Final Exam PHYSICS 102 May 18, 1998

Instructions: Write your answers on these pages. Show all your work and box your final answers. Some parts of the exam are harder than others, so if you get stuck, go on to other parts and come back later if you have time. Always include units of numerical answers.

After you have finished, write and sign the honor pledge: “I pledge my honor that I have not violated the Honor Code during this examination.”

Signature __________________________

1. ______ (1) 6. ______ (2) 11. ______ (4) 16. ______ (6) 17. ______ (7) 18. ______ (10)
2. ______ (3) 7. ______ (1) 12. ______ (5) 19. ______ (11)
3. ______ (2) 8. ______ (2) 13. ______ (6) 20. ______ (12)
4. ______ (3) 9. ______ (2) 14. ______ (17) 21. ______ (13)
5. ______ (3) 10. ______ (6) 15. ______ (5) Total ______ (85)

c = 3.00 \times 10^8 \text{ ms}^{-1}
k = 1.38 \times 10^{-23} \text{ JK}^{-1}
u = 1.66 \times 10^{-27} \text{ kg}

\epsilon = 1.60 \times 10^{-19} \text{ C}
m_e = 9.11 \times 10^{-31} \text{ kg}
u = 931.5 \text{ MeVc}^{-2}

1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}
m_e = 0.511 \text{ MeVc}^{-2}

h = 6.63 \times 10^{-34} \text{ J s}
m_p = 1.66 \times 10^{-27} \text{ kg}

\hbar = 1240 \text{ eV nm} \quad m_p = 938.3 \text{ MeVc}^{-2}

k = 8.99 \times 10^9 \text{ N m}^2 \text{ C}^{-2} 

\frac{\Sigma B}{\Delta l} = \mu_0 I 

f = \frac{k}{l} 

F = l I B \sin \theta 

P = \vec{I} \times \vec{B} 

F = \frac{k Q_1 Q_2}{r^2} 

f_0 = \frac{1}{2} \sqrt{\frac{h}{m} E} 

F = Q E 

N = N_0 e^{-\lambda t} 

N = N_0 e^{-\lambda t} 

\frac{\Delta N}{\Delta t} = -\lambda N = -\lambda N_0 e^{-\lambda t} 

\frac{\Delta P}{\Delta t} = \lambda P = \lambda P_0 

P = IV 
p = \gamma m_0 v = \frac{m_0 v}{\sqrt{1 - \frac{v^2}{c^2}}} 

Q = CV 
r = 1.2 \times 10^{-15} \text{ m} \cdot \text{ A}^{1/3} 

\Delta x \Delta p \geq \hbar 

\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} 

\sin \theta = \frac{\tan \theta}{d} 

\sin \theta = \frac{(m + \frac{1}{2}) \lambda}{d} 

\lambda = \frac{1}{m_0} 

\lambda = \frac{\ln 2}{t_1/t_2} 

\lambda = \frac{\lambda}{n} 

\rho_T = \rho_0 (1 + \alpha \Delta T) 

\tau = RC 

\Phi_B = B A \cos \theta
1. An aluminum wire has a cross-sectional area of $7.9 \times 10^{-7}$ m$^2$. Find the resistance per unit length for this wire. The resistivity of Al is $\rho = 2.82 \times 10^{-8}$ $\Omega \cdot$m. (1 point)

2. A 2.00 $\mu$F and a 4.00 $\mu$F capacitor are connected to a 60.0 V battery. How much charge is supplied by the battery in charging the capacitors when the wiring is (a) in parallel and (b) in series? (3 points)

3. A lightbulb and a parallel plate capacitor (including a dielectric material between the plates) are connected in series to a 60 Hz ac voltage present at a wall outlet. Describe what will happen to the brightness of the bulb when the dielectric material is removed from the space between the plates (and why!). (2 points)
4. What is the equivalent resistance of the resistor network shown? (3 points)

5. A pitcher throws a 150 gram baseball at a measured speed of 42 m/s.
   
   a. What is the wavelength of the baseball? (1 point)

   b. What is the limit that the uncertainty principle sets on the measurability of the position of the baseball, if the speed is measured with an accuracy of 1 m/s? (2 points)
6. Some modern physical theories predict that the proton may be unstable, having a half life of $10^{32}$ years. If you approximate yourself as a 60 kg bucket of water, how long will you typically have to wait for one proton in your body to decay? (2 points)

7. A single photon is incident on a Young double slit apparatus. Will the screen behind the double slits show a single bright spot, interference fringes, or something else? If something else, what? (1 point)

8. A “thermal neutron” is one that has the same kinetic energy as a typical gas particle at room temperature. What is the wavelength of a thermal neutron? (2 points)

9. An electron is moving in a magnetic field of strength $B = 10^{-5}$ T in a circular orbit of radius $R = 0.2$ m. What is the velocity of the electron? (2 points)
10. A bar of length $L = 1.2$ m moves on a horizontal, frictionless pair of tracks with a constant velocity of 100 m/s. The tracks are connected together at one end through a resistor, $R = 1000\Omega$. Assuming that a vertical magnetic field, $B = 0.01$ T points downward, find the following:

a. The induced current in the bar. (3 points)

b. The force on the bar required to keep it in motion at constant speed. (2 points)

c. The power required to keep the bar moving at constant speed. (1 point)

