**General Physics II** **Exam 4 - Chs. 26, 27, 28 - Relativity & Quantum Physics** **Nov. 21, 2013**

Name Rec. Instr. Rec. Time

For full credit, make your work clear. Show formulas used, essential steps, and results with correct units and significant figures. Points shown in parenthesis. For TF and MC, choose the *best* answer.

1. (3) Which system is closest to being an inertial reference frame?

a. A spinning merry-go-round. b. A car rounding a corner at constant speed.
c. A car going 60 mph on a straight highway. d. A car braking to a stop from 60 mph.

2. (3) Albert Einstein was the primary inventor of the special theory of relativity. For what other physical phenomenon did he give the essential theoretical explanation?

a. Electron diffraction. b. Photoelectric effect.
c. Blackbody radiation spectrum. d. Matter waves.

3. (12) A star is 80.0 light-years from Earth, as measured by observers at rest on Earth.

a) (6) How fast must a spaceship travel towards the star, so that the distance is only 20.0 light-years as measured by the occupants of the spaceship? Give the answer as a number times the speed of light, $c$.

b) (6) Traveling at that speed, how much time passes by for the spaceship to reach the star, for the observers on Earth?

4. (8) Einstein tells us that mass increases with speed. What is the speed of a particle whose mass is twice its rest mass? Give the answer as a number times the speed of light, $c$.

5. (18) A muon is a kind of particle in cosmic rays with a rest mass of $1.8484 \times 10^{-28}$ kg.

a) (6) Determine the rest energy of a muon, giving the result in electron-volts.

b) (6) A muon is observed to be traveling at a speed of $v = 0.998c$. Find its kinetic energy, in electron-volts.

c) (6) A positive muon has the same charge as a proton. For a positive muon traveling at $v = 0.998c$, what electric potential difference would bring it to rest?

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6. (3) Which of these phenomena is evidence of the particle-like properties of light? Check all that apply.

a. diffraction. b. Compton scattering. c. photoelectric effect. d. refraction.

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7. (3) In which situation will the wave properties of matter (particles such as electrons or protons) be most apparent? Check all that apply.

a. When the particles' wavelengths are large compared to the obstacles they pass by.
b. When the particles' wavelengths are small compared the the obstacles they pass by.
c. When the particles are very light and slow.
d. When the particles are very heavy and fast.

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8. (8) Electrons in a beam have been accelerated through a potential difference of 4.00 kV. Calculate their de Broglie wavelength.

9. (8) A photon, a proton and an electron enter a bar with the same momentum $p$.

a) (2) Which has the shortest wavelength? a. photon b. proton c. electron d. 3-way tie.

b) (2) Which has the highest speed? a. photon b. proton c. electron d. 3-way tie.

c) (2) Which has the lowest speed? a. photon b. proton c. electron d. 3-way tie.

d) (2) Which has the highest total energy? a. photon b. proton c. electron d. 3-way tie.

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10. (3) It is noticed that for metal X, incident light of 544 nm wavelength and intensity of 1.0 W/m$^2$ does not produce any photoelectric effect. What change will be most likely to initiate a current of photoelectrons?

a. Increase the intensity of the light. b. Decrease the intensity of the light.
c. Increase the wavelength of the light. d. Decrease the wavelength of the light.

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11. (12) In a photoelectric effect experiment on a certain metal, light of 354 nm wavelength produces photoelectrons with a maximum kinetic energy of 0.84 eV.

a) (6) Determine the work function $W_0$ for this metal, in eV.

b) (6) If light of wavelength 412 nm is incident on this metal, will it produce photoelectrons? If so, how large is their maximum kinetic energy, in eV?

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12. (3) According to Bohr's model, what explains the light frequencies coming from a hydrogen atom?

a. The emitted light has a frequency equal to that of circular motion of the electron.
b. The emitted light frequency is integer multiples of the electron's circular motion frequency.
c. An electric charge with centripetal acceleration continuously emits light.
d. A photon of frequency $f$ is emitted when the atom changes energy by amount $\Delta E = hf$.

