Q.1 For questions (I to VI), circle the correct answer: ***(1.5 pts each question)***

(I) The mean lifetime of stationary muons is measured to be 2.2 μs. The mean lifetime of high-speed muons observed from Earth is measured to be 20 μs. The speed of the muons relative to the Earth (in m/s) will be equal to?

a. 2.88×10^8 b. 2.78×10^8 c. 2.68×10^8 (d.) 2.98×10^8 e. none of them

$$\Delta t = \gamma \Delta t_0 = \frac{\Delta t_0}{\sqrt{1-(v/c)^2}} \rightarrow v = \sqrt{1-\left(\frac{\Delta t_0}{\Delta t}\right)^2}\, c = \sqrt{1-\left(\frac{2.2}{20}\right)^2}\, c$$

(II) It is concluded from measurements of the red shift of the emitted light that quasar Q_1 is moving away from us (from the Earth) at a speed of 0.80c. Quasar Q_2, which lies in the same direction in space but is closer to us, is moving away from us at a speed of 0.40c. The velocity (in terms of c) of Q_2 relative to an observer on Q_1 will be equal to?

a. 0.59c (in a direction toward the Earth)
b. 0.39c (in a direction away from Earth)
(c.) 0.59c (in a direction away from Earth)
d. 0.39c (in a direction toward the Earth)
e. none of them

$$u' = \frac{u-v}{1-uv/c^2} = \frac{0.8c-0.4c}{1-(0.8)(0.4)\,c^2/c^2} \cong 0.59\,c$$

(III) A spaceship is receding from an observer on the earth with a speed of 0.90c. A source on the rear of the ship transmit an electromagnetic wave (with frequency of 100 MHz, relative to a passengers on the ship). Relative to the observer on earth, the frequency of the electromagnetic wave (in MHz) will be equal to:

(a.) 22.9 b. 11.5 c. 91.6 d. 45.9 e. None of them

$$f = f_0\sqrt{\frac{1-v/c}{1+v/c}} = 100\sqrt{\frac{1-0.9}{1+0.9}} = 22.9\ \text{MHz}$$

(IV) In the photoelectric effect experiment, the wavelength associated with the cutoff frequency for silver is 325 nm. If we use light with wavelength 400 nm, then:

a. Photoelectrons will be ejected from silver with moderate speed
(b.) No Photoelectrons will be ejected from silver
c. Photoelectrons will be ejected from silver with very high speed
d. Photoelectrons will be ejected from silver with very low speed
e. None of them

$$\lambda > \lambda_0 \rightarrow f < f_0 \rightarrow hf < (\phi = hf_0) \Rightarrow \text{No photoelectrons}$$

(V) In the photoelectric effect experiment, the work function of potassium is 2.23 eV. If we use a light with energy of 4.00 eV, then the maximum kinetic energy of the ejected photoelectrons (in eV) will be equal to:

(a.) 1.77 b. 6.23 c. 6.03 d. 1.57 e. None of them

$$K_{max.} = hf - \phi = 4.00 - 2.23 = 1.77\ \text{eV}$$

(VI) Electrons accelerated to a kinetic energy of 50 GeV. The speed of the electrons (v) will be:

a. v << c (b.) v ≈ c c. v > c d. v >> c e. none of them

$$K = 50\ \text{GeV} = 50{,}000\ \text{MeV} \gg (m_e c^2)$$

↑ rest energy

$$v \simeq c$$

Q.1 For questions (I to VI), circle the correct answer: ***(1.5 pts each question)***

(I) The mean lifetime of stationary muons is measured to be 2.2 μs. The mean lifetime of high-speed muons observed from Earth is measured to be 8.0 μs. The speed of the muons relative to the Earth (in m/s) will be equal to?

(a.) 2.88×10^8 b. 2.78×10^8 c. 2.68×10^8 d. 2.98×10^8 e. none of them

(II) It is concluded from measurements of the red shift of the emitted light that quasar Q_1 is moving away from us (from the Earth) at a speed of 0.80c. Quasar Q_2, which lies in the same direction in space but is closer to us, is moving away from us at a speed of 0.60c. The velocity (in terms of c) of Q_2 relative to an observer on Q_1 will be equal to?

a. 0.59c (in a direction toward the Earth)
(b.) 0.39c (in a direction away from Earth)
c. 0.59c (in a direction away from Earth)
d. 0.39c (in a direction toward the Earth)
e. none of them

(III) A spaceship is receding from an observer on the earth with a speed of 0.90c. A source on the rear of the ship transmit an electromagnetic wave (with frequency of 200 MHz, relative to a passengers on the ship). Relative to the observer on earth, the frequency of the electromagnetic wave (in MHz) will be equal to:

a. 22.9 b. 11.5 c. 91.6 (d.) 45.9 e. None of them

(IV) In the photoelectric effect experiment, the wavelength associated with the cutoff frequency for silver is 325 nm. If we use light with wavelength 400 nm, then:

a. Photoelectrons will be ejected from silver with very high speed
b. Photoelectrons will be ejected from silver with very low speed
(c.) No photoelectrons will be ejected from silver
d. Photoelectrons will be ejected from silver with moderate speed
e. None of them

(V) In the photoelectric effect experiment, the work function of potassium is 2.23 eV. If we use a light with energy of 3.80 eV, then the maximum kinetic energy of the ejected photoelectrons (in eV) will be equal to:

a. 1.77 b. 6.23 c. 6.03 (d.) 1.57 e. None of them

(VI) Electrons accelerated to a kinetic energy of 60 GeV. The speed of the electrons (v) will be:

(a.) $v \approx c$ b. $v \ll c$ c. $v > c$ d. $v \gg c$ e. none of them

Q.2 An observer S (at rest) reports that an event occurred on the x-axis of his reference frame at $x=3.00\times10^8$ m at the time t = 2.50 s. Observer S' and her frame are moving in the positive x-direction at a speed of 0.500c with respect to observer S. Further, $x = x' = 0$ at $t = t' = 0$.

