## Chapter = 19

# DAWN OF MODERN PHYSICS



**WHAT IS MODERN PHYSICS?**

The study physics after 1900 AD is called modern physics. Max Planks is pioneer of it.

**Write the Phenomenon's which could not explain by the laws of classical physics?**

i. Black body radiations ii. Photo electric effect iv. Invariance of speed of light
iv. Emission of spectral line by atoms iii. Compton effect

**Relative motion:** The change of position of an object with respect to another object is called relative motion.

**What is Frame of reference? Define inertial and non-inertial frame of reference.**

**Frame of reference**: Any co-ordinate system according to which measurements are taken is called frame of reference

There are two types of frame of reference

i. Inertial frame of reference
ii. Non inertial frame of reference

**What is general and Special Theory Of Relativity? Write the postulates of STR.**

**Theory of relativity:** The theory of relativity deals with those cases in which observer are in state of relative motion, it has 2 types

i. General theory of relativity
ii. Special theory of relativity

**General theory of relativity**: The theory of relativity which deals with problems involving non inertial frame of reference is called general theory of relativity.

**Special theory of relativity**: The theory of relativity deals with problems involving inertial frame of reference is called specially.

**Postulates of special theory of relativity:** There are following two postulates of special theory of relativity

i. The laws of physics are same in all inertial frame of references
ii. The speed of light in free space has constant value

**Explain the Results of special theory of relativity.**

There are following results of special theory of relativity. STR results can be applied on all timing processes like physical, chemical and biological processes.

**Time dilation**: According to STR time is not absolute quantity. It depends upon the motion of frame of reference and time has dilated due to relative motion of observer and frame of reference.

**Proper time and relativistic time**: The time interval which is measured when observer is at rest is called proper time and the time which is measured when observer is moving with frame of reference is called relativistic time. $t = \frac{t_o}{\sqrt{1 - v^2/c^2}}$. Where $\sqrt{1 - v^2/c^2}$ is called Lorentz factor whose value is always less than one. Aging process is slowed by motion at very high speed.

**Length contraction**: The relative motion of two points the distance b/w two points appears to be shorter than when you were at rest relative to them, this effect is called length contraction.

**Proper length and relativistic length**: The length of an object or distance measured by an observer who is at rest is called proper length and if an observer and object are in relative motion with speed v ten contracted length is called relativistic length. $l = l_o\sqrt{1 - v^2/c^2}$.



**Mass variation:** According to STR result mass of an object is varying quantity

Proper mass and relativistic mass: The mass of an object measured by observer which is at rest is called proper mass. And the mass when the object move relative to the frame of reference. $m = \frac{m_o}{\sqrt{1 - v^2/c^2}}$.

**Energy mass relation**: According to STR results mass and energy are interconvert able by using equation $E = mc^2$.

**What is NAVSTAR?** NAVSTAR stands for Navigation satellite and ranging, it is used to find the position and speed of an object anywhere on earth upto accuracy of **2cm/sec** but if relativity affects are not taken into account the speed could not be determined closer to **20 cm/sec** and position with upto **50m** as compared to **760m** without use of relativistic affects.

## Multiple choice questions



| | | | | | |
|---|---|---|---|---|---|
| 1 | By using NAVSTAR speed of an object can now be determined to an accuracy | 20 cm/sec | 760cm/sec | 50 cm/sec | **2 cm/sec** |
| 2 | Einstein presented special theory of relativity in | 1850 | 1920 | **1905** | 1932 |
| 3 | Aging process of human body is slowed by motion at very high speed according to | Newton | **Einstein** | Faraday | Coulomb |
| 4 | In 1905 special theory of relativity was proposed by | Maxwell | De-Broglie | Bohr | **Einstein** |
| 5 | If rest mass of particle is mo and relativistic mass is m then kinetic energy of particle is | $mc^2$ | $\frac{1}{2} mv^2$ | **$(m-m_o)c^2$** | $m_oc^2$ |
| 6 | All motions are | Absolute | Uniform | **Relative** | Variable |
| 7 | Einstein mass energy equation is | **$E=mc^2$** | $E=mc^3$ | $E=mc$ | $E=m^2c^2$ |
| 8 | Einstein was awarded Nobel prize in Physics | 1905 | 1911 | 1918 | **1921** |
| 9 | The mass of an object will be doubled at speed | **$2.6*10^8$ m/s** | $1.6*10^8$ m/s | $3.6*10^8$ m/s | $0.6*10^8$ m/s |
| 10 | Aging process of human body is – by motion at very high speed | Fast | **slowed** | Remains same | None |



**What are BLACK BODY RADIATIONS? Give example.**



**Thermal radiations:** When the body is heated, it emits radiations which are called thermal radiations. Nature of thermal radiation depends upon Temperature.

**Black body radiations:** The radiations emitted from a hollow black coated having small hole due to temperature are called black body radiations. The wave length of such radiations decrease with increase of temperature.

**Ideal/ perfect black body:** A body which absorbs the entire radiations incident upon it is called an ideal/perfect black body.

**Example**: When platinum wire is heated, it appears **dull red at 500°C**, **cherry red at 900°COrange red at 1100°C**, **yellow at 1300°CWhite at 1600°C.**

