Physics 228 - Final Examination

May 10, 2005

Profs. Shapiro and Bronzan

⟹ Your name sticker with **exam code** ⟹

361

Your signature ______________________

Turn off and put away cell phones now!

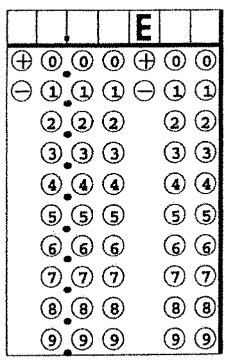
1. **THIS EXAM INCLUDES QUESTIONS WHICH REQUIRE A NUMERICAL ANSWER.**

The format on the machine-graded answer sheets requires that you express your answer is a very specific format. Several examples are shown below:

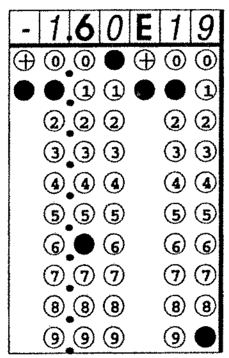
5.30 should be entered as **+5.30+00**

437 should be entered as **+4.37+02**

0.62458 should be entered as **+6.25−01**



Form for numerical answers.



The electron's charge entered.

$-1.602176 \times 10^{-19}$ should be entered as **−1.60−19**.

Note that all answers should be accurate to three **significant** digits. A sample fragment of the mark-sense form is shown. Make sure you darken the circles!

NOTE THAT MULTIPLE CHOICE QUESTIONS START WITH THE NINTH QUESTION, BUT ITS NUMBER IS 16; ENTER THE ANSWERS ON THE MARK SENSE FORM ACCORDING TO THEIR PROBLEM NUMBERS, WHICH INCREASE HORIZONTALLY ACROSS THE FORM.

2. The exam will last from 4:00 PM to 7:00 PM. 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 32 questions on the exam. Several questions require you to enter a numerical answers as described above. **Be sure to fill in the circles as well as writing your answer in the boxes.** The remainder are multiple-choice. For each multiple-choice 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 the rest 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 and have your student ID ready to show to the proctor during the exam.

PHYSICAL CONSTANTS ARE ON THE NEXT PAGE.

Some (possibly) useful information

Physical Constants:

speed of light	c	$2.998 \times 10^{8}\,\mathrm{m/s}$
Planck's constant	h	$6.626 \times 10^{-34}\,\mathrm{J \cdot s}$
hbar	$\hbar = h/2\pi$	$1.055 \times 10^{-34}\,\mathrm{J \cdot s}$
fundamental charge	e	$1.602 \times 10^{-19}\,\mathrm{C}$
amu	u	$931.5\,\mathrm{MeV/c^2}$
electron mass	m_e	$9.109 \times 10^{-31}\,\mathrm{kg}$
proton mass	m_p	$1.673 \times 10^{-27}\,\mathrm{kg}$
Boltzmann's constant	k	$1.381 \times 10^{-23}\,\mathrm{J/K}$
Permeability of free space	μ_0	$4\pi \times 10^{-7}\,\mathrm{Wb/A \cdot m}$
Permittivity of free space	ϵ_0	$8.854 \times 10^{-12}\,\mathrm{C^2/N \cdot m^2}$
Coulomb's constant	$k_e = 1/4\pi\epsilon_0$	$8.988 \times 10^{9}\,\mathrm{N \cdot m^2/C^2}$
Avagadro's number	N_A	6.022×10^{23}

Some quantum numbers:

	Q/e	B	S
u	$2/3$	$1/3$	0
d	$-1/3$	$1/3$	0
s	$-1/3$	$1/3$	[illegible] ← −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

All antiparticles have all quantum number signs reversed.

1. The first order spectal line produced by a diffraction grating occurs at an angle of 11.31° . The grating has 3,660 slits per centimeter. What is the wavelength of the light? Express your answer in **nanometers**, to three significant figures.

