge
6. The factor $\frac{h}{m_oc}$ is called:
   (A) Compton factor (B) Resonance factor (C) Max. Compton shifts (D) Compton wavelength
7. A positron is
   (A) an electron (B) a proton (C) an antiparticle of electron (D) an antiparticle of proton

8. The quantity $\frac{h}{m_o c}$ has the dimensions of :
(A) Length (B) Time (C) Mass (D) Energy

9. The change in wavelength of scattered photon in Compton effect is:
(A) $\frac{h}{m_o c}(1-\cos\theta)$ (B) $\frac{h}{m_o c^2}(1-\cos\theta)$ (C) $\frac{m_o}{hc}(1-\cos\theta)$ (D) $\frac{h}{m_o^2 c^2}(1-\cos\theta)$

10. The Photon with energy greater than 1.02 MeV can interact with matter as:-
(A) Photoelectric Effect (B) Compton Effect (C) Pair Production (D) Annihilation of Matter

11. Compton effect proves
(A) Wave nature of radiation (B) Wave nature of particle (C) Dual nature of particle (D) Particle nature of radiations

12. Disintegration of photon on striking a nucleus into an electron and positron is known as
(A) Annihilation of matter (B) Compton effect (C) Pair production (D) Photo electric effect

13. Comptons shift in Wave Length ($\Delta\lambda$) is zero, when scattered angle of photon is:
(A) 90° (B) 180° (C) 0° (D) 45°

14. A positron is a particle having;
(A) Mass equal to electron (B) Charge equal to electron
(C) Mass equal to proton (D) Mass equal to mass of electron but charge opposite of charge of electron

15. The rest mass energy of an electron positron pair is:
(A) 0.51 MeV (B) 1.02 MeV (C) 1.2 MeV (D) 1.00 MeV

16. In Compton effect the photon behaves as a:
(A) Wave (B) Particle (C) Nucleon (D) A & B

17. Compton's effect is associated with:
(A) Gamma rays (B) Beta rays (C) X-rays (D) Positive rays

18. For an electron, the rest mass energy is:
(A) 0.4111 MeV (B) 0.511 MeV (C) 0.611 MeV (D) 0.711 MeV

19. Compton shift $\Delta\lambda$ will be equal to Compton wave length at an angle of
(A) 90° (B) 180° (C) 45° (D) 0°C

Answers Key

1. C	2. B	3. B	4. D	5. D	6. D	7. C	8. A	9. A	10. B	11. D	12. C
13. C	14. D	15. B	16. B	17. A	18. B	19. A					

Q.12 What is de- Broglie hypothesis of wave nature of particles? Explain

The Wave Nature of Particles

As from Einstein quantum concept, we know that the nature of electromagnetic waves is dual. Some time it behave like waves (reflection,, refraction, interference) and sometime behave like particles (photoelectric effect, Compton Effect).

First of all it was French Physicist de–Broglie who in 1924 wrote in his Ph.D thesis that since photons have wave and particle properties. So each particle like electron, proton, neutron or nucleus of an atom might act like wave under certain circumstances. His Principle argument was that the nature reveals symmetries. de.Broglie argued that the energy of photon having frequency f is given by

$$E = hf \text{ ----- (1)}$$

But according to Einstein mass-energy relation, if m is the mass of photon in motion then its energy is:

$$E = mc^2 \text{ ----- (2)}$$

Comparing equation (1) and (2) we get,

$$mc^2 = hf$$

$$mc = \frac{hf}{c}$$

$$P = \frac{hf}{c} \text{ ----- (3)}$$

This equation given the momentum of photon in terms of frequency f.

Putting $c = f\lambda$ in equation 3

$$P = \frac{hf}{f\lambda}$$

$$P = \frac{h}{\lambda} \text{ ----- (4)}$$

This equation (4) gives the momentum of photon in terms of wavelength.

$$\lambda = \frac{h}{p} \text{-------} (5)$$

de-Broglie predicted that the relationship between matter and electromagnetic radiation is intrinsic (inherent).

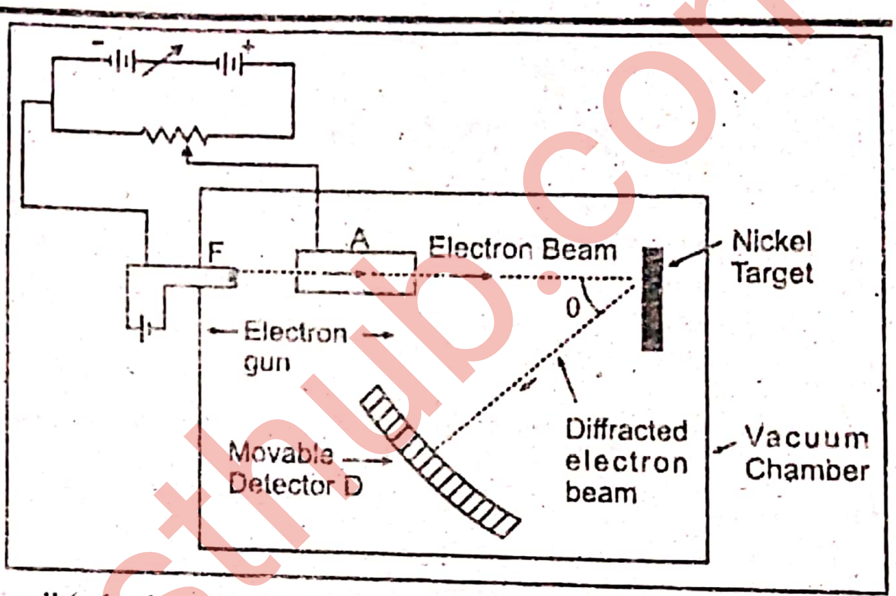
de-Broglie argued that in the same way the wavelength λ assigned to a particle of mass m, moving with the velocity v can be determined by putting p= mv in equation 5

$$\lambda = \frac{h}{mv} \text{------} (6)$$

Thus it is clear that the wavelength of the particle wave depends on its mass, in addition to its velocity. The above equation (6) holds good for microscopic particles such as electron and other sub atomic particles and not for macroscopic bodies such as tennis or billiard ball. For his work on the dual nature of particle de Broglie received the Nobel Prize in Physics in 1929.

Q. Describe Davisson and Germer Experiment to Show the Wave Nature of Particle experimentally?

Davisson and Germer Experiment



The de Broglie relation was confirmed experimentally by Davisson and Germer. They bombarded electrons on a nickel crystal and measured the intensity of the electron beam scattered from the crystal at various angle (Fig 18.12). Electrons emitted from a filament were accelerated through a potential difference applied between the filament and anode in an electron gun. The accelerated electrons are passed through slits and collide with the nickel crystal. The electrons scattered at various angles were detected by the detector D. The whole apparatus was enclosed in a vacuum chamber. It was observed that at certain angles, depending upon the energy of the electrons, the intensity of the scattered beam was large and at other angle it was small (selective reflection).

The results obtained from this experiment were explained by treating the beam of electrons as wave of wavelength given by de Broglie's expression.

- The diffraction of electrons from the crystal was similar to that of x-rays from crystals.
- The wave property of particles (electrons, neutrons, atoms and even molecules) has been verified experimentally.
- The diffraction of electrons and neutrons is used to study the structure of crystals in a similar manner as is done with the help of x-rays.

Theoretical Wavelength

The gain in K.E of electron as it is accelerated by a potential difference V in the electron gun is,

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

$$mv^2 = 2Ve$$

or

$$m^2v^2 = 2mVe$$

$$mv = \sqrt{2mVe}$$

From de Broglie equation,

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

putting value of mv

$$\lambda = \frac{h}{\sqrt{2mVe}}$$

If electrons are accelerated by a potential difference of 54 volt, then the electron are scattered by an angle of 65° after falling on Nickel crystal target, So

$$\lambda = \frac{6.63\times10^{-34}}{\sqrt{2(9.11\times10^{-31})(54)(1.6\times10^{-19})}}$$

$$\lambda = 1.66 \times 10^{-10}\,m \quad \text{\_\_\_\_\_\_\_\_ (1)}$$

or $\lambda = 1.66\,A^\circ$

Experimental Wavelength

Now, by using the Bragg's equation, experimental wavelength was calculated as

For first order = m = 1

Separation between two reflecting planes (For nickel) = $d = 0.91\,A^\circ = 0.91 \times 10^{-10}$ m

Glancing angle = $\theta = 65°$

According to Bragg's equation

$$2dSin\theta = m\,\lambda$$

Putting values, we get

$$\lambda = 2 \times 0.91 \times 10^{-10} \times \sin65^\circ$$

$$\lambda = 1.65 \times 10^{-10} \quad \text{\_\_\_\_\_\_\_\_ (2)}$$

or $\lambda = 1.65\,A^\circ$

The above equation (2) shows that the experimentally observed wavelength is an excellent agreement with theoretical predicted wavelength as given in equation (1).

Diffraction pattern can also be observed with protons, neutrons, hydrogen atoms and helium atoms. So it confirms the wave behavior of the particle.

Q.14 Explain Wave Particle Duality?

The wave – Particle Duality

Behavior of light as waves as well as particles

- Interference, diffraction and polarization of light confirm its wave nature.
- Photoelectric effect and Compton's effect prove the particle nature of light.

Behavior of particle as waves as well as particles

- In the experiment of J.J Thomson to find e/m, he used the particle like nature of electron.
- The experiments of Davisson and Germer and G.P Thomson reveal wave like nature of electrons.

Wave Particle Duality

Matter and radiations have a dual wave-particle nature and this new concept is called wave particle duality.

de Broglie hypothesis tells about the duality of matter.

- Davisson and Germer experiment of electrons diffraction for a Nickel Crystal confirms the dual nature of matter.
- It should be noted that when radiation interacting with macroscopic particles like electron it behaves like a particle.

It should be noted that radiation like light waves and small particles like electron, protons etc. do not show particle and wave properties in a single experiment.

- In some experiments they behave like waves (reflection, refraction, interference) and behave like particles in other experiments (photoelectric effect, Compton Effect).

