Physics 228 - Analytical Physics
SECOND COMMON HOUR EXAM
Thursday, April 5, 2012

SIGN HERE NOW:

1. The exam will last from 9:40 - 11:00 p.m. Use a #2 pencil to make entries on the answer sheet. **Enter ID information items 2-5, now, on the answer sheet before the exam starts.**

2. **In the section labeled NAME (Last, First, M.I.) enter your last name, then fill in the empty circle for a blank, then enter your first name, another blank, and finally your middle initial.**

3. **Under STUDENT # enter your 9-digit RUID Number.**
4. **Enter 228 under COURSE; you may ignore the section number.**
5. **Under CODE enter the exam code from the label above.**

6. During the exam, you may use pencils, a calculator, and one 8.5 x 11 inch sheet (both sides) with formulas and notes.

7. There are 16 multiple-choice questions on the exam. For each question, mark only one answer on the answer sheet. There is no deduction of points for an incorrect answer, so even if you cannot work out the answer to a question, you should make an educated guess. **At the end of the exam, hand in the answer sheet and this SIGNED cover page.** Retain the exam questions attached for future reference and study.

8. When you are asked to open the exam, make sure that your copy contains all 16 questions. Raise your hand if this is not the case, and a proctor will help you. Also raise your hand during the exam if you have a question.

9. Please have your student ID ready to show to the proctor during the exam.
Possibly useful information:
1) Speed of light in vacuum is \( c = 3.00 \times 10^8 \) m/s.
2) 1 eV = \( 1.60 \times 10^{-19} \) J.
3) \( J = \text{kg} \cdot \text{m}^2/\text{s}^2 \).
4) Wien's displacement law constant is \( 2.90 \times 10^{-3} \) m \( \cdot \) K.
5) Rydberg constant is \( R = 1.10 \times 10^7 \) m\(^{-1}\).
6) \( hcR = 13.60 \text{ eV} \).
7) \( h = h/2\pi \).
8) Photon mass is 0.
9) Metric prefixes: 1 G = \( 10^9 \), 1 M = \( 10^6 \), 1 k = \( 10^3 \), 1 m = \( 10^{-3} \), 1 \( \mu \) = \( 10^{-6} \), and 1 n = \( 10^{-9} \).
10) Planck constant is \( h = 6.63 \times 10^{-34} \text{ J} \cdot \text{s} = 4.14 \times 10^{-15} \text{ eV} \cdot \text{s} \).
1. For the following four situations, which answer gives the correct relative size of the uncertainty of the momentum in the x direction? (The mass of the proton is 1836 times the mass of the electron.)
   (A) an electron whose x-coordinate is known to within 2 x 10^{-15} m.
   (B) an electron whose x-coordinate is known to within 4 x 10^{-15} m.
   (C) a proton whose x-coordinate is known within 2 x 10^{-15} m.
   (D) a proton whose x-coordinate is known within 4 x 10^{-15} m.
   \[ \Delta p_x \Delta x > \hbar \]
   \[ \Delta x_1 = 2.10^{-15} \text{m} \quad \Delta x_2 = 4.10^{-15} \text{m} \]
   \[ \Delta p_1 > \Delta p_2 \]
   Since the question asks for momentum, it doesn't matter if it is an e^- or p.

2. A proton has a slightly smaller mass than a neutron. If the proton and the neutron have the same wavelength, which one has more kinetic energy?
   a) Proton.
   b) Neutron.
   c) Since the particles have the same wavelength (\( \lambda \)), they have the same kinetic energy.
   d) Without knowing the speed of particles we cannot compare their kinetic energy.
   e) Depends on their Planck radiation.

\[ \lambda_p = \lambda_n \]
\[ p = m v \]
\[ E_p = \frac{p^2}{2m_p} \]
\[ E_n = \frac{p^2}{2m_n} \]

