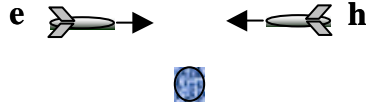


Physics 222 Exam III
Dec. 5, 2006

Soc. Sec # _____ Name _____

1. Stephen Hawking and Albert Einstein each blast off in rockets, labeled “e” and “h” in the figure. In a cosmic game of “chicken,” they fly towards one another on a collision course. Each rocket has a speed of $0.8c$ as measured by a stationary observer on the Earth. What is the speed of Einstein’s rocket as measured by Hawking?



Since both velocities are measured with respect to the Earth, we attach the unprimed coordinate system to the Earth. Take positive velocities to be to the right. Since we are being asked what does Hawking measure for Einstein’s velocity we attach the primed coordinate system to Hawking’s ship. We therefore have that

$$\begin{aligned}v_x &= 0.8c \\v &= -0.8c\end{aligned}$$

We now can transform the velocity of Einstein’s ship into Hawking’s rest frame.

$$\begin{aligned}v'_x &= \frac{v_x - v}{1 - \left(\frac{v}{c}\right) \frac{v_x}{c}} \\&= \frac{0.8c - (-0.8c)}{1 - \left(\frac{-0.8c}{c}\right) (0.8c)} \\&= \frac{1.6c}{1 + 0.64} = \frac{1.6}{1.64}c \\v'_x &= 0.976c\end{aligned}$$

2. Marilyn Monroe and Albert Einstein go for a ride in a rocket ship at a speed of $0.7c$. Albert finds that Marilyn's heart beats 90 times per minute (I think she likes him). What is her heart rate according to a stationary observer on the Earth? Hint: what is the time interval between heart beats?

At 90 beats/minute, the time interval between beats is given by

$$\Delta t = \frac{1}{f} = \frac{1}{90} \text{ min.} = \frac{60}{90} \text{ sec} = 0.667 \text{ sec}$$

Since the the end points of the beats occur at the same place on Marilyn's coordinate system, this is the proper time. Everyone else measures a longer time between intervals.

$$\begin{aligned} T &= \frac{T_0}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} = \frac{2/3}{\sqrt{1 - 0.7^2}} = \frac{2/3}{\sqrt{1 - 0.49}} \\ &= \frac{2/3}{\sqrt{0.51}} = \frac{2/3}{0.714} \\ &= 0.934 \text{ sec} \end{aligned}$$

3. Light falls on a metal which has a work function of 2.0 eV and electrons are emitted with velocities up to a maximum of 6.0×10^6 m/s.

- (a) What is the frequency of the light?

We have for the photoelectric effect that

$$\begin{aligned}K.E. &= hf - \text{Work Function} \\hf &= K.E. + \text{Work Function} \\&= \frac{1}{2}mv^2 + \text{Work Function} \\&= 0.5(9.1 \times 10^{-31})(6.0 \times 10^6)^2 + 2(1.6 \times 10^{-19}) \\&= 1.64 \times 10^{-17} + 3.2 \times 10^{-19} \\&= 1.672 \times 10^{-17} \text{ joules} \\f &= \frac{1.672 \times 10^{-17}}{6.626 \times 10^{-34}} \\&= 2.52 \times 10^{16} \text{ Hz}\end{aligned}$$

- (b) What is the minimum frequency of light needed to produce any photoelectrons?

Minimum frequency occurs when the kinetic energy is zero or

$$\begin{aligned}K.E. &= 0 = hf - \text{Work Function} \\hf &= \text{Work Function} \\f &= \frac{\text{Work Function}}{h} = \frac{2(1.6 \times 10^{-19})}{6.626 \times 10^{-34}} \\&= 4.82 \times 10^{14} \text{ Hz}\end{aligned}$$

4. A radio station is operating at frequency of 1010 kHz. Its total power output is 5.3×10^3 Watts.

(a) What is the energy of a single photon from that radio station?

The energy of a single photon is given by

$$\begin{aligned} E &= hf = (6.626 \times 10^{-34}) (1010 \times 10^3) \\ &= 6.692 \times 10^{-28} \text{ joules} \end{aligned}$$

(b) What is the total number of photons per second that the radio station emits?

$$\frac{\# \text{ photons}}{\text{sec}} = \frac{\text{Power}}{E_{\text{photon}}} = \frac{5.3 \times 10^3}{6.692 \times 10^{-28}} = 7.92 \times 10^{30} \text{ photons/sec}$$

(c) You are at a distance of 5 km from the radio station. Your surface area is approximately 0.5 m^2 . How many photons per second are hitting you?

