Physics 228– Final
MAY 12, 2009
Profs. Rabe and Coleman

Your name sticker ⇒

with exam code

SIGNATURE: ______________________

TURN OFF CELLPHONES NOW!!!

1. 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.

2. 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.

3. Under STUDENT # enter your 9-digit Identification Number.

4. Enter 228 under COURSE, and your section number (see label above) under SEC.

5. Under CODE enter the exam code given above.

6. During the exam, you may use pencils, a calculator, and three **handwritten** 8.5 x 11 inch sheets with formulas and notes, without attachments.

7. There are 30 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.

8. When you are asked to open the exam, make sure that your copy contains all 30 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.

9. 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.

10. Good luck!

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
$k_e = 8.99 \times 10^9$ N $\cdot$ m^2/C^2
N_A = Avogadro's number = 6.022×10^{23} particles/mol
k_B = Boltzmann's constant = 1.38×10^{-23} J/K
Wien's Constant = 2.898×10^{-3} m $\cdot$ K
σ = Stefan's Constant = 5.670×10^{-8} W/(m^2 K^4)
$h = 6.626 \times 10^{-34}$ J-s
$h = 4.136 \times 10^{-15}$ eV-s (in units of electron volts-second)
$\hbar = \frac{h}{2\pi} = 1.054 \times 10^{-34}$Js
hc = 1240 eV $\cdot$ nm = 1240 MeV $\cdot$ fm
1 $eV = 1.602 \times 10^{-19}$ J   1 keV = 1000 eV
μ_B = Bohr Magneton = 5.79×10^{-5}eV/T = 9.27×10^{-24} J/T
g-factor of electron = 2.00232
1 u = 1 atomic mass unit = 931.5 MeV/c^2
m_e = electron mass = 9.11×10^{-31} kg
m_ec^2 = electron rest energy = 0.511 MeV
m_p = proton mass = 1.67×10^{-27} kg
m_pc^2 = proton rest energy = 938.27 MeV
m_nc^2 = neutron rest energy = 939.57 MeV
$m_{\pi^\pm}c^2$ = charged pion rest energy = 139.6 MeV

$m_{\pi^0}c^2$ = neutral pion rest energy = 135.0 MeV
$M(^1_1H) = 1.007825$ u
1rad = 0.01 J/Kg
RBE = Relative Biological Effectiveness
Temperature conversion: T (K) = T (°C)+273.15= 1.8 T (°F)+215.55
Zeroes of temperature scale: 273.15K = 0°C =32 °F
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
Some quantum numbers:

	Q/e	B	S
u	2/3	1/3	0
d	$-1/3$	1/3	0
s	$-1/3$	1/3	-1

	L_e	L_μ	L_τ
e^-, ν_e	1	0	0
μ^-, ν_μ	0	1	0
τ^-, ν_τ	0	0	1

1. Which of the following statements about the "Standard Model" of particle physics is *false*?

   a) Strangeness is not conserved by the weak interaction.
   b) Hadrons are bound states of quarks, or antiquarks.
   [✓ c) Bosons are the matter constituents. Fermions mediate the forces between particles.]
   d) The weak force is short-ranged because of the large mass of the Z and W particles.
   e) There are three known generations of leptons.

2. The Ξ^- particle has the following properties: $B = 1$, $S = -2$, $Q = -1$. Which of the following is a possible quark combination for Ξ^-?

   a) $\bar{c}\bar{s}\bar{s}$
   b) uds
   c) $s\bar{s}$
   d) uss
   [✓ e) dss]

for $S = -2$, has to have 2 s quarks.
s and d are $\frac{Q}{e} = -\frac{1}{3}$, so dss has $\frac{Q}{e} = -1$

3. The threshold frequency for photoemission in silver is 1.14×10^{15} Hz. For what frequency will the photoelectric stopping potential be 1.36 V?