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13. (3) When we viewed the emission spectrum of hydrogen gas in an electrified tube, we saw

a. only one emission line in the red.
b. an emission line in the red and one that looks turquoise.
c. three emission lines: one red, one turquoise, and one blue/violet.
d. four emission lines: one red, one yellow, one turquoise, and one violet.

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These are questions about the Bohr model for a hydrogenic atom or ion with nuclear charge $+Ze$.

14. (2) **T F** The Bohr model applies to atoms or ions with $Z$ electrons.

15. (2) **T F** When the atom is in the ground state, it can emit only one wavelength of light.

16. (2) **T F** When the atom is in an excited state, it can emit more than one wavelength of light.

17. (2) **T F** The radius of the $n^{\text{th}}$ Bohr orbit is linearly proportional to $n$.

18. (2) **T F** The binding energy of the electron in a hydrogen atom in its ground state is 26.2 eV.

19. (10) A hydrogen atom is in its ground state, as described with the Bohr model. The radius of its first Bohr orbit is $0.529 \times 10^{-10}$ m.

a) (4) Bohr could find this orbit by assuming that the circumference is equal to one de Broglie wavelength for the electron. Use this to calculate the de Broglie wavelength for the first Bohr orbit.

b) (6) From the de Broglie wavelength just found, how large is the kinetic energy of the electron in the first Bohr orbit? Give the answer in eV.

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20. (12) Use the Bohr model for a hydrogen atom here. Suppose the atom is initially in the $n = 2$ stationary state, and then makes a transition to the $n = 4$ state.

a) (4) Calculate the initial energy of the atom, in eV.

b) (4) Calculate the wavelength of the photon associated with this transition, in nm.

c) (4) Is the photon absorbed or emitted by the atom? Explain why.

21. (8) Match the concept or principle with the closest possible description on the right.

a) ____ Planck's quantum hypothesis
b) ____ Relativity principle
c) ____ Uncertainty principle
d) ____ Pauli exclusion principle

A. No two electrons in an atom can occupy the same quantum state.
B. The laws of physics are the same in all inertial reference frames.
C. Energies of molecular oscillations are quantized in amounts $E = nhf$.
D. Momentum and position of an object cannot be measured precisely at the same time.
E. Matter has both wave-like and particle-like properties.
F. For large quantum numbers, quantum physics predicts the same as classical physics.

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22. (8) An electron is confined inside a "quantum dot" of length 2.0 nm. Apply the uncertainty principle to estimate its minimum possible speed. Hint: the speed has to be at least as large as its uncertainty.

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23. (3) For a hydrogen atom with principle quantum number $n = 4$, write down the possible values of the orbital quantum number $l$.

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24. (3) For a hydrogen atom where the magnetic quantum number is $m_l = 3$, write down the possible values of orbital quantum number $l$.

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25. (2) Which of the following subshells does not exist in any atom?

a. 4f. b. 4d. c. 4p. d. 3f. e. 3d. f. 3p

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26. (2) Which one of the following electron configurations is not allowed?

a. $1s^1 2s^2 2p^5$ b. $1s^2 2s^2 2p^5$ c. $1s^2 2s^2 3p^5$ d. $1s^2 2s^2 2p^6 3p^3$ e. $1s^1 2s^1 2p^6 3s^3$

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27. (2) Which one of these outer shell electronic configurations corresponds to an alkali metal?

a. $2s^2$ b. $3s^1$ c. $3p^5$ d. $4p^6$ e. $4d^{10}$

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28. (2) Which one of these outer shell electronic configurations corresponds to a noble gas?

a. $2s^2$ b. $3s^1$ c. $3p^5$ d. $4p^6$ e. $4d^{10}$

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 Score = ___________/149.