**Explain Intensity distribution diagram facts.**

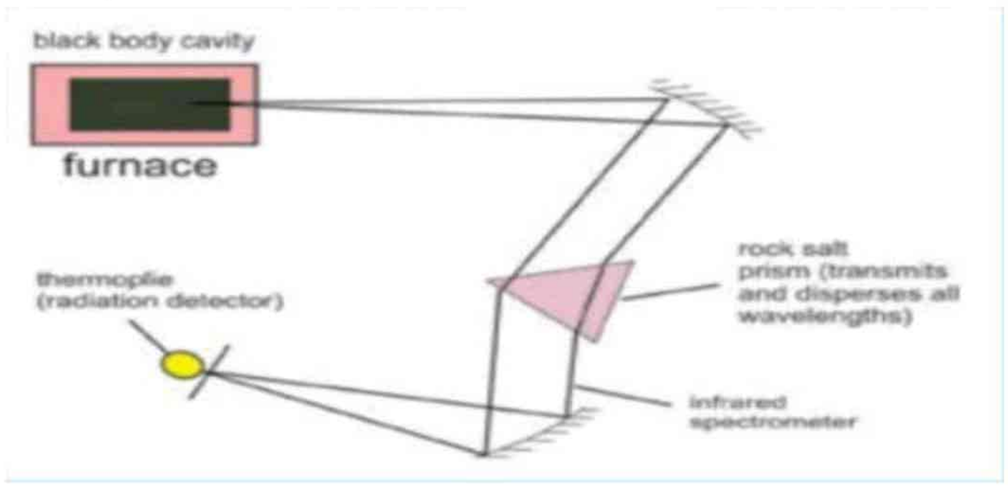
Lummer and Prinshiem measured the intensity of emitted energy with wavelength radiated from black body at different temperatures by the apparatus as shown in fig**.**

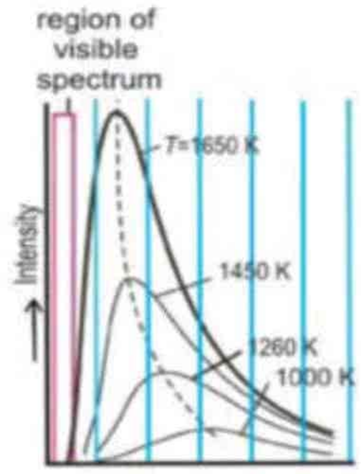
**Facts/Results of energy distribution curves:** There are following facts.

1. The energy is not uniformly distributed in the radiation spectrum of body at a given temperature.

2. **Wien displacement law:** At a given temperature T, wavelength corresponding to maximum energy is inversely proportional to absolute temperature. $\lambda_m \propto \frac{1}{T}$, $\lambda_m T = \text{constant}$ .The value of constant 0.0029 m K.
3. For all wavelengths, an increase in temperature causes an increase in energy emission. The ration intensity increase with increase in wavelength at a particular wavelength $\lambda_{max}$ with further increase in wavelength, the intensity decreases.
4. Area under energy distribution curve represents total energy E radiated per second per square meter. "The amount of energy of all wavelengths radiated per second per unit area of black body is proportional to fourth power of absolute temperature"

$E \propto T^4$, $E = \sigma T^4$ $\sigma = \text{Stephen constant} = 5.67 * 10^{-8}\ Wm^{-2}K^{-4}$.




## EXPLAIN PLANK'S ASSUMPTION ABOUT NATURE OF RADIATIONS.

**Plank's assumption about nature radiation:** Emission of energy from a matter is not continuous but it is emitted or absorbed by atom in black surface in the form of indivisible packet is called quanta. Energy of each quantum is proportional to the frequency. $E \propto f$, $E = hf$, $h = \text{planks constant} = 6.63 * 10^{-34}\ Js$.
He received Nobel Prize in 1918 for discovery of energy quanta.
**Einstein photon theory:** He postulated that light energy consist of packets or tiny bundles or tiny packets of energy which is integral part of all electromagnetic radiations that cannot be subdivided , these indivisible small particles are called photon by $E=mc^2$.

## Multiple choice questions

| | | | | | |
|---|---|---|---|---|---|
| 1 | Platinum wire becomes yellow at temperature | 500˚C | 900˚C | 1100˚C | **1300˚C** |
| 2 | In black body radiations at low temperature a body emits radiation of | **Long wavelength** | Small wave length | Medium wavelength | High wave length |
| 3 | Momentum of moving photon is | Zero | H | **h/λ** | λ/h |
| 4 | Radiation emitted by a human body at normal temperature 37˚ lies in | X-ray region | Visible region | **Infrared region** | UV region |
| 5 | If platinum wire is heated to 500˚C then it appears as | White | Yellow | Cherry red | **Dull red** |
| 6 | When platinum wire is heated, then it becomes --- at temperature about 1600˚C | **White** | Yellow | Green | Dull red |
| 7 | Joule second is the unit of | Energy | Wein constant | **Planks constant** | Boyle law |
| 8 | Which light photon has the least momentum | **Red** | Blue | Yellow | Green |
| 9 | In Stephen boltzman law $E=\sigma T^4$ "σ" is called | Plank constant | Stephen Boltzmann | **Stephen constant** | Boltzman constant |

| | | | | | |
|---|---|---|---|---|---|
| | | | constant | | |
| 10 | The value of planks constant is | Zero | $6.63x10^{-34}$Js | **$6.63x10^{34}$Js** | $9x10^{9}$Js |
| 11 | 0.1 kg mass will be equal to energy | **$9x10^{15}$J** | $9x10^{10}$J | $9x10^{12}$ J | $9x10^{16}$J |
| 12 | Planks constant has the same unit as that of | Linear momentum | **Angular momentum** | Torque | Power |
| 13 | Total amount of energy radiated per unit area of cavity radiator per unit time is directly proportional to | T | $T^2$ | $T^3$ | **$T^4$** |
| 14 | The name of photon for a quanta of light energy was first introduced by | Max plank | Wein | Bohr | **Einstein** |
| 15 | Platinum wire at 1300 C becomes | White | Cherry red | **Yellow** | Orange red |
| 16 | The value of Wein constant | **$2.9x10^{-3}$mK** | $2.9x10^{3}$mK | $5.67x10^{-8}$mK | 0 |
| 17 | Ratio of energies of two photons is same as the ratio of their | **Momentums** | Wavelengths | Range | None |



## WHAT IS PHOTO ELECTRIC EFFECT, STOPPING POTENTIAL AND THRESHOLD FREQUENCY.

**Photo electric effect**: When the light of a suitable frequency is incident on metal surface, the electrons are emitted from surface which are called photo electrons and this process is called photoelectric effect.

