Physics 228– Final Exam

May 8, 2007

Profs. Coleman and Zimmermann

Your name sticker
⇒
with exam code

SIGNATURE: ________________________

1. **Turn off your cell phone now!**
2. The exam will last from 4:00 p.m. to 7:00 p.m. 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 Identification Number.
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 32 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 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 32 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.** A proctor will check your name sticker and your student ID sometime during the exam. Please have them ready.
11. Good luck.

Possibly Useful Information

Speed of light: $c = 3.00 \times 10^8$ m/s

Ångström: 1 Å $= 10^{-10}$ m

Electron charge: $q_e = -e = -1.602 \times 10^{-19}$ C

Elect. mass: $m_e = 0.00055$ u $= 9.11 \times 10^{-31}$ kg $= 0.512$ MeV/c^2

Proton mass: $m_p = 1.007276$ u $= 1.672622 \times 10^{-27}$ kg $= 938.272$ MeV/c^2

Atomic mass unit: u $= 1.660539 \times 10^{-27}$ kg $= 931.494$ MeV/c^2

Boltzmann's constant: $k_B = 8.617 \times 10^{-5}$ eV/K

Rydberg constant = 13.6 eV

Bohr magneton: $\mu_B = 9.274 \times 10^{-24}$ J/T $= 5.788 \times 10^{-5}$ eV/T

$\epsilon_0 = 8.85 \times 10^{-12}$ C^2/(Nm^2)

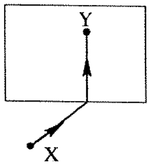
1 eV $= 1.602 \times 10^{-19}$ J

Planck's constant/2π: $\hbar = 1.0545 \times 10^{-34}$Js $= 6.583 \times 10^{-16}$ eVs

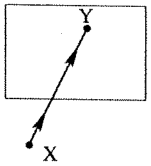
Planck's constant: $h = 6.626 \times 10^{-34}$Js $= 4.136 \times 10^{-15}$ eVs

1. Which diagram below illustrates the path of a light ray as it travels from a given point X in air to another given point Y in glass?

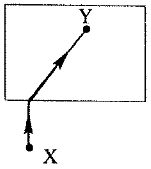
a)



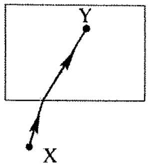
b)



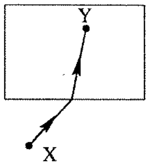
c)



d)



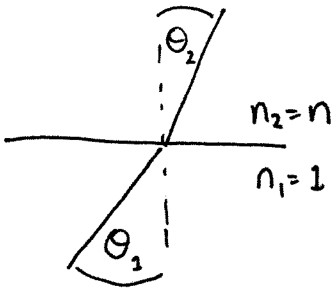
[✓ e)]



2. A concave mirror is to project an image onto a screen 48 cm away from the mirror such that the image is three times bigger than the object. What must be the focal length of the mirror?

a) None of the other answers
b) 0.083 cm
[✓ c)] 12 cm
d) 16 cm
e) 24 cm

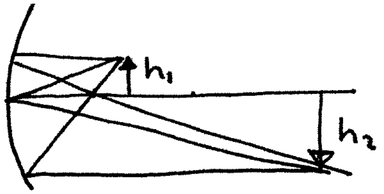
1.



$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = n > 1$$

$$\Rightarrow \theta_1 > \theta_2 \qquad (e)$$

2.



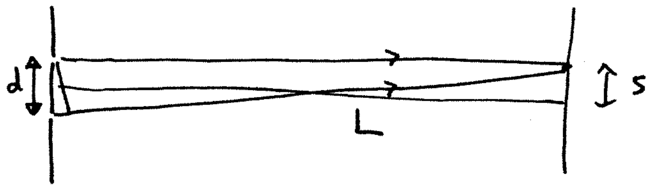
$$m = -\frac{h_2}{h_1} = -\frac{S_2}{S_1} = -3$$

$$\frac{1}{S_1} + \frac{1}{S_2} = \frac{1}{f}$$

$S_2 = 48\text{cm}$
$S_1 = 48/3 = 16\text{cm}$

$$\frac{1}{f} = \frac{1}{16} + \frac{1}{48} \Rightarrow f = 12\text{cm} \quad (c)$$

