Physics 273– Exam II
Fall 2016 – Wednesday, November 9, 2016
Professor John Paul Chou

Your name sticker with exam code

1. The exam will last from 3:35pm to 4:30pm. Use a #2 pencil to make entries on the answer sheet. Enter the following id information now before the exam starts.

2. In the section labelled NAME, 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 Student ID Number. Under COURSE enter 273.

4. During the exam, you may use pencils, a calculator, and ONE 8.5" × 11" sheet of paper with formulas and notes.

5. There are 16 multiple-choice questions on the exam. For each question, mark only one answer on the answer sheet. There is no subtraction 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 only the answer sheet. Retain this question paper for future reference and study.

6. Useful numerical constants are given on the next page. Before starting the exam, make sure that your copy contains the page of constants and all 16 questions. Bring your exam to the proctor if this is not the case.
Elementary charge $e = 1.6 \times 10^{-19}$ C
1 electron volt (eV) = $1.6 \times 10^{-19}$ J
Speed of light $c = 3 \times 10^8$ m/s
Planck’s constant $\hbar = 6.63 \times 10^{-34}$ J · s = 1240 nm · eV/c
$k = \hbar/2\pi$
Compton wavelength of electron $\hbar/mc = 0.0024$ nm
Ground-state energy of hydrogen = $-13.6$ eV
Rydberg constant $R = 0.0109678$ nm$^{-1}$
Avogadro’s number = $6.02 \times 10^{23}$ molecules/mole
Electron mass = $9.11 \times 10^{-31}$ kg = 0.511 MeV/c$^2 = 0.000549$ u
Proton mass = $1.673 \times 10^{-27}$ kg = 938.3 MeV/c$^2$
Neutron mass = $1.675 \times 10^{-27}$ kg = 939.6 MeV/c$^2 = 1.008665$ u
Atomic mass unit 1 u = $931.5$ MeV/c$^2$
Hydrogen atom mass = $1.007825$ u
alpha mass = $4.0026032$ u
Fine structure constant $\alpha = 1/137$
Bohr magneton $\mu_B = 5.79 \times 10^{-5}$ eV/T
Energy ordering of subshells:
1s 2s 2p 3s 3p 4s 3d 4p 5s 4d 5p 6s 4f 5d 6p 7s 5f 6d 7p
Values of $l$ for subshells:

<table>
<thead>
<tr>
<th>s</th>
<th>p</th>
<th>d</th>
<th>f</th>
<th>g</th>
<th>h</th>
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<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Powers of ten:

<table>
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<tr>
<th>femto (f)</th>
<th>pico (p)</th>
<th>nano (n)</th>
<th>micro (\mu)</th>
<th>milli (m)</th>
</tr>
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<tbody>
<tr>
<td>$10^{-15}$</td>
<td>$10^{-12}$</td>
<td>$10^{-9}$</td>
<td>$10^{-6}$</td>
<td>$10^{-3}$</td>
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<td>centi (c)</td>
<td>kilo (k)</td>
<td>Mega (\text{M})</td>
<td>Giga (G)</td>
<td>Tera (T)</td>
</tr>
<tr>
<td>$10^{-2}$</td>
<td>$10^{3}$</td>
<td>$10^{6}$</td>
<td>$10^{9}$</td>
<td>$10^{12}$</td>
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</table>
1. What is the DeBroglie wavelength of a Helium-4 atom traveling at \( v = 0.5c \)?
   a) 1.14 \times 10^{-9} \text{ nm}
   b) 1.52 \times 10^{-6} \text{ nm}
   c) 5.72 \times 10^{-7} \text{ nm}
   d) 6.60 \times 10^{-7} \text{ nm}
   e) It doesn't have one.

2. Suppose we try to constrain a proton to the confines of a nucleus of size 10^{-15} \text{ m}. Using the uncertainty relation, what is the minimum nuclear binding energy required to prevent the proton from escaping freely?
   a) 1 \text{ MeV}
   b) 5 \text{ MeV}
   c) 10 \text{ MeV}
   d) 100 \text{ MeV}
   e) 950 \text{ MeV}

3. A particle in one dimension, constrained to the positive x axis has the wavefunction \( \Psi(x) = Ae^{-x} \). What is the constant \( A \)?
   a) \(1/2\)
   b) 1
   c) \(\sqrt{2}\)
   d) \(i\sqrt{2}\)
   e) 2

4. A particle in one dimension has a wavefunction \( \Psi(x) = \sqrt[4]{x} \sin \frac{\pi x}{L} \) in the region 0 < \(x\) < \(L\) and zero elsewhere. What is the probability to find the particle between \(x = 0\) and \(x = L/3\)?
   a) \(1/\sqrt{3}\)
   b) \(1/2\)
   c) \(1/4\)
   d) \(1/8\)
   e) \(1/\sqrt{2}\)
5. Which of the following statements are true?