**Photo electric current**: the current produced by these photo electrons is called photoelectric current.

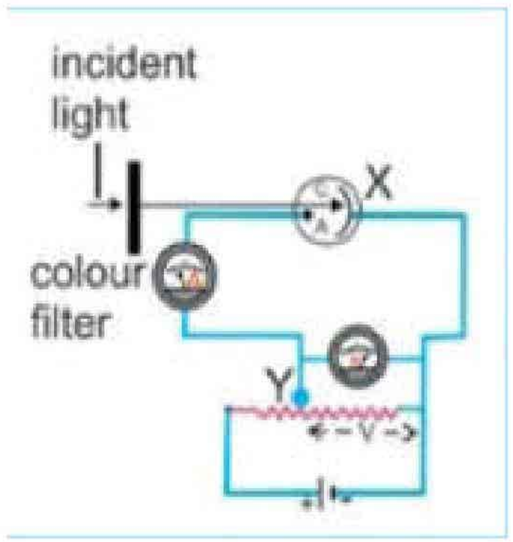
**Explanation**: Apparatus of photoelectric effect is shown in fig. An evacuated glass tube X contain two electrodes. The electrode A connected to the positive terminal of battery is known as anode. The cathode C connected to negative terminal is called cathode. When monochromatic light is allowed to shine on cathode, it starts to emit electrons. These photoelectrons are attracted by the positive anode and resulting current is measured by ammeter. The current stops when light is cut off which shows that current flows because of incident light. Frequency of incident light is proportional to maximum kinetic energy of photoelectrons.

**Stopping potential:** The negative potential of anode at which photoelectric current becomes zero is called stopping potential.Photoelectric current increase with intensity of light.

**Threshold frequency:** The minimum value of frequency of incident light at which electrons are emitted from a metal surface is called threshold frequency.

**Important experimental results of photoelectric effect.**

i. Photoelectrons are emitted with different energies
ii. Maximum energy of photoelectrons depends upon surface metal And frequency of light
iii. Number of emitted electrons depends upon intensity of light.






**Give the Einstein photo electric effect explanation.**

Einstein explains the photoelectric effect on the basis of plank's photon theory. He used the concept of work function

**Work function**: "The minimum energy required to escape the electrons from metal surface is called work function" $\varphi = hf$ . SI unit of work function is joule.

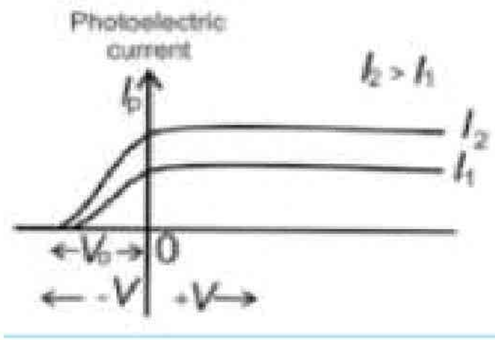
**Einstein photoelectric effect equation:**

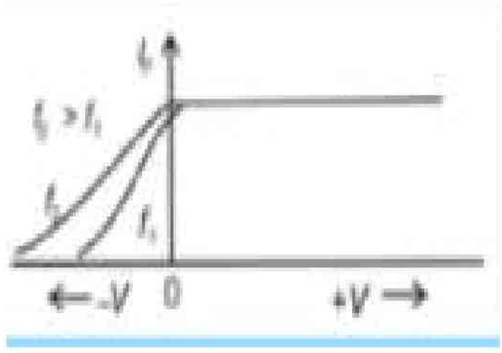
Energy of incident photon = Work function + Max K.E of electrons

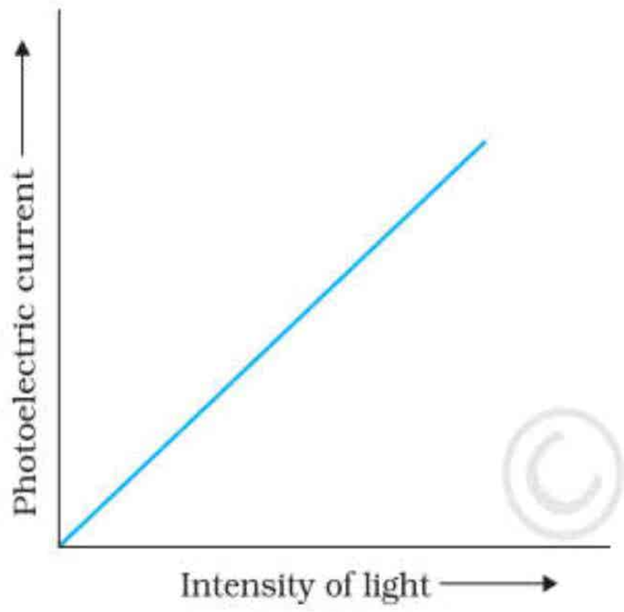
$$hf = \varphi + \frac{1}{2}mv^2$$



$$hf - \varphi = \frac{1}{2}mv^2$$ This is called photoelectric effect equation



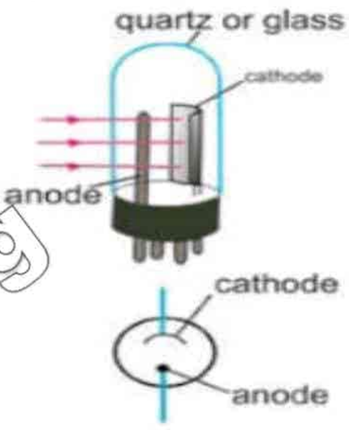

Einstein got Nobel Prize in 1921 for his explanation of photoelectric effect.

**What is Photo cell? Write its uses.**

**Definition:**A device convert's light energy into electrical energy is called photo cell. Principle of photocell is photoelectric effect.