It should be remembered that the duality applies to all the particles and waves which is the basic principle of modern quantum theory. According to this theory the physical interpretation of wave particle duality I that.

The intensity of the particle wave at any given point is proportional to the probability of finding the particle at the point. This is the meaning of wave particle duality.

Finding the value of e/m for an electron J.J. Thomson considered an electron as a particle wile Devision and Germer considered the electron beam as a wave.

MCQ's From Past Board Papers

1. Antiparticle of electron is:
(A) Proton (B) Photon (C) Neutron (D) Positron

2. The Davison and Germer experiment indicates:
(A) Interference, (B) Polarization (C) Electron diffraction (D) Refraction

3. Which phenomenon proves the particle nature of electromagnetic waves? **(Federal 2014)**
(A) Diffraction (B) Polarization (C) Interference (D) Photoelectric effect

4. Wave nature of light appears in:
(A) pair production (B) Compton effect (C) photoelectric effect (D) interference

5. We can find from de Broglie formula:
(A) Wavelength (B) Amplitude of wave (C) Speed of wave (D) Frequency of wave

6. _____ has the largest de Broglie wavelength at same speed.
(A) Proton (B) a - particle (C) Electron (D) All have same

7. A positron is an antiparticle of
(A) Proton (B) Electron (C) Neutron (D) Photon

8. The minimum energy required to create pair production is
(A)1.02keV (B)1.02MeV (C)1.02eV (D)10.2J

9. In a annihilation,emitted photon move in opposite direction to conserve
(A)mass (B)charge (C)energy (D)momentum

10. If a particle of mass m is moving with speed v then de broglie wavelengthλ associated with it will be
(A) $\lambda = \frac{3h}{mV}$ (B) $\lambda = \frac{2h}{mV}$ (C) $\lambda = \frac{h}{mV}$ (D) $\lambda = \frac{h}{2mV}$

11. The existance of positron in 1928 was predicted by
(A)Anderson (B)Dirac (C)Chadwick (D) Plank

12. Pair production can take place only when energy of radiation is equal and greater than 1.02MeV thus correct option is
(A)x-rays (B)Heat radiation (C)γ-rays (D) Ultraviolet rays

13. They following particles have the same energy which particles have the shortest wavelength
(A)α-particles (B)neutrons (C)β-particles (D) protons

14. When an electron combines with a positron,we gain
(A)One photon (B)Three photons (C)Two photons (D) four photons

15. Rest mass energy of electron is
(A) 1.02MeV (B) 0.51MeV (C) 931MeV (D) 200MeV

Answers Key

1. D	2. C	3. D	4. D	5. A	6. B	7. B	8. B	9. D	10. C	11. B	12. C
13. A	14. C	15. B									

Q.15 Write a note on Electron Microscope.

Electron Microscope

An ultra-modern optical device which makes the use of the wave nature of electrons beam is called electron microscope.

> **Check Point**
> Why does the existence of cut-off frequency favour a particle theory for light rather than a wave theory?

Principle: the principle of electron microscope is based on the wave nature of electron beam. Here the electrons beam is focused is the specimen through magnetic lenses by using electric and magnetic fields. The deflection of electrons beam is similar to refraction of light through glass lenses.

Construction and Working:

(i) **Electron Gun:** It eject and accelerates the beam of electron.
(ii) **Magnetic Condenser:** It is used to focus the electron beam on the specimen.
(iii) **Magnetic Objective**
(iv) **Intermediate Image Projector**
(v) **Fluorescent Screen**

The constriction of electron microscope is shown. In electron microscope, electrons from the electron gun are focused on the specimen through magnetic conducting lens. The specimen or slice of material must be very thin typically a few hundreds angstroms in order to minimize the adsorption or scattering of electron. The electrons beam is controlled by electrostatic or magnetic deflection. The projection lens forms the final image, which can be viewed on a fluorescent screen or photograph.

Working Theory: The electrons from heated filament in an electron gun are accelerated through high voltage from 10KV to several megavolts, giving wavelength of the order of 10^{-10}m. The electrons gain high kinetic energy given by,

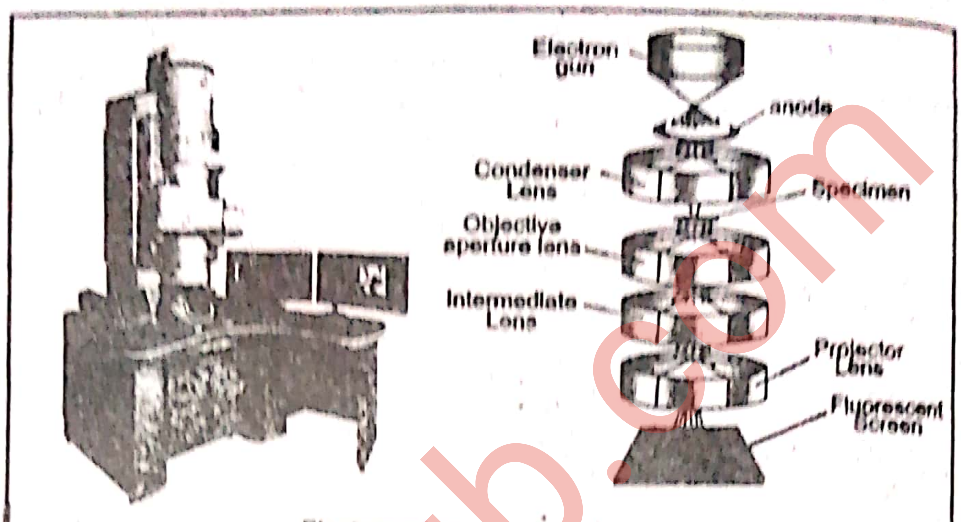
$$K.E = eV_o \text{ ------ } (1)$$

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

$$mv^2 = 2eV_o$$

$$v^2 = \frac{2eV_o}{m}$$

$$v = \sqrt{\frac{2eV_o}{m}} \text{ ---- } (2)$$



Electron microscope ray diagram

Where m is mass and V is speed of an electron. The electrons gain extremely short wavelength, the de Broglie wavelength of electron is

$$\lambda = \frac{h}{mv} \text{ ----- } (3)$$

$$\lambda = \frac{h}{m\sqrt{\frac{2eV_o}{m}}}$$

$$\lambda = \frac{h}{\sqrt{2meV_o}} \text{ ------ } (4)$$

This high energy electrons beam is focused on the specimen by means of magnetic conducting lens. A part of electron beams is scattered from the thicker part of the specimen, while the remaining part is transmitted through the specimen, because the electrons have sufficient energy to penetrate the specimen of reasonable thickness. This transmitted beam diffracts through objective and intermediate lenses and produces a real image. The final image is formed by projection lens, which is obtained on the fluorescent screen or photographed on electron micrograph. A three dimensional image or remarkable quality can be achieved by scanning electron microscope.

Resolving power:

The resolving power of electron microscope is 100 times greater than the optical compound microscope, because, it uses the wave nature of electron beam. A greater the wavelength of light used. The wavelengths of electrons are 100 times shorter than the visible light, used in optical microscope. So electron microscopes are able to show the details of about 100 times smaller objects.

Uses: It is used to

i. investigation of atomic structure
ii. study the crystal structure
iii. to study details of viruses and structure of bacteria
iv. to study the structure of textile fibres
v. to study the composition of paper and plastic.

Q.16 Define and explain the Heisenberg Uncertainty.

Uncertainty Principle

Statement

Position and momentum of a particle cannot both be measured simultaneously with perfect accuracy.

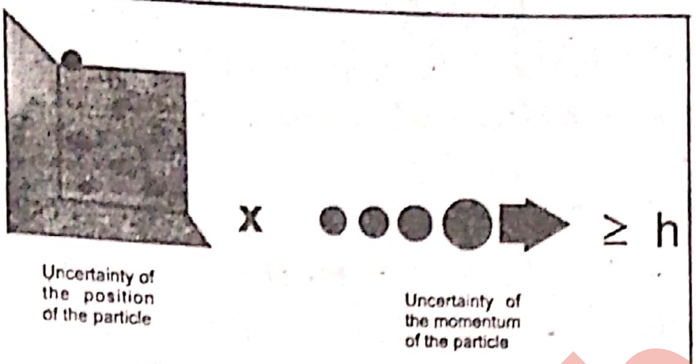
Suppose some one starts thinking of designing a super microscope to see an electron and take observation to know its position and momentum at a particular instant. The question is whether it is possible to make such observations. We shall see below that it is fundamentally impossible to make such observations even if one succeeds to construct an ideal instrument for this purpose.

In order to see an electron we use light of wavelength λ. The light consists of photons – each having a momentum $\frac{h}{\lambda}$. When one of these photons hits the electron, the photon will be scattered and the original momentum of the electron will be changed.

The change of momentum of the electron will be of the same order as the momentum of the photon itself, Hence,

$$\Delta p \approx \frac{h}{\lambda} \quad ...(1)$$

The equation gives the uncertainty in the momentum.



Illustrations of uncertainty principle

In order to reduce the uncertainty in momentum, one must use light of large wavelength.

Now the uncertainty in determining the position of the electron will be of the order of wavelength of light. Hence uncertainty in position is

$$\Delta x \approx \lambda \quad ...(2)$$

In order9 to reduce the uncertainty in position, one must use light of shorter wavelength.

- **For short wavelength**

If one use light of short wavelength, then from eq (2) Δx is smaller i-e uncertainty of position is smaller and the accuracy in position measurement increases

But from eq (1) Δp is greater i-e uncertainty of momentum is greater and the accuracy in the measurement of momentum decreases.

- **For longer wavelength**

If one use light of longer wavelength,from eq (2) Δx is greater i-e uncertainty of position is greater and the accuracy in position measurement decreases.

But from eq (1) Δp is smaller i-e uncertainty of momentum is smaller and the accuracy in momentum measurement increases .

Multiplying the equations 1 and 2, we get.

$$(\Delta p)(\Delta x) \approx h \quad ...(3)$$

This is one form of the uncertainty principle.

