Physics 160
Principles of Modern Physics
(Spring 2008)
Final Examination

Name: Honor Code:

I. Multiple Choice (20 points) Circle all that apply. In some cases there may be multiple correct answers.

1. (1 pt.) What percent of the initial radioactive sample remains after three half-lives?
   (a) 6.25%
   (b) 10%
   (c) 12.5%
   (d) 25%
   (e) 50%
   (f) 75%
   (g) 100%

2. (1 pt.) Alphas emitted by nucleus A have 5 MeV of energy. Alphas emitted by nucleus B have 8 MeV of energy. Which nucleus has the longer half-life?
   (a) nucleus A
   (b) nucleus B
   (c) they have the same energy
   (d) there is not enough information to determine

3. (1 pt.) What nuclear reaction (or set of reactions) is responsible for most of the energy produced in the sun?
   (a) ${}^{2}H+{}^{2}H\rightarrow{}^{3}H + p$
   (b) ${}^{2}H+{}^{3}H\rightarrow{}^{4}He+n$
   (c) proton-proton chain (fusion of protons into alpha particles)
   (d) CNO cycle (fusion of protons into alpha particles)
   (e) triple alpha process (fusion of alpha particles into ^{12}C)

4. (1 pt.) What nuclear reaction (or set of reactions) is the most promising reaction for a nuclear fusion reactor on earth?
   (a) ${}^{2}H+{}^{2}H\rightarrow{}^{3}H + p$
   (b) ${}^{2}H+{}^{3}H\rightarrow{}^{4}He+n$
   (c) proton-proton chain (fusion protons into alpha particles)
   (d) CNO cycle (fusion of protons into alpha particles)
   (e) triple alpha process (fusion of alpha particles into ^{12}C)

5. (1 pt.) What are the two primary strategies for achieving controlled nuclear fusion for electric power production (circle two):
(a) inertial confinement
(b) gravitational confinement
(c) electrostatic confinement
(d) magnetic confinement
(e) solitary confinement
(f) breeder reactors
(g) heavy water reactors

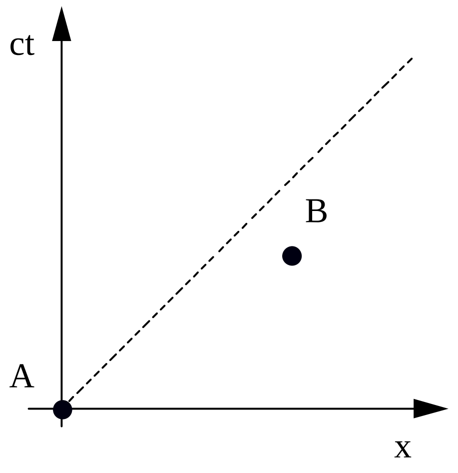
6. (1 pt.) Circle all that apply: muons are …
(a) baryons
(b) leptons
(c) hadrons
(d) mesons
(e) fermions
(f) bosons
(g) made of a quark and an anti-quark
(h) made of three quarks

7. (1 pt.) The gamma ray photons emitted in positron-electron annihilation have energy of approximately …
(a) 0.3 MeV
(b) 0.5 MeV
(c) 1 MeV
(d) 2 MeV
(e) 1 GeV

8. (1 pt.) An object (blackbody) at a temperature of 2000 K radiates 10 Watts of power. To what temperature must you raise it for the radiated power to be 160 W?
(a) 3000 K
(b) 4000 K
(c) 8000 K
(d) 10,000 K
(e) 16,000 K
(f) 32,000 K

9. (1 pt.) Which transition for an electron in a simple harmonic oscillator potential results in emission of the highest energy photon?
(a) $n_i = 4$ to $n_f = 3$
(b) $n_i = 3$ to $n_f = 2$
(c) $n_i = 2$ to $n_f = 1$
(d) $n_i = 1$ to $n_f = 0$
(e) they are all the same
(f) all the same except (d)

10. (1 pt.) The spacetime diagram below shows two events, event A occurs at x=0, t=0 and event B occurs at the location and time shown in some inertial reference frame. Which of the following statements is/are true regarding the spacetime separation of these two events.



(a) A and B are timelike separated
(b) A and B are spacelike separated
(c) A and B are lightlike separated
(d) A and B are simultaneous in some inertial reference frame
(e) A could have caused B
(f) A and B occur at the same place in some inertial reference frame.

