In keeping with the Union College policy on academic honesty, it is assumed that you will neither accept nor provide unauthorized assistance in the completion of this work.
Multiple choice questions worth 2 points each. Please circle the best answer to each question.

1. Which of the following properties make the laser a unique source of light?
(a) Coherent.
(b) Collimated beam.
(c) Monochromatic.
(d) All of the above.

2. Light of wavelength \( \lambda \) in vacuum has which of the following wavelengths when it is traveling in a material whose index of refraction is \( n \)?
(a) \( \lambda \)
(b) \( n\lambda \)
(c) \( \frac{\lambda}{n} \)
(d) \( \frac{\lambda}{n^2} \)

3. Two slits separated by 0.1 mm are illuminated with green light (\( \lambda = 540 \text{ nm} \)). Calculate the distance (in cm) from the central bright-region to the fifth bright band if the screen is 1 m away.
(a) 2.3
(b) 2.5
(c) 2.7
(d) 2.1
(e) 2.0

4. The light reflected from a soap bubble (\( n = 1.4 \)) appears red (\( \lambda = 640 \text{ nm} \)) at its center. What is the minimum thickness (in nm)?
(a) 124
(b) 104
(c) 114
(d) 134
(e) 234

5. Let \( D \) be the width of the central maximum in a single slit diffraction experiment. Which of the following will cause the value of \( D \) to increase?
(a) Increasing the wavelength of the incident light
(b) Increasing the frequency of the incident light
(c) Decreasing the distance between the slit and the screen
(d) None of these

6. The lowest energy excited state of the proton is the \( \Delta \)-particle which has a mass of 1232 MeV/c\(^2\) and a width (uncertainty in energy) of 120 MeV. Calculate the lifetime of this state.
(a) \( 5.5 \times 10^{-24} \text{s} \)
(b) \( 2.7 \times 10^{-24} \text{s} \)
(c) \( 3.3 \times 10^{-23} \text{s} \)
(d) \( 6.9 \times 10^{-9} \text{s} \)
(e) \( 8.4 \times 10^{-17} \text{s} \)
Free response problems worth 22 points each. Please show all work and make your reasoning clear.

1. A laser beam is incident on a fiber-optic waveguide as shown below. The index of refraction of the waveguide is 1.48, and the guide is surrounded by air with an index of refraction of 1.00.

(a) What is the angle of refraction?

(b) What is the critical angle?

(c) Does the laser beam undergo total internal reflection? If it does, how many reflections does the beam undergo, before it emerges from the opposite side of the waveguide?
2. In our laboratory experiment investigating the photoelectric effect we found that the work function of the metal emitter was 2.02 eV.

(a) Calculate the cutoff wavelength above which there will be no photoelectrons ejected.

(b) What stopping potential would be necessary to null the photocurrent when the UV light of mercury ($\lambda = 404.6$ nm) is incident on the emitter?

(c) What is the maximum speed of the photoelectrons ejected for this UV ($\lambda = 404.6$ nm) light?
3. Suppose a Hydrogen atom makes a transition from the n=3 state to the n=2 state.
   (a) How much energy was lost by the atom in the transition?

   (b) What are the frequency and wavelength of the photon emitted as a result of the transition?

   (c) In what part of the electromagnetic spectrum does the photon described in b) lie? (Circle one.)
   x-ray                      visible                      radio                      None of these

   (d) Which of the following take on discrete values in the Bohr model of Hydrogen?
   I The radius of the electron orbit
   II The kinetic energy of the electron
   III The angular momentum of the electron
   A. I only
   B. I and II only
   C. I, II and III
   D. II only
   E. Neither I, II, or III
4. A particle of mass $2.00 \times 10^{-28}$ kg is in the ground state ($n=1$) of a one-dimensional box of width $1.00 \times 10^{-10}$ m.

(a) Sketch the wave function in the box.

(b) Find the particle’s wavelength.

(c) Find its momentum.

(d) Find its energy.
Equations and Constants

\[ \lambda = \frac{\hbar}{2\pi} \]
\[ \theta'_{1} = \theta_{1} \]
\[ n = \frac{\xi}{v} \]
\[ n_{1} \sin \theta_{1} = n_{2} \sin \theta_{2} \]
\[ \sin \theta_{c} = \frac{n_{2}}{n_{1}} \quad (\text{for } n_{1} > n_{2}) \]
\[ \delta = d \sin \theta_{dark} = (m + \frac{1}{2})\lambda \quad (m = 0, \pm 1, \pm 2, \ldots) \]
\[ 2nt = (m + \frac{1}{2})\lambda \quad (m = 0, 1, 2, \ldots) \]
\[ \sin \theta_{dark} = m \frac{\lambda}{\hbar} \quad (m = \pm 1, \pm 2, \pm 3, \ldots) \]
\[ d \sin \theta_{bright} = m\lambda \quad (m = 0, 1, 2, 3, \ldots) \]
\[ E = hf \]
\[ K_{\text{max}} = eV \]
\[ \Delta x \Delta p_{x} \geq \frac{\hbar}{2} \]
\[ \Delta E \Delta t \geq \frac{\hbar}{2} \]
\[ P_{ab} = \int_{a}^{b} |\psi|^{2} \, dx \]
\[ E_{n} = \left( \frac{\hbar^{2}}{8mL^{2}} \right) n^{2} \]
\[ C = \sqrt{\frac{2m(U-E)}{\hbar}} \]
\[ c = 3.00 \times 10^{8} \text{ m/s} \]
\[ h = 6.626 \times 10^{-34} \text{ J} \cdot \text{s} \]
\[ 1.00 \text{ eV} = 1.6 \times 10^{-19} \text{ J} \]
\[ m_{e} = 9.11 \times 10^{-31} \text{ kg} \]
\[ \frac{1}{\lambda} = R_{H} \left( \frac{1}{n_{f}^{2}} - \frac{1}{n_{i}^{2}} \right) \]
\[ \theta_{\text{min}} = 1.22 \frac{\lambda}{d} \]
\[ 2nt = m\lambda \quad (m = 0, 1, 2, \ldots) \]
\[ 2d \sin \theta = m\lambda \quad (m = 1, 2, 3, \ldots) \]
\[ \langle x \rangle = \int_{-\infty}^{+\infty} \psi^{\ast}x\psi \, dx \]
\[ T \approx e^{-2CL} \]
\[ T + R = 1 \]
\[ h = 1.055 \times 10^{-34} \text{ J} \cdot \text{s} \]
\[ e = 1.6 \times 10^{-19} \text{ C} \]
\[ R_{H} = 1.097 \times 10^{7} \text{m}^{-1} \]