UNIT 18

...... Dawn of the Modern Physics.....

After studying this chapter 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 to:
  - – 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 a black body cavity is quantised.
- 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 summarise 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 de 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.
- explain how the very short wavelength of electrons, and the ability to use electrons and magnetic fields to focus them, allows electron microscope to achieve very high resolution.
- describe uncertainty principle.

Modern Physics came with the 20^{th} century and took over where the Newtonian Physics had fallen short. During the 19^{th} century, Newton's laws of physics were firmly established, the behaviour of all types of objects and systems could be predicted with very high degree of accuracy. Further the nature of light had been explained in terms of electromagnetic waves. Just about the time when the physicists started feeling that all the major problems of physics have been solved, there came a series of results of new experiments which could not be explained on the basis of the existing laws of physics. These experiments were concerned with extremely small objects and moving with extremely large velocities. Tremendous amount of hard work and thinking followed and it turned out that these results could only be explained if new concepts and new laws were introduced. Soon a new mechanics followed which were more general and more basic then the Newtonian mechanics. These developments meant complete overhaul and modernisation of the existing physics. Hence named Modern Physics.

Modern Physics does not discard Newtonian Physics. Modern Physics is a set of more general concepts and laws which readily change into the older concepts and laws for those objects and velocities with which we come across in every day life. It should further be pointed out that the so –called modern physics concepts are by no means the last word in physics. Even the 20th century physics has its problems and the coming years may witness a yet another revolution in the concepts and laws of physics.

This chapter is about the two great theories of modern physics, the theory of relativity and the quantum theory. Both theories, Discovered at the end of 19th century, revolutionized physics in the 20th century. The quantum theory is about observations, processes and interactions involving events at a sub microscopic scale. Information technology and communication would not have developed without the quantum theory which provide the theoretical basis for devices such as transistor and integrated circuits.

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.

Relativity theory is about the nature of space, time, mass and energy. Nuclear power and discoveries such as quarks and black holes are the consequences of the theory of relativity.

18.1 Reference Frames

All motion must be measured in some particular reference frame, which we usually represent as a set of coordinate axis as shown in (fig 18.1)

Suppose two people walk hand –in –hand on a moving sidewalk in an airport. They might walk at 1.3 m/s with respect to a reference frame attached to the moving side walk and at 2.4 m/s with respect to reference frame attached to the building. The two reference frames are equally valid.

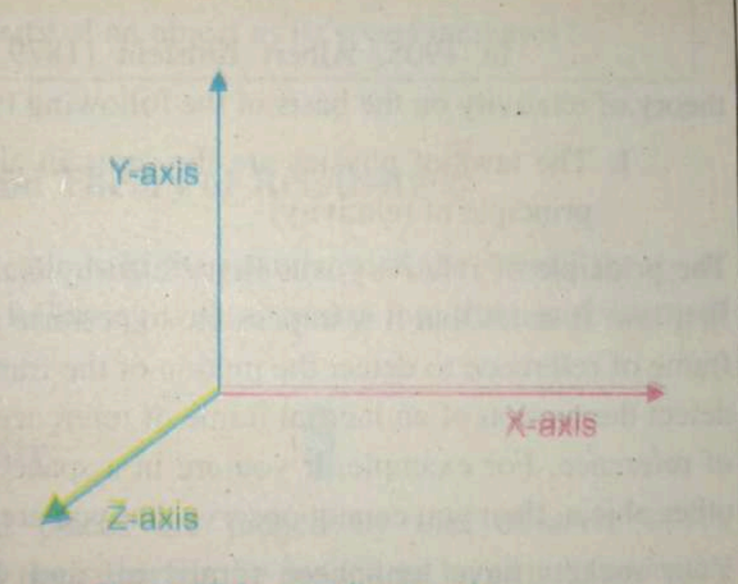


Figure 18.1 : coordinate axis

An inertial reference frame is one in which no accelerations are observed in the absence of external forces. In non-inertial reference frames, bodies have accelerations in the absence of applied forces because the reference frame itself is accelerating with respect to an inertial frame. In such frames, Newton's laws do not hold good unless appropriate pseudo force are added to the real force on the other hand Newton's laws hold good in all inertial reference frames with out the addition of fictitious forces.

For many purposes, the Earth's surface can be considered to be an inertial frames, even though strictly speaking it is not. The Earth's rotation causes phenomena such as the rotatory motion of hurricanes and trade wind, which in a reference from attached to the Earth's surface, are acceleration not caused by the applied force.

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.

18. 2 Special Theory of Relativity

In 1905, Albert Einstein (1879 -1955) formulated his special theory of relativity on the basis of the following two postulates.

1. The laws of physics are the same in all inertial reference frames. (The principle of relativity)

The principle of relativity was first stated by Galileo and embodied in Newton's first law. It states that it is impossible to perform an experiment with in an inertial frame of reference to detect the motion of the frame of reference. The only way to detect the motion of an inertial frame of reference is by referring to another frame of reference. For example, if you are in a spacecraft far from any planet, star or other object, then you cannot observe that you are moving.

Your rockets have long been turned off and you are coasting along to your destination with uniform velocity. However, without referring to outside objects, it is impossible to measure or even detect your velocity.

2. The speed of light in vacuum is the same in all inertial reference frames, regardless of the motion of the source or the observer. (Principle of the constancy of the speed of light).

Imagine that you are sitting in a train facing forwards. The train is moving at the speed of light you hold up a mirror in front of you, at arm's length will you be able to see your reflection in the mirror? Yes, the reflection will be seen because, according to the principle of relativity, it would not be possible for any person in train to do any thing to detect the constant motion with which he or she is traveling. In classical physics, space (That is, displacement, position and velocity, including the speed of light) can be relative to an observer, but time is an absolute quantity, passing identically for every body.

In the theory of relativity, which assumes that velocity of light is constant for all observers, then time is relative as well as space. In other words, time passes differently for different observers, depending upon how fast they are moving.

Check Point

What happens to the density of an object as its speed increases?

18.3 Consequences of Special Theory of Relativity

Some of the applications of the postulates of the special theory of relativity are summarized in the following without going into their mathematical derivations.

The relativity of simultaneity:

If two events in different places are judged by one observer to be simultaneous then they will not generally be judged to be simultaneous by another observer in different reference frame in relative motion. In other words, whether or not two events are seen by you to be simultaneous depends upon where you are standing.

Let a train is fitted with light operated doors. The light in the centre of the roof, and is operated by a train traveler standing in the middle of the floor. When the train is traveling at half the speed of light, the train traveler turns on the light. The light travels forwards and backwards with equal speed and reach both doors at the same time. The doors then open, and the train traveler sees them opening simultaneously. An observer standing outside the train watches that happen, but sees the back door opening before the front. This is because the back door is advancing on the light waves coming from the light, while the front door moving away from the light waves.

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 a 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?

Example 18.1

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

Solution:

Rest mass energy of electron $E = m_o c^2$

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

$$E = 8.199\times10^{-14}\ \text{j}$$

$$E = 0.512\ \text{MeV}$$

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.

$$L = L_o\sqrt{1-\frac{v^2}{c^2}} \quad ...(18.1)$$

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

Example 18.2

A spaceship is measured 100 m long while it is at rest with respect to an observer of this spaceship now flies by the observer with a speed of 0.99c. What length will the observer find for the spaceship?

Solution:

We know from equation 18.1

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

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

$$L = 14\,m$$

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.

$$t = \frac{t_o}{\sqrt{1 - \frac{v^2}{c^2}}} \quad ...(18.2)$$

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.