It states that the product of the uncertainty Δp in the momentum of a body at some instant and the uncertainty in its position Δx at the same instant is approximately equal to Planck's constant.

This means that it is impossible to measure the position and momentum of the electron simultaneously with perfect accuracy even with an ideal instrument.

As h is a very small and, therefore, in the case of large objects with which we come across in our daily life, the limitation imposed on measurements by the uncertainty principle is negligible, but when we are working with sub atomic particles, these limitations are not negligible.

Another form of uncertainty principle can be obtained through similar reasoning.

$$(\Delta E)(\Delta t) \approx h \quad ...(4)$$

Which states that the product of the uncertainty in a measured amount of energy and the time available for the measurement is approximately equal to Planck's constant.

The uncertainly principle tells us that it is impossible to know everything about a particle. There will be uncertainty about its exact momentum at a given position and its exact energy at a given time.

FORMULAE

1	Time dialation	$t = \frac{t_o}{\sqrt{1-\frac{v^2}{c^2}}}$		
2	Mass variation	$m = \frac{m_o}{\sqrt{1-\frac{v^2}{c^2}}}$		
3	Length contrction	$l = l_o\sqrt{1-\frac{v^2}{c^2}}$		
4	Einstein's Equation	$E = mc^2$		
5	Change in mass	$\Delta m = \frac{\Delta E}{c^2}$		
6	Wein's Law	$\lambda_{max} \times T =$ constant		
7	Stefan Boltzmann law	$E = \sigma T^4$		
8	Energy of photon	$E = hf$		
9	Momentum of photon	$p = \frac{h}{\lambda}$		$E = pc$
10	Maximum K.E. of photo electrons	$(K.E)_{max} = V_o e$		$\frac{1}{2} mv^2_{max} = V_o e$
11	Photoelectric equation	$hf = \phi + K.E_{max}$	$hf = \phi + \frac{1}{2} mv^2_{max}$	$hf - hf_o = K.E_{max}$
12	Compton shift	$\Delta\lambda = \frac{h}{m_o c}(1-\cos\theta)$		
13	Compton wavelength	$\Delta\lambda = \frac{h}{m_o c}$		
14	Pair production	Total energy $\geq 2m_o c^2$		$hf = 2m_o c^2 + K.E_{(e-)} + K.E_{(e+)}$
15	Annihiiation of matter	$e^+ + e^- \longrightarrow \gamma + \gamma$		
16	De-Broglie hypothesis	$\lambda = \frac{h}{p} = \frac{h}{mv}$		

17	Davisson and Germer Experiment	$\lambda = \frac{h}{\sqrt{2mVe}}$	
18	Uncertainity in position	$\Delta x \approx \lambda$	
19	Uncertainity in momentum	$\Delta P \approx \frac{h}{\lambda}$	
20	Uncertanity principle	$(\Delta x)(\Delta P) \approx h$	$(\Delta E)(\Delta t) \approx h$
21	For more careful calculation	$\Delta x \,.\, \Delta P \geq \hbar$	$\Delta E \,.\, \Delta t \geq \hbar$
22	h-Bar	$\hbar = \frac{h}{2\pi}$	

UNITS

1	Wein's constant	mK	
2	Stefan Boltzmann constant	$Wm^{-2}k^{-4}$	
3	Plank's contant	J-s	
4	Work function	J	eV
5	Compton wavelength	M	

CONSTANTS

1	Wein's constant	2.9×10^{-3} mK
2	Stefan Boltzmann constant	5.67×10^{-8} $Wm^{-2}k^{-4}$
3	Plank's contant	6.63×10^{-34} J sec
4	Compton wavelength	2.43×10^{-12} m
5	h-Bar	1.05×10^{-34} J s

Key Points

- Frame of reference is a coordinate system such as the OXYZ system, which is required to describe relative of an object.
- A reference frame moving with constant velocity is called an inertial frame of reference.
- A frame of reference that is accelerating is a non-inertial frame of reference.
- Special theory of relativity is based on two postulates.
  - a. The laws of physics are the same in all inertial frame.
  - b. The speed of light in free space has the same value for all observers, regardless of their state of motion.
- $E = mc^2$ is an important result of special theory of relativity.
- A black body is solid block having a hollow cavity within. It has small hole and the radiation can enter or escape only through this hole.
- Stephen Boltz Mann law states that total energy radiated over all wave lengths at a particular temperature is directly proportional to the fourth power of that Kelvin temperature.
- The emission of electrons from a metal surface when exposed to light is called photo electric effect. The emitted electrons are known as photo electrons.
- When x-rays are scattered by loosely bound electrons from a graphite target, it is known as Compton effect.
- The change of very high energy photon into electron-positron pair is called pair production.
- When a position comes close to an electron, they annihilate and produce two photons in the r-rays range. It is called annihilation of matter.
- Radiation and matter exhibit particle as well as wave like properties. This is known as wave=particle duality.
- Position and momentum of a particle cannot both be measured simultaneously with perfect accuracy. There is always fundamental uncertainty associated with any measurement. It is a consequence of the wave particle duality of matter and radiation. It is known as Heisenberg uncertainty principle.

Solved Examples

Example 18.1:

The rest mas of an electron is $9.11\times10\times10^{-31}$kg. Calculate the corresponding rest energy.

Solution:

Rest mass energy of electron. $E = m_oC^2$

$$E = (9.11\times10^{-31}kg)(3\times10^8 m/s)^2$$

$$E = 8.199\times10^{-14}J$$

$$E = 0.512 MeV$$

Example 18.2:

A spaceship is measure 100 m long while it is at rest with respect to an observer of this spaceship now flies by the observer with a sped of 0.99c.

Solution:

We know from equation 18.1

$$L = L_o\sqrt{1-\frac{v^2}{c^2}}$$

$$L = 100m\sqrt{1-\frac{(0.99c)^2}{c^2}}$$

$$L = 14\,m$$

Example 18.3:
Superman, who has an exceptionally strong arm, throws a fast ball with a speed of 0.9c. If the rest mass of the ball is 0.5 kg, what is its mass in flight?

Solution:
Using equation 18.3 we have.

$$m = \frac{m_o}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$= \frac{0.5\,kg}{\sqrt{1-\frac{(0.9c)^2}{c^2}}} = 1.15\,kg$$

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Example 18.4:
The temperature of the skin is approximately 35°C. What is the wavelength at which peak occurs in the radiation emitted from the skin?

Solution:

$$\lambda_{max}T = 0.2898\times10^{-2}\,m.k$$

Solving for λ_{max} nothing that 35°C is corresponds to an absolute Temperature of 308k,

We have,

$$\lambda_{max} \frac{0.2898\times10^{-2}\,m.k}{308\,k}$$

$$\lambda_{max} = 9.4\mu m$$

The radiation is in the infrared region of the spectrum.

Example 18.5:
A sodium surface is illuminated with light of wavelength 300nm. The work function for sodium is 2.46 eV. Find
(a) The K.E of the ejected electrons and
(b) The cut-off wavelength for sodium.

Solution:

(a) $E = hf = \frac{hc}{\lambda}$

$$E = \frac{(6.63\times10^{-34}\,J.s)(3\times10^{8}\,m/s)}{300\times10^{-9}\,m}$$

$$= 6.63\times10^{-19}\,J$$

$$\text{or} = \frac{6.63\times10^{-19}\,J}{1.60\times10^{-19}\,J/eV} = 4.14\,eV$$

$$k.E_{max} = hf - \phi$$
$$k.E_{max} = 4.14eV - 22.46eV$$
$$k.E_{max} = 1.68\ eV$$

(b)

$$\phi = 2.46eV = (2.46eV)(1.60\times10^{-19}\,J/eV) = 3.94\times10^{-19}\,J$$

$$\lambda_o = \frac{hc}{\phi} = \frac{(6.63\times10-^{34}\,J.s)(3\times10^{8}\ m/s)}{3.94\times10^{-19}\,J}$$

$$\lambda_o = 5.05\times10^{-7}\,m = 505nm$$

This wavelength is in the green region of the visible spectrum

Example 18.6:

The stopping potential to prevent electron from flowing across a photo electric cell is 4.0 V. What maximum K.E. is given to the electrons by the incident light?

Solution:

$$K.E_{max} = eV$$
$$= 1.6\times10^{-19}c\times4\,Jc^{-1}$$
$$= 6.4\times10^{-19}\ J$$

Example 18.7:

X-rays of wavelength $\lambda = 0.20$nm are scattered from a block of carbon. The scattered X-rays are observed at an angle of 45° to the incident beam calculate the wavelength of the scattered X-rays at this angle.

Solution:

The shift in wavelength of the scattered X-rays is given,

$$\Delta\lambda = \frac{h}{m_o c}(1-\cos\theta)$$

$$= \frac{6.663\times10^{-34}\,J.s}{(9.11\times10^{-31}\ kg)(3\times10^{8}\ m/s)}(1-\cos45°)$$

$$= 7.11\times10^{-13}\,m = 0.000711\ nm$$

Hence, the wavelength of the scattered X – ray at this angle is

$$\lambda' = \Delta\lambda + \lambda$$
$$\lambda' = 0.000711nm + 0.20nm$$
$$\lambda' = 0.200711nm$$

Example 18.8:

Find the threshold wavelength for a photon to produce an electron position pair.

Solution:

The minimum photon energy to create an electron-positron pair is

$$E = 2m_oc^2 = 1.022\ MeV$$

Now to find the wave length of a photon with this energy.

$$E = hf = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{E} = \frac{6.63\times10^{-34}\,J.s\times3\times10^{8}\,m/s}{(1.022\times10^{6}eV)}$$

$$= \frac{1240\,eV\text{-}nm}{1.022\times10^{6}\,eV} = 0.000121\,nm$$

Example 18.9:

Determine the wavelength of an electron that hs been accelerated through a potential difference of 100 V.