11. (1 pt.) Planck's constant has the same units as …
(a) energy
(b) momentum
(c) angular momentum
(d) mass
(e) frequency
(f) wavelength

12. (1 pt.) A rocket of proper length 100 meters traveling at a velocity of 0.8c ($\gamma = 5/3$) passes through a tunnel of length 60 meters. Is the rocket ever completely inside the tunnel?
(a) No, you can't put a 100 meter rocket in a 60 meter tunnel.
(b) Yes, from the perspective of an observer at rest with respect to the tunnel, the rocket momentarily disappears inside the tunnel.
(c) No, from the perspective of the rocket the tunnel is contracted so that the rocket cannot possibly fit.
(d) Both b) and c) are correct.

13. (1 pt.) Electrons bound in a square well potential are allowed to have only certain, discrete energies because

(a) The Bohr hypothesis states that only certain states are stable.

(b) Only certain energies result in wavefunction solutions to the Schrodinger Equation that satisfy the boundary conditions.

(c) The Heisenberg Uncertainty Principle requires that there be certain minimum gaps between the energies of a quantum system.

(d) The DeBroglie hypothesis says that only certain electron momenta are allowed.

14. (1 pt.) Which element has a ground state electron configuration of $1s^2 2s^2 2p^5$?

(a) Oxygen
(b) Fluorine
(c) Neon
(d) Chlorine
(e) Argon

15. (1 pt.) Fine structure in atomic spectra refers to …

(a) Splitting of a beam of atoms in a non-uniform magnetic field.
(b) Splitting of spectral lines when a magnetic field is applied.
(c) Splitting of spectral lines due to “spin-orbit coupling.”
(d) Scattering of photons off electrons

16. (1 pt.) Which general class of particles obeys the Pauli exclusion principle

(a) only electrons
(b) only photons
(c) bosons (all integer spin particles)
(d) fermions (all half-odd integer spin particles)

17. (1 pt.) Nuclei with the same number of protons but different numbers of neutrons are called …

(a) Isometrics
(b) Isomers
(c) Isotones
(d) Isotopes
(e) Isobars
(f) “I-so-don’t-know”

18. (1 pt.) Which If an unstable nuclide has a (mean) lifetime of 1000 seconds, what is the probability that a given nucleus will decay in a particular second?

(a) 0.01%
(b) 0.1%
(c) 1%
(d) 10%
(e) 100%
(f) 1000%

19. (1 pt.) Given the mean lifetimes below, which excited state has the smallest natural linewidth?

(a) state 1: $\tau = 10^{-12}$ s
(b) state 2: $\tau = 10^{-10}$ s
(c) state 3: $\tau = 10^{-8}$ s
(d) they all have the same linewidth

20. (1 pt.) What particle (or particles) mediates (or communicates) the weak force?

(a) graviton
(b) photon
(c) W^+, W^-, Z^0
(d) mesons
(e) gluons
(f) destructons

II. Short Answer Section (40 points)

21. (5 pts.) Examine each of the following reactions and indicate either that it is permitted or that it is forbidden. If it is forbidden, indicate which conservation law(s) is(are) violated.

(a) $p \to \pi^+ + \pi^0$

(b) $\pi^+ \to \mu^+ + \nu_\mu$

(c) $\pi^+ \to \mu^+ + n$

(d) $\mu^- \to e^- + \gamma$

(e) $e^+ \to \mu^+ + \nu_\mu + \overline{\nu}_e$

22. (5 pts.) Write down the chemical symbol and atomic mass number for the nuclides that result from each of the following reactions.

(a) negative beta decay of ^{14}C:

(b) positive beta decay of ^{40}K:

(c) electron capture of ^{57}Co:

