CONCEPTUAL QUESTIONS

18.1. Imagine a world in which c = 50 m/s. How would the everyday events appear to us?

Ans: If speed of light reduces to c = 50 m/s then relativistic theory and relativistic effects will remain unchanged but according to principle of constancy of light, the upper limit of speed for material particles will now become 50 m/s i.e., it will be impossible for material objects to reach c = 50 m/s. Even at a speed of 40 m/sec, relativistic effects would be apparent for material bodies.

18.2. Both Zarak and Samina are twenty years old. Zarak leaves earth in a space craft moving at 0.8c, while Samina remains on the earth. Zarak returns from a trip to star 30th light years from earth, which one will be of greater age. Explain?

Ans

For Samina:

Time in which spaceship returns back to earth is;

$$t = \frac{2d}{v} \qquad (1)$$

Where d is distance of a star 30 light years away i.e,

d = 30 x c years

Now (1)⇒

$$t = \frac{2\,(30 \times c \text{ years})}{0.8\,c} = 75 \text{ years}$$

SO THE AGE OF SAMINA = 20 + 75 = 95 years

For Zarak:

As he moves with relativistic speed, distance will contract as per Lorentz length contraction given by Lorentz factor

$$d' = \sqrt{1 - \left(\frac{v^2}{c^2}\right)}\, d = \sqrt{1 - \left(\frac{(0.8c)^2}{c^2}\right)}\, d$$

$$d' = 0.6\, d$$

Now total time of his journey is

$$t = \frac{2\,d'}{v} = \frac{2\,(0.6\,d)}{0.8\,c}$$

Since d = 30 x c years

So

$$t = \frac{2\,(0.6 \times 30 \times c \text{ years})}{0.8\,c} = 45 \text{ years}$$

Now after he returns from trip, time taken as per clock in spaceship is 45 years.

So THE AGE OF ZARAK = 20 + 45 = 65 years

This shows that Samina will be aged by 40 years more than Zarak. This phenomena is called twin paradox.

In physics, twin paradox is a thought experiment in relativity involving identical twins, one of whom makes a journey into space in a high-speed rocket & returns home to find that the twin who remained on earth has aged more.

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

Ans: A photon with ultraviolet radiation is more energetic than photon of yellow light. As we know from equation

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

Wavelength of yellow light photons = 597×10^{-9} m

So its energy is $E = hc / 597 \times 10^{-9}$ m

$E = 3.34 \times 10^{-19}$ j = 2.1 ev

Wavelength of ultraviolet (U.V) photons = 400×10^{-9} m

So its energy is $E = hc / 400 \times 10^{-9}$ m

$E = 5.0 \times 10^{-19}$ j = 3.1 ev

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

Ans: Astronomers use the color of stars to estimate their temperature by using Wein's displacement law given by;

$\lambda T = 2898$ μm K

Hence $T = 2898$ μm K / λ

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

$T = 2898$ μm K / 700 nm

$T = 2898 \times 10^{-6}$ m K / 700×10^{-9} m

$T = 4140$ K

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

$T = 2898$ μm K / 475 nm

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

$T = 6100$ K

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

Ans: The heat radiations which emit from a star are identical to black body radiations. Therefore

$E \propto T^4$

$E = \sigma T^4$

According to Quantum Theory

$E = hf$

So

$hf = \sigma T^4$

As h, σ are constant

$f \propto T^4$

As $f_{blue} > f_{red}$ so $T_{blue} > T_{red}$

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

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

$$\lambda = \frac{h}{P} \quad (1)$$

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

$$K.E = \frac{P^2}{2m} \Rightarrow P = \sqrt{2m K.E}$$

put this in (1) we get;

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

Now as K.E = qV_o, So eq (2) in terms of potential difference V_o becomes

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

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

$$\lambda = k\frac{1}{\sqrt{m}}$$

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

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

18.6. All objects radiate energy. Explain why we are not able to see objects in a dark room?

Ans: We can only see those objects which radiate energy in the visible range of electromagnetic spectrum and cannot see those objects which radiate energy in the range after red (infra-red) or before violet (ultraviolet) as our eyes are not sensitive to respond to these radiation. Now radiation emitted by objects in a dark room lye in the infra-red region of electromagnetic spectrum. Therefore, we cannot see objects lying in a dark room.

18.7. 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?

Ans: No. The reason is that all metals have work function ϕ different from one another. So if electrons are emitted when a radiation shines on a metal surface then it is not guaranteed that same phenomena will be observed for any other metal. If work function of the other metal is equal to or lesser than work function of the first metal then photoelectric effect can be observed, otherwise not.

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

Ans: When a material object of actual mass m_o moves with relativistic speed then its apparent mass m according to the results of special theory of relativity is given by equation

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

Now if we suppose that the object moves with speed of light c then its apparent mass according to eq (1) is

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

It means apparent mass becomes infinite at this speed c. As the mass of any material object cannot be infinite, in a similar way, speed equal to speed of light is also impossible to achieve.

Therefore, it is impossible for a material particle to move faster than speed of light.

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

Ans: According to Einstein's photon theory of light;

$$E = h f$$

$$\Rightarrow \quad E \propto f$$

As Ultraviolet radiation contains photons of very high frequency therefore these photons when incident, can damage or even burn the cells and tissues on our skin. In contrast to U.V. radiation, visible light has comparatively smaller frequency and energy photons. Also it does not damage our skin as U.V radiation does. Therefore, U.V radiation is harmful to our skin while visible light is not.