Prefixes

a=$10^{-18}$, f=$10^{-15}$, p=$10^{-12}$, n=$10^{-9}$, $\mu = 10^{-6}$, m=$10^{-3}$, c=$10^{-2}$, k=$10^{3}$, M=$10^{6}$, G=$10^{9}$, T=$10^{12}$, P=$10^{15}$

Physical Constants

$k = 1/4\pi\epsilon_0 = 8.988$ GN·m$^2$/C$^2$ (Coulomb's Law)
$\epsilon_0 = 1/4\pi k = 8.854$ pF/m (permittivity of space)
$e = 1.602 \times 10^{-19}$ C (proton charge)
$\mu_0 = 4\pi \times 10^{-7}$ T·m/A (permeability of space)
$m_e = 9.11 \times 10^{-31}$ kg (electron mass)
$m_p = 1.67 \times 10^{-27}$ kg (proton mass)
$c = 3.00 \times 10^8$ m/s (speed of light)
$c = 2.99792458 \times 10^8$ m/s (exact value in vacuum)
$h = 6.62607 \times 10^{-34}$ J·s (Planck's constant)
$\hbar = 1.05457 \times 10^{-34}$ J·s (Planck's constant/$2\pi$)
$\sigma = 5.67 \times 10^{-8}$ W/(m$^2$·K$^4$) (Stefan-Boltzmann const.)
$hc$ =1239.84 eV·nm (photon energy constant)

Units

$N_A = 6.02 \times 10^{23}$/mole (Avogadro's #)
1 u = 1 g/$N_A$ = $1.6605 \times 10^{-27}$ kg (mass unit)
1.0 eV = $1.602 \times 10^{-19}$ J (electron-volt)
1 V = 1 J/C = 1 volt = 1 joule/coulomb
1 F = 1 C/V = 1 farad = 1 C$^2$/J
1 H = 1 V·s/A = 1 henry = 1 J/A$^2$
1 A = 1 C/s = 1 ampere = 1 coulomb/second
1 Ω = 1 V/A = 1 ohm = 1 J·s/C$^2$
1 T = 1 N/A·m = 1 tesla = 1 newton/ampere·meter
1 G = $10^{-4}$ T = 1 gauss = $10^{-4}$ tesla

Chapter 22 Equations

Electromagnetic waves:

$|\vec{E}|/|\vec{B}| = c = 1/\sqrt{\epsilon_0\mu_0}$, (fields)
$f\lambda = c$ (wave equation)

Approximate wavelengths $\lambda$ for types of EM waves:

0 ($\gamma$-rays) 30 pm ($x$-rays) 3 nm (uv) 400 nm (visible) 700 nm (ir) 300 $\mu$m ($\mu$-waves) 3 cm (radio) $\infty$

$\longrightarrow$ $\longrightarrow$ $\longrightarrow$ increasing wavelength $\longrightarrow$ $\longrightarrow$ $\longrightarrow$

Chapter 26 Equations

Time dilation and length contraction:

$\Delta t = \gamma \Delta t_0 = \Delta t_0/\sqrt{1 - v^2/c^2}$
$L = L_0/\gamma = L_0\sqrt{1 - v^2/c^2}$
$\gamma = 1/\sqrt{1 - v^2/c^2}$ (relativistic factor)
$v/c = \sqrt{1 - 1/\gamma^2}$ (velocity)

Dyanmics, mass, energy:

$p = \gamma m_0 v$ (relativistic momentum)
$m_{\text{rel}} = \gamma m_0$ (relativistic mass)
$E_0 = m_0 c^2$ (rest energy)
$E = \gamma m_0 c^2 = m_{\text{rel}} c^2$ (relativistic energy)
$\text{KE} = E - E_0 = (\gamma - 1) m_0 c^2$ (kinetic energy)
$E = E_0 + \text{KE} = \sqrt{p^2c^2 + m^2c^4}$ (relativistic energy)