Solution:

Gain in K .E of the electron in falling through a potential difference of V volts is:

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

$$= \sqrt{\frac{2eV}{m}}.$$

$$= \sqrt{\frac{2\times1.6\times10-^{19}\,c\times100V}{9.1\times10^{-31}\,kg}}$$

$$= 5.9\times10^{6}\,m/s$$

The de-Broglie wavelength of electron is

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

$$= \frac{6.63\times10^{-34}\,js}{(9.1\times10^{-31}\,kg)\times(5.9\times10^{6}\,m/sec)} = 1.2\times10^{-10}\,m$$

Example 18.10:

A particle of mass 5.0 mg moves with speed of 8.0 m/s. Calculate de Broglie wavelength.

Solution:

$$m = 5.0mg = 5.0\times10^{-6}kg$$

$$v = 8.0\,m/s$$

$$h = 6.33\times10^{-34}\,Js$$

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

$$\Rightarrow \lambda = \frac{6.630+10^{-34}\,Js}{5.0\times10^{-6}\,kg\times8.0\,m/s}$$

$$\Rightarrow \lambda = 1.68\times10^{-29}\,m$$

Text Book Exercises

Q.1 Select the correct answer of the following questions.

(i) If the K.E of free electron double, its de Broglie wavelength changes by the factor.

(a) $\sqrt{2}$ (b) $\frac{1}{\sqrt{2}}$ (c) 2 (d) $\frac{1}{2}$

(ii) Einstein's photoelectric equation is $E_k = hf = \phi$ in this equation E_k refers to:

(a) K.E of all the emitted electrons (b) Mean K.E emitted electrons
(c) Maximum K.E of emitted electrons (d) Minimum K.E of emitted electrons

(iii) De-Broglie waves are associated with:

(a) Moving charged particles only (b) Moving neutral particles only
(c) All moving particles (d) All particles whether in motion or at rest

(iv) A perfect absorber must be also be perfect:

(a) Cavity (b) Source of radiation (c) Radiator (d) None of them

(v) Pair production occurs only when energy of photon is at least equal to:

(a) 1.02 ke V (b) 1.02 eV (c) 1.02 Me V (d) 1.02 Ge V

(vi) Pair production cannot take place in vacuum because:

(a) Mass is not conserved (b) Momentum is not conserved
(c) Energy is not conserved (d) Charge is not conserved

(vii) The positron has charge which is in magnitude equal to the charge on:

(a) Electron (b) Proton (c) β-particle (d) All

(viii) We can never accurately describe all aspects of subatomic particles simultaneously. It is correct according to:

(a) Uncertainty Principle (b) De-Broglie Theory (c) Einstein Theory (d) Photo electric effect

(ix) An electron microscope employs which to one of the following principles?

(a) Electron have a wave nature (b) Electron can be focused by an electric field
(c) Electron can be focused by a magnetic field (d) All of the above

No.	Option	ANSWER	EXPLANATION
(i)	(b)	$\frac{1}{\sqrt{2}}$	As $\lambda = \frac{h}{\sqrt{2m\,Ve}}$ or $\lambda = \frac{h}{\sqrt{2m\,(K.E)}}$ and $\lambda' = \frac{h}{\sqrt{2m\,2(K.E)}}$ $= \frac{1}{\sqrt{2}}\left(\frac{h}{\sqrt{2m\,(K.E)}}\right)$ $\lambda' = \frac{1}{\sqrt{2}}\lambda$
(ii)	(c)	Maximum K.E of emitted electrons	As $hf = \phi + E_k$ or $E_k = hf - \phi$ where E_k represents the kinetic energy of the photo electrons.
(iii)	(c)	All moving particles	As $\lambda = \frac{h}{mv}$ Which shows that the De Broglie wavelength is applicable for both

(iv)	(c)	Radiator	charged and uncharged moving particles. Because the dark colours, especially black colour is a very good absorber and emit the more radiations on their heating.
(v)	(c)	1.02 Me V	Minimum energy required pair production is $2m_oC^2 = 2\times 9.11\times 10^{-3}\times(3\times 10^8)^2$ $= 1.02$ MeV
(vi)	(b)	momentum is not conserved	In order to stop the γ-ray photon, a nucleus is required.
(vii)	(d)	All	All of these possible has the same numerical value of charge i.e., 1.6×10^{-19} C
(viii)	(a)	Uncertainty Principle	This is the statement of Heisenberg uncertainty principle.
(ix)	(d)	All of the above	All the given properties holds for electron.

Comprehensive Questions

Q.2 Write short answers of the following questions.

1. State Einstein's postulate of the special theory of relativity. Discuss its various results.

Ans: See Theory Question No. 2

2. What are the main features of the thermal radiation from a black body?

Ans: See Theory Question No. 4

3. What are the main feature of photoelectric effect? Discuss the failure of classical physics and success of photon concept in explaining this effect.

Ans: See Theory Question No. 6

4. What is Compton's effect. Develop a mathematical relation for the Compton's wave shift.

Ans: See Theory Question No. 9

5. Write note on pair production and annihilation of matter.

Ans: See Theory Question No. 10 & 11

6. What is de Broglie hypothesis? Describe an experiment to show that particle has wave characteristics.

Ans: See Theory Question No. 12

7. What is meant by wave-particle duality? Explain.

Ans: See Theory Question No. 14

8. State and explain Heisenberg's uncertainty principle. Justify the validity of this principle by a thought experiment

Ans: See Theory Question No. 16

Conceptual Questions

1. Imagine a world in which c = 50 m/s. How would every day events appear to us?

Ans: If the speed of light reduces to c = 50 m/s, then relativistic effects will remain unchanged.

Explanation:

According to principle of constancy of light(2nd postulate), the upper limit of speed for material particles will now become 50 m/s i.e. it will be impossible for material objects to attain such speed. Even as a speed of 40 m/s, relativistic effects would be apparent for material bodies.

2. Both Zarak and samina are twenty years old. Zarak leaves earth in a spacecraft moving at 8c, while Samina remains on the earth. Zarak returns from a trip to star 30^{th} light years earth, which one will be of greater age. Explain?

Ans: Samina will be older than Zarak by difference of about 30 years, due to the relativistic effects of time dilation

Explanation:

A light year is the distance travel by the light in one year.

Samina will stay on earth and the time past for her will be:

$$t_x = \frac{2d}{v} \rightarrow (1)$$

Where d is the distance of a star 30 light years away i.e., de = 30 × c years.

Now equation (1) $t_x = \frac{2(30 \times c \text{ years})}{0.8e} = 75 \text{ years}$

Samina will Spend 75 years at earth during the Zarak's journey. As her age is 20 by the time Zarak left so at his return her age will be 20 y + 75y to 95 y.

Due to relativistic time dilation effect these 75 years will appear to Zarak

$$t_x = t \times \sqrt{1 - \frac{v^2}{c^2}}$$

or $$t_x = 75y \times \sqrt{1 - \frac{(0.8c)^2}{c^2}}$$

$$t_x = 75y \times \sqrt{1 - 0.64}$$

or $$t_x = 75y \times \sqrt{0.36}$$

$$t_x = 75y \times 0.6$$

or $$t_x = 45y$$

Therefore, time of Zarak will be 45y.

When Zarak returns from journey he will be 20y + 45y = 65y. Thus, then Zarak returns, he will be only 65 years of age whereas Samina will 95 years of age, about 30 years older than Zarak returns, he will be only 65 years of age whereas Samina will 95 years of age, about 30 years older than Zarak.

3. Which has more energy, a photon of ultraviolet radiation or a photon of yellow light? Explain.

Ans: Energy of photon is given by

$$E = \frac{hC}{\lambda}$$

$$E \propto \frac{1}{\lambda}$$

$$\lambda_{violet} < \lambda_{yellow}$$

Therefore energy of violet photon is greater than energy of yellow photon.

4. Some stars are observed to be reddish, and some are blue. Which stars have the higher surface temperature? Explain.

Ans: The stars that appear to be bluish have higher surface temperatures as compared to the stars that are observed as reddish.

Explanation: Astronomers use the colour to stars to estimate their temperature by using Wein's displacement law given by;

$$\lambda T = 2898 \ \mu m \ K$$

$$T = 2898 \ \mu m \ K/\lambda$$

For stars of red colour; $\lambda = 700$ nm

$$T = 2898 \ \mu m \ K/700 \ nm$$

$$\Rightarrow T = 2898 \times 10^{-4} \ m \ K/700 \times 10^{-4} \ m$$

$$\Rightarrow T = 4140 \ K$$

For stars of blue colour; $\lambda = 475$ nm

$$T = 2898\ \mu m\ K/475\ nm$$

$$\Rightarrow \quad T = 2898 \times 10^{-6}\ m\ K/475 \times 10^{-9}\ m$$

$$\Rightarrow \quad T = 6100\ K$$

Therefore, looking at the colour of distant stars, we can determine which one will have higher surface temperature.

5. An electron and proton are accelerated from rest through the same potential difference. Which particle has the longer wavelength? Explain.

Ans: The electron, with its smaller mass, has the greater De-Broglie wavelength.

Explanation: From De-Broglie's hypothesis, wavelength attached with a material body in motion is given by;

$$\lambda = \frac{h}{p} \rightarrow (1) \qquad \lambda = \frac{h}{\sqrt{2Vqm}}$$

Where P is the momentum and it is related to kinetic energy K.E by

$$K.E = \frac{p^2}{2m}$$

$$p = \sqrt{2m\,K.E}$$

Putting this in equation (1), we get;

$$\lambda = \frac{h}{\sqrt{2m\,K.E}} \rightarrow (2)$$

Now as $K.E = qV_o$, so equation (2) in terms of potential difference V_o becomes

$$\lambda = \frac{h}{\sqrt{2m\,(qV_o)}}$$

Where h is a constant, V_o is same for both the electron and proton, magnitude of charge q is also same for both particles. So, considering all the other quantities same, wavelength inversely depends upon mass as,

$$\lambda \propto \frac{1}{\sqrt{m}}$$

Hence that particle will have longer wavelength whose mass is smaller and that is electron.

6. All objects radiate energy. Explain why, then, are we not able to see objects in a dark room.

Ans: Because the emitted energy is in form of infrared radiations.

