Physics 228 - Exam 2
8 April 2010
Profs. Rabe and Coleman

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Your name sticker with **exam code**
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SIGNATURE ______________________________

Turn off and put away cell phones now!

1. The exam will last from 9:40pm to 11:00pm.
2. Use a #2 pencil to make entries on the answer sheet. Enter the following ID information now, before the exam starts.
3. In the section labelled 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.
4. Under STUDENT # enter your 9-digit student ID.
5. Enter 228 under COURSE, and your section number (see label above) under SEC.
6. Under CODE enter the exam code given above.
7. During the exam, you may use pencils, a calculator, and one **handwritten** 8.5 x 11 inch sheet with formulas and notes, without attachments.
8. 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 ened of the exam, **hand in the answer sheet and the cover page.** Retain this question paper for future reference and study.
9. 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.
10. Please SIGN the cover sheet under your name sticker and have your student ID ready to show to the proctor during the exam.

Useful information

c = speed of light = 3.00×10^8 m/s
$q_e = -e$ = charge on an electron = -1.602×10^{-19} Coulombs
$q_p = +e$ = charge on a proton = $+1.602 \times 10^{-19}$ Coulombs
m_e = electron mass = 9.11×10^{-31} kg
$m_e c^2$ = electron rest energy = 0.511 MeV
m_p = proton mass = 1.67×10^{-27} kg
$m_p c^2$ = proton rest energy = $938.27 MeV$
$m_n c^2$ = neutron rest energy = $939.57 MeV$
k_B = Boltzmann's constant = 1.38×10^{-23} J/K
Wien's Constant = $2.898 \times 10^{-3} m \cdot K$
σ = Stefan's Constant = $5.670 \times 10^{-8} W/(m^2 K^4)$
$\hbar = \frac{h}{2\pi}$
$h = 6.626 \times 10^{-34}$ J-s
$h = 4.136 \times 10^{-15}$ eV-s (in units of electron volts-second)
hc = 1240 eV · nm = 1240 MeV · fm
1 nm = 10^{-9} m
1 Å = 10^{-10} m = 0.1 nm
1 μm = 10^{-6}m
1 mHz = 10^{-3} Hz   1 kHz = 10^{+3} Hz
1 MHz = 10^{+6} Hz   1 GHz = 10^{+9} Hz

1. A photon, an electron, and a baseball have the same momentum. Which has the largest de Broglie wavelength?

   a) photon
   b) all have the same wavelength
   c) electron
   d) baseball and electron
   e) baseball

$\lambda = \frac{h}{p}$ depends only on momentum.

Same momentum → same λ.

2. A particle is confined inside a cube of side length L, with one corner at the origin. The potential height of the walls of the cube is infinite. The normalized wave function of the particle, which is in the ground state, is

$$\psi(x, y, z) = \left(\frac{2}{L}\right)^{3/2} \sin \pi x \sin \pi y \sin \pi z, \qquad 0 < x,\ y,\ z < L$$

What is the maximum value of the probability distribution function for an electron in this state?

   a) $\left(\frac{1}{L}\right)^{3/2}$
   b) $\frac{8}{L^3}$
   c) $\left(\frac{2}{L}\right)^{3/2}$
   d) $\frac{1}{L^3}$
   e) $\frac{8}{L}$

$\psi^* \psi = \left(\frac{2}{L}\right)^3 \sin^2 \pi x \sin^2 \pi y \sin^2 \pi z$

$\sin^2 \leq 1$ so max value of $\psi^* \psi$ is $\left(\frac{2}{L}\right)^3 = \frac{8}{L^3}$

3. A perfectly black body at a temperature of 100°C emits light of intensity I that has strongest intensity at wavelength λ. The temperature of the black body is now increased to 200°C. The hotter black body now emits light most strongly at a wavelength closest to

   a) 0.5λ
   b) λ
   c) 2λ
   d) 1.3λ
   e) 0.8λ

use Wien law $\lambda_m T = 2.90 \times 10^{-3}$ m K

$\lambda_{hotter} = \frac{2.90 \times 10^{-3} \text{ mK}}{473 \text{ K}} = \underbrace{\frac{2.90 \times 10^{-3} \text{ mK}}{373 \text{ K}}}_{\lambda} \cdot \frac{373}{473}$