**Uses of photocell.**There are following uses of photocell

i. Automatic door system
ii. Security system
iii. Counting system
iv. Exposure meter for photography
v. Sound track for movies
vi. Automatic street lightening




**What is COMPTON EFFECT? Explain Compton shift formula.**

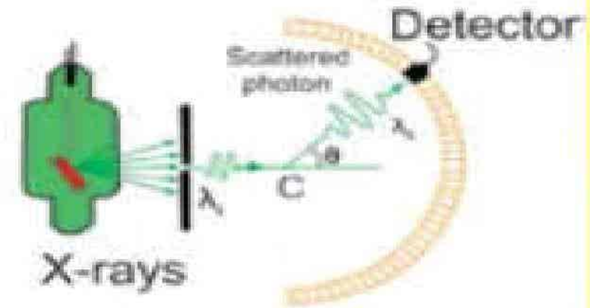
**Compton Effect:** The phenomenon in which the wavelength of scattered X-rays is larger than wavelength of incident rays is called Compton Effect. It was observed by Holy Compton in 1923.

**Formula for Compton shift:**The change in wavelength is called Compton shift. $\Delta\lambda = \frac{h}{m_o c}(1-\cos\theta)$.

Compton suggests that X-rays consists of photons when they collide with electron like billiards balls. In this collision, a part of incident photon energy and momentum is transferred to an electron as shown in fig.

**Calculation of Compton shift:**

Put Θ=90°, $m_o$ =9.1*10$^{-31}$kg C=3*10$^8$ m/s in formula $\Delta\lambda = \frac{h}{m_o c}(1-\cos\theta)$




$\Delta\lambda = \frac{6.63*10^{-34}}{9.1*10^{-31}*3*10^8}(1-\cos 90^o)$=2.43*10$^{-12}$m. $\frac{h}{m_o c}$ Has the dimension of length. This is called Compton wavelength. This confirms the particle like nature of electromagnetic radiation with matter.Holy Compton received Nobel Prize in 1927.

**What is Pair production?**

**Pair production**: When a high energy of gamma ray photon is converts into an electron and positron pair by collision of heavy nucleus is called pair production.

**Materialization of energy**: Because According to Einstein equation $E=mc^2$ energy (light) is converted into matter (electron, positron). It is called materialization of energy.

**Positron:** It is a particle having mass and charge equal in magnitude to that of electron but charge being of opposite nature. It is anti-electron. The existence of positron predicted by Dirac in 1928 and discovered by Anderson in 1932 and received Nobel Prize in 1935.



Minimum energy is required for pair production is 1.02 MeV. Pair production applied the law of conservation of charge, energy and momentum.

**Prove that $2m_oc^2$=1.02 MeV**

Put $m_o$=9.1*$10^{-31}$kg c=3*$10^8$ m/s=2*9.1*$10^{-31}$kg $(3*10^8)^2$
=163.8*$10^{-18}$= 163.8*$10^{-15}$/1.6*$10^{-19}$=1.02*$10^6$eV

**What is ANNIILATION OF MATTER?**

**Definition**: When electron and positron come close enough so that they destroy each other and converted into two photons in the range of gamma rays is called Annihilation of matter. It is Reverse process of pair production.

**Particle and anti-particle theory**: It states that every particle has a corresponding antiparticle with same mass and opposite charge. A particle and its anti-particle cannot exist together at one place, because when they meet and annihilate each other. Proton and anti-proton annihilation has been observed at Lawrence Barkley laboratory.

## Multiple choice questions



| | | | | | |
|---|---|---|---|---|---|
| 1 | Momentum of photon is given by | hf/λ | **hf/c** | fλ | Hλ |
| 2 | Compton effect is observed with | **X-rays** | Visible light | Radio waves | All of these |
| 3 | Photon with energy greater then 1.02 MeV can interact with matter as | Photo electric effect | Compton effect | **Pair production** | All of these |
| 4 | Maximum Compton shift in the wavelength of scattered photon will at | **180˚** | 90˚ | 45˚ | 60˚ |
| 5 | The rest mass of X-ray photon is | Infinite | **Zero** | $9.1x10^{-31}$kg | None |
| 6 | Photo electric current depends on | Frequency of light | **Intensity of light** | Speed of light | Polarization of light |
| 7 | Electron is an anti particle of | Proton | Photon | **Positron** | Deuteron |
| 8 | The minimum energy required by a photon to produce electron positron pair is | 2MeV | **1.02MeV** | 0.51MeV | Zero |
| 9 | Due to annihilation of electron and positron the number of photons produced is | 1 | **2** | 3 | 4 |
| 10 | Compton effect prove nature of light | Wave nature of light | **Particle nature of light** | Dual nature of light | All of these |
| 11 | Photo diode can be used as | **Light** | Heat | Current | Magnet |
| 12 | The rest mass of photon is | m | Infinity | **Zero** | C |
| 13 | Compton shift is equal to Compton wavelength when scattered X-ray photon are observed at angle of | 0˚ | **90˚** | 45˚ | 60˚ |
| 14 | Maximum kinetic energy of photo electrons depends upon --- of incident light | **Frequency** | Intensity | Brightness | Power |
| 15 | In photo electric effect, which factor increases by increasing the intensity of incident photon | Kinetic energy of electrons | Stopping potential | Work function | **No. of emitted electrons** |
| 16 | The reverse process of photo electric effect is | Compton effect | **X-ray production** | Pair production | Annihilation |

| | | | | | |
|---|---|---|---|---|---|
| 17 | Free electrons are | Tightly bound | Fixed | **Loosely bound** | Tightly fixed |
| 18 | A positron is a particle having | **Mass equal to electron** | Charge equal to electron | Equal mass but opposite to electron | Mass equal to proton |
| 19 | The number of electrons emitted depends upon | Color of target surface | Shape of surface | Frequency of incident light | **Intensity of incident light** |
| 20 | The pair production is also called | Pair production | **Materialization of energy** | Fusion reaction | Fission |
| 21 | Wavelength associated with particle of mass m and moving with velocity v is | mv/h | hv/m | **h/mv** | m/hv |
| 22 | Photo diode can turn its current on and off in | Milli second | Micro second | **Nano second** | Pico second |
| 23 | Photo electric effect was explained by | Hertz | **Einstein** | Ruther ford | Bohr |
| 24 | Rest mass energy of an electron in MeV is equal to | **0.51** | 0.61 | 0.902 | 1.02 |
| 25 | Which one is the most energetic photon | **Gamma rays** | X rays | Uv rays | Visible light |
| 26 | When an electron combine with a positron we get | One photon | **Two photon** | Three photon | Four photon |
| 27 | The light of suitable frequency falling on a metal surface eject electrons this phenomenon is called | X-rays emission | Compton effect | **Photo electric effect** | Nuclear fission |
| 28 | Compton shift will be equal to Compton wavelength at angle of | 0˚ | **90˚** | 45˚ | 60˚ |
| 29 | Einstein was awarded Nobel prize in Physics | 1905 | 1911 | 1918 | **1921** |
| 30 | Potassium cathode in photocell emit electrons for a light | **Visible** | Infrared | Ultra violet | X-rays |