Explanation:

At any temperature the object emits the thermal radiation from its surface. The properties of these radiations depend on the temperature and surface of the object. The spectrum of these radiations shows that these radiations consist of a continuous distribution of wavelengths in electromagnetic spectrum. If the object is at room temperature, the wavelengths of thermal radiation are mainly in the infrared region and hence the radiation is not detected by the human eye.

As the temperature increases, the object finally starts to glow and red colour become visible. At very higl temperatures, the glowing object appears white, as in the hot tungsten filament of an incandescent light bulb. Thermal radiation is emitted from the surface of any object. The peak wavelength is related to wavelength is related to the surface temperature through Wien's displacement law. If λ_{max} is the wavelength at which intensity peak is obtained and T is absolute temperature than;

$$\lambda_{max} \times T = \text{constant} \qquad (\text{Where constant} = 0.2898 \times 10^{-2}\ m\ K.)$$

Ordinary objects are at room temperature of T = 27°C = 300K, so

$$\lambda_{max} = \frac{0.2898 \times 10^{-2}\ m\ K}{300K} = 9.66 \times 10^{-6}\ m$$

This wavelength corresponds to the infrared region of the spectrum. So the peak of the radiation is in the infrared region of the spectrum, it shows that most of the energy emitted by objects is not visible to us.

7. If photoelectric effect is observed for one metal, can you conclude that the effect will also be observed for another metal under the same conditions?

Ans: No, it is not possible.

Work function is given by

$$\phi = hf_o$$

$$\phi = \frac{hC}{\lambda_o}$$

As work function is different for different metals. Therefore it is not possible to observe the photoelectric effect for one metal and then for other metals under the same condition.

→ If ϕ is smaller then light of low frequency can eject electrons from metal surface.

→ If ϕ is greater then light of high frequency can eject electrons from metal surface.

8. Explain why it is impossible for a particle with mass to move faster than the speed of light.

Ans: Special theory of relativity will never permits us to move an object with the speed greater than the speed of light.

Explanation:

The relativistic results of variation of mass, time and length involve the term $1 - \frac{v^2}{c^2}$

For object with speed equal to speed of light ($v = c$). The object with mass cannot even go with the speed of light ($v = c$). The special relativity equation for the relativistic mass is; $m = \frac{m_o}{\sqrt{1 - \frac{v^2}{c^2}}}$

Consider what happens to m when v approaches c ($v = c$), So

$$m = \frac{m_o}{\sqrt{1 - \frac{v^2}{c^2}}} = \frac{m_o}{\sqrt{1 - 1}} = \frac{m_o}{0} = \infty$$

Division of a non-zero real number by zero is infinite or undefined. Thus, an object has infinite inertia and an infinite energy will be required to move an object with the speed of light, so an object's speed must be less than the speed of light. Thus it is impossible to move the object move with the speed of light so to move with speed grater than $v = c$ is out of question.

9. Use photon model to explain why the ultraviolet radiation is harmful to your skin while visible light is not.

Ans: Energy of photon is given by

$$E = \frac{hC}{\lambda}$$

Where λ is wavelength of photon as h and C are constant

$$E \propto \frac{1}{\lambda}$$

$$\lambda_{ultraviolet} < \lambda_{visible}$$

$$E_{ultraviolet} > E_{visible}$$

Hence ultraviolet radiation have high energy photons which are harmful to skin as compared to visible light having low energy photon.

10. Explain why the annihilation of an electron and positron creates a pair of photons rather than a single photon.

Ans: To satisfy the law of conservation of energy and momentum, the two photons are emitted in opposite direction when annihilation of electron and positron takes place.

Explanation:

Electron is a particle and positron is its anti-particle. When an electron and a positron combine, the pair annihilation takes place. In this process, the conservation of energy, charge and momentum will hold.

Conservation of mass and charge may even holds if a single photon is produced in this process.
But in order to conserve the momentum, it is necessary to produced two photons of energy, so that the total momentum before and after, remains constant.

11. When a particle's K.E increases, what happen to its de Broglie wavelength?

Ans: When the kinetic energy of the particle is increased its de Broglie wavelength decrease.

Explanation:

The de Broglie wavelength λ is related to the magnitude of the momentum P by the equation;

$$\lambda = \frac{h}{p} \rightarrow (1)$$

Where P is the momentum and it is related to kinetic energy K.E by

$$K.E = \frac{p^2}{2m}$$

$$p = \sqrt{2m\,K.E}$$

Putting this in equation (1), we get;

$$\lambda = \frac{h}{\sqrt{2m\,K.E}} \rightarrow (2)$$

$$\lambda \propto \frac{1}{\sqrt{K.E}}$$

So de-Broglie's wavelength is inversely related to square root of K.E, therefore when a particle's K.E increases, its de-Broglie's wavelength decreases.

12. Explain why we can experimentally; observe the wave like properties of electrons, but not of billiard ball?

Ans: We cannot observe wave like properties associated with billiard ball because of its large mass.

Explanation:

As the De-Broglie wavelength varies inversely with the mass. So it is not possible to observe it for massive particles like billiard ball.

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

So for massive object De-Broglie wavelength become too small to be measured and quantum mechanical results will no longer remain prominent.

Electron is a tiny object having very small mass and its typical velocity is 10^5 m/s. Wavelength associated with it according to De-Broglie.

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{6.62607004 \times 10^{-34}}{9.1 \times 10^{-31} \times 10^5} = 7.3 \times 10^{-9}\ m$$

and it is detectable due to which its wave like properties e.g., diffraction, are observable.

But the billiard ball is enormously massive (m = 150 g = 0.15 kg) than an electron and its velocity can be about 3 m/s. De-Broglie wavelength will be so small that there is no such device or instrument that could measure or even detect such a small wavelength.

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{6.62607004 \times 10^{-34}}{0.15 \times 3} = 1.72 \times 10^{-35}\ m$$

Thus, we can experimentally observe wave like properties of election but not of a billiard ball.

13. Does a light bulb at a temperature of 2500 K produce as white a light as the sun at 6000K? Explain.

Ans: No, a light bulb at 2500 K does not produce as white light as the sum at 6000 K.

Explanation:

According to Wien's displacement law, $\lambda_{max}\,T = 0.2898$ m K $\rightarrow$ (1)

Where λ_{max}, is the wavelength corresponding to maximum intensity and T is absolute temperature. Now for ordinary light at 2500 K, equation (1) implies that the peak at which maximum intensity occurs λ_{max} = 1.16 pm which is not in the visible range (most part of filament bulb light is in infrared region while for sun at 6000 K, equation (1) shows that the peak at which maximum intensity occurs λ_{max} = 683 nm is in the visible range. Thus, we conclude that a light bulb at 2500 K does not produce as white light as the sun at 6000 K.

14. A beam of red light and a beam of blue light have exactly the same energy. Which light contains the greater number of photons?

Ans. Beam of ***red light*** contains greater number of photons

Reason

As energy of a photon is

$$E = hf = \frac{hc}{\lambda} \quad , \quad (\text{As } v = f\lambda)$$

So energy of a photon is

$$E_n = n\frac{hc}{\lambda}$$

OR

$$n = \frac{E_n\lambda}{hc}$$

As E_n, h and c are same

So $n \propto \lambda$

As $\lambda_{red} > \lambda_{blue}$, so red beam will have greater number of photons.

The red light is less energetic and has low frequency than blue light. Since $\frac{f_{blue}}{f_{red}} > 1$, therefore red light will contain more photons than blue beam of light.

15. In Compton scattering experiment, an electron is accelerated straight ahead in the direction of the incident X-rays photon. Which way does the scattered photon move? Explain.

Ans: The scattered photon will either move at 0° or at 180°.

Explanation: In Compton scattering experiment, the scattered X-ray photon can move either in the same direction as initially moving (0°) or scatter backwards (180°). Compton shift is given by;

$$\Delta\lambda = \frac{h}{m_o c}(1 - \cos\theta) \rightarrow (1)$$

The maximum energy that a recoil electron can obtain in Compton scattering is in a head-on collision in which the electron scatters at 0° whereas the X-ray photon itself is scattered backward at the angle of 180°.
So above equation becomes;

$$\Delta\lambda = \frac{h}{m_o c}(1 - \cos 0°) = \frac{h}{m_o c}(1 - 1) = 0$$

$$\Delta\lambda = \frac{h}{m_o c}(1 - \cos 180°) = \frac{h}{m_o c}(1 + 1) = \frac{2h}{m_o c}$$

So incident photon either scatters at 0° or at 180°.

6. Why must the rest mass of a photon be zero? Explain.

Ans: When a material object of actual mass no moves with high speed then its apparent mass m according to the results of special theory of relativity is given by equation.

$$m = \frac{m_o}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Now we know that a photon always travels with speed of light and if we replace v by c in above equation, we get;

$$m = \frac{m_o}{\sqrt{1-\frac{c^2}{c^2}}} = \frac{m_o}{\sqrt{1-1}} = \frac{m_o}{0} = \infty$$

Hence in order to escape from this mathematical controversy, we take rest mass of photon to be zero.

17. What happens to total radiation from black body if its absolute temperature is doubled?

Ans: If the absolute temperature of a black body is doubled, then the intensity of the total radiation increases by 16 times.

Explanation: For a blackbody, Stefan-Boltzmann's law shows that total radiation emitted by a black body per unit time per unit area is E and is given by equation;

$$E = \sigma T^4$$

Where σ is Stefan-Boltzmann constant and T is absolute temperature. Now if absolute temperature is doubles i.e., T = 2T then,

$$E' = \sigma(T)^4$$
$$E' = \sigma(2T)^4$$
$$E' = 16\,\sigma(T)^4$$
$$E' = 16E$$

Thus, by doubling the absolute temperature, intensity of total radiation increases by 16 times.

18. Why don't we observe Compton's effect with visible light?

Ans: We cannot observe Compton's effect with visible light because of smaller energy and frequency. Visible light photon transfer all its energy to electron and disappear.

Explanation:

We do not observe Compton's effect with visible light because for Compton's effect to occur, high energy and high frequency photon is required for instance X-rays but visible light has not got enough energy to carry out Compton's effect. In comparison to X-rays, energy of visible light is quite smaller than the minimum energy required for Compton's effect to occur. That is why we cannot observe Compton's effect with visible light.