3. The ground-state energy of a harmonic oscillator is 5.60 eV. If the oscillator undergoes a transition from its n=3 to n=2 level by emitting a photon, what is the energy of the photon?
   a) 2.80 eV
   b) 5.60 eV
   c) 8.40 eV
   d) 11.20 eV
   e) 22.40 eV
   \[ E_n = (n + \frac{1}{2}) \hbar \omega \]
   \[ E_2 = \frac{1}{2} \hbar \omega \]
   \[ E_3 = (3 + \frac{1}{2}) \hbar \omega = \frac{7}{2} \hbar \omega \]
   \[ E_3 - E_2 = \hbar \omega = 2 E_0 \]

4. An X-ray undergoes Compton scattering. At which scattering angle is the longest wavelength observed in the scattered X-rays?
   a) 0
   b) \( \pi/4 \)
   c) \( \pi/3 \)
   d) \( \pi/2 \)
   e) \( \pi \)
   \[ \lambda' - \lambda = \frac{\lambda}{mc} (1 - \cos \phi) \]
   So for \( \cos \pi = -1 \) \( \lambda' - \lambda \) is the biggest.
5. A meter stick moves past you at high speed. Its motion relative to you is parallel to its long axis. You measure the length of the moving stick to be 1 ft (1 ft = 0.3048 m). At what speed is the meter stick moving relative to you?

\[
\frac{1}{\gamma} = \frac{l_0}{l} = \frac{1}{\gamma} = \frac{1}{0.3048} = \frac{1}{\sqrt{1-u^2/c^2}}
\]

a) \(0.99c\)  
b) \(0.89c\)  
c) \(1.99c\)  
d) \(0.85c\)  
e) \(0.95c\)

6. A photon has momentum \(8.24 \times 10^{-28}\) kg \cdot m/s. What is its energy?

\[
E = p \cdot c
\]

a) \(2.47 \times 10^{-19}\) eV  
b) \(1.54\) eV  
c) \(8.04 \times 10^{-27}\) eV  
d) \(5.00 \times 10^{11}\) eV  
e) \(3.04\) eV

7. A spaceship moving away from the earth at 0.9c fires a robot space probe in the same direction as its motion at 0.7c relative to the spaceship. What is the probe's velocity relative to the earth?

\[
\gamma \cdot 0.9c = u \\
\gamma \cdot 0.7c = \frac{u_x^1 + u}{1 + u \frac{u_x^1}{c^2}} = \frac{(0.9 + 0.7)c}{1 + 0.63 \frac{c^2}{c^2}} = 1.69 \cdot 1.63 = 0.98c
\]

8. The photoelectric effect threshold wavelength of a tungsten surface is 272 nm. Calculate the maximum kinetic energy of the electrons ejected from this tungsten surface by ultraviolet radiation of frequency \(1.45 \times 10^{15}\) Hz.

\[
E = hf - \Phi
\]

a) \(4.54\) eV  
b) \(5.98\) eV  
c) \(1.44\) eV  
d) \(3.74\) eV  
e) \(8.68\) eV

\[
E = hf = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \cdot 3 \times 10^8}{272 \times 10^{-9} \cdot 1.6 \times 10^{-19}} = 4.57\ eV
\]

\[
E = hf = \frac{1.45 \times 10^{-15} \cdot 6.63 \times 10^{-34}}{1.6 \times 10^{-19}} = 6\ eV
\]

\(6\ eV - 4.57\ eV = 1.43\ eV\)
13. Determine the wavelength ($\lambda_{max}$) at the peak intensity of the radiation of a blackbody at a temperature of 2.90 mK.

a) 1000 m
b) 1 m
c) 10 m
d) 100 m
e) 0.1 m

\[
\lambda_m = \frac{0.0029 \text{ m.K}}{2.9 \times 10^{-3} \text{ K}} = 1 \text{ m}
\]

14. An electron is trapped in a one-dimensional infinite potential well of width $L$. What is the ratio of energy emitted when the electron makes a transition from the second excited state ($n=3$) to the ground state ($n=1$) to that emitted when the electron makes a transition from the fourth excited state ($n=5$) to the ground state ($n=1$)?

a) $9/25$
b) $1/2$
c) $3/5$
d) $1/3$
e) The answer cannot be determined without knowing $L$.