**What is de-Broglie hypothesis about Wave Nature Of Particle?**

**De Broglie hypothesis:** "Electromagnetic waves as well moving electrons sometimes behave like wave and sometimes like particles" this is called de-Broglie hypothesis. He proposed this hypothesis in 1924.

**De-Broglie wavelength:** The formula for de-Broglie wavelength $\lambda = \frac{h}{p} = \frac{h}{mv}$ holds only for microscopic particle.

**De-Broglie wavelength for electron:** $\lambda = \frac{h}{mv} = = \frac{6.63*10^{-34}}{9.1*10^{-31}*1*10^{6}} = 7*10^{-10}$ m .

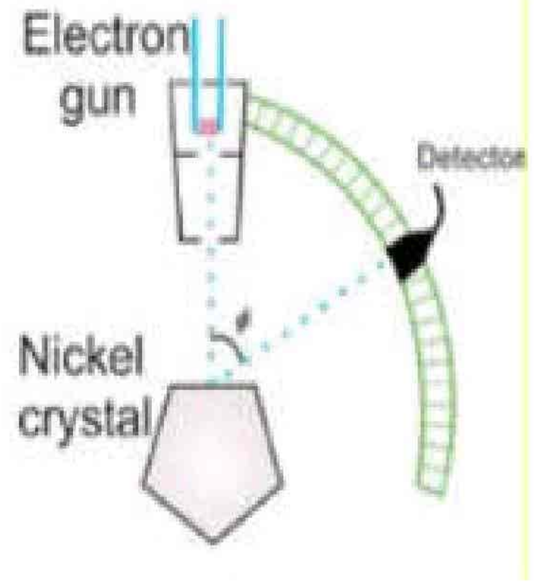
De- Broglie wavelength associated in X-rays range

## DESCRIBE DAVISSON AND GERMER EXPERIMENT.

First experimental proof of de-Broglie wavelength was given by Davisson and Germer in 1926.

**Experimental arrangement**: The apparatus used in this experiment is shown in fig, in which the electron from a heated filament are accelerated by an adjustable applied voltage. Electron beam is incident on a nickel crystal and diffracted from crystal surface enters a detector and recorded as current I. The detector can move on a circular scale and Θ is the angle at which diffracted beam of electron is recorded and wavelength is calculated as follows.






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

$$K.E = eV_o$$

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

$$mv^2 = 2eV_o \qquad \text{Multipling both sides by m}$$

$$m^2v^2 = 2meV_o$$

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

Using de - Broglie equation $\lambda = \frac{h}{mv}$

$$\lambda = \frac{h}{\sqrt{2meV_o}} = \frac{6.63*10^{-34}}{\sqrt{2(9.1*10^{-31})(1.6*10^{-19})(54)}} = 1.66*10^{-10}\,m = 1.66A^o \text{ -----(1)}$$

Now by using Bragg's equation $2d\sin\theta = m\lambda \quad \theta = 65^o, d = 0.91*10^{-10}\ m,\ m = 1$

$$(1)\lambda = 2*0.91*10^{-10}*\sin 65^o$$

$$\lambda = 1.65*10-10m = 1.65A^o \text{ ----------(2)}$$

Equation (1) and (2) shows that wavelength has same value.

For this work of dual nature of particle, de Broglie received nobel prize in 1929 and in 1937 Davisson and Germer shared the prize for this confirmation of hypothesis.

**wave particle duality:** Light behave as stream of particles/photons from a source when propagated act as wave and when it strike anything and exchange energy it acts as particle, interference and diffraction confirms its wave nature and photoelectric effect, Compton effect prove its particle nature.

## WRITE A NOTE ON ELECTRON MICROSCOPE.

**Definition**: The device which is used for highly magnified and resolved image of object by means of highly energetic electrons is called electron microscope.

**Principle**: An electron microscope works on the principle of wave behavior of an electron.

**Construction**: Electron microscope has following main parts

**Electron gun**: This provide the beam of electrons by a potential difference of 30KV to several mega volt.

**Magnetic condenser**: This focus the electron beam on specimen.
In this microscope electric and magnetic field are used to focus.

**Magnetic objective**: Electrons falling on specimen are scattered out from thicker part of specimen enter the magnetic objective and first image of specimen is formed.

**Intermediate image projector**: This image projector is a magnetic coil which produces a real intermediate image.

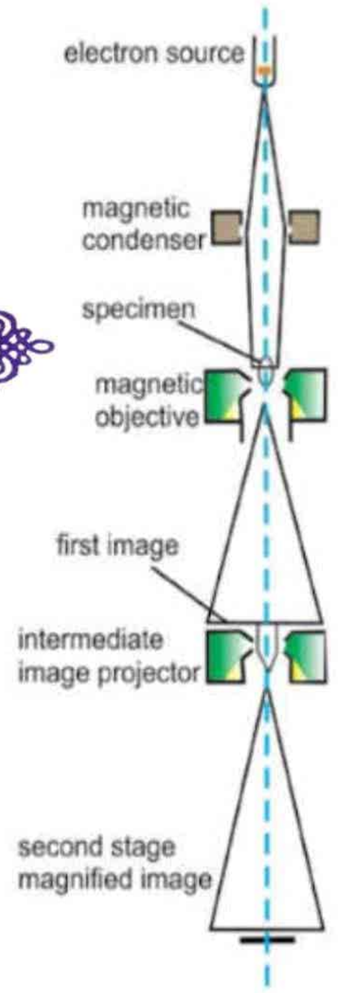
**Fluorescent screen**: It is used to receive the highly magnified image of extremely small object under examination.
Image can be displayed on a special film is called electron micrograph.