4. An elementary particle with rest mass m spontaneously decays into two ~~equal~~ particles with rest masses $\frac{m}{3}$. What are the kinetic energies of these particles? ^equal

a) $\frac{mc^2}{3}, \frac{mc^2}{6}$
b) $\frac{mc^2}{3}, 0$
c) $\frac{mc^2}{3}, \frac{mc^2}{3}$
d) $\frac{mc^2}{6}, \frac{mc^2}{6}$
e) $\frac{mc^2}{6}, 0$

$$mc^2 = \left(\frac{m}{3}c^2 + K\right) \times 2$$

$$K = \frac{mc^2}{6}$$

5. If light incident on a metallic surface is doubled in intensity, the maximum kinetic energy of electrons produced by the photoelectric effect will change from K to:

a) 4K
b) 2K
c) K/4
d) K/2
e) K (no change)

Kinetic energy of outgoing electrons depends only on f of incoming light, not I.

6. As a spaceship heads directly to earth at a velocity of 0.8c, it sends a radio signal to earth. When those radio waves arrive on earth, their velocity relative to earth is:

a) $\sqrt{c^2 + v_E^2}$, where v_E is the velocity of the earth.
b) c.
c) $\sqrt{(.8c)^2 + v_E^2}$, where v_E is the velocity of the earth.
d) 1.8 c.
e) 0.8 c.

The speed of light is c in all reference frames.

7. Accelerating voltages in cathode-ray-tube (CRT) TV's are about 24.0 kV. What is the shortest wavelength of the x-rays that are produced when the accelerated electrons hit the screen?

a) 52nm
b) 5.6×10^{18}Hz
c) 0.008nm
d) 0.052 nm
e) 7.8nm

energy of incoming electron is 24×10^3 eV
assume full conversion of energy to single photon

$$E = \frac{hc}{\lambda} \qquad \lambda = \frac{hc}{E} = \frac{1240 \text{ eV}\cdot\text{nm}}{24000 \text{ eV}} = 0.052 \text{ nm}$$

8. A meter stick moves in the laboratory along the direction of its length with a speed of 1.2×10^8 m/sec. Its length, as seen by an observer at rest in the laboratory, is:

a) 1.09 m
b) 1.19 m
c) 0.917 m
d) 0.84 m
e) 1.00 m

length contraction $L = \frac{L_o}{\gamma}$

$L_o = 1m$, $\gamma = \frac{1}{\sqrt{1-\left(\frac{1.2}{3}\right)^2}} = 1.09$

9. A hydrogen atom undergoes a transition from the $n = 6$ to the $n = 2$ state by emitting a photon. According *to the Bohr model of the atom*, if the angular momentum is conserved, what is the angular momentum of the photon that is emitted?

a) $3\hbar$
b) $0\hbar$
c) $4\hbar$
d) $1\hbar$
e) $2\hbar$

$L_n = n\hbar \qquad L_6 - L_2 = 4\hbar$

10. The uncertainty in position of an electron in a certain state is 5×10^{-10} m. The uncertainty in its momentum (in kg·m/s) must be:

a) less than 10^{-23}
b) greater than 10^{-20}
c) less than 10^{-25}
d) greater than 10^{-25}
e) greater than 10^{-23}

Heisenberg uncertainty principle

$\Delta p \Delta x \geq \hbar$

$\Delta p \geq \frac{\hbar}{\Delta x} = \frac{6.626 \times 10^{-34} Js}{2\pi \cdot 5 \times 10^{-10} m} = 2 \times 10^{-25} \frac{kg\,m}{s}$

11. Consider an electron with the free-particle wavefunction

$$\psi(x,t) = A \exp[i(kx - \omega t)].$$

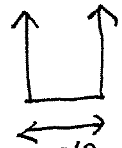
Which of the following is false?

a) the energy of the electron is $\hbar\omega$.
b) A can be chosen to be a pure imaginary number.
c) $\psi(x,t)$ is not a stationary state.
d) the momentum of the electron is $\hbar k$.
e) the probability distribution function is independent of x.