Mass Dilation:

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

$$m = \frac{m_o}{\sqrt{1 - \frac{v^2}{c^2}}} \quad ...(18.3)$$

Where m= relativistic mass of particle.

m_o =rest mass of particle

v=the 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.

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.

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

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

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

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

Application of time dilation and length contraction for space travel:

Let a spaceship is traveling to a star at a half of the speed 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.

18.4 Black Body Radiation:

An object at any temperature is known to emit radiation sometimes referred to as thermal radiation. The characteristics of this radiation depends on the temperature and properties of the object. At low temperature, the wavelength of the thermal radiation are mainly in the infrared region and hence are not observed by the eye. 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. From a classical viewpoint, thermal radiations (electromagnetic waves) originate from accelerated charged particles near the surface of the object, which emit radiation much like small antennas. The thermally agitated charges can have a distribution of acceleration, which accounts for the continuous spectrum of radiation emitted by the object. By the end of the 19th century, it had become apparent that the classical theory of thermal radiation was inadequate. The basic problem was in understanding the observed distribution of wavelength in the radiation emitted by a black body. By definition a black body is an ideal system that absorbs all radiation incident on it.

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.

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.

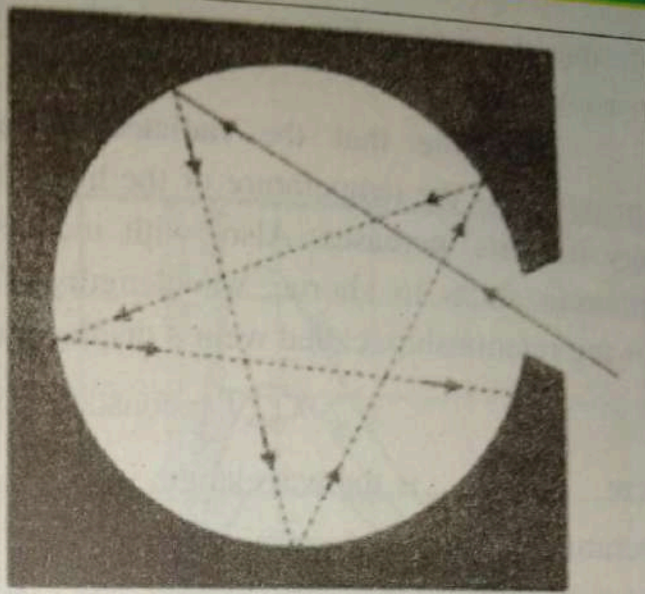


Figure 18.2: black body

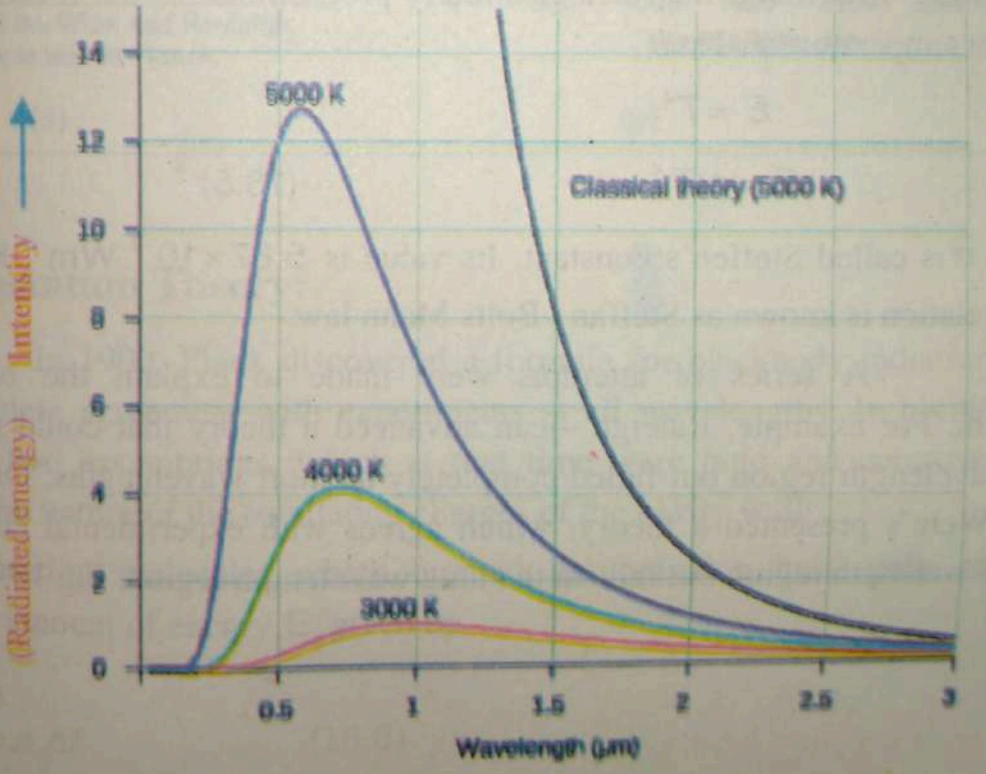


Fig 18.3 intensity of black body radiation versus wavelength at three different temperature

Note that the total radiation emitted (the area under the curve) increases with increasing temperature.

Note that the radiated energy varies with wavelength and temperature. As the temperature of the black body increases, the total amount of energy it emits increases. Also, with increasing temperature, the peak of the distribution shifts to shorter wavelengths. This shift was found to obey the following relationship, called wein's displacement law:

$$\lambda_{max} T = \text{constant} = 0.2898 \times 10^{-2} m \cdot k \cdots\cdots\cdots 18.4$$

Where λ_{max} is the wavelength which the curve peaks and T is the absolute temperature of the object emitting radiation.

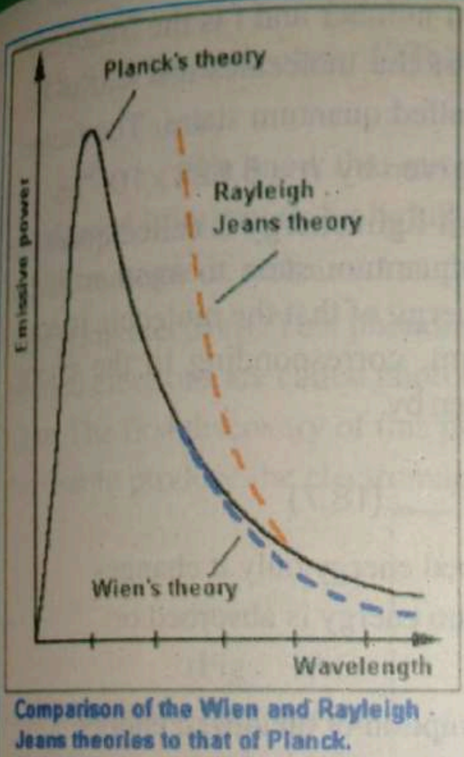
Also the area under each curve represents the total energy E radiated per second per square meter over all wavelengths at a particular temperature. It is found that area is directly proportional to the fourth power of absolute temperature T. Thus

$$E \propto T^4$$

$$E = \sigma T^4 \qquad \cdots(18.5)$$

Where σ is called Steffen's constant. Its value is $5.67\times10^{-8}\ Wm^{-2}\ K^{-4}$ and the above relation is known as Steffan –Bolts Mann law.