3

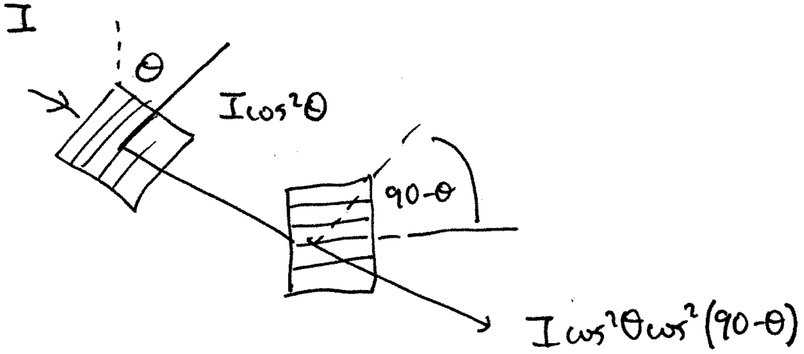


$d\sin\theta = n\lambda \simeq d\theta$

$\frac{\Delta s}{L} = \frac{\lambda}{d}$ $\qquad L = \frac{\Delta s . d}{\lambda} = \frac{4.8\times10^{-3}\times 0.2\times10^{-3}}{600\times10^{-9}}$

$= 1.6m$

4



$\theta = 30°$ $\qquad I_f = I\cos^2 30° \cos^2 60°$

$= 0.19I$

5

$V_{rel} = \frac{v-u}{1-vu/c^2}$ $\qquad \frac{V_{rel}}{c} = \frac{0.4-(-0.4)}{1-(0.4)(-0.4)} = 0.69$

$V_{rel} = 0.69c$

3. A double-slit experiment uses a slit spacing of 0.2 mm, and light of wavelength 600 nm. On a screen located far from the slits, it is found that adjacent bright fringes are separated by 4.8 mm. What is the distance L of the screen from the slits?

   [✓ a)] $L < 1.8$ m
   b) $1.8 \leq L < 2.0$ m
   c) $2.0 \leq L < 2.2$ m
   d) $2.2 \leq L < 2.4$ m
   e) $L \geq 2.4$ m

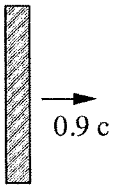
4. A beam of linearly polarized light strikes two polarizing sheets. The characteristic (i.e. polarizing) direction of the second sheet is oriented at 90° with respect to the initial polarization. The characteristic direction of the first sheet is at angle θ with respect to the initial polarization. If the $\theta = 30°$, what fraction of the incident beam intensity is transmitted through the two polarizers?

   a) .87
   b) .75
   c) .50
   d) .43
   [✓ e)] .19

5. Two rockets each move with speed 0.4 c in opposite directions in the laboratory frame of reference. What is the speed of one rocket, as determined by an observer in the other?

   a) .8 c
   b) .75 c
   [✓ c)] .69 c
   d) .95 c
   e) .44 c

6. A stick has proper length 100 cm. Relative to an observer, it moves at a speed of 0.9c in a direction perpendicular to its length. What is the stick's length as measured by the observer?



- a) 526 cm
- b) 43.6 cm
- c) 19 cm
- [✓ d)] 100 cm
- e) 229 cm

7. The threshold wavelength for photoemission in calcium is 384 nm. If the light of wavelength 200 nm is used, what will be the photoelectric stopping potential V_s in volts?

- a) $V_s < 2.1$
- b) $2.1 \leq V_s < 3.1$
- c) $3.1 \leq V_s < 4.1$
- d) $4.1 \leq V_s < 5.1$
- e) $V_s \geq 5.1$

8. An example of the remarkable sensitivity of the human eye is that the retina can detect visible light (entering the eye) of power as low as 10^{-18} W. If light of wavelength 600 nm reflects off an object, what is the minimum number of photons per second that must enter the eye in order to see the object?

