General Physics II **Exam 4 - Chs. 26, 27, 28 - Relativity & Quantum Physics** **Nov. 17, 2016**

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. c is the speed of light.

1. (3) James Clerk Maxwell developed the theory of electromagnetic waves, which predicts that light travels

   a. always at speed c b. at speed c plus that of the source c. at speed c minus that of the observer.
   d. at a speed determined by c and the motions of both source and observer.

2. (3) An inertial reference frame is an object or coordinate system in which

   a. all objects are at rest. b. Newton's first law is valid.
   c. Newton's second law is invalid. d. Newton's third law is invalid.

3. (3) By thinking about time, Einstein concluded that

   a. clocks can be synchronized in an inertial reference frame using light flashes.
   b. as you move faster, you will see your own time-piece run slower and slower.
   c. time is the same for all inertial reference frames.
   d. all of the above. e. none of the above.

4. (3) Cathode rays were shown around 1897 by J.J. Thomson to actually be

   a. protons b. photons. c. neutrons. d. electrons.

5. (12) In an electron microscope, an electron is accelerated from rest through a potential difference of 124 kV.

   a) (4) How large is the electron's final kinetic energy, in eV?

   b) (4) How large is the electron's relativistic factor, γ?

   c) (4) As a fraction of the speed of light, v/c, how fast is the electron going?

6. (12) Astronauts in the spacecraft *Firefly* have embarked on a one-way journey to a star system that is known to be 48 light-years from Earth. Relative to Earth, the speed of the vehicle is $0.975c$.

a) (6) How many years pass by on Earth while the *Firefly* travels to the star system?

b) (6) The astronauts take clocks and calendars with them. With every year that passes by for them, they send a New Year's message back to Earth. How many will they send during the journey?

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7. (6) If 2.50 grams of matter could be converted completely into energy, how much would result, in kilowatt-hours?

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8. (2) **T F** Diffraction of light through a grating is evidence of the wave properties of light.

9. (2) **T F** Compton scattering is evidence of the wave properties of light.

10. (2) **T F** The photo-electric effect shows a particle property of light.

11. (2) **T F** As an object gets hotter, the peak in its blackbody spectrum moves to longer wavelength.

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12. (3) Which of the following is an example of a continuous spectrum?

a. light from electrified hydrogen atoms.
b. light from electrified mercury atoms.
c. light from an incandescent light bulb.
d. light from a laser pointer.

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13. (3) Max Planck was able to explain the blackbody spectrum of hot objects by supposing that

a. light energy is quantized.
b. light always travel at the same speed, c.
c. photo-electrons are produced by the absorption of light.
d. light carries momentum.

14. (3) In the photo-electric effect, an electron ejected from a metal corresponds to absorption of

a. one photon.
b. several photons whose total energy surpasses the work function.
c. a large number of photons, which depends on the intensity of the light.

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15. (3) A metal produces no photo-electrons when illuminated with light of 550 nm wavelength and 5.0 W/m^2 intensity. What can be done to start the emission of photo-electrons?

a. increase the intensity of the light.
b. increase the wavelength of the light.
c. increase the temperature of the metal.
d. either a or b or c.
e. none of the above.

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16. (12) Yellow-green light of wavelength 548 nm incident on a certain metal produces photo-electrons with a maximum kinetic energy of 0.36 eV.

a) (6) How large is the work function of the metal, in eV?

b) (6) What is the upper limit of light wavelength that will produce photo-electrons with this metal?

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17. (3) Which classical physics effect **does not** take place in Bohr's model for hydrogen?

a. The nucleus and electron attract each other according to Coulomb's Law.
b. The angular momentum of the electron around the nucleus is quantized.
c. The electron undergoes centripetal acceleration towards the center of the orbit.
d. The accelerated electron continuously emits electromagnetic radiation.

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18. (2) **T F** Bohr's model works only for atoms or ions with one electron.
19. (2) **T F** The quantum number n determines both the energy and angular momentum in Bohr's model.
20. (2) **T F** Bohr's model explains only the emission spectrum.
21. (2) **T F** Bohr's model predicts a continuous spectrum.
22. (2) **T F** Bohr's model predicts the intensity of the light spectrum.

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23. (8) An electron's velocity is measured to be 4.5×10^5 m/s with a precision of 1.0 %. According to Heisenberg's uncertainty principle, how precisely can its position be measured, at best (i.e., find Δx)?