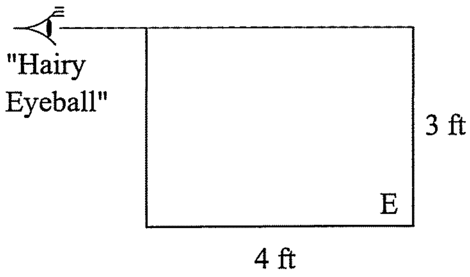
   a) 3.29×10^{14} Hz
   [✓ b) 1.47×10^{15} Hz]
   c) 2.36×10^{15} Hz
   d) 1.71×10^{15} Hz
   e) 8.15×10^{14} Hz

$eV_0 = hf - \phi$ with $\phi = hf_{threshold}$

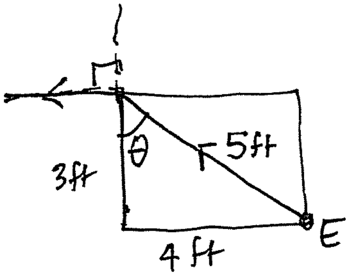
$$f = f_{threshold} + \frac{eV_0}{h} = 1.14 \times 10^{15}\,Hz + \frac{1.36\,eV}{4.136 \times 10^{-15}\,eV \cdot s}$$

$$= 1.47 \times 10^{15}\,Hz$$

4. The rectangular metal tank shown is filled with an unknown liquid. The observer, whose eye is level with the top of the tank, can just see corner E. The index of refraction of the liquid is:



- a) 1.50
- b) 1.67
- c) 1.75
- [✓ d) 1.25]
- e) 1.33



Snell's law

$n \sin\theta = 1$

$\sin\theta = \frac{4}{5}$

$\rightarrow n = \frac{5}{4} = 1.25$

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

- a) baseball and electron
- [✓ b) all have the same wavelength]
- c) electron
- d) photon
- e) baseball

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

6. A K_α X-ray emitted from a sample has an energy of 4.08keV. What is the atomic number of the element producing this X-ray?

- a) 401
- [✓ b) 21]
- c) 19
- d) 400
- e) 20

$f = (2.48\times10^{15}\,Hz)(Z-1)^2$ (Eq 41.29)

$E = hf = 10.2\,eV\,(Z-1)^2$

$Z = 1 + \sqrt{\frac{4.08\times10^{3}\,eV}{10.2\,eV}} = 21$

7. When a nonrelativistic beam of electrons is focused down to a diameter Δx, it is found that the electrons' velocities perpendicular to the beam can be measured to a precision of Δv_e. If a nonrelativistic beam of protons is focused to the same diameter, the protons' perpendicular velocities can be determined to a precision of about $\Delta v_p =$

- a) $10\Delta v_e$
- [✓ b) $\frac{\Delta v_e}{2000}$]
- c) $2000\Delta v_e$
- d) $\frac{1}{2}\Delta v_e$
- e) Δv_e

Heisenberg: $\Delta x \Delta p \gtrsim \hbar$

$\Delta v \gtrsim \frac{\hbar}{m\Delta x}$

$m_p \approx 2000\, m_e \rightarrow \Delta v_p = \frac{1}{2000}\Delta v_e$

8. In a Young's double-slit experiment, light of wavelength 500 nm illuminates two slits which are separated by 1 mm. The separation between adjacent bright fringes on a screen that is 5 m from the slits is:

a) 0.50 cm
b) 1.0 cm
c) none of the other answers
d) 0.10 cm
[✓ e) 0.25 cm]

$$y_m = \frac{Rm\lambda}{d} \rightarrow \Delta y = \frac{R\lambda}{d} = \frac{(5m)\cdot 500\times10^{-7}cm}{0.001m}$$

$$= 0.25\ cm.$$

9. A diffraction grating of total width 4 cm is illuminated with light of wavelength 577 nm. The <u>second</u>-order principal maximum is formed at an angle of 41.25°. What is the total number of lines (slits) in the grating?

a) About 12000
b) About 5000
[✓ c) About 23000]
d) About 8000
e) About 19000

$$d\sin\theta = m\lambda \rightarrow d = \frac{2\times577\times10^{-7}\,cm}{\sin(41.25°)} = 1.8\times10^{-4}\,cm$$

$$N = \frac{4cm}{d} = 22,854$$

10. Two electrons with opposite spin are in an $l = 0$ orbital. A magnetic field of 1 T is present. What is the energy separation between the two electron levels?