**Scanning electron microscope:** A three dimensional image of very high quality can be Achieved by modern version, called scanning electron microscope.

**Advantages of electron microscope**: Electron microscope has following advantages

1) Electron microscope produces much higher magnification than optical microscope.
2) It has higher resolving power than optical microscope





3) A resolution of 0.5 nm to 1 nm is possible with 50 KV electron microscope while an optical microscope has best resolution has best optical resolution 0.2μm.

**STATE AND EXPLAIN HEISENBERG UNCERTAINTY PRINCIPLE.**



Statements: Uncertainty principle has two forms

**Position- momentum uncertainty**

i. Position and momentum of a particle cannot be measured at same time with perfect accuracy. $\Delta p \Delta x = h$ Where h is Plank's constant h=6.63*10$^{-34}$Js

**Energy time uncertainty**:

ii. The product of uncertainty in a measured amount of energy and time interval is equal to plank's constant. $\Delta E \Delta t = h$ .

$$\Delta x \Delta P \geq \hbar$$

For more careful calculations we can use $$\text{where } \hbar = \frac{h}{2\pi} = \frac{6.63*10^{-34}}{2*3.14} = 1.05*10^{-34}\ Js$$

Heisenberg received Nobel Prize in 1932 for the development of quantum mechanics.

**Practice MCQs**

| | | | | | |
|---|---|---|---|---|---|
| 1 | Uncertainty principle related uncertainties in the measurement of energy and | Velocity | Momentum | **Time** | Mass of particle |
| 2 | Momentum of moving photon is | Zero | H | **h/λ** | λ/h |
| 3 | Davisson and Germer experiment indicates the | Interference | Polarization | **Electron diffraction** | Refraction |
| 4 | Free electrons are | Tightly bound | Fixed | **Loosely bound** | Tightly fixed |
| 5 | Who gave the idea of matter waves? | **De Broglie** | Plank | Einstein | Huygen |
| 6 | X-rays diffraction implies that radiation has a | Particle nature | **Wave nature** | Wave particle nature | None of these |
| 7 | The value of ħ in uncertainty principle | Zero | 1.05x10$^{-34}$Js | **1.05x10$^{34}$Js** | 9x10$^{9}$Js |

## Exercise short questions



**1. **What are the measurements on which two observers in relative motion will always agree upon?**

There are following measurements on two observer agree

i. Speed of light in free space
ii. Force on moving particle

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

According to special theory of relativity, time is relative Time seems to pass more slowly when an observer in one system in relativistic motion takes the measurement of the other system. $t = \frac{t_o}{\sqrt{1 - v^2/c^2}}$

**3.**If you are moving in a spaceship at a very high speed relative to the Earth, would you notice a difference (a) in your pulse rate (b) in the pulse rate of people on Earth?**

The pulse rate of a person who is travelling in a spaceship is not changed with respect to clock inside the spaceship.
But the person in spaceship will experience the change in pulse rate of the people on earth.

**4. **If the speed of light were infinite, what would the equations of special theory of relativity reduce to?**

If speed of light $C=\infty$ then $\frac{v^2}{c^2}=0$

$t=\frac{t_o}{\sqrt{1-v^2/c^2}}$, $t=t_o$ no time dilation

$m=\frac{m_o}{\sqrt{1-v^2/c^2}}$ $m=m_o$ no mass variation



$l=l_o\sqrt{1-v^2/c^2}$, $l=l_o$ no length contraction occur

$E=mc^2$ so $E=\infty$

**5.** 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?**

Yes, the compressed spring will have more mass because work done in compressed spring is converted into energy according to Einstein eq. $E=mc^2$

**6. **As a solid is heated and begins to glow, why does it first appear red?**

At lower temperature, a body emits radiation of low energy (longer wavelength). Since longest visible wavelength is red, so it appears red first.

**7.** What happens to total radiation from a blackbody if its absolute temperature is doubled?**

Total energy radiated per second is increased 16 time because according to Boltzmann law

$E=\sigma T^4$, in this case $T'=2T$, so $E'=\sigma(2T)^4$

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

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

Beam of red light contain greater number of photons because when they have same energy then according to relation E=hf=hc/λ, number of photons is directly proportional to wavelength so red light has greater wavelength then blue light so it has greater no of photons.

**9.** Which photon, red, green, or blue carries the most (a) energy and (b) momentum?**

Blue light has most energy and momentum according to relation E=hc/λ, as blue light has shorter wavelength. And for momentum p=h/λ so it has maximum momentum due to shorter wavelength of blue light.

**10. **Which has the lower energy quanta? Radiowaves or X-rays?**

According to relation E=hc/λ radio waves have larger wavelength so it has lower quanta as compared to x rays.

11.****Does the brightness of a beam of light primarily depend on the frequency of photons or on the number of photons?**

The brightness of a beam depends upon intensity (number of photons) and not on the frequency of light. Thus brightness increases with intensity of light

**12. When ultraviolet light falls on certain dyes. Visible light is emitted. Why does this not happen when infrared light falls on these dyes?**

When ultra violet light falls on the dyes, the atoms of dyes are excited to higher energy states, on de excitation electrons return to lower energy level in steps so they emit visible light

In case of infrared light, photons emitted by atoms of dyes have frequency less than the least frequency of visible light

**13.** Will bright light eject more electrons from a metal surface than dimmer light of the same color?**

Since "number of electrons" ejected from metal surface depend upon the intensity of light (number of photons). Therefore, bright light being more intense will eject more electrons from a metal surface than dimmer light of same color.