24. (16) A hydrogen atom is initially in its third excited state. Using the Bohr model,

a) (4) Calculate the energy of the atom in its third excited state.

b) (6) Determine the longest wavelength of light that can be absorbed.

c) (6) What wavelength of light will ionize the atom and give the ejected electron 1.2 eV of kinetic energy?

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25. (3) Which atomic subshell configuration would be impossible?

a. $2s^1$ b. $2s^2$ c. $3p^6$ d. $3d^{10}$ e. $4d^{12}$

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26. (3) Which of the following outer subshell configurations would correspond to a nobel gas?

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

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27. (3) Which of the following outer subshell configurations would correspond to a halogen?

a. $2s^2$ b. $2p^2$ c. $2p^5$ d. $4p^6$ e. $3d^9$

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28. (10) The highest atomic subshells for nickel (Ni) in its ground state have the configuration $3d^8 4s^2$.

a) (3) The value of orbital quantum number l in the 3d subshell is a. 0 b. 1 c. 2 d. 3 e. 4

b) (4) List the possible values of magnetic quantum number m_l and spin quantum number m_s in a 3d subshell.

c) (3) Which diagram shows how the 3d electron spins line up in the ground state of nickel?

a. ↑↑↑↑↑↑↑↑ b. ↑↑↑↑↑↑↑↓ c. ↑↑↑↑↑↑↓↓ d. ↑↑↑↑↑↓↓↓ e. ↑↑↑↑↓↓↓↓

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29. (3) Into how many different energy levels might the 3d subshell be split when a magnetic field is applied ("Zeeman effect")?

a. 2 b. 3 c. 4 d. 5 e. 7 f. 10

Score = ____________/133.

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)
$e = 1.602 \times 10^{-19}$ C (proton charge)
$m_e = 9.109 \times 10^{-31}$ kg (electron mass)
$c = 2.998 \times 10^{8}$ m/s (speed of light)
$h = 6.62607 \times 10^{-34}$ J·s (Planck's constant)
$\sigma = 5.67 \times 10^{-8}$ W/(m^2·K^4) (Stefan-Boltzmann const.)

$\epsilon_0 = 1/4\pi k = 8.854$ pF/m (permittivity of space)
$\mu_0 = 4\pi \times 10^{-7}$ T·m/A (permeability of space)
$m_p = 1.6726 \times 10^{-27}$ kg (proton mass)
$c = 2.99792458 \times 10^{8}$ m/s (exact value in vacuum)
$\hbar = 1.05457 \times 10^{-34}$ J·s (Planck's constant/2π)
hc =1239.84 eV·nm (photon energy constant)

Units

$N_A = 6.02 \times 10^{23}$/mole (Avogadro's #)
1.0 eV = 1.602×10^{-19} J (electron-volt)
1 F = 1 C/V = 1 farad = 1 C^2/J
1 A = 1 C/s = 1 ampere = 1 coulomb/second
1 T = 1 N/A·m = 1 tesla = 1 newton/ampere·meter

1 u = 1 g/N_A = 1.6605×10^{-27} kg (mass unit)
1 V = 1 J/C = 1 volt = 1 joule/coulomb
1 H = 1 V·s/A = 1 henry = 1 J/A^2
1 Ω = 1 V/A = 1 ohm = 1 J·s/C^2
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 λ for types of EM waves:

0 (γ-rays) 30 pm (x-rays) 3 nm (uv) 400 nm (visible) 700 nm (ir) 300 μm (μ-waves) 3 cm (radio) ∞

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

Chapter 26 Equations

Time dilation and length contraction:

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

$L = L_0/\gamma = L_0\sqrt{1 - v^2/c^2}$
$v/c = \sqrt{1 - 1/\gamma^2}$ (velocity)

Dyanmics, mass, energy:

$p = \gamma m_0 v$ (relativistic momentum)
$E_0 = m_0 c^2$ (rest energy)
$\mathrm{KE} = E - E_0 = (\gamma - 1)m_0 c^2$ (kinetic energy)

$m_{\mathrm{rel}} = \gamma m_0$ (relativistic mass)
$E = \gamma m_0 c^2 = m_{\mathrm{rel}} c^2$ (relativistic energy)
$E = E_0 + \mathrm{KE} = \sqrt{p^2c^2 + m^2c^4}$ (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)

$\lambda = h/p$ (de Broglie wavelength)

KE$= p^2/2m$ (kinetic energy, $v \ll c$)

$\Delta\text{KE} + q\Delta V = 0$ (acceleration thru potential)

$v = \sqrt{2q\Delta V/m}$ (acceleration thru potential, $v \ll c$)

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 (1st 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.)