A series of attempts were made to explain the black body spectrum. For example, Raleigh –jean advanced a theory that could predict the long wavelength region but failed completely at short wavelengths. On the other hand, Wein's presented a theory, which agrees with experimental curve in the short wavelength region but fails in the long wavelength region. Fig 18.4.(a)



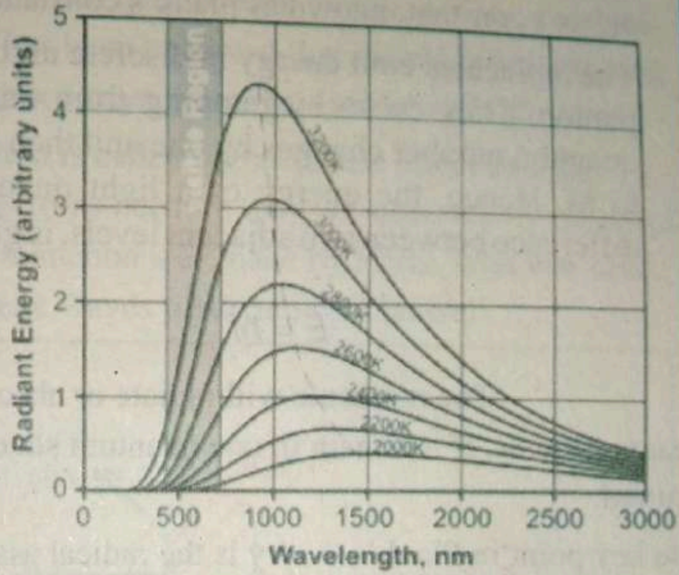


Figure 18.4: (a) (b)

Plank's Quantum Theory:

In 1900, Plank discovered a formula for blackbody radiation that was in complete agreement with experiments at all wavelengths. In his theory, plank made two assumptions, which at that time were bold and controversial, concerning the nature of the oscillating charges of the cavity walls.

1. The vibrating molecules which emitted the radiation have only certain discrete amount of energy, E_n given by.

$$E_n = n\,hf \qquad \cdots(18.6)$$

$n = 1, 2, 3, \ldots\ldots$

Where n is a positive integer called a quantum number and f is the frequency of vibration of the molecules. The energies of the molecules are said to be quantized, and the allowed energy state are called quantum states. The factor "h" is a constant, known as plank's constant, given by $h = 6.626 \times 10^{-34}$ js.

2. The molecules emit energy in discrete units of light energy is called quanta or photon. They do so by jumping from one quantum state to another. If the quantum number changes by one unit then energy of that the molecule is equal to hf. Hence, the energy of a light quantum, corresponding to the energy difference between two adjacent levels, is given by.

$$E = hf \qquad ...(18.7)$$

The molecule will radiate or absorbed energy only it changes quantum states. If it remain in one quantum state, no energy is absorbed or emitted.

The key point in Plank's theory is the radical assumption of quantized energy state, this development marked the birth of the quantum theory.

Example 18.4

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

Solution:

$$\lambda_{max} T = 0.2898 \times 10^{-2} \, m \cdot k$$

Solving for λ_{max} noting that 35°C is corresponds to an absolute temperature of 308k.

We have,

$$\lambda_{max} = \frac{0.2898 \times 10^{-2} m \cdot k}{308k}$$

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

This radiation is in the infrared region of the spectrum.

18.5 Photoelectric Effect

We know that metals, when heated, emit electrons. Can electrons be released from metals by light? It has been observed that metals, when exposed to electromagnetic radiations such as x – rays, γ – rays, visible, and infra –red light, emit electrons. This phenomenon is called photoelectric effect and the emitted electrons are called photoelectrons because they are liberated by means of light. The first discovery of this phenomenon was made by Hertz, who was also the first to produce the electromagnetic waves predicted by Maxwell.

(Fig 18.5) is a schematic diagram of an apparatus in which the photoelectric effect can occur. An evacuated glass tube contains a metal plate, *C*, connected to the negative terminal of a battery.

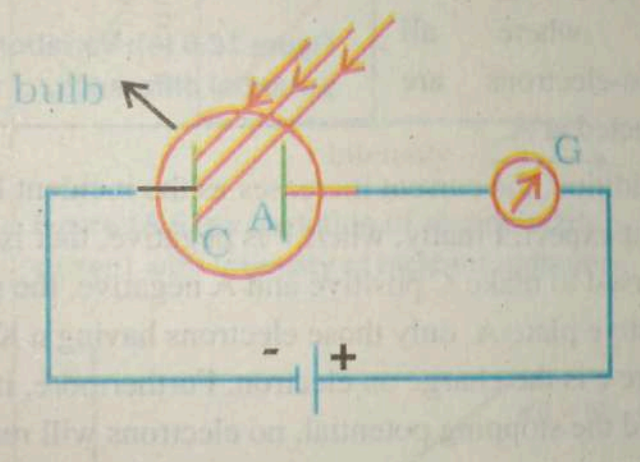


Figure 18.5 : circuit diagram for observing the photoelectric effect.

Another metal plate, A, is maintained at a positive potential by the battery. When the tube is kept in dark, the galvanometer, G, reads zero, indicating that there is no current in the circuit. However, when monochromatic light of the appropriate wavelength shine on plate, *C*, a current is detected by the galvanometer, indicating a flow of charges across the gap between *C* and A. The current associated with this process arises from electrons emitted from the negative plate and collected at the positive plate.

A plot of the photo-electric effect current versus the potential difference, *V*, between A and *C* is shown in (fig 18.6.a) for three light intensities.

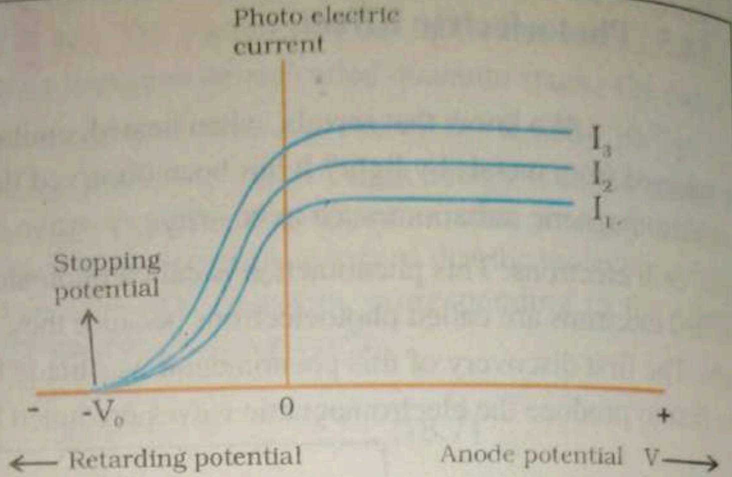


Figure 18.6 (a): Variation of photoelectric current with potential difference.

Note that for large values of V, the current reaches a maximum value, corresponding to the case where all photo-electrons are collected at A.

In addition, the current increases as the incident light intensity increases, as you might expect. Finally, when V is negative, that is, when the battery in the circuit is reversed to make C positive and A negative, the photoelectrons are repelled by the negative plate A. only those electrons having a K.E greater than eV will reach A, where e is the charge on electron. Furthermore, if V is greater than or equal to V_o, called the stopping potential, no electrons will reach A and the current will be zero.

The stopping potential is independent of the radiation intensity. The maximum K.E of the photoelectrons is related to the stopping potential through the relation.

$$K \cdot E_{max} = eV_o \qquad (18.7)$$

Effect of intensity of incident radiation on photo electric current

Keeping the frequency of the incident radiation and the potential difference between the cathode and the anode at constant values, the intensity of incident radiation is varied. The corresponding photoelectric current is measured in the microammeter.

It is found that the photo electric current increases linearly with the intensity of incident radiation (Fig 18.6. b). Since the photoelectric current is directly proportional to the number of photoelectrons emitted per second, it implies that the number of photoelectrons emitted per second is proportional to the intensity of incident radiation.