11. A diffraction grating with 6000 lines per cm is illuminated with monochromatic light with wavelength 633 nm.

a. How many principal maxima would you see? (2 points)

b. If a screen is placed 1 m away from the grating, what is the minimum width it must have to see all the principal maxima? (2 points)
12. Two identical converging lenses with focal length \( f = 27 \) cm are placed 16.5 cm apart. An object is placed 35 cm in front of the first lens.

a. Where will the final image formed by the second lens be located? It might help to draw a picture! (3 points)

b. What is the total magnification? (2 points)

13. It is sometime in the next century. The *New York Times* reports that a starship has just returned from a five year voyage during which it traveled at 0.92c.

a. If the reporter means the ship was gone for five years of Earth time, how much have the astronauts aged? (2 points)

b. If the reporter means that the astronauts chronometers show five years of elapsed time, how much time has elapsed on Earth since the ship left? (2 points)

c. If the rest mass of the ship is \( 10^5 \) kg, what was its kinetic energy? (2 points)
14. A DC circuit is shown below:

![Circuit Diagram]

a. What is the potential drop, $V_L$ across the inductor? (2 points)

b. What is the current $I_L$ in the inductor? (2 points)

c. What is the power dissipated by the resistor? (2 points)
We now replace the DC battery with an AC voltage generator that produces a voltage, $V(t) = V_o \cos(\omega t)$. Here, $V_o = 10 \, \text{V}$.

![Circuit Diagram]

d. What are the impedances of the resistor, capacitor, and inductor? (3 points)

e. What is the total impedance? (2 points)

f. For very high frequencies, what does the circuit look like? What is the equivalent impedance of the circuit, now? (2 points)
g. For very low frequencies, what does the circuit look like? What is the equivalent impedance of the circuit, now? (2 points)

h. What is the resonant frequency $f_r$ of the LC loop in this circuit? Give your answer in units of Hertz. (2 points)
15. Two long, thin concentric cylinders of radii $a$ and $b$ with $a < b$ are shown in the diagram below. The cylinders have equal and opposite charges per unit length $\lambda$.

Find the electric field $E$ for the following (5 points total)

a. $r < a$

b. $a < r < b$

c. $r > b$
16. a. How many electrons are there in a tablespoon (15 cm³) of water? (3 points)

b. What is the total charge of all these electrons? (1 point)

c. Imagine that you could remove all of the electrons from two tablespoons of water. If one tablespoon of this fully-ionized water were placed on the Earth, and the other on the Sun (at a distance of \(1.5 \times 10^8\) km), what would be the electrostatic force between the earth and the sun (magnitude and direction)? (2 points)
17. The relative abundance for the naturally occurring isotopes of uranium are 0.72% for $^{235}\text{U}$ and 99.27% for $^{238}\text{U}$. Both isotopes are radioactive, with half-lives of 0.704 billion years for $^{235}\text{U}$ and 4.468 billion years for $^{238}\text{U}$. Because their half-lives are comparable to the age of the Universe, they are found in nature even though they are disappearing with time, owing to their radioactive decay.

a. What would be the decay rate, in disintegrations per second, of 1 kg of natural uranium? Specify the rate for each isotope. (3 points)

b. The lower abundance of $^{235}\text{U}$ is connected to the fact that its half-life is considerably shorter than that of $^{238}\text{U}$. Assuming that the two isotopes were originally made in equal abundance (in supernova explosions!), calculate the elapsed time between the creation of the uranium and now. Hint: you should consider the decay of both isotopes during the time interval in question. (4 points)
18. The radon isotope $^{222}\text{Rn}$ (half-life 3.825 days) is one of the decay products (or "daughters") of naturally occurring $^{238}\text{U}$. In areas where the soil has a high uranium concentration, the radiation of the decay from this radon isotope can be a serious health hazard.

The following sequence illustrates the decay of $^{222}\text{Rn}$ to $^{218}\text{Po}$ (polonium) by alpha emission:

$$^{222}\text{Rn} \rightarrow ^{218}\text{Po} + ^4\text{He}.$$ 

a. The atomic number of Rn is 86. Specify the number of protons and neutrons in the nucleus $^{218}\text{Po}$. (2 points)

b. The atomic masses for these nuclides, in atomic mass units u, are as follows:

$$M(^{222}\text{Rn}) = 222.017\,570\,u$$
$$M(^{218}\text{Po}) = 218.008\,966\,u$$
$$M(^4\text{He}) = 4.002\,603\,u$$

Calculate the energy released in this decay process. Calculate the energy in Joules and MeV. (3 points)

c. The energy released is shared between the $^{218}\text{Po}$ and $^4\text{He}$ nuclei. Use the computed energy release and energy and momentum conservation to calculate the energy of the $^4\text{He}$ nucleus (alpha particle) in MeV. (5 points)