- [✓ a)] About 3
- b) About 100
- c) About 1000
- d) About 300
- e) About 30

6. Perpendicular distances do not contract

$L' = L = 100\text{cm}.$ d)

7. $hf - W = eV_s$

$W = hc/\lambda_T \qquad hf = \dfrac{hc}{\lambda}$

$$\frac{hc}{\lambda} - \frac{hc}{\lambda_T} = eV_s$$

$$V_s = \frac{hc}{e}\left(\frac{1}{\lambda} - \frac{1}{\lambda_T}\right)$$

$$= \frac{6.6\times10^{-34} \times 3\times10^{8}}{1.6\times10^{-19}}\left(\frac{1}{200\times10^{-9}} - \frac{1}{384\times10^{-9}}\right)$$

$$= 2.96\text{V}$$ b)

8. $I_0 = 10^{-18}\text{W} = nhf = \dfrac{nhc}{\lambda}$

$$\Rightarrow n = \frac{I_0\lambda}{hc} = \frac{10^{-18} \times 600\times10^{-9}\text{m}}{6.6\times10^{-34}\text{Js} \times 3\times10^{8}\text{m/s}} \simeq \underline{\underline{3}}$$

a)

9 $\frac{E_A}{E_B} = 2$ $E = pc$ $\Rightarrow \frac{p_A}{p_B} = 2$ d)

10. $L = n\hbar$ means r & v are also quantized.

11. There is no way to determine an "absolute velocity", because according to the principle of special relativity, the laws of physics are the same in all inertial reference frames.

12. $N = \frac{1}{16} N_0$. $N = N_0 2^{-t/T_{1/2}}$

$\frac{N}{N_0} = \frac{1}{16} = 2^{-t/T_{1/2}} = 2^{-4}$

$\Rightarrow \frac{t}{T_{1/2}} = 4$ $T_{1/2} = t/4 = \frac{1}{2}$ hr ≡ 30mn b)

9. Photon A has twice the energy of photon B. What is the ratio of the momentum of photon A to that of Photon B.

a) 1/4
b) 1/2
c) 1
[✓ d)] 2
e) 4

10. In the Bohr model of the hydrogen atom, let the electron's orbital angular momentum be L, its orbital radius be r, and its speed be v. Pick the correct statement.

a) L and r are quantized; v is not
b) L and v are quantized; r is not
c) r and v are quantized; L is not
[✓ d)] L, r, and v are all quantized
e) L is quantized; r and v are not

11. An observer is in a closed laboratory in the gravity-free environment of outer space. She wishes to determine whether the laboratory is at rest or in motion at a constant velocity.

a) She can find out by performing the Michelson-Morley experiment.
b) She can find out by bouncing a perfectly elastic ball off the wall in various directions and measuring the velocity before and after the bounce.
[✓ c)] None of the other answers will work.
d) She can find out by comparing two different clocks in the laboratory over a period of time.
e) She can find out by measuring her mass.

12. After 2 hours, $\frac{15}{16}$ of the initial amount of a certain radioactive isotope has decayed. The half-life of the isotope is

a) 15 min.
[✓ b)] 30 min.
c) 45 min.
d) 60 min.
e) 2 hours

13. The de Broglie wavelength of an electron whose kinetic energy is 54.0 eV is

a) 2.50 nm
b) 0.962 nm
c) 23.0 nm
[✓ d)] 0.167 nm
e) 0.333 nm

14. A hydrogen atom is in the 3d state (n = 3, $\ell = 2$). How many distinct values of the z component of the electron's total angular momentum are possible? (Include electron spin.)

a) 1
b) 2
c) 4
[✓ d)] 6
e) 8

15. In a metal, at the absolute zero of temperature

a) all motion ceases
b) the Fermi energy is zero
c) the Fermi speed is zero
d) the average kinetic energy of the conduction electrons is zero
[✓ e)] the average kinetic energy of the conduction electrons differs significantly from zero

16. The reaction $^2H + {}^2H \rightarrow {}^3H + {}^1H$ produces protons. The Q of the reaction is

a) 3.27 MeV
b) 4.03 MeV
c) 17.59 MeV
d) 1.04 MeV
e) 7.06 MeV

The needed masses are hydrogen: 1.007825 u, deuterium: 2.014102 u, ^3H 3.016049 u, ^3He 3.016029 u, ^4He 4.002603 u, neutron 1.008665 u.