Experimental Results:

This experiment yields the following interesting results.

1. Brighter light causes an increase in current (more electrons ejected) but does not cause the individual electrons to gain higher energies. In other words, the maximum K.E of the electrons is independent of the intensity of the light. Classically more intense light has larger amplitude and thus delivers more energy. That should not only enable a larger number of electrons to escape from the metal; it should also enable the electrons emitted to have more K.E.

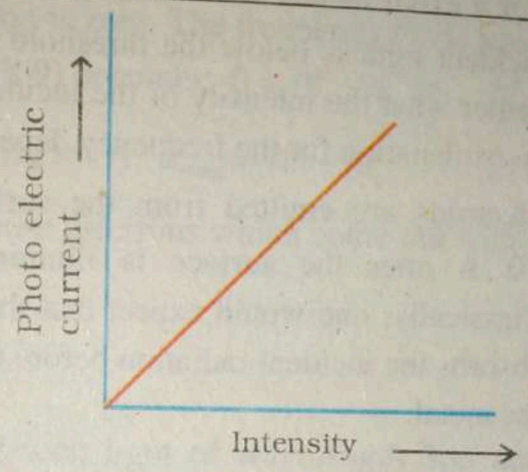


Figure 18.6 (b): Variation of photoelectric current with intensity of incident radiation.

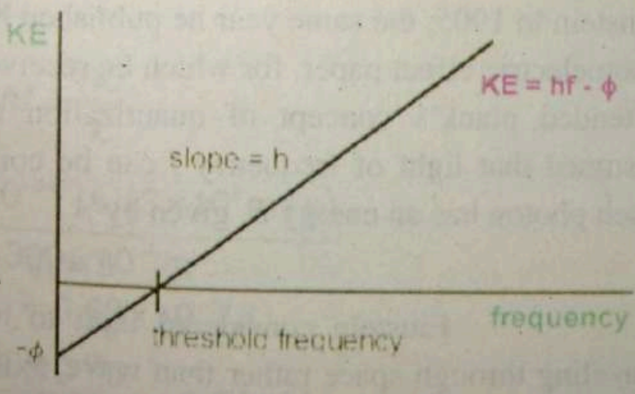


Figure 18.7: Variation of stopping potential with frequency of incident radiation.

2. The maximum K.E of emitted electrons depends on the frequency of the incident radiation (Fig 18.7).

Thus, if the incident light is very dim (low intensity) but high frequency, electrons with large K.E are released. Classically, there is no explanation for a frequency dependence.

3. For a given metal; there is a threshold frequency f_o. If the frequency of the incident light is below the threshold frequency, no electrons are emitted no matter what the intensity of the incident light is. Again, classical physics has no explanation for the frequency dependence.

4. Electrons are emitted from the surface almost instantaneously (less than 10^{-9}s after the surface is illuminated), even at low light intensities. Classically, one would expect that the electrons would require some time to absorbs the incident radiation before they acquire enough K.E to escape from the metal.

Photon Theory of Photoelectric Effect:

A successful explanation of the photo electric effect was given by Einstein in 1905, the same year he published his special theory of relativity. In his photoelectric effect paper, for which he received the Nobel Prize in 1921, Einstein extended plank's concept of quantization to the electromagnetic waves. He assumed that light of frequency f can be considered to be a stream of photons. Each photon has an energy E, given by

$$E = hf$$

Einstein considered light to be much like a stream of particles traveling through space rather than wave. Where each particle could be absorbed as a unit by an electron. Furthermore, Einstein argued that when the photon's energy is transferred to an electron in a metal, the energy acquired by the electron must be hf. However, the electron must also pass through the metal surface in order to be emitted and some energy is required to overcome this barrier. The amount of energy ϕ required to escape the electron from metal surface is known as the work function of the substance and is of the order of a few electron volt for metals. Hence in order to conserve energy, the maximum K.E of the ejected photoelectrons is the difference between the photon energy and the work function of the metal, $K \cdot E_{max} = hf - \phi$ ...(18.9) Where, $\phi = hf_o$

That is, the excess energy $hf - \phi$ equal to the maximum K.E the liberated electron can have outside the surface. (Eq 18.9) is called Einstein's photo electric equation. When K.E of the photo electron is zero. The frequency f is equal to threshold frequency f_o , hence the Eq (18.9) becomes. $0 = hf_o - \phi \Rightarrow hf_o = \phi$

Hence we can also write photoelectric Eq as $K \cdot E_{max} = hf - hf_o$ ...(18.9a)

The Eq(18.9a) holds good only for those electrons which come out with full surplus energy.

Example 18.5

A sodium surface is illuminated with light of wavelength 300 nm. 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.

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

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

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

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

$$k \cdot E_{max} = hf - \phi$$

$$k \cdot E_{max} = 4.14\text{eV} - 2.46\text{eV}$$

$$k \cdot E_{max} = 1.68\text{eV}$$

b.

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

Hence

$$\lambda_c = \frac{hc}{\phi} = \frac{(6.63\times10^{-34}\text{j.s})(3\times10^{8}\text{m/s})}{3.94\times10^{-19}\text{j}}$$

$$\lambda_c = 5.05\times10^{-7}\text{m} = 505\text{nm}$$

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

Applications of the photo electric Effect

Photocell

A photocell is based on photo electric effect. A simple photocell is shown in (fig 18.8). It consists of an evacuated glass bulb with a thin anode rod and cathode of an appropriate metal surface. The material of the cathode is selected to suit to the frequency range of incident radiation over which the cell is operated. For example sodium or potassium cathode emits electrons for infrared light and some other metals respond to ultraviolet radiation. When photo–emissive surface is exposed to appropriate light, electron are emitted and a current flows in the external circuit which increases with the increase in light intensity. The current stops when the light beam is interrupted. The cell has wide range of applications.

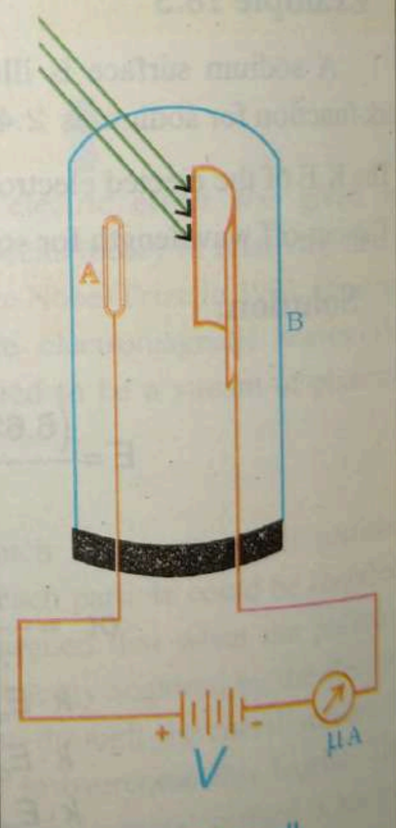


Figure 18.8: Photocell

Some of these are to operate.

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

Solar Cell:

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.

Example 18.6

The stopping potential to prevent electrons 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:

$$K \cdot E_{max} = eV$$
$$= 1.6 \times 10^{-19}\, c \times 4 J\, c^{-1}$$
$$= 6.4 \times 10^{-19} J$$

18.6 Compton's Effect

Further justification for the photon theory of light came from an experiment conducted by Arthur H. Compton in 1923 in his experiment Compton directed a beam of X–rays of wavelength λ toward a block of graphite. He found that the scattered X–rays had a slightly longer wavelength, λ′ than the incident X–rays, and hence the energies of the scattered rays were lower. The amount of energy reduction depended on the angle at which the X–rays were scattered. The change in wavelength, Δλ, between a scattered X–ray and an incident X–rays is called the Compton shift.

