Physics 228 - Final Exam
May 11, 2004
Profs. Shapiro and Conway

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Your name sticker with **exam code**

Turn off and put away cell phones now!

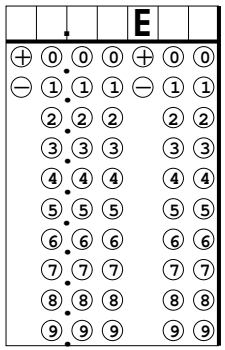
1. **THIS EXAM INCLUDES QUESTIONS WHICH REQUIRE A NUMERICAL ANSWER.**

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

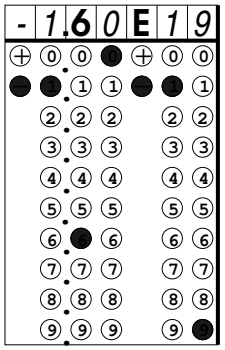
5.30 should be entered as **+5.30+00**

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.

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.

Possibly Useful Information

speed of light, c	3.00×10^{8} m/s
Planck's constant, h	6.626×10^{-34} J·s
hc	1240 eV-nm
Boltzmann's constant	1.380×10^{-23} J/K
Rydberg constant R_H	1.097×10^{7} m^{-1}
Bohr radius a_0	0.0529 nm
hydrogen ground state energy	-13.6 eV
elementary charge e	1.602×10^{-19} C
electron mass	9.11×10^{-31} kg
	5.4858×10^{-4} u
proton mass	1.673×10^{-27} kg
	1.007276 u
neutron mass	1.675×10^{-27} kg
	1.008665 u
atomic mass unit u	1.66×10^{-27} kg
	931.49 MeV/c^2
r_0 (nuclear radii $\sim r_0 A^{1/3}$)	1.2×10^{-15} m
visible light wavelengths	approx. 400-700 nm
1 meter	= 100 cm = 1000 mm
	= 10^6 μm = 10^9 nm
	= 10^{12} pm = 10^{15} fm
1 eV	1.602×10^{-19} J

1. A ray of light passes from air into a cube of glass having index of refraction 1.8. The angle of incidence between the incoming beam and the normal to the surface is 20.0 degrees. The angle of the beam inside the glass to the normal is (in degrees)

2. Calculate the minimum thickness (in nm) of a flat soap film in air which will transmit light minimally (that is, reflect it most strongly). Assume that the light is normally incident on the film and has a wavelength in air of 500.0 nm, and that the soap has index of refraction 1.6.

3. Calculate the wavelength (in nm) of a photon emitted in the transition of a hydrogen atom from the $n = 5$ state to the $n = 4$ state.

4. A certain insulator has a band gap of 1.5 eV, and a filled valence band. The Fermi energy is half way between the valence band and the conduction band. At a temperature of 290 K, calculate the probability that a given state at the bottom of the conduction band is occupied.

5. Nuclear warheads contain tritium, which has a half-life of 12.33 y. What fraction of the original tritium remains in a warhead 18 years after its manufacture?

6. Using the data in the table below calculate the energy released or absorbed (in MeV) in the following reaction:

$$n + {}^{12}C \rightarrow {}^{13}C + \gamma$$

Note: if energy is absorbed, enter a **negative** number.

atomic species	atomic mass (u)
${}^{1}_{0}n$	1.008665
${}^{12}C$	12.000000
${}^{13}C$	13.003354
${}^{14}N$	14.003074
${}^{15}N$	15.000108
${}^{16}O$	15.994915
${}^{17}O$	16.999132
${}^{18}F$	18.000938
${}^{19}F$	18.998403

7. A certain galaxy is observed to recede from us at a rate of 13,600 km/s. If the galaxy is believed to be a distance of 600 Mly (1 Mly = 10^6 light years), then from this observation alone make an estimate of the Hubble expansion parameter, in units of m/s·ly.

8. The mass of a hypothetical Z' particle is 200 GeV/c^2. This particle decays at rest in the laboratory to two W bosons, each having mass 80.1 GeV/c^2. Calculate the momentum of each W boson in the laboratory, in GeV/c.