13. $E = 54\text{eV} \ll 0.5\,\text{MeV} \Rightarrow$ can use non-relativistic formula.

$$E = \frac{p^2}{2m} \Rightarrow p = \sqrt{2mE} = \frac{h}{\lambda}$$

$$\lambda = \frac{h}{\sqrt{2mE}} = \frac{6.6\times10^{-34}}{\sqrt{2\times 9.1\times10^{-31}\times 54\times1.6\times10^{-19}}}$$

$$= 1.67\times10^{-10}\text{m.} \equiv \underline{\underline{0.167\,\text{nm}}}$$

14. $\ell = 2 \Rightarrow m_z = -2, -1, 0, 1, 2$

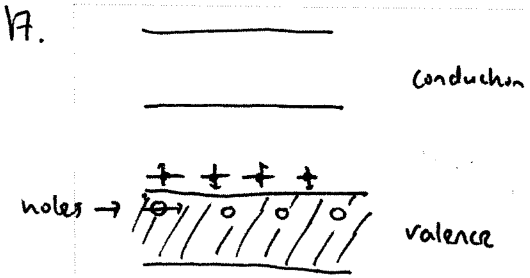
$s = 1/2 \quad m_s = \pm 1/2$

$$J_z = \hbar(m_z + m_s) = \underbrace{-\frac{5}{2}, \frac{-3}{2}, \frac{-1}{2}, \frac{1}{2}, \frac{3}{2}}_{6\text{ values.}}, \frac{5}{2}.$$

15. $\langle E \rangle = \frac{3}{5} E_{\text{FERMI}} \neq 0.$ e)

16. $Q = (2\times2.014102 - 3.016029 - 1.007825)$
$\times 931.5$ MeV
$= 0.00435 \times 931.5\,\text{MeV} = 4.03\,\text{MeV}$

17.



holes in the valence band carry the current

18.

$m_H < m_e + m_p$ ✓ TRUE (13.6eV binding E)

$m_{He} < 2m_p + 2m_n$ ✓ TRUE (Binding energy)

$13 \times 4 + 4 = 56$ $13 \times 2 = 26$ ✓ TRUE

$$m\left(^{235}_{92}U\right) > m\left|^{110}_{44}Ru\right| + m\left[^{122}_{48}Cd\right] + 3m_n$$

Because fission is possible. d) is FALSE.

19.

$$d\sin\theta = 1.22\lambda$$

$$\theta = \frac{1.22\lambda}{d} = \frac{s}{L} \Rightarrow s = \frac{1.22\lambda L}{d}$$

$$s = \frac{256\times 10^3 m \times 1.22 \times 500 \times 10^{-9}}{6\times 10^{-3} m}$$

$$= 25.6m$$ a)

20. 4f $\ell = 3$ $\# = 2\times(2\ell+1) = 2\times 7 = \underline{14}$.

17. In a doped semiconductor material of the p-type

a) the density of conduction electrons far exceeds the density of holes
b) the holes carry negative charge
c) the current is carried mainly by the electrons
[✓ d)] the current is carried mainly by the holes
e) the valence band is full

18. Which of the following is <u>not</u> true?

a) The rest mass of a hydrogen atom is less than the sum of the rest masses of an electron and a proton.
b) The rest mass of a helium nucleus is less than the sum of the rest masses of two protons and two neutrons.
c) The rest mass of an iron nucleus ($^{56}_{26}$Fe) is less than the sum of the rest mass of 13 α particles and 4 neutrons.
d) The rest mass of a uranium nucleus ($^{235}_{92}$U) is less then the sum of the rest masses of $^{110}_{44}$Ru, $^{122}_{48}$Cd, and 3 neutrons.

