Multiple Choice - Be sure to put answers in boxes provided

1. (5 pts)

☐ An infrared light bulb emitting 700 nm wavelength light and an ultraviolet light bulb emitting 400 nm light are each rated at 500 W. What is the ratio of the number of photons emitted per second by the infrared lamp to the ultraviolet lamp?

A. 1/1  B. 4/7  C. 7/4  D. 7/5  E. 5/4  F. 28/25

2. (5 pts)

☐ A student attending a concert finds himself directly in front of a large speaker which is 0.4 m wide. His distance from the speaker is 10 m. He is deafened by the music but though he cannot move farther away, he is able to move sideways. Assuming the music is mainly of wavelength 0.1 m, approximately how far to the side should he move so as to minimise the sound from the speaker?

A. 0.2 m  B. 0.4 m  C. 0.75 m  D. 1.3 m  E. 0.25 m  F. 2.5 m
3. (5 pts)

Consider a particle of energy $E < V_0$ in the following potential

Which of the following is a possible solution for the probability density?

A. B. C. D. E. F.

4. (5 pts)

Electrons of rest mass $m_0$ are traveling at a speed $v = c/2$. What is their wavelength?

A. $\frac{\sqrt{3}h}{m_0c}$  B. $\frac{h}{m_0c}$  C. $\frac{2h}{m_0c}$  D. $\frac{4h}{m_0c}$  E. $\frac{8h}{m_0c}$  F. $\frac{m_0c}{\sqrt{3}h}$
1. (15 pts) A metal surface of known work function $\phi$ is facing an electrode $E$ which has a voltage difference $V$ produced by battery $B$. The electrical current $i$ through the battery is measured by an ammeter. Light of wavelength $\lambda$ is shone on the metal surface.

For wavelengths for which the photons have sufficient energy to overcome the work function, the current is observed to vary in the following way when the incident light intensity is $I_0$.

where the relation between $V_0$, $\phi$ and the wavelength $\lambda$ of the photons is

$$eV_0 = \frac{hc}{\lambda} - \phi$$

a) (5 pts) With the wavelength of the light set at $\lambda = \frac{hc}{2\phi}$ the intensity is doubled to $2I_0$.

Sketch a graph of the current $i$ as the voltage $V$ is varied over the range $-\phi/e$ to $+\phi/e$ indicating the values of important features.
b) (5 pts) Now the wavelength is changed to $\lambda_1 = \frac{2hc}{\phi}$ and the intensity is changed to $I_0/2$. Sketch a graph of the current $i$ as the voltage $V$ is varied over the range - $\phi/e$ to $+\phi/e$.

\[ i \text{ microamps} \]

\[ \begin{array}{cccc}
-\phi/e & 1 & 2 & 3 & 4 \\
\end{array} \]

\[ \begin{array}{cccc}
\phi/e & 1 & 2 & 3 & 4 \\
\end{array} \]

c) (5 pts). Calculate the speed of the most energetic electrons emitted when the wavelength $\lambda = \frac{hc}{4\phi}$. The mass of the electron is $m_0$. Express your answer in terms of $\phi$, $m_0$ and any other quantities.

2 (15pts). An electron initially at rest with a rest mass $m_0$ is Compton scattered by a photon of wavelength $\lambda_1$. The electron recoils at a speed $v$ and the photon’s wavelength is increased to $\lambda_2$. One of the conservation equations governing the motion can be written as

\[ \frac{hc}{\lambda_1} + m_0c^2 = \frac{hc}{\lambda_2} + \gamma m_0c^2 \]

- B

a) (5 pts) State what quantity is being conserved in equation B and give the identity of each of the terms.
b). (10 pts) For scattering which results in small electron speeds the function $\gamma$ can be approximated by $\gamma = 1 + \frac{v^2}{2c^2}$. In this case show from equation B that the fractional increase $\frac{\lambda_2 - \lambda_1}{\lambda_1}$ in the wavelength of the scattered photon is given by

$$\frac{\lambda_2 - \lambda_1}{\lambda_1} \approx \frac{\text{classical KE of recoiling electron}}{\text{energy of scattered photon}}$$

3. (25 pts)

A particle of mass $m$ is subject a potential $V(x)$ of the following form

The region I is $x < 0$, region II is $0 < x < a$ and region III is $x > a$. The parameters $V_1$ and $V_2$ are adjustable.
a). (3 pts) Write down the time-independent Schroedinger Equation for each of the regions I, II and III.

b). (3 pts) The parameters are initially set so that $V_1 = 0$ and $V_2 = \infty$. Sketch the wavefunctions of the first three quantum states for this situation.

c). (6 pts) The parameters are set at $V_1 = 0$ and $V_2 = \infty$. The particle is excited from the ground state to the third state by absorbing a photon. What possible photon frequencies would be observed when it drops back to the ground state by emission of photons?
d). (7 pts) The parameters are set so that $V_1 = V_0$ and $V_2 = \infty$. With the condition that the wavefunction is zero at $x = 0$ and $x = a$, use the time-independent Schrödinger Equation to calculate the energy of the ground state $E_1$.

e). (6 pts) Sketch the form of a possible wavefunction for a particle of total energy $E$ for the two cases shown below.
4. (25 pts) The following diagram shows ten phasors of equal amplitude $A_0$ and phase difference $\pi/10$, at an instant of time $t$. The phasors represent the superposition of the light waves from ten lasers of slightly different wavelength. Each individual laser has a beam intensity $I_0$.

**a. (5 pts)** What is the intensity of the light from all the lasers at $t = 0$?

**b. (5 pts)** Estimate the intensity at the instant shown.

**c. (5 pts)** At what time after $t = 0$ is the intensity first zero?
d. (5 pts) What is the first time after $t = 0$ when the intensity is again the same as at $t = 0$?

e. (5 pts) An interference experiment is done with ten very narrow slits, uniformly spaced apart by a distance $d$. The slits are illuminated with light of wavelength $\lambda$ and the interference pattern is observed on a screen a distance $D$ away. You may assume that angles are small so that $\sin \theta = \theta$. Sketch the intensity pattern $I(x)$ seen on the screen, up to the first order interference peaks on either side of the central maximum, indicating the positions and widths of the peaks in terms of $d$, $D$ and $\lambda$. 