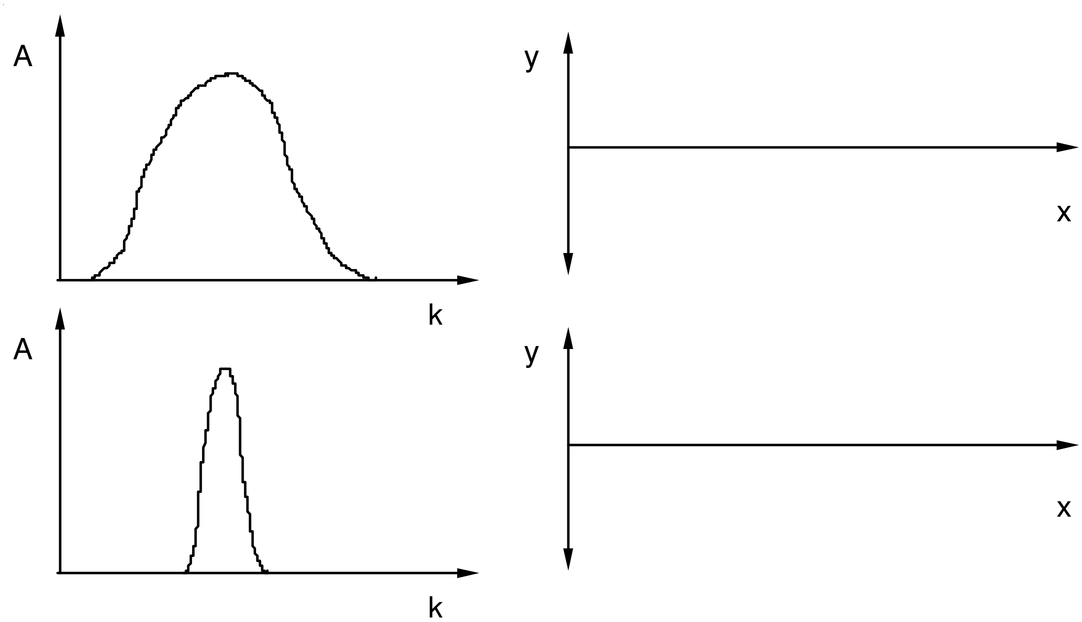
(d) alpha decay of ^{232}Th:

(e) neutron capture by ^{107}Ag:

23. (6 pts.) Why is water a good material to use as a moderator in a nuclear (fission) reactor?

24. (6 pts.) If the work function for a metal is 3.5 eV, what is the minimum photon frequency and wavelength that will cause emission of photoelectrons?

25. (6 pts.) Qualitatively sketch the spatial appearance of the wave packets corresponding to the two amplitude distributions shown below. The amplitude distribution is related to the spatial structure of the wave through $y(x,t) = \int A(k)\cos(\omega t - kx)dk$



26. (5 pts.) Draw Feynman diagrams for the following processes:

(a) electron – electron scattering
(b) electron – positron pair production
(c) electron – positron annihilation
(d) Compton scattering
(e) negative muon decay

27. (7 pts.) In the Compton scattering process, what scattering angle results in the largest wavelength change? What is the maximum wavelength change? Discuss why Compton used X-rays or γ-rays to test his theory, rather than visible light.

III. Exercises (40 points) Do TWO of the following THREE problems. Be sure to indicate which problem you do NOT want graded.

28. (20 pts.) Radioactive Decay

(a) The decay constant for ^{14}C is $3.8x10^{-12}$ s-1. What is the half-life of ^{14}C in years?

(b) How many atoms of ^{14}C would you need to have a sample with an activity of 1 mCi?

(c) Approximately how many years would you have to wait until the 1 mCi sample decayed to an activity of 1 μCi?

(d) ^{14}C decays by negative beta decay. Write down the decay reaction including all particles present after the decay.

29. (20 points) Pion Decay

(a) One of the particles that emerges from the decay of a negative pion ($m_\pi c^2$=139.6 MeV) is a negative muon ($m_\mu c^2$=105.7 MeV). The muon always comes out with the same energy. What does that tell you about the number of particles present after the decay?

(b) Complete the reaction equation

$$\pi^- \rightarrow \mu^- +$$

(c) If the pion is initially at rest, what is the total kinetic energy of the particles produced in this reaction? Which particle will end up with the larger fraction of this energy? Why?

(d) If the pion is not at rest, as is the case when pions are created by cosmic rays in the atmosphere, then the decay products can have more energy. If the muon ends up with kinetic energy equal to three times its rest mass energy, how fast is it moving? Hint: the total (relativistic) energy must be equal to the rest mass energy plus the kinetic energy.

(e) At rest, the muon has a lifetime $\tau = 2.2\times10^{-6}$ s. In the frame in which it is moving at the speed found in part (c), how long does it live? If you did not get an answer to part (c), use u = .7c.

(f) How far does the muon in part (d) travel before decaying? In the muon's frame, how far does the lab (or the earth) move? Why are these two distances different?

30. (20 points) Hydrogen atom
(a) How many states in the hydrogen atom have n=3, l=2?

(b) What is the spectroscopic notation for the states in part (a)?

(c) To which lower energy states can the electron make a transition without violating the selection rules for electric dipole transitions?

(d) Calculate the wavelength(s) (in nm) of the photon(s) emitted when the electron makes the transition(s) described in part (c).

(e) If the electron in the hydrogen atom was replaced by a muon (with rest mass energy of 105.7 MeV), what would be the radius of this "muonic" hydrogen atom in its ground state?

(f) Given your answer to part (e), and what you know about quantum mechanics, why might the production of "muonic" deuterium and "muonic" tritium be a possible strategy for catalyzing nuclear fusion reactions?