19. What is the approximate distance between two bright point sources of light on Earth that astronauts can just resolve by eye when they are orbiting 250 km above the Earth? Assume a wavelength of 500 nm, and a pupil diameter of 6 mm. Assume index of refraction of the eye = 1.00.

[✓ a)] 25.4 m
b) 40.6 m
c) 0.025 m
d) 135 m
e) 61.3 m

20. How many electrons can be accomodated in the 4f level of an atom?

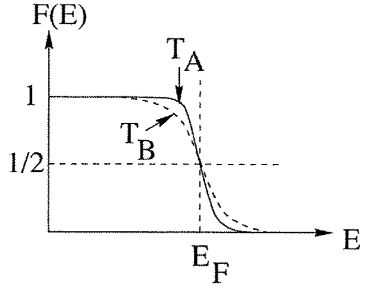
a) 3 b) 4 c) 7 d) 12 [✓ e)] 14

21. The half-life of the ^{14}C nucleus is 5730 years. A sample of bone at an archeological dig is found to have an activity of 100 decays/sec. How many ^{14}C nuclei are contained in the bone? (Note: 1 year = 3.16×10^7 sec .)

a) 573
b) 1.8×10^{11}
[✓ c)] 2.6×10^{13}
d) 5.7×10^{5}
e) 6.02×10^{23}

22. The figure shows the Fermi function for a solid at two different temperatures T_A and T_B. From the shape of these curves we can tell that:

a) $T_A < T_B$
b) $T_A > T_B$
c) $T_B = 0$ K
d) states above the Fermi energy are more likely to be occupied at T_A than at T_B.
e) the solid is an insulator.



23. If an electron is in the $n = 3$ level of a hydrogen atom, what is the maximum value for the magnitude of the orbital angular momentum, $|L|$?

a) $3\hbar$
b) $2\hbar$
c) $6\hbar$
d) $\sqrt{12}\hbar$
[✓ e)] $\sqrt{6}\hbar$

21. $R = \lambda N_0$

$$N = N_0 e^{-\lambda t} = N_0 2^{-t/T_{1/2}} = N_0 e^{-t\ln 2/T_{1/2}}$$

$$\lambda = \ln 2/T_{1/2}$$

$$N_0 = \frac{R}{\lambda} = \frac{R\,T_{1/2}}{\ln 2} = \frac{100 \times 5730 \times 3.16 \times 10^7}{0.693}$$

$$= 2.61 \times 10^{13}$$ ⓒ

22.

$T_B > T_A$ ⓐ

23. $n > \ell$ $\quad \ell_{max} = 2$

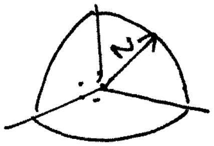
$$L = \hbar\sqrt{2(2+1)} = \hbar\sqrt{6}.$$ ⓔ

24. $K.E = (\gamma - 1) mc^2$

$$\gamma = \frac{1}{\sqrt{1-u^2/c^2}} = \frac{1}{\sqrt{1-(12/13)^2}} = \frac{13}{5}.$$

$$\gamma - 1 = \frac{8}{5} = \underline{1.6}. \qquad \underline{K.E = 1.6 mc^2} \text{ ⓔ}$$

25.



$$\#e = \overset{\text{SPIN}}{\overset{\downarrow}{2}} \times \frac{1}{8} \times \frac{4\pi}{3} N^3 = \frac{\pi}{3} N^3$$

$$N\frac{\lambda}{2} = L \Rightarrow N = \frac{2L}{\lambda}$$

$$\#e = \frac{\pi}{3}\left(\frac{2L}{\lambda}\right)^3 = \frac{8\pi}{3}\left(\frac{L}{\lambda}\right)^3 = \frac{8\pi}{3} \times \left(\frac{1\,nm}{0.2\,nm}\right)^3$$