(i) What coordinate would observer S' report for the event? *(2 pts)*

$$x' = \gamma(x - vt) = \frac{1}{\sqrt{1-\left(\frac{v}{c}\right)^2}}(x - vt)$$

$$= \frac{1}{\sqrt{1-(0.5)^2}}(3\times10^8 - 0.5\times3\times10^8\times2.5) = -0.87\times10^8 \text{ (m)}$$

(ii) What time would observer S' report for the event? *(2 pts)*

$$t' = \gamma\left(t - \frac{vx}{c^2}\right) = \frac{1}{\sqrt{1-(0.5)^2}}\left(2.5 - \frac{0.5\times3\times10^8}{3\times10^8}\right)$$

$$\cong 2.31 \text{ (s)}$$

Q.3 A proton has a kinetic energy twice its rest energy.

(i) Find the speed of this proton? *(2 pts)*

$$K = 2(m_pc^2) = (\gamma-1)m_pc^2 \Rightarrow 2 = \gamma - 1 \Rightarrow \gamma = 3$$

$$\frac{1}{1-\frac{v^2}{c^2}} = (3)^2 = 9 \rightarrow v = \sqrt{1-\frac{1}{9}}\,c = \sqrt{1-\frac{1}{9}}\,3\times10^8 = 2.83\times10^8 \text{ (m/s)}$$

(ii) Find the proton's total energy? *(2 pts)*

$$E = K + m_pc^2 = 2m_pc^2 + m_pc^2 = 3m_pc^2$$

$$= 3\times1.67\times10^{-27}\times(3\times10^8)^2 = 4.509\times10^{-10} \text{ (J)}$$

or $E = \gamma m_pc^2$

(iii) For the proton to reach this kinetic energy, it requires and accelerating voltage (V). Find V? *(1 pt)*

$$|\Delta K| = |\Delta U| \rightarrow 2m_pc^2 = eV$$

$$V = \frac{2m_pc^2}{e} = \frac{2\times1.67\times10^{-27}\times(3\times10^8)^2}{1.6\times10^{-19}}$$

$$= 1.88\times10^9 \text{ (Volts)}$$

Q.4 In a particular Compton scattering experiment (between an incident photon and a proton at rest) Gamma rays of energy 0.60 MeV are used.

(i) At what scattering angle will the shift in the photon's wavelength be maximum? And find the magnitude of the momentum of the recoiled proton in this case? *(3 pts)*

$$\Delta\lambda = \frac{h}{m_p c}(1-\cos\phi) \rightarrow \text{when } \phi = 180^\circ \rightarrow (\Delta\lambda)_{max} = 2\left(\frac{h}{m_p c}\right)$$

$$\lambda' = \lambda + \Delta\lambda = \left(\frac{hc}{E}\right) + \frac{2h}{m_p c}$$

$$P_{proton} = (P_{photon})_i - (P_{photon})_f = \frac{h}{\lambda} - \frac{h}{\lambda'} = \frac{h}{hc/E} - \frac{h}{\frac{hc}{E} + \frac{2h}{m_p c}}$$

$$= \frac{0.6\times10^6 \times 1.6\times10^{-19}}{3\times10^8} - \frac{1}{\left(\frac{3\times10^8}{0.6\times10^6\times1.6\times10^{-19}} + \frac{2}{1.67\times10^{-27}\times3\times10^8}\right)}$$

$$= 4.08\times10^{-25}\,(\text{kg}\cdot\text{m/s})$$

OR $(K.E)_{proton} = E_{photon} - E'_{photon} = E_{photon} - \frac{hc}{\lambda'} \Rightarrow P_{proton} = \sqrt{2m_{pro}(K.E)_{pro}}$

(ii) If the scattering angle φ = 60°, find the wavelength of the scattered photon? *(2 pts)*

$$\Delta\lambda = \lambda' - \lambda \Rightarrow \lambda' = \lambda + \Delta\lambda = \frac{hc}{E} + \frac{h}{m_p c}(1-\cos\phi)$$

$$\lambda' = \frac{6.63\times10^{-34}\times3\times10^8}{0.6\times1.6\times10^{-19}} + \frac{6.63\times10^{-34}}{1.67\times10^{-27}\times3\times10^8}(1-\cos 60^\circ)$$

$$\cong 2.073\times10^{-12}\,(\text{m})$$

Q.5 An ultraviolet lamp emits light of wavelength 350 nm at the rate of 500 W. Find how many photons will this lamp emit in 2 hrs? *(2 pts)*

$$N = R*(\text{time}) = \left(\frac{\text{No of Photons}}{\text{sec.}}\right)*(\text{time})$$

$$= \frac{P}{E_{per\ photon}}(\text{time}) = \frac{P*t}{(hc/\lambda)}$$

$$= \frac{500*(2\times60\times60)}{[6.63\times10^{-34}\times3\times10^8/(350\times10^{-9})]}$$

$$\cong 6.34\times10^{24}\,(\text{photons})$$