\[
E_n = \frac{n^2 \hbar^2}{8mL^2} \quad E_n \propto n^2
\]

\[
E_{3-1} \propto 3^2 - 1^2 = 8
\]

\[
E_{5-1} \propto 5^2 - 1^2 = 24
\]

15. Stanley, on a train going through the New Brunswick train station at 30 m/s, shines a flashlight to the front of the train. Mavis, on the platform, precisely measures the speed of the flashlight beam. What does she get?

b) $c$
b) $c - 30$

c) $c + 30$
d) None of the above.
e) It depends on whether the light is shining towards or away from Mavis.

\[
\frac{E_{3-1}}{E_{5-1}} = \frac{8}{24} = \frac{1}{3}
\]

16. If you measure the position of a particle in the ground state of an infinite square well, where are you most likely to find the particle?

a) Near the left edge.
b) Near the right edge.
c) Near the center.
d) Outside the well.
e) Equally likely anywhere in the well.

See lecture notes.
9. What is the speed of a particle whose kinetic energy is equal to its rest energy.

\[ E = \gamma mc^2 = K + mc^2 \quad K = (\gamma - 1) mc^2 \]
\[ \gamma = \frac{1}{\sqrt{1 - \frac{u^2}{c^2}}} \]
\[ \frac{1}{\gamma} = 1 - \frac{u^2}{c^2} \]
\[ \frac{u^2}{c^2} = \frac{3}{4} \]
\[ u = 0.866c \]

\[ \gamma - 1 = 1 \quad \frac{\gamma - 1}{\gamma} = 2 \]

\[ a) \quad 0 \]
\[ b) \quad c \]
\[ c) \quad 0.567c \]
\[ d) \quad 0.866c \]
\[ e) \quad \text{It depends on the mass of the particle.} \]

10. An electroscope is positively charged. Can I remove the positive charge with ultraviolet (UV) light?

\[ y \]
\[ y = \frac{1}{\sqrt{1 - \frac{u^2}{c^2}}} \]
\[ \frac{1}{\gamma} = 1 - \frac{u^2}{c^2} \]
\[ \frac{u^2}{c^2} = \frac{3}{4} \]
\[ u = 0.866c \]

\[ a) \quad \text{Yes, because UV light kicks out the extra charges.} \]
\[ b) \quad \text{Yes, because UV light kicks electrons from air into the electroscope.} \]
\[ c) \quad \text{No, because you need visible light to kick out positive charges.} \]
\[ d) \quad \text{No, because UV light will tend to kick out more electrons from the electroscope and there are already too few of them.} \]
\[ e) \quad \text{No, because light interacts only with negative charges.} \]

11. A single electron is bound to a helium nucleus (He), in the ground state, instead of a hydrogen nucleus (H). (The He nucleus has 2 protons and 2 neutrons while the H nucleus has 1 proton.) You expect its energy to:

\[ a) \quad \text{be the same as for hydrogen} \]
\[ b) \quad \text{be greater, because of the uncertainty principle and because it is constrained to a smaller volume} \]
\[ c) \quad \text{be greater, due to the stronger electric attraction} \]
\[ d) \quad \text{be more negative (more bound), because of the uncertainty principle} \]
\[ e) \quad \text{be more negative (more bound), due to the stronger electric attraction} \]

12. A hydrogen atom initially in the ground level \((n = 1)\) absorbs a photon, which excites it to the \(n = 4\) level. Determine the wavelength of the photon.

\[ a) \quad 97 \text{ nm} \]
\[ b) \quad 121 \text{ nm} \]
\[ c) \quad 152 \text{ nm} \]
\[ d) \quad 145 \text{ nm} \]
\[ e) \quad 103 \text{ nm} \]

\[ \frac{1}{\lambda} = R \left( \frac{1}{4^2} - \frac{1}{1^2} \right) = 1.1 \times 10^{-7} \text{ m}^{-1} \]
\[ \frac{15}{16} \]

\[ \lambda = 0.973 \times 10^{-7} \text{ m} \]
\[ = 97 \text{ nm} \]