19. If the following particles all have the same K.E, which has the shortest wavelength? Electron, alpha particle, neutron and proton?

Ans: Alpha particle will possess shortest De-Broglie's wavelength.

Explanation: From the De-Broglie's hypothesis, wavelength attached with a moving particle is given by;

$$\lambda = \frac{h}{p} \rightarrow (1)$$

Where P is the momentum and it is related to kinetic energy K.E by

$$K.E = \frac{p^2}{2m}$$
$$p = \sqrt{2m\,(K.E)}$$

Putting this in equation (1), we get;

$$\lambda = \frac{h}{\sqrt{2m\,(K.E)}} \rightarrow (2)$$
$$\lambda \propto \frac{1}{\sqrt{m}}$$

From above equation, we conclude that the massive particle will have shortest wavelength and alpha particle is the heaviest of all given. So alpha particle will possess shortest De-Broglie's wavelength.

20. If an electron and a proton have the same de Broglie wavelength, which particle has greater speed?

Ans: Speed of electron will be greater than speed of proton.

Explanation:

De-Broglie's wavelength can be written as:

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

As given that wavelength of both electron and proton is same (constant), So, we can write the above equation as;

$$v \propto \frac{1}{m}$$

From last expression, it can be concluded that particle with smaller mass will have higher speed. As mass of electron is lesser than mass of proton, so it will have higher speed than proton.

Thus, we conclude that speed of electron is greater than speed of proton provided that both particles have same de-Broglie's wavelength.

21. Why ultraviolet radiation is harmful to skin while visible light is not?

Ans: Question repeated.

22. An incandescent light bulb is connected to a dimmer switch. When the bulbs operate at full power, it appears white, but as it is dimmed it looks more and more red. Explain.

Ans: As intensity (brightness) of light beam depends upon number of photons whereas the visibility depends upon its frequency. When the bulb operates at full power, it appears white. Because the maximum power dissipation through its filament is $P = I^2R$.

As a result of power dissipation the temperature of the bulb will increase and emit radiation of shorter wavelength maximum intensity. This follows Wein's displacement law which is $\lambda_{max} \times T = \text{constant} (= 0.2898 \times 10^{-2}\ \text{m K})$

The bulb becomes dim by decreasing the current through it, which ultimately decreasing power dissipation and finally temperature. Since the nature of radiation depends upon then temperature of the radiator. So at low temperature, the bulb emits radiations of longer wavelengths and appears red.

Numerical Problems

1. The length of space ship is measure to be exactly one-third of its proper length. What is the speed of the space ship relative to the observer? [0.9428c]

Given: Length $\Delta L = \frac{1}{3}\Delta L_P$

To Find: Speed v = ?

Solution:

By relativistic equation for the length contraction

$$\Delta L = \Delta L_P \sqrt{1 - \frac{v^2}{C^2}}$$

Or

$$\sqrt{1 - \frac{v^2}{C^2}} = \frac{\Delta L}{\Delta L_P}$$

Putting values:

$$\sqrt{1 - \frac{v^2}{C^2}} = \frac{\Delta L_P/3}{\Delta L_P}$$

$$\sqrt{1 - \frac{v^2}{C^2}} = \frac{\Delta L_P}{3 \times \Delta L_P}$$

$$\sqrt{1 - \frac{v^2}{C^2}} = \frac{1}{3}$$

Squaring both sides

$$1 - \frac{v^2}{C^2} = \frac{1}{9}$$

$$-\frac{v^2}{C^2} = \frac{1}{9} - 1$$

Multiplying with negative sign on the both sides

$$\frac{v^2}{C^2} = 1 - \frac{1}{9}$$

$$\frac{v^2}{C^2} = 0.889$$

$$v^2 = 0.889C^2$$

Taking square root both sides

$$\sqrt{v^2} = \sqrt{0.889C^2}$$

$$v = \sqrt{0.889} \times \sqrt{C^2}$$

$$\boxed{v = 0.94287\ C}$$

2. The time period of a pendulum is measured to be 3s in inertial frame of the pendulum. What is the period when measured by an observer moving with a speed of 0.95c with respect to the pendulum?

Given:

Proper time $\Delta t_P = 3.00s$

Speed $v = 0.95\ C$

To Find: Dilated time $(\Delta t) = ?$

Solution:

The relativistic equation for the time dilation is

$$\Delta t = \frac{\Delta t_P}{\sqrt{1 - \frac{v^2}{C^2}}}$$

$$\Delta t = \frac{3.0s}{\sqrt{1 - \frac{(0.95C)^2}{C^2}}}$$

Or $$\Delta t = \frac{3.0s}{\sqrt{1 - \frac{0.9025C^2}{C^2}}}$$

hence, $$\Delta t = \frac{3.0s}{\sqrt{1 - \frac{0.9025C^2}{C^2}}}$$

Hence, $$\Delta t = \frac{3.0s}{\sqrt{1 - \frac{0.9025C^2}{C^2}}}$$

$$\boxed{\Delta t = 9.61s}$$

3. An electron, which has mass 9.11×10^{-31} kg, moves with a speed of 0.75c. Find its relativistic momentum and compare, this value with momentum calculated from classical expression.

Given: Rest mass of electron $\Delta m_o = 9.11 \times 10^{-11}$ kg

Speed $v = 0.75C$

To Find: Relativistic momentum $\Delta_P = ?$

Classical momentum $P = ?$

Solution:

By relativistic equation for the momentum

$$\Delta p = \Delta m \times v$$

Therefore, $$\Delta p = \frac{\Delta m_o}{\sqrt{1-\frac{v^2}{C^2}}} \times v$$

Putting values: $$\Delta p = \frac{(9.11 \times 10^{-31}\text{kg})}{\sqrt{1 \times \frac{(0.750C^2)}{C^2}}} \times 0.750C$$ since, $$\Delta m = \frac{\Delta m}{\sqrt{1-\frac{v^2}{C^2}}}$$

$$\Delta p = \frac{(9.11 \times 10^{-31}\text{kg})}{\sqrt{1-\frac{(0.5625C^2)}{C^2}}} \times 0.750 \times 3 \times 10^8 \text{ rms}^{-1}$$

$$\boxed{\Delta p = 3.10 \times 10^{-22} \text{ kg ms}^{-1}}$$

By classical equation the momentum is

$$p = m \times v$$

$$p = (9.11 \times 10^{-31} \text{ kg}) \times 0.750 \times 3 \times 10^8 \text{ rms}^{-1}$$

$$\boxed{P = 2.05 \times 10^{-22} \text{ kg ms}^{-1}}$$

Result: Hence when electron is moves with high speed. The electron carries momentum, but the magnitude of its momentum is not given by P = mv because the speed is relativistic. The correct relativistic result is 60% greater than the classical result.

4. AN electron moves with a speed of v = 0.85c. Find its total energy and K.E in electron volt.

Given:

Speed of electron $v = 0.85C$

Rest mass of electron $\Delta m_o = 9.11 \times 10^{-31}$ kg

To Find:

Total energy E = ?

Kinetic energy KE = ?

Solution:

By Einstein famous mass energy relationship, the rest mass energy is:

$$E_o = \Delta m_o C^2$$

$$E_o = 9.102 \times 10^{-31} \text{ kg} \times (3 \times 10^8 \text{ ms}^{-1})^2$$

$$E_o = 8.1918 \times 10^{-14} \text{ J}$$

In electron volts $$E_o = \frac{8.1918 \times 10^{-14} \text{ J}}{1.602 \times 10^{-19} \text{ C}}$$

$$E_o = 0.511 \times 10^6 \text{ eV}$$

$$E_o = 0.511 \text{ MeV}$$

Also by Einstein mass energy relationship

$$E = \Delta m C^2$$

$$E = \frac{\Delta m_o}{\sqrt{1-\frac{v^2}{C^2}}} \times C^2$$ since $$\Delta m \frac{\Delta m_o}{\sqrt{1-\frac{v^2}{C^2}}}$$

Since

$$E_o = \Delta m_o C^2$$

therefore $$E = \frac{E_o}{\sqrt{1-\frac{v^2}{C^2}}}$$

Putting values:

$$E=\frac{0.51MeV}{\sqrt{1-\frac{(0.85\times C)^2}{C^2}}}$$

$$E=\frac{0.51MeV}{\sqrt{1-\frac{0.7725C^2}{C^2}}}$$

$$E=\frac{0.51MeV}{\sqrt{1-0.7725}}$$

Or

$$E=0{,}51MeV\times 1.90$$

$$\boxed{E=0.970MeV}$$

The total energy is the sum of kinetic and rest mass energy, therefore

$$E=E_o+K.E$$

$$K.E=E-E_o$$

$$K.E=0.970MeV-0.511MeV$$

$$\boxed{KE=0.459MeV}$$

5. The rest mass of a proton is 1.673×10^{-27} kg. At what speed would the mass of the proton be tripled?

Given:

Relativistic mass $\Delta m=3\ \Delta m_o$

Rest mass of proton $\Delta m_o=1.673\times10^{-27}$ kg

To Find: Speed v = ?