In order to explain this effect, Compton assumed that if a photon behaves like particle, its collision with other particles is similar to that between two billiard balls. Hence, both energy and momentum must be conserved. If the incident photon collides with an electron initially at rest, as in (fig 18.9), the photon transfers some of its energy and momentum to the electron.

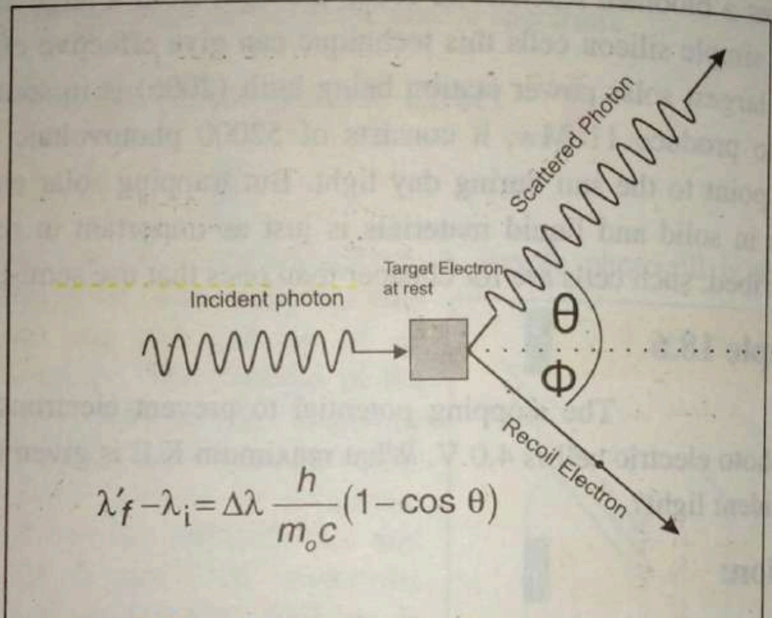


Figure 18.9: incident photon collision with electron

Consequently, the energy and frequency of the scattered photon are lowered and its wavelength increases.

Applying relativistic energy conservation to collision described in (fig 18.9), we have

$$hf = K \cdot E + hf' \qquad ...(18.10)$$

Where hf is the energy of the incident photon, K.E is the kinetic energy given to the recoiling electron, and hf' is the energy of scattered photon. Conservation of momentum requires:

$$\vec{p} = \vec{p_o} + \vec{p'} \qquad ...(18.11)$$

Where p_o and p' represents the momentum of scattered photon and recoiling electron

According to classical electromagnetic Theory, EM waves carry momentum of magnitude E/c, where E is the energy of waves and c is the speed of light. In the photon picture, each photon carries a little bit of that momentum in proportion to the amount of energy it carries.

The momentum of a photon is

$$p = \frac{\text{photon energy}}{c} = \frac{hf}{c} = \frac{h}{\lambda} \quad \text{...(18.12)}$$

Using the incident photon's direction as the x –axis, we can separate this into two components equations.

Along x –axis $$\frac{h}{\lambda} = p_e \cos\theta + \frac{h}{\lambda'}\cos\phi \quad \cdots(18.13)$$

Along y –axis $$0 = -p_e \sin\theta + \frac{h}{\lambda}\sin\phi \quad \cdots(18.14)$$

From Eq (18.12), (18.13) and (18.14), Compton derived this relationship.

$$\lambda' - \lambda = \frac{h}{m_o c}(1 - \cos\theta) \quad \cdots(18.15)$$

The quantity $\frac{h}{m_o c}$ is known as the Compton wavelength because it has the dimension of a wavelength it has a value 0.00243 nm. In term of frequency (Eq 18.15) can be written as

$$\frac{1}{f'} = \frac{1}{f} + \frac{h}{m_o c^2}(1 - \cos\theta) \quad \cdots(18.16)$$

Example 18.7

X –rays of wavelength $\lambda = 0.20\,\text{nm}$ 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,

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

$$= \frac{6.663\times10^{-34}\,J.s}{(9.11\times10^{-31}\,kg)(3\times10^{8}m/s)}(1\text{-}\cos 45°)$$

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

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

$$\lambda' = \Delta\lambda + \lambda$$

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

$$\lambda' = 0.200711nm$$

18.7 Pair Production

An energetic photon can create a positron and an electron where no such particles existed before. The photon is totally absorbed in this process. Energy must be conserved in any process, so in order for pair production to occur,

$$E_{Photon} = E_{electron} + E_{positron} \qquad \cdots(18.17)$$

The total energy of a particle with mass m is the sum of its kinetic energy and its rest mass energy. A particle of mass m has rest energy.

$$E = m_o c^2 \qquad \cdots(18.18)$$

Thus, a photon must have energy of at least $2m_o c^2$ in order to create an electron –positron pair. If the photon energy is greater than $2m_o c^2$, 1.02 MeV the excess energy appears as kinetic energy of the electron and positron. A photon is massless and thus, has no rest energy; the total energy of a photon is

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

Charges must also be conserved in this process. Note it is impossible for a photon to produce a single electron, a single positron, two electrons, or two positron, because the photon have zero charge and then charge will not be conserved.

Momentum must also be conserved.

$$\frac{hf}{c} = mv_{e^-} + mv_{e^+} \qquad \cdots 18.19$$

Where $\frac{hf}{c}$ is the momentum of photon, mv_{e+} is the momentum of positron and mv_{e^-} is the momentum of electron.

Pair production can only occur when the photon passes near a massive particle such as an atomic nucleus (Fig 18.10). The recoil of the massive particle satisfies momentum conservation without carrying off a significant amount of energy, so our assumption that all the energy of the photon goes into the electron –positron pair is a good approximation.