$$= \frac{8}{3} \times 125 \times \pi = \underline{1047}. \text{ ⓒ}$$

26. $R = R_0 A^{1/3}$ $\quad R_u / R_{Fe} = (235/56)^{1/3}$

$$R_u = 4.6 \times (235/56)^{1/3} = \underline{7.4\ fm} \text{ ⓔ}$$

27. $mc^2 = E \Rightarrow m = \frac{E}{c^2} = \frac{338 \times 10^9}{(3 \times 10^8)^2} = 3.76 \times 10^{-6}\,kg$

$$= \underline{3.76 mg} \text{ ⓐ}$$

24. A particle is moving at 12/13th the speed of light. Its Kinetic energy is

a) 5/13th of the rest energy
b) 2.6 times the rest energy
c) 6.76 time the rest energy
d) 0.426 times the rest energy
[✓ e)] 1.6 times the rest energy

25. Electron waves move inside a nano-cube of metal of side length 1 nm. Suppose the fastest electrons have a wavelength of 0.2 nm and all the states below the Fermi energy are filled. Approximately how many electrons are in the nano-cube?

a) 105
b) 131
c) 1047
d) 625
e) 157

26. A $^{56}_{26}$Fe (iron) nucleus has a radius of 4.6 fm (femtometers). What is the approximate radius of a $^{235}_{92}$U (uranium) nucleus?

a) 19.3 fm
b) 16.3 fm
c) 9.4 fm
d) 21.9 fm
[✓ e)] 7.4 fm

27. The average New Jerseyan consumes 338 Gigajoules (Giga = 10^9) of energy a year. If you had a perfect device for converting matter into energy (e.g., by annihilating matter and antimatter), how much matter and antimatter you would have to burn each year to provide for your energy needs?

[✓ a)] 3.76 μg
b) 1.13 g
c) 1130 kg
d) 3.76 mg
e) 363 u

28. The atomic number of carbon is 6, that of nitrogen 7. If a small fraction of carbon atoms in the crystal lattice of diamond (an insulator with a bandgap of 5.4 eV) are replaced by nitrogen atoms ("nitrogen-doping" of diamond), what kind of solid is formed?

a) An intrinsic semiconductor
[✓ b)] An n-type semiconductor
c) A p-type semiconductor
d) A metal
e) A superconductor

N has one more electron than C

∴ it is an electron donor

∴ n-type semiconductor.

29. The following decay and reaction each involve a neutrino.
$K^+ \rightarrow \mu^+ + ?$
$? + n \rightarrow p^+ + e^-$
What are the identities of the missing neutrinos in the first and second equations, respectively?

a) $\bar{\nu}_\mu$, $\bar{\nu}_e$
b) ν_μ, $\bar{\nu}_e$
c) ν_μ, ν_μ
d) ν_τ, $\bar{\nu}_e$
[✓ e)] ν_μ, ν_e

$$\begin{array}{lcccc} & K^+ & \longrightarrow \mu^+ & + & \nu_\mu \\ L_\mu & 0 & -1 & & +1 \end{array}$$

(e)

$$\begin{array}{lccccc} & \nu_e + & n \longrightarrow & p & + & e^- \\ L_e & 1 & 0 & 0 & & 1 \end{array}$$

30. A particle is a combination of a down quark (d) and an anti-up quark (ū). The particle is a

a) p^-
b) n
c) π°
d) π^+
[✓ e)] π^-

$d\bar{u} \Rightarrow Q = -\frac{1}{3} - \frac{2}{3} = -1$

$\Rightarrow$ meson

π^-.

31. Baryons differ from mesons in that baryons:

a) have two quarks.
b) have integer spin.
c) have half-integer baryon number.
d) contain both quarks and antiquarks.
[✓ e)] have three quarks.

Baryons — qqq or $\bar{q}\bar{q}\bar{q}$

Mesons $q\bar{q}$

(e)

32. The strong interaction is mediated by:

[✓ a)] gluons
b) photons
c) neutrinos
d) quarks
e) Z^0 particles