a) 2.9×10^{-5} eV
[✓ b) 1.16×10^{-4} eV]
c) 5.65×10^{-3} eV
d) 3.2×10^{-2} eV
e) 1.54×10^{-8} eV

$$\Delta E = -(\mu_{z\uparrow} - \mu_{z\downarrow})B \qquad \mu_z = -2.00232\frac{e}{2m}S_z$$

$$= 2.00232\frac{e\hbar}{2m}B = 2.00232\times5.788\times10^{-5}\,eV$$

11. At room temperature (T = 300K), the occupation probability of an electron state in the valence band of Zn with kinetic energy 10% greater than the Fermi energy ($E_F = 11.72$ eV) is about:

a) 0.94
b) 2.1×10^{-2}
[✓ c) 2.0×10^{-20}]
d) 0.11
e) 9.2×10^{-16}

$$f(E) = (\exp((E-E_F)/k_BT)+1)^{-1}$$

$$E-E_F = 1.172\,eV, \quad k_BT \cong \frac{1}{40}eV = 0.0259$$

12. A diatomic molecule is in a vibrational and rotational state having energy 0.50 eV when it absorbs a photon of frequency 9.67×10^{13} Hz. What is the energy of the final state of the molecule?

a) 0.56eV
[✓ b) 0.90eV]
c) 0.10eV
d) 0.43eV
e) 0.50eV

$$E_f = 0.50eV + h\cdot 9.67\times10^{13} Hz$$
$$= 0.50eV + 4.136\times10^{-15} eV\cdot s \times 9.67\times10^{13} s^{-1}$$
$$= 0.90 eV$$

13. For a diatomic molecule, it is found that the rotational states l=0 and l=1 are separated in energy by 4×10^{-4} eV. The moment of inertia of the molecule is:

[✓ a) 1.7×10^{-46} kg m^2]
b) not enough information.
c) 1.3×10^{-65} kg m^2
d) 4.2×10^{-47} kg m^2
e) 8.4×10^{-47} kg m^2

$$E_l = l(l+1)\frac{\hbar^2}{2I} \rightarrow E_1 - E_0 = \frac{\hbar^2}{I} = 4\times10^{-4}eV$$
$$I = \left(\frac{4\times10^{-4}eV\cdot 2\pi}{4.136\times10^{-15}eV\cdot s}\cdot 1.054\times10^{-34}Js\right)^{-1}$$

14. If you were in a spaceship traveling at a constant speed close to the speed of light (with respect to earth), you might make the following observations:

(I)That some of your physical dimensions were reduced.
(II)That your mass was greatly increased.
(III)That your pulse rate is a lot slower due to time dilation.

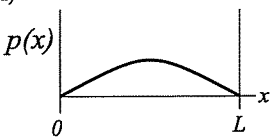
Which of these observations could actually take place?

[✓ a) None of these effects would occur.]
b) More than one of these effects would occur.
c) (III)
d) (I)
e) (II)

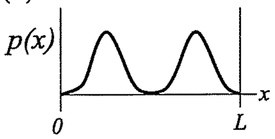
Since you are making the observations in the frame at which you are at rest, the results are the same as if you made the observations while at rest on earth.

15. A particle in a box of length L is in the $n = 3$ state. Which diagram in the figure best describes its probability distribution $p(x)$?

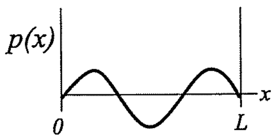
(I)



(II)



(III)



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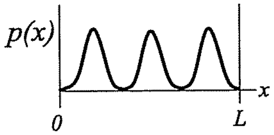
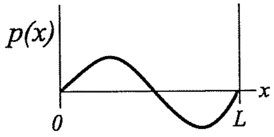
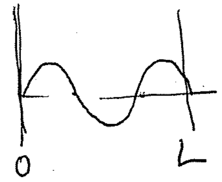


(V)

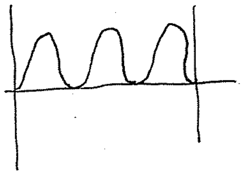


a) III
b) I
c) II
d) V
[✓ e)] IV

for $n = 3$ ψ



$p = \psi^2$



16. The average person receives a dose of 102 m rem/year. If the average RBE of the radiation received is 1.5, how much energy, in Joules, is absorbed per year by a 70 kg person?

a) 0.1071
b) 4.76
[✓ c)] 0.0476
d) 7.14
e) 0.0714

$1 \text{ rem} = \text{RBE} \times 0.01 \frac{J}{kg.}$

here, $\frac{100 \cdot \text{Energy/yr}}{70 \text{ kg}} \cdot \text{RBE} = 102 \times 10^{-3} \frac{\text{rem}}{\text{yr}}$

$\text{Energy/yr} = \frac{102 \times 10^{-3} \times 70}{100 \cdot \text{RBE} = 1.5} \frac{J}{yr} = 0.0476 \frac{J}{yr}$

17. K-mesons have an average proper lifetime τ. How fast must they move with respect to the earth so that an earth-based experimenter will measure an average lifetime of 1.5 τ ?