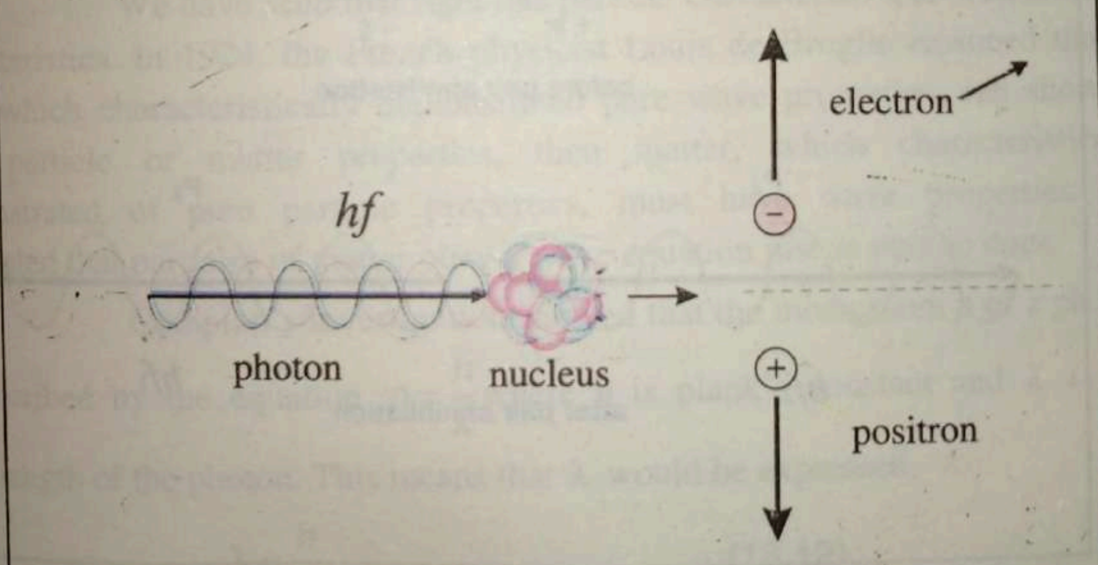
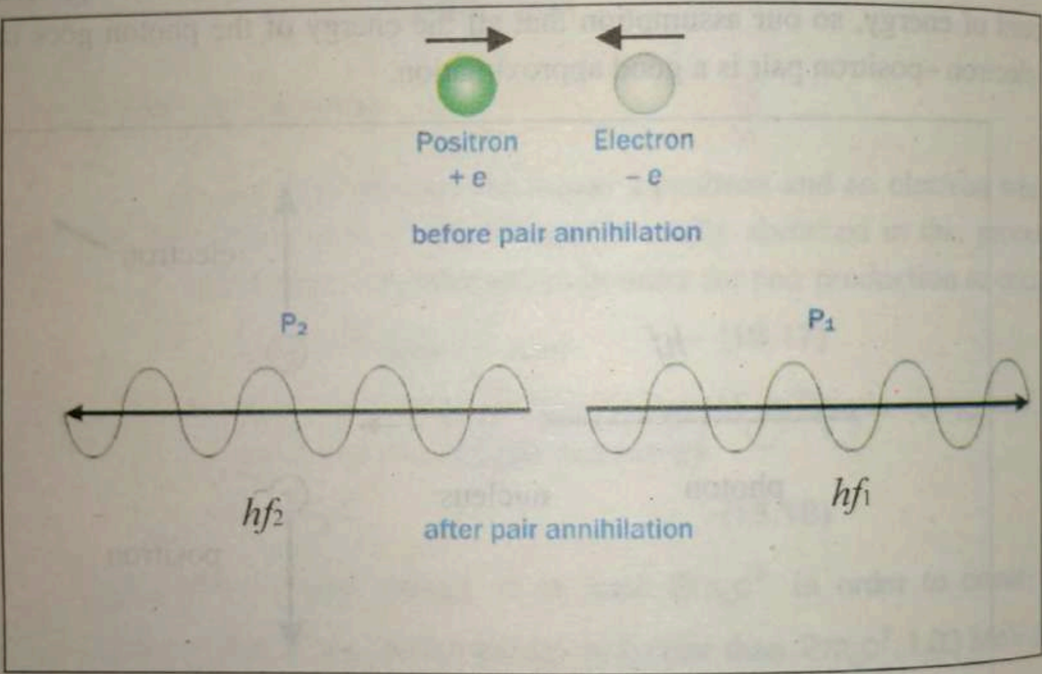


Figure 18.10: pair production, a photon passes near an atomic nucleus. After collision the photon vanishes by creating an electron –positron pair.

18.8 Pair Annihilation

Pair annihilation is a process in which an electron –positron pair produces two photons, which is the inverse of pair production. Pair annihilation cannot create just one photon, because it is required to conserve both energy and momentum. The total energy of the two photons must be equal to the total energy of the electron –positron pair. Ordinarily the kinetic energies of the electron and positron are negligible compared to their rest energies, so for simplicity we assume they are at rest; then their total energy is just their rest energy, $2m_oc^2$, and their total momentum is zero. Annihilation of the pair then produces two photons, each with energy $E = hf = m_oc^2 = 511\,\text{keV}$, traveling in opposite direction (Fig 18.11). Besides confirming the photon model of EM radiation, pair annihilation and pair production clearly illustrate Einstein's idea about mass and rest energy.



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

$$E = 2m_oc^2 = 1.022\,\text{MeV}$$

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

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

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

$$= \frac{1240\ eV\text{-}nm}{1.022\times10^{6}\,eV} = 0.00121\ nm$$

18.9 The Wave Nature of Particles

We have seen that light has particle characteristics as well as wave characteristics. In 1924, the French physicist Louis de Broglie reasoned that if light, which characteristically demonstrated pure wave properties, can show to have particle or matter properties, then matter, which characteristically demonstrated of pure particle properties, must have wave properties. He postulated that particles of matter obey a wave equation just as photon does.

Compton's investigation showed that the momentum *p* of a photon is described by the equation $p = \frac{h}{\lambda}$ where *h* is plank's constant and λ is the wavelength of the photon. This means that λ would be expressed,

$$\lambda = \frac{h}{p} \qquad \cdots(18.19)$$

As nature reveals symmetry, de Broglie asserted that (Eq: 18.19) is a completely general formula that applies to material particles as well as to photons. The momentum of a particle of mass *m* and velocity "*V*" is

$$p = mv$$

and consequently its de Broglie wave wavelength is

$$\lambda = \frac{h}{mv} \qquad \cdots 18.20$$

The greater the particle's momentum, the shorter its wave length. In (Eq 18.20) m is the relativistic mass.

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

Thus, de Broglie contended that the relationship between matter and electromagnetic radiation is more intrinsic than was previously believed.

de Broglie's equation for the wavelength of matter waves explains why the wave nature of large particles is not observable. Consider the de Broglie wavelength of a cricket ball of approximate mass 0.25 kg when it leaves a bat with a speed of 20 m/s

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

$$\lambda = \frac{6.63\times10^{-34}\ \text{j.s}}{0.25\,\text{kg}\times 20\ \text{m/s}} = 1.3\times10^{-34}\,\text{m}$$

This wavelength is far too small to be observed.

On the other hand, calculate the de Broglie wavelength of an electron moving with a typical speed of 10^6 m/s,

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

$$\lambda = \frac{6.6\times10^{-34}\ \text{j.s}}{9.1\times10^{-31}\,\text{kg}\times10^{6}\ \text{m/s}} = 7.3\times10^{-10}\,\text{m}$$

This wavelength approximates the distance between the atoms in a crystal. It makes the wavelength suitable for diffraction and interference. Thus, the wavelengths of very small particle of matter are readily observable.

18.9.1 Davisson and Germer Experiment

The de Broglie relation was confirmed 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 passed through slits and collided 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.

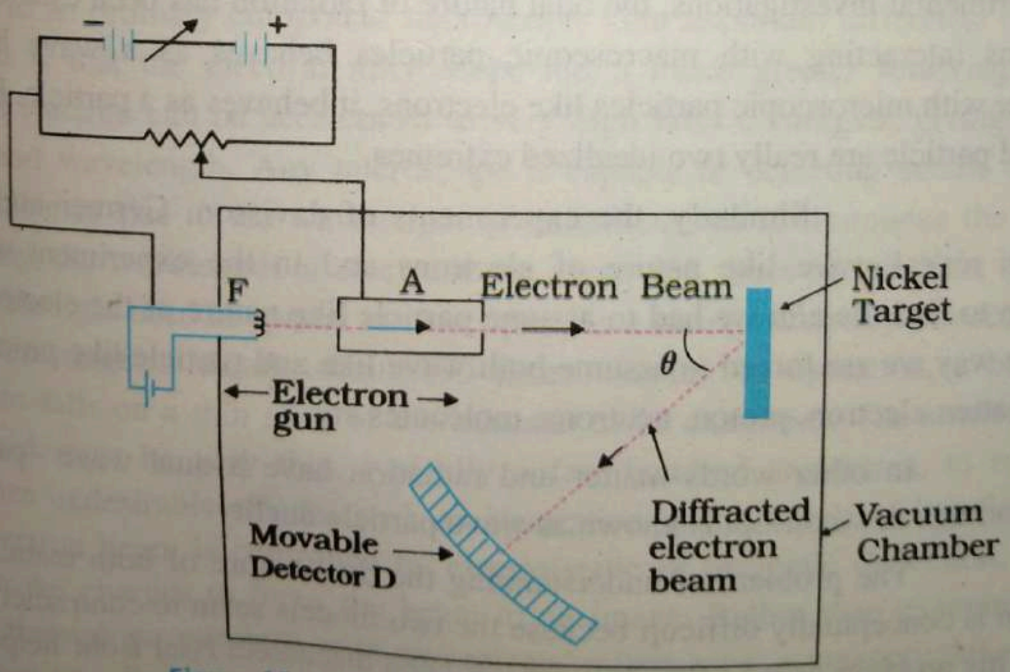


Figure 18.12 :Davisson and Germer experiment illustration

18.9.2 The wave –Particle Duality

Is the radiation emitted by an atom a particle or a wave? A noncommittal answer to this question is that it is both, a wave as well as a particle. The experimental observation of interference and diffraction of light, and their successful interpretation on the basis of the wave theory, suggest that light is a wave. On the other hand, the experiments on photo-electric effect can be interpreted only in term of the quantum theory.