\( \checkmark \) I: The Heisenberg Uncertainty Principle applies to electrons, but not to protons.

\( \checkmark \) II: The Heisenberg Uncertainty Principle applies only to electrically charged particles, like electrons.

\( \times \) III: A particle of finite lifetime cannot have a precisely defined mass.

\( a) \) I and III are true; II is false

\( b) \) II and III are true; I is false

\( c) \) III is true; I and II are false

\( d) \) II is true; I and III are false

\( e) \) All three statements are false

6. A photon, an electron, and a proton all have the same kinetic energy. List them in order of increasing DeBroglie wavelength, i.e. smallest \( \lambda \) first, largest \( \lambda \) last.

\[ \lambda = \frac{h}{P} = \frac{h}{\sqrt{E^2 - m^2 c^4}} = \frac{h}{\sqrt{E^2 c^2 - m^2 c^4}} \]

\( \text{small } \lambda \text{ means large } m, \text{ so order by decreasing mass.} \)

\( a) \) Photon, electron, proton

\( b) \) Photon, proton, electron

\( c) \) Electron, photon, proton

\( d) \) Proton, photon, electron

\( e) \) Proton, electron, photon

7. For a particle in a one-dimensional infinite square well, the DIFFERENCE in energy between the first excited state and the ground state is 12 eV. What is the ground state energy?

\[ E_n = n^2 \Rightarrow E_2 - E_1 = 4k - 1k = 12 eV \]

\( \downarrow \)

\[ k = 4 eV \]

\( \Rightarrow E_1 = 4 eV \)

\( \text{e) None of the other answers} \)

8. For an electron in a subshell with quantum numbers \( n = 2 \) and \( l = 1 \), what are the possible angles that the orbital angular momentum vector can make with the z-axis (which could be the direction of an external magnetic field)?

\( a) \) 45°, 90°, and 135°

\( b) \) 0° and 90°

\( c) \) 0° and 180°

\( d) \) 45° and 135°

\( e) \) 0°, 90°, and 180°
9. What is one of the shortcomings of the Schrödinger equation?
   a) It does not take into account the wave nature of matter.
   b) It cannot account for the Coulomb attraction between the electron and proton in the Hydrogen atom.
   c) It can only be solved for one-dimensional potentials.
   d) It does not account for relativistic properties of particles.
   e) Its solutions for the Hydrogen atom are in serious disagreement with the predictions of the Bohr model.

10. How many separate \((j, m_j)\) states are possible for the Hydrogen 3D state?
   a) 1
   b) 2
   c) 6
   d) 7
   e) 10

11. What is the smallest value that \(\ell\) may have if \(\vec{L}\) is within 10° of the z axis?
   a) 33
   b) 45
   c) 92
   d) 339
   e) 1089

12. Consider a hydrogen atom in a state of zero orbital angular momentum. What will be the value of the g-factor?
   \(\ell = \frac{1}{2}, \quad j = \frac{1}{2}\)
   a) 0
   b) 1
   c) 2
   d) 1.33
   e) 1.67

13. Suppose a hydrogen atom in a \(3^2D_{5/2}\) state is placed in an external magnetic field \(B\). Into how many substates will it split?
   a) 2
   b) 4
   c) 5
   d) 6
   e) None of the other answers

\[
\Delta E = m_j \cdot g \cdot \mu_B \cdot B
\]
14. Suppose a complex atom in a \( 4^3D_3 \) state is placed in an external magnetic field \( B \). What will be the spacing in energy between adjacent magnetic substates?

\[
\Delta E \propto g \mu_B \cdot B \cdot m_z
\]

\[ m_z = \pm 1 \]

a) \( 0.67 \mu_B B \)

b) \( 1.33 \mu_B B \)

c) \( 2.00 \mu_B B \)

d) \( 1.50 \mu_B B \)

e) \( 0.67 \mu_B B \)

15. Which of these radioactive decays does not change the parent nucleus's element type?

a) \( \gamma \) decay

b) \( \alpha \) decay

c) \( \beta \) decay

d) Electron Capture.

e) \( \beta \) decay and Electron Capture.

16. What is the binding energy for an \( \alpha \) particle?

a) \( 932 \text{ MeV} \)

b) \( 237 \text{ MeV} \)

c) \( 7.08 \text{ MeV} \)

d) \( 3757 \text{ MeV} \)

e) \( 28.3 \text{ MeV} \)

\[
\begin{align*}
\Delta m_4 &= 4.0026032u \\
m_\alpha &= 1.008665u \\
2m_\alpha + 2m_\alpha - 4m_\alpha &= 0.0304u = 28.3 \text{ MeV}
\end{align*}
\]