**14. **Will higher frequency light eject greater number of electrons than low frequency light?**

No, the higher frequency light will not eject greater number of electrons than low frequency light. It is because of the reason that number of electrons emitted from metal surface depends upon intensity of light (number of photons) and not frequency of light.

**15.** When light shines on a surface, is momentum transferred to the metal surface?**

Yes momentum is transferred to metal surface. Because according to Einstein light photon behave like particles so when it is incident on metal surface, it transfer both its momentum and energy. For example in photo electric effect this occurs.

**16.** **Why can red light be used in a photographic dark room when developing films, but a blue or white light cannot?**

As the frequency of red light is less as compared to blue light, so red light has less energy as compared to blue so cannot affect the photographic film. That's why red light can be used when developing films.

**17. **Photon A has twice the energy of photon B. What is the ratio of the momentum of A to that of B.?**



Momentum of photon A is twice the momentum of photon B,

$E = mc^2 = (mc)c = Pc$

as $E_A = 2E_B$

$$\text{Momentum of photon A} = P_A = \frac{E_A}{c} = \frac{2E_B}{c} \quad \text{.....(1}$$

$$\text{Momentum of photon B} = P_B = \frac{E_B}{c} \quad \text{..... (2}$$

dividing both equations to get the result

$$\frac{P_A}{P_B} = \frac{\frac{2E_B}{c}}{\frac{E_B}{c}} = \frac{2}{1}$$

**18. **Why don't we observe a Compton Effect with visible light?**

We don't observe a Compton Effect with visible light because photons of visible light has low energy photon and momentum then the photon of X-rays.

**19. **Can pair production take place in vacuum? Explain.**

No, pair production can't take place in vacuum. Because, in vacuum, there is no heavy nucleus present. Pair production always takes place in the presence of a heavy nucleus.

**20.** **Is it possible to create a single electron from energy? Explain.**

No it is not possible to create a single electron from energy. The creation of single electron from energy is violation of law of conservation of charge and momentum. Whenever pair production takes place, the electrons and positrons are created at the same time.

**21. **If electrons behaved only like particles, what pattern would you expect on the screen after the electrons passes through the double slit?**

If electron behave only like particles then then no interference pattern is observed. After passing through the double slit, only those parts of the screen are affected which are in front of the slit.

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

Electron will have the greater speed. According to de Broglie hypothesis velocity is inversely proportional to mass so electron have least mass and greater speed. $\lambda = \frac{h}{p} = \frac{h}{mv}, \lambda \propto \frac{1}{v}$

**23. **We do not notice the de Broglie wavelength for a pitched cricket ball. Explain why?**

According to de-Broglie hypothesis $\lambda = \frac{h}{p} = \frac{h}{mv}$ cricket ball has large mass, therefore wavelength associated with it is so small that it is not detected.

**24.** **If the following particles have the same energy, which has the shortest wavelength? Electron, alpha particle, neutron, proton.**

Alpha particles have shortest wavelength

From the de-Broglie hypothesis, wavelength associated with moving particle is inversely proportional to mass, and alpha particles have greater mass then other so they have shortest wavelength. $\lambda \propto \frac{1}{\sqrt{m}}$.

**25. **When does light behave as a wave as a particle?**

Light behave as a wave when it travel from a source, like in interference, diffraction and polarization, light behave as particle when it interact with matter like in photo electric effect, Compton effect, pair production.

**26.** **What advantages an electron microscope has over an optical microscope?**

There are following advantage of electron microscope

i. The resolving power of electron microscope is thousand times greater than an Optical microscope.
ii. The internal structure of an object can also be obtained by electron microscope which is not possible with optical microscope

**27.**If measurements show a precise position for an electron, can those measurements show precise momentum also? Explain.** No, those measurements cannot show precise momentum also. Because according to uncertainty principle position and momentum of a particle cannot be measured at the same time, if one measurement is precise then other will be uncertain. $\Delta x \Delta p = h,\ \Delta p = \frac{h}{\Delta x}$

# Numerical problems

**19.1: A particle called the pion lives on the average only about $2.6\times10^{-8}s$ when at rest in the laboratory. It then changes to another form. How long would such a particle live when shooting through the space at 0.95c?**

$\text{Given Data}: t_o = 2.6*10^{-8}\Omega, v = 0.95c, t = ?$

$$t = \frac{t_o}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{2.6*10^{-8}}{\sqrt{1-\frac{(0.95c)^2}{c^2}}} = \frac{2.6*10^{-8}}{\sqrt{1-\frac{(0.95)^2c^2}{c^2}}} = 8.3*10^{-8}\ \text{sec}$$

**19.2: What is the mass of a 70 kg man in a space rocket traveling at 0.8 c from us as measured from Earth?**

$\text{Given Data}: m_o = 70Kg, v = 0.8c, m = ?$

$$m = \frac{m_o}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{70}{\sqrt{1-\frac{(0.8c)^2}{c^2}}} = \frac{2.6*10^{-8}}{\sqrt{1-\frac{(0.8)^2c^2}{c^2}}} = 116.7\ \text{Kg}$$

**19.3: Find the energy of photo in**

**(a) Radiowave of wavelength 100m**
**(b) Green light of wavelength 550 nm**
**(c) X-ray with wavelength 0.2 nm**

$\text{Given Data}: \lambda_1 = 100m,\quad \lambda_2 = 550nm = 550*10^{-9}\ m,\quad \lambda_3 = 0.2*10^{-9}\ m\quad E_1, E_2, E_3 = ?$

$$E_1 = \frac{hc}{\lambda_1} = \frac{6.63*10^{-34}*3*10^8}{100} = 19.89*10^{-28}J \Rightarrow \frac{19.89*10^{-28}}{1.6*10^{-19}} = 1.24*10^{-8}eV$$

$$E_2 = \frac{hc}{\lambda_2} = \frac{6.63*10^{-34}*3*10^8}{550*10^{-9}} = 0.036*10^{-17}J \Rightarrow \frac{0.036*10^{-17}}{1.6*10^{-19}} = 2.25eV$$

$$E_3 = \frac{hc}{\lambda_3} = \frac{6.63*10^{-34}*3*10^8}{0.2*10^{-9}} = 99.45*10^{-17}J \Rightarrow \frac{99.45*10^{-17}}{1.6*10^{-19}} = 6215.6eV$$