According to wave theory, the radiant energy spreads out continuously in the form of waves but, according to the quantum theory, the radiant energy spread out in discrete packets (or quanta), each having the energy hf. The two theories are apparently contradictory. One group of experimental facts can be explained by one theory and the other group by the second theory. The physicists were faced with a dilemma. One theory could not be rejected in favors of the other.

Could both be right? With the development of quantum mechanics and experimental investigations, the dual nature of radiation has been established. Radiations interacting with macroscopic particles behaves as a wave but in encounter with microscopic particles like electrons, it behaves as a particle. Hence wave and particle are really two idealized extremes.

Similarly, the experiments of davisson, Germer and G P Thomson reveal wave like nature of electrons and in the experiment of J.J. Thomson to find the e/m we had to assume particle like nature of the electron. In the same way we are forced to assume both wave like and particle like properties for all matter: electron, proton, neutrons, molecules etc.

In other words matter and radiation have a dual wave –particle nature and this new concept is known as wave particle duality.

The problem of understanding the dual nature of both matter and radiation is conceptually difficult because the two models seem to contradict each other. This problem as it applies to light has been discussed. Niel Bohr helped to resolve this problem in his principle of complementarity, which states that the wave and particle models of either matter or radiation complement each other.

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Neither model can be used exclusively to adequately describe matter or radiation. A complete understanding is obtained only if the two models are combined in a complementary manner.

Check Point

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

18.10 Electron Microscope

A practical device that is based on the wave characteristics of electron is the electron microscope. (Fig.18.13) which is in many respects similar to an ordinary compound microscope. One important difference between the two is that the electron microscope has a much greater resolving power because electron can be accelerated to very high kinetic energies, giving them a very short wavelength. Any microscope is capable of detecting details that are comparable in size to the wavelength of radiation used to illuminate the object. Typically, the wavelength of electrons are about 100 times shorter than those of the visible light used in optical microscopes. As a result, electron microscope, are able to distinguish details about 100 times smaller. In operation, a beam of electrons falls on a thin slice of the material to be examined. The section to be examined must be very thin, typically a few hundred angstroms, in order to minimize undesirable effects, such as absorption or scattering of the electrons. The electron beam is controlled by electro-static or magnetic deflection, which acts on the charges to focus the beam to an image. Rather than examining the image through an eyepiece as in an ordinary microscope, a magnetic lens forms an image on a fluorescent screen. The fluorescent screen is necessary because the image produced would not otherwise be visible.

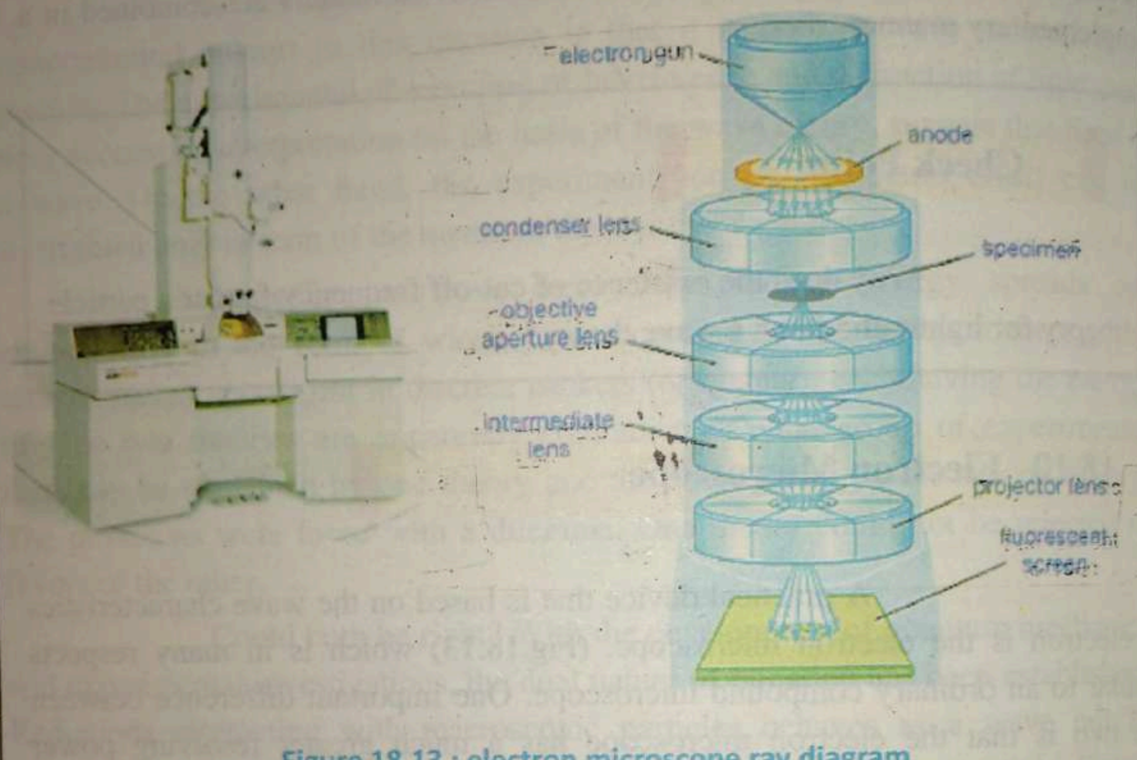

Figure 18.13 : electron microscope ray diagram

Example 18.9

Determine the wavelength of an electron that has 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

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

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

$$=\sqrt{\frac{2\times1\cdot6\times10^{-19}c\times100V}{9\cdot1\times10^{-31}kg}}$$

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

The de –Broglie wavelength of electron is

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

$$=\frac{6.63\times10^{-34}\,js}{(9.1\times10^{-31}kg)\times(5.9\times10^6 m/sec)}=1\cdot2\times10^{-10}m$$

$$\lambda=0.12\,nm$$

Example 18.10

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

Solution:

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

$$v=8.0m/s$$

$$h=6.63\times10^{-34}\,js$$

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

$$\Rightarrow\lambda=\frac{6.63\times10^{-34}\,js}{5\cdot0\times10^{-6}kg\times8.0m/s}$$

$$\Rightarrow\lambda=1.66\times10^{-29}m$$

18.11 Uncertainty Principle

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 h/λ. When one of these photons hits the electron, the photon will be scattered and the original momentum of the electron will be changed.

One cannot predict the exact change in the momentum Δp of the electron. But one can say that change of momentum of the electron will be of the same order as the momentum of the photon itself, Hence,

$$\Delta p \approx \frac{h}{\lambda} \qquad \cdots 18.20$$

The equation gives the uncertainty in the momentum.