$d \sin\theta = n\lambda \quad n=1 \quad d = \frac{0.01}{3660} \quad \lambda = 536\,nm$

2. The Fermi energy of a free electron gas at absolute temperature zero is 4.22 eV. What is the density of free electrons? You may find the following expression to be useful: $\frac{N}{V} = \frac{(2m_e)^{3/2}}{3\pi^2\hbar^3} E_{F0}^{3/2}$ (42.19)

$$\frac{(2m_e)^{3/2}}{3\pi^2\hbar^3} = 7.081 \times 10^{55} \quad kg^{-3/2}\ m^{-6}\ s^3.$$

$= 7.081 \times 10^{55} \times (4.22 \times 1.602 \times 10^{-19})^{3/2} = 3.94 \times 10^{28} / m^3$

Express your answer in electrons per m^3, to three significant figures.

3. The *kinetic energy* of a particle is 0.215 times its *rest energy.* What is the speed of the particle? Express your answer as a fraction of the speed of light, to three significant figures.

$\gamma = \frac{E}{mc^2} = \frac{K}{mc^2} + 1 = 1.215 = \frac{1}{\sqrt{1 - v^2/c^2}} \quad , \; v = .568\,c$

4. An alpha particle beam is incident on a target of $^{12}_{6}C$ nuclei at rest. The final nuclei after the collision are $^{15}_{7}N$ and $^{1}_{1}H$. The atomic masses of these atoms, in order, are 4.002602 , 12.000000 , 15.000108 and 1.007825 . What minimum kinetic energy for the alpha particles is required to make this reaction possible? Express your answer in MeV.

$(15.000108 + 1.007825 - 4.002602 - 12.00000) \times 931.5 = 4.97\ MeV$

5. A certain nucleus has a half-life of 1.35×10^8 seconds. How long does it take for 90.0 percent of the original sample to disappear, as measured by its activity? Express your answer in seconds, to three significant figures.

$.1 = e^{-\lambda t} \quad \lambda = \frac{\ln 2}{T_{1/2}} = 5.13 \times 10^{-9} = \frac{-\ln .1}{t} = \frac{2.3026}{t}$

$t = \frac{2.3026}{5.19 \times 10^{-9}} = 4.48 \times 10^8\ s$

6. An alpha particle having total energy E is incident on an $^{54}_{26}Fe$ nucleus at rest. The atomic weights of the atoms are 4.002602 and 53.939613 repectively. What must E be to produce an available energy of 75.7 GeV? Give your answer in GeV, to three significant figures.

$E_a^2 = (75.7)^2 = 2(53.939613 \times .9315) E + a^2 + (4.002602 \times .9315)^2$

$E = 31.8\ GeV$

7. The Hubble constant is 71.0 (km/sec) per megaparsec. Light from stars in a galaxy at a distance of 750 megaparsecs is observed with a spectroscope. Consider the Balmer line in the hydrogen spectrum, caused by the transition n=3 → n=2. This line has a wavelength of 656 nm is the laboratory. What is the wavelength of this line as seen in the spectrum of the galaxy's light? Give your answer in **nanometers**, to three significant figures.

$v = 5.325 \times 10^7\ m/s = 0.1775\,c$

$\lambda_o = \lambda_s \sqrt{\frac{c+v}{c-v}} = 656 \sqrt{\frac{1.1775}{.8225}} = 785\ nm$

8. The ϕ meson has a rest energy of 1019.4 MeV, and a measured energy half-width of ΔE= 2.23 MeV. Use the uncertainty principle (with $\hbar/2$ on the right side) to find the lifetime of the meson. Express your answer in seconds, to three significant figures.