Assume that the photons are radiated uniformly in all directions. We then have

$$\begin{aligned} \# \text{ photons hitting you} &= \frac{\text{your area}}{\text{surface area of sphere}} \times \frac{\# \text{ photons}}{\text{sec}} \\ &= \frac{0.5}{4\pi (5000)^2} 7.92 \times 10^{30} \\ &= \frac{3.96 \times 10^{30}}{4\pi (25 \times 10^6)} \\ &= 1.26 \times 10^{22} \text{ photons/sec} \end{aligned}$$

Physics 222 Test III Formula Sheet

Special Relativity

$$x' = \frac{x - vt}{\sqrt{1 - v^2/c^2}}$$

$$y' = y$$

$$z' = z$$

$$t' = \frac{t - vx/c^2}{\sqrt{1 - v^2/c^2}}$$

$$v'_x = \frac{v_x - v}{1 - (v/c^2)v_x}$$

$$v'_y = \frac{v_y \sqrt{1 - v^2/c^2}}{1 - (v/c^2)v_x}$$

$$v'_z = \frac{v_z \sqrt{1 - v^2/c^2}}{1 - (v/c^2)v_x}$$

$$T = \frac{T_0}{\sqrt{1 - (v/c)^2}}$$

$$L = L_0 \sqrt{1 - (v/c)^2}$$

$$E = \frac{m_0 c^2}{\sqrt{1 - (v/c)^2}}$$

$$E = KE + m_0 c^2$$

$$E^2 = p^2 c^2 + m_0^2 c^4$$

Blackbody Radiation

$$\lambda_{\max} T = 2.90 \times 10^{-3} \text{ m K}$$

$$I_{\text{Total}} = \sigma T^4$$

$$I(\lambda) = \frac{2\pi h c^2}{\lambda^5 \left(e^{hc/kT} - 1 \right)}$$

$$E = n h f$$

Photoelectric Effect

$$KE = h f - B.E.$$

Compton Scattering

$$\lambda' - \lambda_0 = \frac{h}{m_e c} (1 - \cos \theta)$$

Bohr Model

$$L = m v r = n \frac{h}{2\pi}$$

$$E_n = -\frac{1}{\epsilon_0^2} \frac{m_e e^4}{8 n^2 h^2}$$

$$E_n = -\frac{13.6}{n^2} \text{ eV}$$

$$r_n = \epsilon_0 \frac{n^2 h^2}{\pi m_e e^2}$$

$$r_n = n^2 (0.53 \text{ Angstroms})$$

DeBroglie Hypothesis

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

Heisenberg Uncertainty Principal

$$\Delta p_x \Delta x \geq \frac{h}{2\pi}$$

$$\Delta E \Delta t \geq \frac{h}{2\pi}$$

Hydrogen Atom

$$E_n = -\frac{1}{\epsilon_0^2} \frac{m_e e^4}{8 n^2 h^2}$$

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

$$L = \sqrt{l(l+1)} \hbar$$

$$l = 0, 1, 2, \dots, n-1$$

$$L_z = m \hbar$$

$$m = 0, \pm 1, \pm 2, \dots, \pm l$$

Nuclear Stuff

$$N = N_0 e^{-\lambda t}$$

$$R = -\frac{dN}{dt} = R_0 e^{-\lambda t}$$

$$t_{1/2} = \frac{0.693}{\lambda}$$

$$\tau = \frac{1}{\lambda}$$

Physical Constants

$$c = 3 \times 10^8 \text{ m / s}$$

$$v_{\text{sound}} = 1100 \text{ ft / sec}$$

$$\epsilon_0 = 8.854 \times 10^{-12} \text{ C}^2 / \text{N} \cdot \text{m}^2$$

$$\mu_0 = 4\pi \times 10^{-7} \text{ T m / A}$$

$$e = 1.6 \times 10^{-19} \text{ C}$$

$$m_e = 9.109 \times 10^{-31} \text{ kg}$$

$$= 0.511 \text{ MeV} / c^2$$

$$m_p = 1.672 \times 10^{-27} \text{ kg}$$

$$= 938.27 \text{ MeV} / c^2$$

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ joules}$$

$$\sigma = 5.67 \times 10^{-8} \frac{\text{W}}{\text{m}^2 \text{K}^4}$$

$$h = 6.626 \times 10^{-34} \text{ joule sec}$$

Useful Geometry

Circle

$$\text{Area} = \pi r^2$$

$$\text{Circumference} = 2\pi r$$

Sphere

$$\text{Surface Area} = 4\pi r^2$$

$$\text{Volume} = \frac{4}{3}\pi r^3$$

Cylinder

$$\text{Lateral Area} = 2\pi r L$$

$$\text{Volume} = \pi r^2 L$$