**19.4: Yellow light of 577 nm wavelength is incident on a cesium surface. The stopping voltage is found to be 0.25V. Find**

**(a) The Maximum K.E. of the photoelectrons**
**(b) The work function of cesium**

$\text{Given Data}: \lambda = 577nm = 577*10^{-9}\ m,\ Vo = 0.25V, (K.E)_{max} = ?\ \text{work function} = \varphi = ?$

$(K.E)_{max} = eVo = 1.6*10^{-19}*0.25 = 4*10^{-20}J$

$$hf = (K.E)_{max} + \varphi \Rightarrow \varphi = hc/\lambda - (K.E)_{max} = 6.63*10^{-34}*3*10^8/577*10^{-9} - 4*10^{-20} = 30.4*10^{-20}J \Rightarrow \frac{30.4*10^{-20}}{1.6*10^{-19}} = 1.9eV$$

**19.5: X-rays of wavelength 22 pm are scattered from a carbon target. The scattered radiation being viewed at 85° to the incident beam. What is Compton shift?**

$\text{Given Data}: \lambda = 22pm = 22*10^{-12}\ m, \theta = 85^o, m_o = 9.1*10^{-31}Kg, c = 3*10^8\ m/s, \Delta\lambda = ?$

$$\Delta\lambda = \frac{h}{m_o c}(1-\cos\theta) = \frac{6.63*10^{-34}}{9.1*10^{-31}*3*10^8}(1-\cos 85^o) = 2.2*10^{-12}\ m$$

Asad Abbas
Lecturer Physics
M. Phil Physics, M. Ed
(Gold Medalist)

**19.6: A 90 keV X-ray photon is fired at a carbon target and Compton scattering occurs. Find the wavelength of the incident and the wavelength of the scattered photon for scattering angle of (a) 30° (b) 60°**



$$\text{Given Data}: E = 90KeV = 90*10^{3}*1.6*10^{-19} = 144*10^{-16}\,J\ ,\ \lambda = ?\ ,\ \lambda' = ?, \lambda'' = ?$$

$$\lambda = \frac{hc}{E} = \frac{6.63*10^{-34}*3*10^{8}}{144*10^{-16}} = 13.8*10^{-12}\,m = 13.8\,pm$$

$$\text{For } \lambda' \text{ using } \Delta\lambda = \frac{h}{m_o c}(1-\cos\theta) \Rightarrow \lambda' - \lambda = \frac{h}{m_o c}(1-\cos\theta) \Rightarrow \lambda' = \frac{h}{m_o c}(1-\cos\theta) + \lambda$$

$$\lambda' = \frac{6.63*10^{-34}}{9.1*10^{-31}*3*10^{8}}(1-\cos 30^{o}) + 13.8*10^{-12} = 14.12*10^{-12}\,m = 14.12\,pm$$

$$\lambda'' = \frac{6.63*10^{-34}}{9.1*10^{-31}*3*10^{8}}(1-\cos 60^{o}) + 13.8*10^{-12} = 15.01*10^{-12}\,m = 15.01\,pm$$

**19.7: What is the maximum wavelength of the two photons produced when a positron annihilates an electron? The rest mass energy of each is 0.51 MeV.**

$$\text{Given Data}: E = 0.51MeV = 0.51*10^{6}*1.6*10^{-19} = 8.16*10^{-14}\,J,\ \ \lambda = ?$$

$$\lambda = \frac{hc}{E} \Rightarrow \frac{6.63*10^{-34}*3*10^{8}}{8.16*10^{-14}} = 2.43*10^{-12}\,m = 2.43\,Pm$$

**19.8: Calculate the wavelength of**

**(a): A 140 g ball moving at 40ms$^{-1}$**

$$\text{Given Data}: m = 140g = 140*10^{-3}\,Kg,\ v = 40\ m/s,\ \lambda = ?\ \ \lambda = \frac{h}{mv} = \frac{6.63*10^{-34}}{140*10^{-3}*40} = 1.18*10^{-34}\,m$$

**(b): A proton moving at the same speed**

$$\text{Given Data}: m = 1.67*10^{-27}\,Kg,\ v = 40\ m/s,\ \lambda = ?\ \ \lambda = \frac{h}{mv} = \frac{6.63*10^{-34}}{1.67*10^{-27}*40} = 9.92*10^{-9}\,m$$

**(c): An electron moving at the same speed**

$$\text{Given Data}: m = 9.1*10^{-31}\,Kg,\ v = 40\ m/s,\ \lambda = ?\ \ \lambda = \frac{h}{mv} = \frac{6.63*10^{-34}}{9.1*10^{-31}*40} = 1.82*10^{-5}\,m$$

**19.9: What is the de Broglie wavelength of an electron whose kinetic energy is 120 eV?**

$$\text{Given Data}: K.E = 120eV = 120*1.6*10^{-19}\,J = 192*10^{-19}\,J, m = 9.1*10^{-31}\,Kg, \lambda = ?$$

$$\text{Using eq. } \lambda = \frac{h}{\sqrt{2m(KE)}} = \frac{6.63*10-34}{\sqrt{2*9.1*10^{-31}(192*10^{-19})}} = 1.12*10^{-10}\,m$$

**19.10: An electron is placed in a box about the size of an atom that is about $1.0\times10^{-10}\,m$. What is the velocity of the electron?**

$$\text{Given Data}: \text{size} = \Delta x = \lambda = 1*10^{-10}\,m,\ m = 9.1*10^{-31}\,kg,\ h = 6.63*10^{-34}\,Js$$

$$\lambda = \frac{h}{mv} \Rightarrow v = \frac{h}{m\lambda} = \frac{6.63*10^{-34}}{9.1*10^{-31}*1*10^{-10}} = 7.29*10^{6}\,m/s$$