[✓ a)] 0.75c
b) 0.40c
c) 0.90c
d) 0.50c
e) 0.80c

earth based experimenter measures lifetime $\gamma\tau$

$\rightarrow \gamma = 1.5 = \frac{1}{\sqrt{1 - (\frac{v}{c})^2}} \rightarrow (\frac{V}{c})^2 = 1 - \frac{1}{(1.5)^2}$

$V = 0.75c$

18. An atom with N electrons will be chemically inert if N=:

a) 5 b) 25 c) 20 [✓ d)] 10 e) 15

$N = 10 \rightarrow 1s^2 2s^2 2p^6$ filled shells → chemical inertness.

19. A concave mirror forms a real image which is twice the size of the object, but inverted. If the object is 20 cm from the mirror, the focal length of the mirror must be about:

a) 27 cm
[✓ b)] 13 cm
c) 40 cm
d) 10 cm
e) 20 cm

$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$ $m = -\frac{s'}{s} = -2 \rightarrow s' = 40\text{ cm}$

$\frac{1}{20} + \frac{1}{40} = \frac{1}{f}$ $f = \frac{40}{3}\text{ cm} \sim 13\text{ cm}$

20. An object placed in front of a thin lens of focal length +5 cm produces an image 10 cm from the lens on the same side as the object. How far is the object from the lens?

a) 20 cm b) 10 cm c) 5 cm d) 2.8 cm
[✓ e)] 3.3 cm

$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f} \rightarrow \frac{1}{s} + \left(\frac{1}{-10}\right) = \frac{1}{5}$ $s = \frac{10}{3}\text{ cm} \sim 3.3\text{ cm}$

21. In the energy level diagrams shown, the shaded region represents the occupied electron states beneath the Fermi energy. The white regions represent the empty electron states. Which answer best describes solids (I), (II), and (III)?

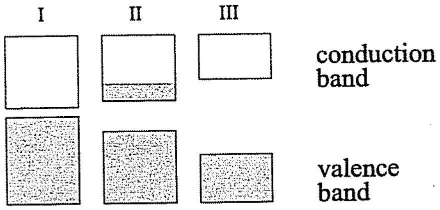
a) (I) insulator, (II) metal, (III) semiconductor

[✓ b) (I) semiconductor, (II) metal, (III) insulator]

c) (I) metal, (II) metal, (III) semiconductor

d) (I) insulator, (II) metal, (III) metal

e) (I) metal, (II) insulator, (III) semiconductor



completely filled valence band, completely empty conduction band, small gap → Semiconductor

" " , large gap → insulator

" , partially filled conduction band → metal

22. The following rest energies are known:

$$\begin{aligned} m_e c^2 &= \text{ electron rest energy} = 0.511\ MeV \\ m_p c^2 &= \text{ proton rest energy} = 938.27 MeV \\ m_n c^2 &= \text{ neutron rest energy} = 939.57 MeV \\ m_{\pi^\pm} c^2 &= \text{ charged pion rest energy} = 139.6 MeV \\ m_{\pi^0} c^2 &= \text{ neutral pion rest energy} = 135.0 MeV \end{aligned}$$

A few months from now, the Large Hadron Collider (LHC) at CERN in Geneva will be operating. Suppose that a head-on collision between protons and antiprotons, each having a kinetic energy of 1700 MeV, produces the reaction

$$\mathrm{p} + \bar{\mathrm{p}} \rightarrow \pi^+ + \pi^- + \mathrm{H}$$

where H is the newly discovered "Higgs particle". The Higgs is at rest and the π^+ and π^- depart in opposite directions, each with a kinetic energy of 110 MeV. What is the rest mass of the Higgs?

a) 2388 MeV/c^2
[✓ b)] 4777 MeV/c^2
c) 658 MeV/c^2
d) 1420 MeV/c^2
e) 3180 MeV/c^2

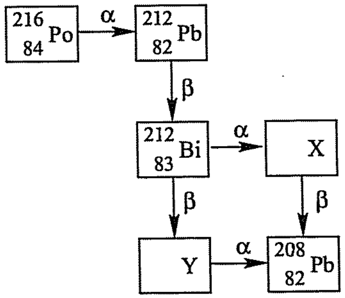
use energy conservation

$1700 + 1700 + 938.27 + 938.27 = 2 \times 139.6 + 2 \times 110 + M_H$

$\rightarrow M_H = 4777$ MeV

23. Consider the decay sequence shown. Which of the following correctly identifies nucleus Y?

a) $^{209}_{83}$Bi
b) $^{208}_{81}$Tl
c) $^{210}_{82}$Pb
d) $^{202}_{80}$Hg
[✓ e)] $^{212}_{84}$Po



A = 212
Z = 84

24. In the Bohr model of the hydrogen atom, which of the following transitions emits a photon with the longest wavelength?