Solution: By relativistic equation for increase in mass is

$$\Delta m=\frac{\Delta m_o}{\sqrt{1-\frac{v^2}{C^2}}}$$

Or

$$\sqrt{1-\frac{v^2}{C^2}}=\frac{\Delta m_o}{\Delta m}$$

Putting values:

$$\sqrt{1-\frac{v^2}{C^2}}=\frac{\Delta m_o}{3\Delta_o m_o}$$

$$\sqrt{1-\frac{v^2}{C^2}}=\frac{1}{3}$$

Squaring both sides

$$1-\frac{v^2}{C^2}=\frac{1}{9}$$

$$\frac{v^2}{C^2}=\frac{1}{9}-1$$

Multiplying with negative sign on both sides

$$\frac{v^2}{C^2}=1-\frac{1}{9}$$

$$\frac{v^2}{C^2}=0.8889$$

$$v^2=0.8889C^2$$

Taking square root on both sides

$$\sqrt{v^2}=\sqrt{0.8889}\sqrt{C^2}$$

$$\boxed{V=0.9428C}$$

6. At what fraction of speed of light must a particle move so that it K.E is one and a half times its rest energy?

Given: Kinetic energy $KE = \frac{1}{2}E_o$

Solution:

The total energy is the sum of kinetic and rest mass energy,

$$E = E_o + KE$$

$$E = E_o = \frac{E_o}{2}$$

$$E = Eo\left(1 + \frac{1}{2}\right)$$

$$E = \frac{3}{2}E_o$$

By Einstein famous mass energy relationship

$$E = \frac{m_o C^2}{\sqrt{1 - v^2/C^2}}$$

$$E = \frac{3}{2}\frac{m_o}{C^2}$$

Re-arranging $\sqrt{1 - \frac{v^2}{C^2}} = \frac{2}{3}$ squaring both sides

$$1 - \frac{v^2}{C^2} = \frac{4}{9}$$

$$-\frac{v^2}{C^2} = \frac{4}{9} - 1$$

Multiplying with negative sign on both sides

$$\frac{v^2}{C^2} = \frac{4}{9} \Rightarrow \frac{v^2}{C^2} = 0.555 \Rightarrow v^2 = 0.555C^2$$

Taking square root on both sides

$$\sqrt{v^2} = \sqrt{0.555}\sqrt{C^2}$$

$$\boxed{v = 0.74535C}$$

7. A metal, whose work function is3.0 eV, is illuminated by light of wavelength 3×10^{-7}m. Calculate (a) threshold frequency, (b) The maximum energy of photoelectrons (c) The stopping potential.

Given: Plank's constant $h = 6.626 \times 10^{-34}$ Js

Wavelength $\lambda = 3 \times 10^{-7}$ m

Work function $\phi = 3.0$eV

$\phi = 3.0\text{eV} \times 1.602 \times 10^{-19}\text{ C} = 4.806 \times 10^{-19}$ J

To Find: (a) Threshold frequency $f_o = ?$

(b) Maximum $K.E_{max} = ?$

(c) The stopping potential $v_o = ?$

Solution:

(a) The threshold frequency is $f_o = \frac{\phi}{h}$

Putting values: $f_o = \frac{4.806 \times 10^{-19}\text{ J}}{6.626 \times 10^{-34}\text{ Js}}$

$$\boxed{f_o = 0.72 \times 10_{15}\text{ Hz}}$$

(b) $K.E_{max} = hf - hf_o$

$$K.E_{max} = \frac{hC}{\lambda} - hf_o$$

$$= \frac{6.63 \times 10^{-24} \times 3 \times 10^8}{3 \times 10^{-7}} - 6.63 \times 10^{-34} \times 0.723 \times 10^{15}$$

$$K.E_{max} = 1.83 \times 10^{-195}\text{J}$$

$$K.E_{max} = \frac{1.83 \times 10^{-19}}{1.6 \times 10^{-19}}$$

$$\boxed{K.E_{max} = 1.14\text{eV}}$$

(c) $K.E_{max} = V_o e$

$$V_o = \frac{K.E_{max}}{e}$$

$$= \frac{1.83 \times 10^{-19}}{1.6 \times 10^{-19}}$$

$$\boxed{V_o = 1.14\text{V}}$$

8. The thermal radiation from the sun peaks in the visible part of the spectrum. Estimate the temperature of the sun.

Given:

Wien's constant = 0.2898×10^{-2} mk

To Find:

Temperature T = ?

Solution:

The visible part of the spectrum peaks at wavelength of wavelength at which the curve peak and T is absolute then by Wien's displacement law.

$$\lambda_{max} T = \text{constant}$$

Where constant = 0.2898×10^{-2}mk

$$T = \frac{\text{constant}}{\lambda max}$$

putting values

$$T = \frac{0.2898 \times 10^{-2} \text{ mk}}{0.5 \times 10^{-6}\text{m}}$$

$$\boxed{T = 0.5796 \times 10^{4}\text{k} = 5796\text{k} = 5800\text{k}}$$

9. A 50 keV X-ray is scattered through an angle of 90°. What is the energy of the X-ray after Compton scattering?

Given:

Angle $\theta = 90^{\circ}$

Rest mass of electron $m_o = 9.11 \times 10^{-31}$kg

Speed of light $C = 3 \times 10^{8}$ ms^{-1}

Energy of photon E = hf = 50KeV

To Find:

Energy after scattering E = hf = ?

Solution:

By Compton's scattering formula we have

$$\frac{1}{f'} = \frac{1}{f} + \frac{h}{m_oC^2}(1 - \cos\theta)$$

Dividing equation on both sides by (h), we get

$$\frac{1}{hf'} = \frac{1}{hf} + \frac{1}{m_oC^2}(1 - \cos\theta) \longrightarrow \text{(i)}$$

By Einstein famous mass energy relationship, the rest mass energy is $E_o = \Delta m_oC^2$

$$E_o = \Delta m_oC^2$$

$$m_oC^2 = 9.102 \times 10^{-31} \text{ kg} \times (3 \times 10^{8} \text{ ms}^{-1})$$

$$m_oC^2 = 8.1918 \times 10^{-14}\text{J}$$

In electron volts $m_oC^2 = \frac{8.1918 \times 10^{-14}\,J}{1.602 \times 10^{-19}\,C}$

$$m_oC^2 = 0.511 \times 10^6\ eV$$

$$m_oC^2 = 0.511MeV$$

$$m_oC^2 = 511KeV$$

Putting values in equation (i), we get

$$\frac{1}{hf'} = \frac{1}{50KeV} + \frac{1}{511KeV}(1 - \cos 90^\circ)$$

Sin cos 90° = 0 $\frac{1}{hf'} = \frac{1}{50KeV} + \frac{1}{511KeV}(1 - 0)$

Or $\frac{1}{hf'} = \frac{561}{25550KeV}$

$$\boxed{hf' = 45.5\ KeV}$$

The remaining energy 50KeV – 45.5KeV = 4.5KeV is carried by electron as its kinetic energy.

10. Calculate the wavelength of de Broglie waves associated with electrons accelerated through a potential difference of 200V.

Given:

Potential difference $\Delta v = 200v$
Rest mass of electron $m = 9.11 \times 10^{-31}$ kg
Charge on electron $q = 1.602 \times 10^{-19}$ C
Plank's constant $h = 6.626 \times 10^{-34}$ Js

To Find:

De Broglie wavelength $\lambda = ?$

Solution:

$$\lambda = \frac{h}{\sqrt{2Vem}} \longrightarrow (i)$$

$$= \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 200 \times 1.6 \times 10^{-19} \times 9.1 \times 10^{-31}}}$$

$$= 0.868 \times 10^{-10}\ m$$

$$= 0.868\ \text{Å}$$

11. An electron is accelerated through a potential difference of 50V. Calculate its de Broglie Wavelength.

Given:

Potential difference $\Delta V = 50V$
Rest mass of electron $m = 9.11 \times 10^{-31}$ kg
Charge on electron $q = 1.602 \times 10^{-19}$ C
Plank's constant $h = 6.626 \times 10^{-34}$ Js

To Find:

De- Broglie wavelength $\lambda = ?$

Solution:

$$\lambda = \frac{h}{\sqrt{2Vem}} \longrightarrow (i)$$

$$= \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 50 \times 1.6 \times 10^{-19} \times 9.1 \times 10^{-31}}}$$

$$\lambda = 1.74 \times 10^{-10}\ m$$

$$\lambda = 1.74 \times \text{Å}$$

12. The speed of an electron is measured to be 5×10^3 m/s to an accuracy of 0.003%. Find the uncertainty in determining the position of this electron.

Given:

Speed $v = 5 \times 10^{-3}\ ms^{-1} \pm 0.003\%$

Mass of electron $m = 9.11 \times 10^{-31}$ kg

Planck's constant $h = 6.626 \times 10^{-34}$ Js

To Find:

Uncertainty in position $\Delta x = ?$

Solution:

In fractional uncertainty the speed 'v' of electron is

$$v = 5 \times 10^{-3}\ ms^{-1} \pm \frac{0.003 \times 5 \times 10^{-3}\ ms^{-1}}{100}$$

$$v = 5 \times 10^{-3}\ ms^{-1} \pm 0.15 ms^{-1}$$

Thus the fractional uncertainty Δv the speed 'v' is $\Delta v = 0.1\ ms^{-1}$

By Heisenberg uncertainty principle we have

$$\Delta x\, \Delta P_x = h$$

$$\Delta_x = \frac{h}{\Delta P_x}$$

$$\Delta x = \frac{h}{m\Delta v} \qquad \text{Since } \Delta p_x = m\Delta v$$

$$\Delta x = \frac{6.626 \times 10^{-34}\ Js}{9.11 \times 10^{31}\ kg \times 0.15 ms^{-1}}$$

$$\boxed{\Delta x = 4.85 \times 10^{-3}\ m}$$

Result: The fractional value given for the accuracy of the electron's speed can be interpreted as the fractional uncertainty in its momentum. This uncertainty corresponds to a minimum uncertainty in the electron's position through the uncertainty principle.

13. The life time of an electron in an exited state is about 10^{-8}s. What is its uncertainty in energy during this time?