$\psi^* \psi = A^* A$

12. An electron is trapped in a one-dimensional infinite potential well of width 10^{-10} m. What is the energy of the photon emitted when the electron makes a transition from the first excited state ($n = 2$) to the ground state ($n = 1$)?

   a) 0.062 eV
   b) 37.4 eV
   c) 113 eV
   d) 127 eV
   e) 150 eV



$L = 10^{-10}\ m$

$$E_n = \frac{\hbar^2}{2m} \cdot \left(\frac{n\pi}{L}\right)^2 \qquad \Delta E = 3\,\frac{\hbar^2\pi^2}{2mL^2}$$

$$= \frac{3}{4 \cdot 2} \cdot \frac{4.136\times10^{-15}\,eV\cdot s \times 6.626\times10^{-34}\,Js}{9.11\times10^{-31}\,kg \cdot 10^{-20}\,m^2}$$

13. A distant star is receding from earth at a speed such that the 434-nm emission line of hydrogen is Doppler shifted to 650 nm. At what speed is the star receding?

   a) 0.667c
   b) 0.383c
   c) 0.9999c
   d) 0.5c
   e) 0.995c

$$f = \sqrt{\frac{c-u}{c+u}}\, f_0 \rightarrow \lambda = \sqrt{\frac{c+u}{c-u}}\, \lambda_0$$

$$\left[\frac{c+u}{c-u}\right] = \left(\frac{650}{434}\right)^2 = 2.24$$

can solve quadratic eqn
or
try the 5 answers and see which one works

14. The wave character of electrons is best illustrated by which of the following?

   a) The fact that hot objects emit electromagnetic radiation.
   b) The diffraction pattern observed when a beam of electrons is scattered by a crystal.
   c) The scattering of alpha particles from gold foil.
   d) The ejection of electrons from a metal surface illuminated by light.
   e) The fact that a rainbow consists of a continuous spectrum of colors.

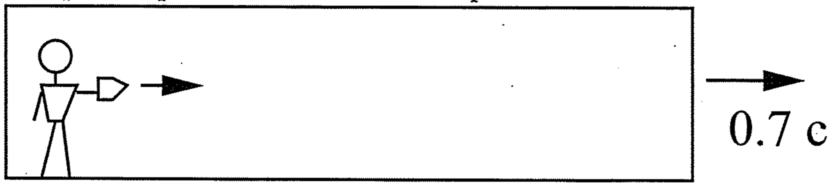
diffraction is a wave property.

15. $\psi(x)$ is the normalized wave function for a particle moving along the x axis. The probability that the particle is in the interval from $x = a$ to $x = b$ is given by:

   a) $|\psi(b)|^2 - |\psi(a)|^2$
   b) $\psi(b) - \psi(a)$
   c) $\int_a^b \psi(x)dx$
   d) $\int_a^b |\psi(x)|^2 dx$
   e) $|\psi(b) - \psi(a)|^2$

$$\int_a^b \psi^* \psi\, dx = \int_a^b |\psi(x)|^2 dx$$

16. A spaceship is moving at speed 0.70c to the right relative to earth. Standing at the rear of the ship, a woman fires a space gun, and the bullet goes forward inside the ship at a speed of 0.90c *relative to the spaceship*. What is the bullet's speed *as measured from earth?*



a) 1.60c
b) 0.98c
c) 0.92c
d) 0.54c
e) 0.20c

$$V = \frac{v' + u}{1 + \frac{uv'}{c^2}} = \frac{0.9c + 0.7c}{1 + 0.9 \cdot 0.7} = 0.98c$$