$\tau = \Delta t = \frac{\hbar}{2\Delta E} = \frac{1.055 \times 10^{-34}}{2 \times 2.23 \times 10^6 \times 1.602 \times 10^{-19}}$

$= 1.48 \times 10^{-22}\ s$

16. An object is placed a distance s in front of the concave mirror of focal length +3 cm. The image is on the same side of the mirror as the object, and lies 8 cm closer to the mirror than the object, i.e. the distance between the object and the image is 8 cm. In which of the following ranges does the value of s lie?

a) $14 < s \leq 17$ cm
b) $8 < s \leq 11$ cm
c) $11 < s \leq 14$ cm
d) $s > 20$ cm
e) $17 < s \leq 20$ cm

17. Light from an incandescent bulb is passed through a filter which transmits yellow light, and then serves as the source for a Young's double slit experiment. Which of the following changes would cause the interference fringes to be more closely spaced?

a) move the light source farther away from the slits
b) use a light source of higher intensity
c) use slits that are closer together
d) use a filter which transmits blue instead of yellow
e) use a light source of lower intensity

18. A light beam consists of two components, one of unknown wavelength and the other of 504 nm wavelength. When this light is incident on a single slit, diffraction pattern shows that the third minimum of the unknown coincides with the fourth minimum of the 504 nm light. What is the unknown wavelength.

a) 2016 nm
b) 168 nm
c) 378 nm
d) 672 nm
e) Cannot be determined without knowing the width of the slit

19. 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) .50
b) .43
c) .19
d) .87
e) .75

20. A rocket of proper length 20 m is moving past the earth at a speed of 0.6 c. Lights are mounted at each end of the rocket. According to observers on earth, the lights flash simultaneously. According to observers in the rocket, what is the time interval between flashes? (Just find the absolute value; don't worry about the sign.

a) 1.1×10^{-7} s
b) 5.0×10^{-8} s
c) 1.4×10^{-7} s
d) 3.2×10^{-8} s
e) 4.0×10^{-8} s

21. A particle is in the ground state in a one dimensional infinite square well of width L. The probability, P, that the particle is in the left quarter of the well ($0 \leq x \leq L/4$) is:

a) $0.6 \leq P$
b) $0.01 < P \leq 0.2$
c) $0 \leq P \leq 0.01$
d) $0.2 < P \leq 0.3$
e) $0.3 < P < 0.6$

22. A hydrogen atom is in its fifth excited state. The atom emits a 1,090 nm wavelength photon. What is the maximum possible orbital angular momentum quantum number of the electron after emission?

a) 1
b) 0
c) 3
d) 2
e) No maximum. Orbital angular momentum can be arbitrarily high.

23. If we lived in a 4 dimensional space instead of 3 dimensional, the density of states in a free electron gas would be proportional to E instead of $E^{\frac{1}{2}}$. What would be the average energy, in terms of E_F, of the electrons in a conductor at zero temperature?

a) $2E_F/3$
b) E_F
c) 0
d) $E_F/2$
e) $3E_F/5$

24. A meson has strangeness -1 and charge -1. The quark content of the meson is:

a) ssd
b) $s\bar{u}$
c) $s\bar{d}$
d) sdd
e) $d\bar{u}$

25. A beam of protons of kinetic energy K collides with a hydrogen target (which contains protons essentially at rest). Pions are produced by the reaction

$$p + p \longrightarrow p + p + \pi^+ + \pi^- .$$

Denote the rest energy of a proton by Mc^2, and of a pion by mc^2. The minimum kinetic energy K that will produce the reaction is:

a) $K = mc^2[2 + 4(m/M)]$
b) $K = mc^2[4 + 4(m/M)]$
c) $K = mc^2[2 + 3(m/M)]$
d) $K = mc^2[4 + 2(m/M)]$
e) $K = mc^2[2 + 2(m/M)]$

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

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

The needed masses are hydrogen 1.007825 u, deuterium (d) 2.01410[illegible] u, ^{3}H 3.016049 u, ^{3}He 3.016029 u, ^{4}He 4.002603 u, neutron 1.008665 u.