Given:

Uncertainty in time $\Delta t = 10^{-8}$s

Plank's constant $h = 6.626 \times 10^{-34}$ Js

To Find:

Uncertainty in energy $\Delta E = ?$

Solution:

By Heisenberg uncertainty principle we have

$$\Delta E\, \Delta t = h$$

$$\Delta E = \frac{h}{\Delta t}$$

Putting values:

$$\Delta E = \frac{6.626 \times 10^{-34}\ Js}{10^{-8} s}$$

$$\boxed{\Delta E = 6.626 \times 10^{-26}\ J}$$

Additional Conceptual Short Questions With Answers

1. The length of a spaceship is measured to be exactly half its proper length. Find the velocity of spaceship.

Ans. $\ell = \ell_o\sqrt{1-\frac{V^2}{C^2}}$

As $\ell = \frac{\ell_o}{2}$

$$\frac{\ell_o}{2} = \ell_o\sqrt{1-\frac{V^2}{C^2}}$$

$$\frac{1}{2} = \sqrt{1-\frac{V^2}{C^2}}$$

Squaring both sides

$$\frac{1}{4} = 1-\frac{V^2}{C^2}$$

$$\frac{V^2}{C^2} = 1-\frac{1}{4}$$

$$\frac{V^2}{C^2} = \frac{4-1}{4}$$

$$\frac{V^2}{C^2} = \frac{3}{4}$$

$$\frac{V^2}{C^2} = 0.75$$

$$V^2 = 0.75C^2$$

Taking square root of both sides

$$V = 0.866C$$

2. An electron has mass $\frac{5}{3}m_o$ during motion. Find K.E of electron.

Ans. $K.E = mc^2 - m_oc^2$

$$m = \frac{5}{3}m_o$$

$$K.E = \frac{5}{3}m_oc^2 - m_oc^2$$

$$K.E = \frac{5m_oC^2 - 3m_oC^2}{3}$$

$$K.E = \frac{2m_oC^2}{3}$$

3. Two metals A and B have work functions 2eV and 4eV respectively. Which metal have lower threshold wavelength for photoelectric effect?

Ans. Work function of metal A

$$\varphi_A = \frac{hc}{\lambda_o} = 2ev$$

Work function of metal B

$$\varphi_B = \frac{hc}{\lambda'_o} = 4ev$$

As $\varphi_A \propto \frac{1}{\lambda_o}$

As $\varphi_B > \varphi_A$

Therefore metal B has shorter threshold wavelength of incident photon then metal A

$\lambda'_o < \lambda_o$

4. When light from a lamp falls on a wooden table, no photoelectrons are emitted from it. Why?

Ans. The work function of wood is greater than that of energy of the incident photon so electrons cannot be ejected from the wood.

5. If the frequency of incident light on the cathode of photocell is doubled, how will the following change?

(i) K.E of ejected electrons

(ii) Photoelectric current

(iii) stopping potential

Ans. If frequency of incident light is doubled then

(i) K.E of ejected electron will be greater than twice.

(ii) The current will not change

(iii) The stopping potential will also be greater than twice, because it depends on K.E.

6. What are dimensions of Plank's constant h?

Ans. $E = hf$

$h = \frac{E}{f}$

dimension of energy are $E = [ML^2T^{-2}]$

dimension of frequency $f = [T^{-1}]$

Dimension of h

$$h = \frac{[ML^2T^{-2}]}{[T^{-1}]}$$

$$h = [ML^2T^{-1}]$$

7. Calculate the Compton's wavelength for electron and a proton.

Ans.

$$\Delta\lambda = \frac{h}{m_o c}$$

(i) **For electron:** Putting $m_o = 9.11 \times 10^{-31}$ kg,

$$\text{So } \Delta\lambda = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 3 \times 10^8} = 2.43 \times 10^{-12}\text{m}$$

(ii) **For proton:** Putting $m_o = 1.67 \times 10^{-27}$ kg,

$$\text{So } \Delta\lambda = \frac{6.63 \times 10^{-34}}{6.67 \times 10^{-27} \times 3 \times 10^8} = 3.31 \times 10^{-16}\text{m}$$

8. What is a positron?

Ans. An anti-particle of electron is called Positron. Positron has the same mass as that of electron but it carriers positive charge.

9. Does the dilation means that time really passes more slowly in moving system or that it only seems to pass more slowly?

Ans. According to time dilation formula

$$t = \frac{t_o}{\sqrt{1-\frac{V^2}{C^2}}}$$

This result shows that the time dilation means that time really passes more slowly for relativistic motion.

10. A beam of red light and a beam of blue light have exactly the same energy. Which beam contains the greater number of photons?

Ans. As energy of single photon is

$$E = hf$$

For a photons, energy is

$$E = nhf \qquad \because c = f\lambda$$

$$E = \frac{nhc}{\lambda} \qquad \text{and } f = \frac{c}{\lambda}$$

or $$n = \frac{E\lambda}{hc}$$

As red and blue have the same energies, so E, h and c have constant values, thus

$$n = \text{constant} \times \lambda$$

or $$n \propto \lambda$$

That relation shows that greater wavelength will have a large number of photons.

As wavelength of red-light is greater than that of blue light (i.e., $\lambda_{red} > \lambda_{blue}$), so beam of red light will contain a greater number of photons.

1. Will bright light eject more electrons from a metal surface than dimmer light of the same colour?

ns. Yes, as in photoelectric effect, the number of photoelectrons emitted from the surface of metal is directly proportional to the intensity of light. therefore, bright light being more intense will emit more electrons from a metal surface than the dimmer light of same color.

Self-Assessment Paper 1

Q.No.1 Encircle the correct option. **Total Marks: 30**

(1 × 10 = 10)

1. **The speed of cathode rays is**
   (A) equal to the speed of light (B) greater than the speed of light
   (C) less than the speed of light (D) none of these
2. **A photon of wavelength 900 nm behaves like a particle of mass ______**
   (A) 5.53×10^{-36} kg (B) 0 kg (C) 2.46×10^{-36} kg (D) 1.84×10^{-44} kg
3. **The resolution of 50 kV electron microscope is**
   (A) 0.2 to 0.5 μm (B) 0.5 to 1 nm (C) 0.5 to 1 μm (D) 0.2 nm
4. **For confinement of electron in a box of radius 10^{-14} m, the electron speed should be ______**
   (A) 10^7 m/sec (B) should be greater than speed of light
   (C) be zero (D) equal to speed of light
5. **The energy radiated is directly proportional to fourth power of Kelvin's temperature is ______**
   (A) Karl – wein's law (B) Reylrigh Jeans law (C) Stephens law (D) Planck's law
6. **For an electron, the rest mass energy is:**
   (A) 0.411MeV (B) 0.511MeV (C) 0.611MeV (D) 0.711MeV
7. **When platinum is heated, it becomes orange is**
   (A) 500°C (B) 900°C (C) 1100°C (D) 1300°C
8. **Compton shift in wave length ($\Delta\lambda$) is zero, when scattered angle of photon is**
   (A) 90° (B) 180° (C) 0° (D) 45°
9. **The converse of pair production**
   (A) Hertz effect (B) Compton effect (C) black body (D) annihilation of matter
10. **The condition hf > 2 m_oc^2 refers to**
    (A) Compton effect (B) pair production (C) photoelectric effect(D) annihilation of matter

Q.No.2 Write Short Answers any SIX of the following questions. **(6 × 2 = 12)**

1. If the speed of light were infinite, what would the equations of special theory of relativity reduce to?
2. What happens to total radiation from a black body if its absolute temperature is doubled?
3. When ultraviolet light falls on a certain dyes, visible light is emitted. Why does this not happen when infrared light falls on these dyes?
4. Can pair production take place in vacuum? Explain.
5. If electrons behaved only like particles, what pattern would you expect on the screen after the electrons pass through the double slit?
6. What is the difference between photoelectric effect and compton's effect
7. What is photo cell, give some of its uses.
8. What advantages an electron microscope has over an optical microscope?

Q.No.3 Extensive Question. **(5 + 3 = 8)**

Q. (a) Explain intensity distribution diagram of black body radiation.
(b) An electron is placed in a box about the size of an atom that is about 1 x 10^{-10}m. What is the velovity of the ed,

Self-Assessment Paper 2

Total Marks: 30

Q.No.1 Encircle the correct option. (1 × 10 = 10)

1. **Rest mass of photon is**
   (A) $1.67\times10^{-27}kg$ (B) $9.1\times10^{-21}kg$ (C) infinite (D) zero
2. **If an object moves with speed of light, its mass will be**
   (A) zero (B) maximum (C) infinity (D) minimum
3. **Photon 'A' has twice the energy to that of photon 'B' the ratio of momentum of 'A' to that of 'B' is**
   (A) $\frac{P_A}{P_B}=1$ (B) $\frac{P_A}{P_B}=\frac{1}{2}$ (C) $\frac{P_A}{P_B}=2$ (D) $\frac{P_A}{P_B}=4$
4. **Radiations emitted by a human body at normal temperature (37oC) lies in**
   (A) X – rays region (B) visible region (C) infrared region (D) ultraviolet region
5. **In photoelectric effect, which factor increases by increasing the intensity of incident photon?**
   (A) kinetic energy of electrons (B) stopping potential
   (C) work function (D) number of emitted electrons
6. **Every particle has corresponding antiparticle with**
   (A) same mass (B) different mass
   (C) opposite charge (D)same mass and opposite charge
7. **Which phenomenon proves the particle nature of electromagnetic waves?**
   (A) diffraction (B) polarization (C) interference (D) photoelectric effect
8. **At what speed would the mass of an electron become double of its rest mass?**
   (A) 0.5 c (B) 0.707 c (C) 0.866 c (D) 0.99 c
9. **A resolution of ....is possible with a 50kV electron microscope.**
   (a) 0.2 to 0.5μm (b) 0.2 to 0.5nm (c) 0.5 to 1 nm (d) 0.5 to 1μm
10. **............received Nobel Prize for the development of quantum mechanics**
   (a) Einstein (b) Heisenberg (c) G.P Thomson (d) Louis de Broglie

Q.No.2 Write Short Answers any SIX of the following questions. (6 × 2 = 12)

1. Since mass is a form of energy, can we conclude that a compressed spring has more mass than the same spring when it is not compressed?
2. Give the postulates of special theory of relativity.
3. A solid is heated and begins to glow, why does it first appears red?
4. Why we don't observe the compton's effect with visible light?
5. Write down the principle of complementarty to describe the nature of light?
6. Is it possible to create a single electron from energy? Example
7. Does the brightness of a beam of light primarily depend o n the frequency of photons or on the number of photons?
8. What the two main frontiers of modern physics?

Q.No.3 Extensive Questions. (5 + 3 = 8)

(a) Explain Davison-Germer experiment.
(b) At what is faction of the speed of light must a particle move so that kinetic energy is one half times its rest energy?