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

Ans: During the process of annihilation of electron and positron, two photons are formed rather than a single photon because this process needs to conserve momentum as well as energy along with the other conservation laws. The two photons thus formed, travel opposite in direction in order to conserve the momentum and also they must have total energy, equal to the energy of electron-positron pair.

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

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

$$\lambda = \frac{h}{P} \qquad (1)$$

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

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

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

Putting in (1); we get

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

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

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

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

Ans: Electron is a tiny object having very small mass. Wavelength associated with it according to De-Broglie,

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

and it is detectable due to which its wave like properties e.g, diffraction, are observable. But the billiard ball is enormously massive than an electron and its De-Broglie wavelength is so small that there is no such device or instrument that could measure or even detect such a small wavelength.

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

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

Ans: No, a light bulb at 2500 K does not produce as white light as the sun at 6000 K. According to Wien's displacement law

$$\lambda_{max} T = 0.2898 \times 10^{-2} \text{ m K} \qquad (1)$$

where λ_{max}, is the wavelength at which peak occurs and T is absolute temperature. Now for ordinary light at 2500 K, eq (1) implies that the peak at which maximum intensity occurs $\lambda_{max} = 1.16\ \mu m$ which is not in the visible range (most part of filament bulb light is in infrared region) while for sun at 6000 K, eq(1) shows that the peak at which maximum intensity occurs $\lambda_{max} = 683$ nm is in the visible range.

Thus we conclude that a light bulb at 2500 K does not produce as white light as the sun at 6000K.

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

Ans: We know that quantized energy of n photons is

$$E = n\,hf$$

Now

$$E_{red} = n_{red}\, h\, f_{red} \qquad (1)$$

&

$$E_{blue} = n_{blue}\, h\, f_{blue} \qquad (2)$$

Given that the energy of both blue and red are same so we can write;

$$E_{red} = E_{blue}$$

$$n_{red}\, \hbar\, f_{red} = n_{blue}\, \hbar\, f_{blue}$$

$$\Rightarrow \quad n_{red}\, f_{red} = n_{blue}\, f_{blue}$$

$$\Rightarrow \quad \frac{n_{red}}{n_{blue}} = \frac{f_{blue}}{f_{red}}$$

$$\Rightarrow \quad n_{red} = \frac{f_{blue}}{f_{red}} \times n_{blue}$$

The red light is less energetic and has low frequency than blue light. Since $\frac{f_{blue}}{f_{red}} > 1$

therefore red light will contain more photons than blue beam of light.

18.15. 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.

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

$$\Delta\lambda = \frac{h}{m_0 c}(1 - \text{Cos}\theta) \qquad (1)$$

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

So above equation becomes

$$\Delta\lambda = \frac{h}{m_0 c}(1 - \text{Cos}180^\circ) = \frac{h}{m_0 c}(1+1)$$

$$\Delta\lambda = \frac{2h}{m_0 c} \qquad (\text{max Compton shift})$$

Minimum energy that a recoil electron receives, is during the collision in which the photon's trajectory remains same and scattering angle of photon is zero while electron scatters at nearly 90°. Probability for an electron to be scattered at an angle of zero increases with incident photon energy. Now in this case

Eq (1) ⇒
$$\Delta\lambda = \frac{h}{m_0 c}(1 - \text{Cos}\,0^\circ) = \frac{h}{m_0 c}(1-1)$$

$$\Delta\lambda = 0 \qquad (\text{minimum Compton shift})$$

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

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

Ans: When a material object of actual mass m_o moves with high speed then its apparent mass m according to the results of special theory of relativity is given by equation;

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

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

$$m = \frac{m_0}{\sqrt{1-(\frac{c^2}{c^2})}} = \frac{m_0}{\sqrt{1-1}} = \frac{m_0}{0} = \infty$$

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

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

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

$$E = \sigma T^4$$

Where "σ" is Stefan's constant and "T" is absolute temperature. Now if absolute temperature is doubled i-e, $T' = 2T$ then

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

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

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

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

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

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

$$\lambda = \frac{h}{P} \qquad (1)$$

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

$$K.E = \frac{P^2}{2m} \quad \text{or}$$
$$P = \sqrt{2m\,K.E} \qquad \text{put this in (1) we get}$$
$$\lambda = \frac{h}{\sqrt{2\,m\,K.E}}$$

So if all the given particles have same K.E, then De-Broglie's wavelength is inversely related to square root of the mass of the particle.

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

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

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

Ans: De-Broglie's wavelength can be written as

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

$$V = \frac{h}{m\lambda}$$

As given that wavelength of both electron and proton is same. So we can write above equation as

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

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

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

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

Ans. Read question 9. Its repetition of the question.

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

Ans: Dimmer switch is a resistor introduced in series with incandescent light bulb to reduce the current in it. When the dimmer switch is turned ON, more resistance is offered and hence less current passes through the bulb. As current in the bulb reduces, so does the temperature and filament comes to a relatively lower temperature. With lower temperature, λ_{max} according to Wien's displacement law ($\lambda_{max} T = 0.2898 \times 10^{-2}$ m K), shifts to larger values.

On the other hand, when bulb operates at full power, maximum current flows only through the bulb due to which bulb is at higher temperature and lower value of λ_{max}.

Hence by introducing the dimmer switch, wavelength shifts from smaller to larger values leading to more and more reddish appearance of bulb. Dimmed bulbs waste most of the power as invisible infra-red light (heat) across resistor.