



Department of Physics
University of California
San Diego

Modern Physics (2D)
Prof. V. Sharma
Quiz # 3

Some Relevant Formulae, Constants and Identities

$$E = KE + mc^2 = \gamma mc^2$$

$$p = \gamma mu$$

$$\text{Centripetal Acc.} = \frac{u^2}{r}$$

$$E^2 = (pc)^2 + (mc^2)^2$$

$$E = hf = \Phi + KE$$

$$n\lambda = 2d \sin \theta$$

$$\Delta\lambda = \left(\frac{h}{m_e c} \right) (1 - \cos \theta) = (0.0243 \text{ \AA}) (1 - \cos \theta)$$

$$\text{Coulomb's Constant } k = 8.988 \times 10^9 \text{ N.m}^2/\text{C}^2$$

$$\text{Planck's Constant } h = 6.626 \times 10^{-34} \text{ J.s} = 4.136 \times 10^{-15} \text{ eV.s}$$

$$1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$$

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

$$\text{Speed of Light in Vacuum } c = 2.998 \times 10^8 \text{ m/s}$$

$$\text{Electron Charge} = 1.602 \times 10^{-19} \text{ C}$$

Pl. write you answer in the Blue Book in indelible ink. Make sure your code number is prominently displayed on each page.



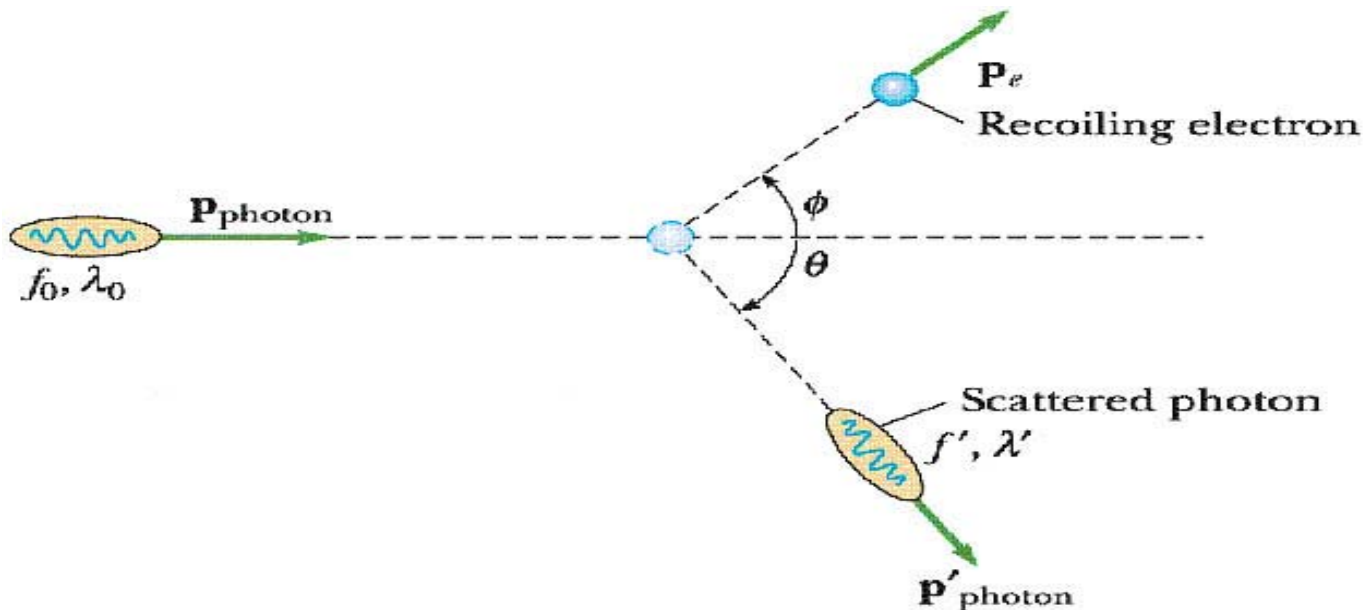
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Problem 1 : International Metal of Mystery! [10 pts]

Light of wavelength 500 nm is incident on a metallic surface. If the stopping (retarding) potential for the photoelectric effect is 0.45V, find (a) the maximum energy of the emitted photoelectrons (b) the work function ϕ and (c) the cutoff wavelength beyond which no photoelectric effect is possible, no matter what the intensity of radiation.