- a) $n=4 \longrightarrow n=2$
- b) $n=6 \longrightarrow n=7$ absorbs photon
- c) $n=2 \longrightarrow n=1$
- [✓ d)] $n=6 \longrightarrow n=5$
- e) $n=5 \longrightarrow n=3$

looking for smallest $E_n - E_m$.

$E_n \propto \frac{1}{n^2}$ so compare. a) $\frac{1}{4} - \frac{1}{16} = \frac{3}{16}$ b) absorbs ~~e)~~ $1 - \frac{1}{4} = 3/4$

d) $\frac{-1}{36} + \frac{1}{25} = 0.01$ e) $\frac{1}{9} - \frac{1}{25} = 0.07$

25. A radioactive source consists of 10^{22} atoms. It is observed that 10^{11} atoms decay per second. What is the half-life of the radioactive material?

- [✓ a)] 2200 years
- b) 3200 years
- c) 1740 years
- d) 1520 years
- e) 10^{-11} years

$$\lambda = \frac{10^{11}}{10^{22}s} \qquad T_{1/2} = \frac{0.693}{\lambda} = 0.693 \times 10^{11} s \cdot \frac{1 yr}{3600 \times 24 \times 365}$$

$$= 2,197 \text{ years}$$

26. Protons are accelerated in a cyclotron with an internal field of 0.2 T. If beam exits at a radius of 2 m from the center of the cyclotron, what is the energy of the protons?

- a) 15.3 MeV
- b) 14 GeV
- c) 38.3 MeV
- [✓ d)] 7.67 MeV
- e) 1.92 MeV

$$\frac{mv^2}{r} = qvB \Rightarrow v = \frac{qBr}{m} \quad K = \frac{1}{2}mv^2 = \frac{1}{2}\frac{q^2B^2r^2}{m}$$

$$= \frac{1}{2} \cdot \frac{(1.6\times10^{-19}C)^2 \cdot (0.2T)^2 \, 4m^2}{1.67\times10^{-27}kg} \cdot \frac{1 MeV}{1.6\times10^{-13}J}$$

$$= 7.66 \text{ MeV}$$

27. A perfectly black body at 100^0C emits light of intensity I. The temperature of this body is now raised to 200^0C. The hotter black body now radiates light of intensity closest to:

- a) 2.0 I
- b) 8.0 I
- c) 1.4 I
- [✓ d)] 2.6 I
- e) 4.0 I

$$I \propto T^4 \qquad I_{hotter} = I_0 \left(\frac{473K}{373K}\right)^4 = 2.6\, I_0$$

28. Suppose the ratio of the density of free electrons in aluminum to to that in potassium is 3:1. If the Fermi energy in potassium is 1.3eV what is the Fermi energy in aluminum?

- a) 1.9 eV
- [✓ b)] 2.7 eV
- c) 11.7 eV
- d) 6.7 eV
- e) 3.9 eV

$E_F \propto n^{2/3}$ $E_{F,pot} = 1.3eV$

$E_{F,Al} = (1.3eV)\frac{(n_{Al})^{2/3}}{(n_{pot})^{2/3}} = (1.3eV)3^{2/3}$

29. The following masses are known:

^1_0n	1.008665u
^1_1H	1.007825u
^7_3Li	7.016004u.

Given this information, the binding energy of ^7_3Li, in MeV, is expected to be closest to:

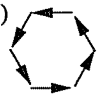
- [✓ a)] 39
- b) 56
- c) 52
- d) 48
- e) 43

$(7.016004 - 3(1.007825) - 4(1.008665)) \times 931.5\ MeV$
$= -39.25\ MeV$

30. In the diffraction pattern from a six slit diffraction grating, which phasor diagram represents the combination of electric fields from the six slits when the path length difference between light from neighboring slits is a third of a wavelength?

(I)

(II)



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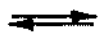

(IV)

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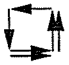

- a) II
- [✓ b)] IV
- c) III
- d) I
- e) V