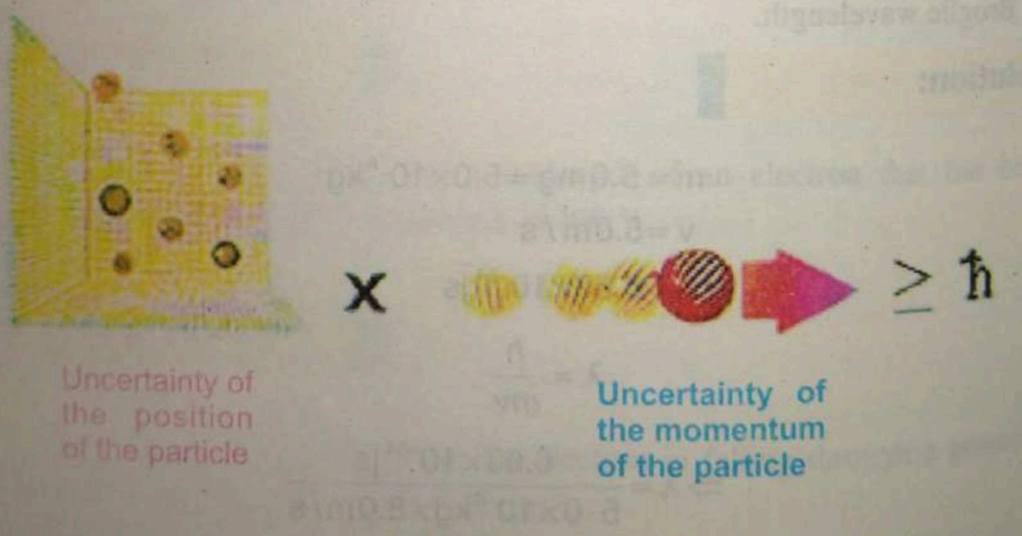

Figure 18.14 : illustrations of uncertainty principle

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

$$\Delta x \approx \lambda \qquad \cdots(18.21)$$

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

If one use light of short wavelength, the accuracy in position measurement increases but the accuracy in the measurement of momentum decreases. On the other hand if one use light of large wavelength, the accuracy in momentum measurement increases but the accuracy in position measurement decreases. Multiplying the two equations, we get.

$$(\Delta p)(\Delta x) \approx h \qquad \cdots(18.22)$$

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 plank'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 quantity 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.

$$(\Delta E)(\Delta t) \approx h \qquad \cdots(18.23)$$

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 plank'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.

Example 18.11

An electron is placed in a box about the size of an atom that is about 1×10^{-10} m. What is the velocity of the electron?

Solution:

Using uncertainty principle

$$\Delta P\Delta x \approx h$$

$$\Delta P \approx \frac{h}{\Delta x}$$

$$m\Delta v \approx \frac{h}{\Delta x}$$

$$\Delta v \approx \frac{h}{m\Delta x}$$

$$\Delta v \approx \frac{6.63\times10^{-34}\,\text{j}\cdot\text{s}}{9.1\times10^{-31}\,\text{kg}\times1\times10^{-10}\,\text{m}}$$

$$\Delta v \approx 7.29\times10^{6}\,\text{m s}^{-1}.$$

Key points

- Frame of reference is a coordinate system such as the OXYZ system, which is required to describe the relative position 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 frames.
  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 a 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 positron 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.

Exercise ?

Multiple choice questions:

Each of the following questions is followed by four answers. Select the correct answer in each case.

1. If the K.E of a free electron doubles, its de Broglie wavelength changes by the factor.

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

2. 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 of emitted electrons

   c. Maximum K.E of emitted electrons

   d. Minimum K.E of emitted electrons

3. 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

4. A perfect absorber must also be perfect

   a. Cavity b. Source of radiation

   c. Radiator d. None of them

5. Pair production occurs only when energy of photon is at least equal to

   a. 1.02 keV b. 1.02 eV

   c. 1.02 MeV d. 1.02 GeV

6. 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

7. The positron has charge which is in magnitude equal to the charge on

a. Electron
b. Proton
c. $\beta-$particle
d. All

8. We can never accurately describes 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

9. An electron microscope employs which to one of the following principles?

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

Conceptual Questions

1. Imagine a world in which $c = 50\ m/s$. How would the every day events appear to us?
2. Both zarak and samina are twenty years old. Zarak leaves earth in a space craft moving at .8*c*, while samina remains on the earth. Zark returns from a trip to star 30th light years from earth, which one will be of greater age. Explain?
3. Which has more energy, a photon of ultraviolet radiation or a photon of yellow light? Explain.
4. Some stars are observed to be reddish, and some are blue. Which stars have the higher surface temperature? Explain.
5. An electron and a proton are accelerated from rest through the same potential difference. Which particle has the longer wavelength? Explain.

6. All objects radiate energy. Explain why, then, are we not able to see objects in a dark room.
7. If the photo electric effect is observed for one metal, can you conclude that the effect will also be observed for another metal under the same conditions?
8. Explain why it is impossible for a particle with mass to move faster than the speed of light.
9. Use photon model to explain why the ultraviolet radiation is harmful to your skin while visible light is not.
10. Explain why the annihilation of an electron and positron creates a pair of photons rather than a single photon.
11. When a particle's K.E increases, what happen to its de Broglie wavelength?
12. Explain why we can experimentally; observe the wave like properties of electrons, but not of billiard ball?
13. Does a light bulb at a temperature of 2500 K produce as white a light as the sun at 6000K? Explain.
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?
15. In Compton scattering experiment, an electron is accelerated straight ahead in the direction of the incident X –ray photon. Which way does the scattered photon move? Explain.
16. Why must the rest mass of a photon be zero? Explain.
17. What happens to total radiation from black body if its absolute temperature is doubled?
18. Why don't we 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?
20. If an electron and a proton have the same de Broglie wavelength, which particle has greater speed?

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

Comprehensive Questions

1. State Einstein's postulate of the special theory of relativity. Discuss its various results.
2. What are the main features of the thermal radiation from a black body? Discuss plank's quantum theory and its importance in physics.
3. What are the main feature of photoelectric effect? Discuss the failure of classical physics and success of photon concept in explaining this effect.
4. What is Compton's effect. Develop a mathematical relation for the Compton's wave shift.
5. Write note on pair production and annihilation of matter.
6. What is de Broglie hypothesis? Describe an experiment to show that particle has wave characteristics.
7. What is meant by wave–particle duality? Explain.
8. State and explain Heisenberg's uncertainty principle. Justify the validity of this principle by a thought experiment.

Numerical Problems

1. The length of a 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]

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?

[9.6s]

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

(3.10×10^{-22} kgms^{-1}, 2.1×10^{-22} kgms^{-1}, 50%)

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

[0.970MeV, 0.459 MeV]

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

[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?

[0.916c]

7. A metal, whose work function is 3.0 eV, is illuminated by light of wavelength 3×10^{-7}m. Calculate (a) The threshold frequency, (b) The maximum energy of photoelectrons (c) The stopping potential.

[0.72×10^{15} Hz, 1.16eV , 1.16V]

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

[5800 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?

[45.5keV]

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

[0.86 A°]

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

$[\lambda = 1\cdot 74 \times A^0]$

12. The speed of an electron is measured to be $5\times10^3 m/s$ to an accuracy of 0.003%. Find the uncertainty in determining the position of this electron.

$[4.84\times10^{-3}m]$

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?

$[6.6\times10^{-26}J]$