Problem 2: Quantum Pool Anyone ? [10 pts]



High energy photons of energy $E = 1.02 \text{ MeV}$ are scattered from electrons that are initially at rest. If the Compton scattering process is symmetric, that is, if scattering angles $\phi = \theta$ (see figure above) find (a) the scattering angle θ and (b) the energy of the scattered photons. Hint: What conservation rules should you use ?

1. Physics 2D Quiz 3 Solutions

Problem 1

1a. Since the stopping potential is 0.45 V, the maximum energy an electron can have is 0.45 eV. Thus, $KE_{max} = 0.45$ eV.

1b. Energy conservation gives $E_{photon} = KE_{max} + \phi$. Since $E_{photon} = hc/\lambda$, we can plug in $hc = 1240$ eV.nm, $\lambda = 500$ nm, and $KE_{max} = .45$ eV to get $\phi = 2.03$ eV.

1c. At the cutoff wavelength, $KE_{max} = 0$ because the photon is just energetic enough to overcome the work function. Thus,

$$\frac{hc}{\lambda_{cutoff}} = \phi.$$

Plugging in ϕ from above yields $\lambda_{cutoff} = 610$ nm.

Problem 2

2a. We have three independent conservation laws we can use: Conservation of energy, conservation of momentum in the x direction, and conservation of momentum in the y direction (let's say the initial photon moves in the x direction, and the y direction is the other transverse direction). Conservation of y momentum implies $p_e \sin \phi = p_{\gamma'} \sin \theta$, which implies $p_e = p_{\gamma'}$ since $\phi = \theta$. Conservation of x momentum implies

$$p_{\gamma} = p_e \cos \phi + p_{\gamma'} \cos \theta = 2p_{\gamma'} \cos \theta,$$

where we've used $\phi = \theta$ and $p_e = p_{\gamma'}$ to get the last equality.

Now, we need to use conservation of energy, $E_{\gamma} + m_e c^2 = E_e + E_{\gamma'}$. Writing $E_{\gamma} = p_{\gamma} c$, $E_{\gamma'} = p_{\gamma'} c$, and $E_e = \sqrt{p_e^2 c^2 + m_e^2 c^4} = \sqrt{p_{\gamma'}^2 c^2 + m_e^2 c^4}$, we can perform the following manipulations:

$$\begin{aligned} E_{\gamma} - E_{\gamma'} + m_e c^2 &= E_e \\ ((p_{\gamma} - p_{\gamma'})c + m_e c^2)^2 &= p_{\gamma'}^2 c^2 + m_e^2 c^4 \\ p_{\gamma}^2 c^2 - 2p_{\gamma} p_{\gamma'} c^2 + p_{\gamma'}^2 c^2 + 2(p_{\gamma} - p_{\gamma'})m_e c^3 + m_e^2 c^4 &= p_{\gamma'}^2 c^2 + m_e^2 c^4 \\ 2p_{\gamma'}(p_{\gamma} + m_e c) &= p_{\gamma}(p_{\gamma} + 2m_e c) \\ 2p_{\gamma'} &= \frac{p_{\gamma}(p_{\gamma} + 2m_e c)}{p_{\gamma} + m_e c} \end{aligned} \tag{1.1}$$

Now, we can use $\cos \theta = p_\gamma/2p_{\gamma'}$ to arrive at

$$\cos \theta = \frac{p_\gamma + m_e c}{p_\gamma + 2m_e c}.$$

This is good, since this implies that $\cos \theta < 1$. Plugging in $p_\gamma = 1.02 \text{ MeV}/c$ and $m_e c = 0.511 \text{ MeV}/c$, we get $\cos \theta = 0.75$, which means $\theta = 41.4^\circ$.

2b. We can use our expression for $p_{\gamma'}$ above to give

$$E_{\gamma'} = \frac{1}{2} \left(\frac{p_\gamma + 2m_e c}{p_\gamma + m_e c} \right) p_\gamma c.$$

Plugging in yields $E_{\gamma'} = 0.68 \text{ MeV}$.