27. The following decay is forbidden:

$$\pi^+ \rightarrow \mu^+ + \nu_e + \nu_\mu .$$

because it is not possible to conserve:

a) charge
b) electron lepton number
c) baryon number
d) muon lepton number
e) energy

28. The strong interaction is mediated by:

a) photons
b) gluons
c) neutrinos
d) quarks
e) Z^o particles

29. The following reaction can occur by the strong interaction: $\pi^0 + n \rightarrow K^+ + \Sigma^-$. If the quark composition of the n is (udd), the π^0 is $(u\overline{u})$, and the K^+ is $(u\overline{s})$, find the quark composition of the Σ^-.

a) $\overline{u}s$
b) sss
c) dds
d) $dd\overline{s}$
e) uds

30. The ground state vibrational energies of the CO and N_2 molecules are 0.125 eV and 0.100 eV, respectively. The ratio of their effective spring constants (i.e. K_{CO} / K_{N_2}) is about:
(Note: $A_C = 12$; $A_N = 14$; $A_O = 16$)

a) 1.25 b) 1.53 c) 0.75 d) 1.0 e) 2.35

31. In the Fermi gas model for valence electrons in a metal, the Fermi energy is:

a) The minimum kinetic energy of an electron at T = 0.
b) The maximum kinetic energy of an electron at T = 0.
c) The maximum kinetic energy of an electron at high temperatures.
d) The average kinetic energy of the electrons.
e) The kinetic energy of all electrons at T = 0.

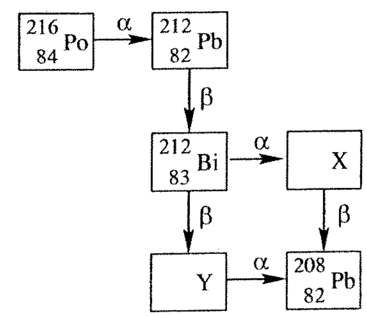
32. At room temperature (T = 300K), the probability that a valence electron in Al has kinetic energy 10% greater than the Fermi energy (E_F = 11.7 eV) is about:

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

33. Which one of the following statements concerning electron energy bands in solids is true?

a) the bands occur as a direct consequence of the Fermi-Dirac distribution function
b) an insulator has a large energy separation between the highest filled band and the lowest empty band
c) electrical conduction arises from the motion of electrons in completely filled bands
d) within a given band, all electron energy levels are equal to each other
e) only insulators have energy bands

34. Consider the decay sequence shown. Which of the following correctly identifies nucleus X?



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

35. How much energy is released in the α-decay of ${}^{238}_{92}$U:

${}^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} + {}^{4}_{2}\text{He}$.

Where:
M(${}^{238}_{92}$U) = $238.050786u$
M(${}^{234}_{90}$Th) = $234.043583u$
M(${}^{4}_{2}$He) = $4.002603u$

a) 0.05 MeV b) 52.75 MeV c) 4.29 MeV
d) 9.73 MeV e) 1.06 MeV

36. Consider the following energies:

I. minimum energy needed to excite a hydrogen atom.
II. energy needed to ionize a hydrogen atom.
III. energy released in ^{235}U fission.
IV. energy needed to remove a neutron from a ^{12}C nucleus.

In order of increasing magnitude they are:

a) II, IV, I, III
b) I, II, IV, III
c) I, III, II, IV
d) II, I, IV, III
e) I, II, III, IV

37. 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) 3200 years
b) 10^{-11} years
c) 1740 years
d) 2200 years
e) 1520 years

38. What is the correct decay path for the antineutron, $\bar{n}$?

a) $\bar{n} \rightarrow \pi^o + e^+ + e^-$
b) $\bar{n} \rightarrow p + \pi^-$
c) $\bar{n} \rightarrow p + e^-$
d) $\bar{n} \rightarrow \bar{p} + \nu_e + e^+$
e) $\bar{n} \rightarrow \bar{p} + e^+ + e^-$

39. 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) ν_μ, ν_μ
b) $\bar{\nu}_\mu$, $\bar{\nu}_e$
c) ν_μ, $\bar{\nu}_e$
d) ν_τ, $\bar{\nu}_e$
e) ν_μ, ν_e