## Chapter 27 Equations

Blackbody radiation, photons, photo-electric effect:

- $\lambda_p T = 2.90$ mm·K (Wien's Law)
- $I = \sigma T^4$ (intensity or power/area)
- $E = nhf,\ n = 1, 2, 3...$ (quantized radiation energy)
- $E = hc/\lambda = (1240 \text{ eV} \cdot \text{nm})/\lambda$ (photons)
- $E = hf = W_0 + \text{KE}_{\text{max}}$ (photo-electrons)
- $hc/\lambda_{\text{max}} = W_0$ (work function)
- $\text{KE}_{\text{max}} = eV_0$ (stopping potential)
- $v_{\text{max}} = \sqrt{2\text{KE}_{\text{max}}/m}$ (max. speed)

Momentum, matter waves:

- $p = h/\lambda$ (photon momentum)
- $\lambda' = \lambda + \frac{h}{mc}(1 - \cos\phi)$ (Compton effect)
- $\lambda = h/p = h/(mv)$ (de Broglie wavelength)
- $v = \sqrt{2q\Delta V/m}$ (acceleration thru potential)

Bohr Model:

- $hf = E_n - E_{n'}$ (quantum jump)
- $L = mvr = n\frac{h}{2\pi}$ (Bohr's quantization)
- $r_n = \frac{n^2}{Z} r_1$ (Bohr radii)
- $r_1 = \frac{h^2}{4\pi^2 mke^2} = 52.9$ pm ($1^{\text{st}}$ Bohr radius)
- $E_n = -(13.6 \text{ eV})\frac{Z^2}{n^2}$ (Bohr energies)
- $E_n = \frac{1}{2}mv^2 - \frac{kZe^2}{r_n}$ (total energy)
- $n = 1, 2, 3, ...$ (Bohr's quantum number)

## Chapter 28 Equations

Wave functions:

- $N \propto I \propto |\vec{E}|^2$ (photon detection)
- $N \propto |\Psi|^2$ (particle detection)

Heisenberg Uncertainty Principle:

- $\Delta x\ \Delta p_x \geq \hbar$ (uncertainty principle)
- $\hbar = \frac{h}{2\pi} = 1.05459 \times 10^{-34}$ J·s
- $\Delta E\ \Delta t \geq \hbar$ (energy-time form)
- ($\leftarrow$ These are approximate relations.)
- $\Delta E = \Delta m \cdot c^2$ (Einstein's mass-energy equivalence)
- ($\leftarrow$ This one is exact.)

Quantum numbers for atoms:

- principle quantum number $n = 0, 1, 2, 3...$
- $E_n = -(13.6 \text{ eV})/n^2$ (energy of hydrogen states)
- orbital quantum number $l = 0, 1, 2...(n-1)$
- $L = \sqrt{l(l+1)}\ \hbar$ (angular momentum mag.)
- magnetic quantum number $m_l = -l$ to $+l$
- $L_z = m_l\hbar$ ($z$-component of $\vec{L}$)
- spin quantum number $m_s = -\frac{1}{2},\ +\frac{1}{2}$
- $S_z = m_s\hbar$ ($z$-comp., spin angular momentum)
- *shell* means a particular value of ($n$) is given.
- *sub-shell* means values of $(n, l)$ are given.
- *orbital* means particular $(n, l, m_l)$ are given.
- *state* means particular $(n, l, m_l, m_s)$ are given.

$l = 0, 1, 2, 3, 4, 5, 6...$ are indicated with respective letters: s, p, d, f, g, h,...

**Pauli exclusion principle:** *No two electrons in an atom can occupy the same quantum state.*

Subshells in order of increasing energy: 1s, 2s, 2p, 3s, 3p, 4s, 3d, 4p, 5s, 4d, 5p, 6s, 4f, 5d, 6p, 7s, 5f, 6d, 7p

(They fill in order of increasing $n + l$, or increasing $n$ if there is a tie.)