16. When a single-lens camera is focused on an object at infinity, the lens-to-film distance is 40.0 mm. To focus on an object 0.54 m in front of the lens, the film-to-lens distance must be:

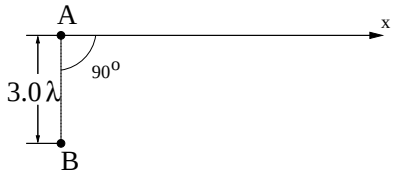
a) not changed.
b) decreased by 2.7 mm
c) decreased by 3.2 mm
d) increased by 2.7 mm
e) increased by 3.2 mm

17. A real object placed closer to a converging lens than its focal length always makes an image that is

a) Virtual, upright, smaller
b) Virtual, upright, bigger
c) Real, inverted, smaller
d) Real, inverted, bigger
e) Real, upright, smaller

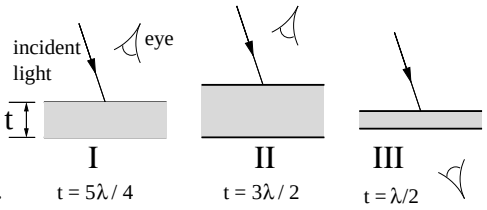
18. A and B are two identical radiators of waves that are in phase and of the same wavelength, λ. The radiators are separated by a distance of 3.0λ. Find the distance from A, along the line Ax, for which the *next to last* destructive interference occurs (as a function of increasing x).

a) $\frac{5}{4}\lambda$
b) $\frac{35}{4}\lambda$
c) $\frac{9}{4}\lambda$
d) $\frac{11}{20}\lambda$
e) 4λ



19. Three experiments involving a thin film (in air) are shown. If t denotes the film thickness and λ denotes the wavelength of the light *in the film*, which experiments will produce constructive interference as seen by the observer? In all experiments, the origin of the light is above the film. In experiments I and II, the observer is **above** the film, but in experiment III, the observer is **below** the film.

a) I only.
b) II only.
c) III only.
d) I and III only.
e) II and III only.



20. A circular disk radar antenna on a navy ship radiates and receives electromagnetic waves of 0.020 m wavelength to detect two small boats located 9 km from the ship. If the small boats are 100 m apart from each other, what must be the minimum diameter of the antenna so that the boats can be distinguished as two objects, rather than as one small object? **Important:** for resolving power, circular disk radar antenna can be considered to behave just like a circular aperture.

a) 0.45 m
b) 0.27 m
c) 1.1 m
d) 1.4 m
e) 2.2 m

21. In a single slit illuminated with monochromatic light produces a diffraction pattern on a distant screen. If the width of the slit is doubled and all other parameters are unchanged, **by what factor** does the width of the central maximum of the diffraction pattern change? (The small-angle approximation can be used here.)

a) 2 b) 4 c) $\frac{1}{2}$ d) $\frac{1}{4}$ e) 1

22. A spaceship of proper length 50 m is moving away from the earth at a speed of 0.8c. According to observers in the ship, their journey takes 6.0 hours. According to observers on earth, what is the length of the ship, and how long does the journey take?

a) 83 m; 10 hours
b) 30 m; 3.6 hours
c) 83 m; 3.6 hours
d) 50 m; 3.6 hours
e) 30 m; 10 hours

23. An electron and a proton each have a kinetic energy of 1 GeV. As a result:

a) the total energy of the electron is greater than that of the proton and the momentum of the electron is greater than that of the proton
b) the total energy of the electron is greater than that of the proton and the momentum of the electron is less than that of the proton
c) the total energy of the electron is less than that of the proton and the momentum of the electron is greater than that of the proton
d) the total energy of the electron is less than that of the proton and the momentum of the electron is less than that of the proton
e) the total energy of the electron is the same as that of the proton and the momentum of the electron is greater than that of the proton

24. 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) $\sqrt{2}$
b) 1/2
c) 1
d) 2
e) 4

25. A 100 watt red light bulb converts electrical energy into red light ($\lambda = 6.2 \times 10^{-7}$ m) with an efficiency of 5%. The momentum of each photon produced is

a) 2.0 eV/c
b) 0.5 eV/c
c) 1.0 eV/c
d) 1.5 eV/c
e) none of these

26. The spectrum of the mercury arc lamp contains a line at 435.8 nm in the blue. What is the difference in energy levels in the atom that gives rise to this spectral line?

a) 1.85 eV
b) 2.55 eV
c) 2.84 eV
d) 3.15 eV
e) 3.45 eV

27. Gold has an atomic number of 79. Consider one of its electrons when it is farther from the nucleus than any of the other electrons. Compare the magnitude of the electric field in which it moves with that experienced by an electron in a hydrogen atom when it is just as far from the nucleus. In the gold atom the magnitude of the electric field is

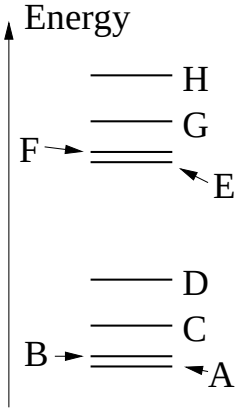
a) much bigger
b) much smaller
c) about the same
d) bigger for high angular momentum and smaller for low angular momentum.
e) bigger for low angular momentum and smaller for high angular momentum.

28. 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

29. The energy levels of a diatomic gas have been reconstructed from the spectrum of its emission, giving the energy levels shown. Which one of the following could be true?

a. State A is the ground state. B, C, and D are in the vibrational ground state but have non-zero angular momentum. State E is an excited vibrational state.
b. State A is the ground state. B, C, and D are in progressively more rapidly vibrating states, while state E is not vibrating but is rotating.



c. States A–D are states in which the atoms move nonrelativistically, while in states E-H they move relativistically.
d. States A–D are motion in a square well, while for states E–G the atoms have jumped to another, narrower square well.
e. States A–D are the states for one of the atoms while states E–G are states of the other one.

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

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

31. 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) 1740 years
c) 3200 years
d) 1520 years
e) 10^{-11} years

32. Identify the wrong relation:

a) ${}^{11}_{6}\mathrm{C} \rightarrow {}^{11}_{5}\mathrm{B} + e^+ + \nu$
b) ${}^{239}_{92}\mathrm{U} \rightarrow {}^{239}_{93}\mathrm{Np} + e^- + \bar{\nu}$
c) ${}^{66}_{29}\mathrm{Cu} \rightarrow {}^{66}_{30}\mathrm{Zn} + e^- + \bar{\nu}$
d) ${}^{66}_{29}\mathrm{Cu} \rightarrow {}^{66}_{30}\mathrm{Zn} + \gamma$
e) ${}^{234}_{90}\mathrm{Th} \rightarrow {}^{230}_{88}\mathrm{Ra} + \alpha$

33. Estimate The binding energy **per nucleon** for ${}^{93}_{41}\mathrm{Nb}$. Note: M$({}^{93}_{41}\mathrm{Nb}) = 92.906378$ u (atomic mass) and M$({}^{1}_{1}\mathrm{H})$=1.007825 u.

a) 805.8 MeV
b) 196.5 MeV
c) 155.0 MeV
d) 0.865 MeV
e) 8.664 MeV

34. A piece of wood taken from an archaeological excavation has a ratio of ^{14}C to ^{12}C which is about a fourth as large as the ratio in a recently cut tree. If the half-life of ^{14}C is about 5700 years, what is the approximate age of the piece of wood?

a) 5,700 years
b) 11,400 years
c) 17,100 years
d) 22,850 years
e) 1,425 years

35. In classical mechanics, the energy of a harmonic oscillator is given in terms of its velocity or momentum and its displacement x from equilibrium by

$$E = \frac{1}{2}mv^2 + \frac{1}{2}kx^2 = \frac{p^2}{2m} + \frac{1}{2}kx^2.$$

The equation which characterizes the quantum mechanical harmonic oscillator is

a) $-\frac{\hbar^2}{2m}\frac{d^2\psi}{dx^2} + \frac{1}{2}kx^2\psi = E\psi$
b) $E = \left(\frac{h^2}{8mk^2}\right) n^2$
c) $\frac{d^2\psi}{dx^2} = \frac{1}{2}kx^2\psi$
d) $E = \frac{\hbar^2}{2kx^2}v$
e) $E = \frac{h}{2\pi}\sqrt{\frac{k}{m}}$

36. High temperatures are required in thermonuclear fusion so that

a) some nuclei are moving fast enough to overcome the Coulomb barrier to fusion.
b) there is a high probability some nuclei will strike each other head on.
c) electrons will boil off from the atoms.
d) fused nuclei are in high energy states.
e) the Pauli exclusion principle does not prohibit fusion.

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

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

38. The sun derives its energy from:

a) combustion of carbon atoms.
b) fission of plutonium nuclei.
c) fission of iron nuclei.
d) fusion of hydrogen nuclei.
e) fusion of iron nuclei.

39. The velocities of distant objects in the universe indicate that the time elapsed since the big bang is approximately:

a) 10^7 y
b) 10^{10} y
c) 10^{13} y
d) 10^{16} y
e) 10^{19} y