Physics 7C, Fall 2000

Midterm I

Thursday, October 1, 7:00-9:00 p.m.

Print Name:

Signature:

Student ID:

Discussion Section #:

Discussion Section GSI:

For grading use:

Problem 1 (25 points):

Problem 2 (25 points):

Problem 3 (25 points):

Problem 4 (25 points):

Directions: The allotted time is 110 minutes. No notes or calculators are allowed. The 4 problems count equally, and some parts are easier than others, so you will want to take a look at all of them.

a) Write your name, discussion section, discussion GSI name, and student ID at the top of any materials you wish to be graded. Staple all submitted materials together (the proctor has a stapler).

b) Box or circle all of your final answers.

c) Explain briefly how you reached your answer. A clear explanation of what you are doing also helps in getting partial credit if there is a mistake somewhere. When a numerical answer is called for, an accuracy of 5% is sufficient.

Please do not turn this sheet over until the proctor starts the exam. You may ask the proctor for help if a question's meaning is unclear.

1. A spaceship moves away from Earth at velocity v. Express your answers in terms of v and the speed of light c.

(a) (5 points) According to a clock on the spaceship, it sends a radio pulse to Earth every 1 s. On Earth, how much time elapses between pulses?

(b) (5 points) If the radio pulse sent to Earth is from a source on the spaceship that emits frequency 1 MHz (i.e., $f_0 = 10^6$ Hz), what is the measured frequency of the pulse at Earth?

(c) (5 points) The spaceship is 1 km long in its rest frame. How long does it appear in the Earth's frame?

(d) (10 points) Suppose that, from the perspective of an observer at the middle of the spaceship, two events happen at the same time at different ends of the spaceship. Do these events appear to happen at the same time from the perspective of observers stationary with respect to the Earth? If not, which one happens first? By how much time is this event first to the Earth observer (in terms of the velocity v, and using that the spaceship is 1 km long)? Draw a picture to explain your result.

2. Consider a monochromatic plane wave

$$\mathbf{E}(\mathbf{r}, t) = \mathbf{E_0} \cos(\omega t - \mathbf{k} \cdot \mathbf{r} + \phi). \tag{1}$$

(a) (5 points) If this wave propagates in vacuum, how are ω and the magnitude of $\mathbf{k}$ related? What is the numerical value of ω if $|\mathbf{k}| = 1\ \mathrm{m}^{-1}$?

(b) (5 points) What is the wavelength for this value of $|\mathbf{k}|$?

(c) (5 points) What requirements are there on the direction of $\mathbf{E}_0$? Write an equation for the magnetic field $\mathbf{B}(\mathbf{r}, t)$ associated with this plane wave. Specify its direction clearly.

(d) (5 points) If $\mathbf{E}_0$ is doubled, how much does the energy density of this wave increase?

(e) (5 points) How is the relationship between ω and the magnitude of $\mathbf{k}$ modified if, instead of propagating in vacuum, the wave propagates in a medium with dielectric constant $3\epsilon_0$, where ϵ_0 is the dielectric constant of vacuum?

3. Suppose that initially one billiard ball with mass m moves right (along $+\hat{\mathbf{x}}$) with velocity $3c/5$, and that another billiard ball with mass $m/2$ moves left with velocity $4c/5$.

(a) (5 points) Write the initial total energies for each billiard ball.

(b) (5 points) Write the initial momenta for each billiard ball.

(c) (15 points) Suppose that the two balls hit each other and stick together, conserving momentum and energy. What are the final momentum, mass, and *kinetic* energy of the resulting object?

4. A nuclear fusion reaction occurs in which one deuterium nucleus (one proton plus one neutron) combines with one tritium nucleus (one proton plus two neutrons) to form a helium nucleus (two protons plus two neutrons; this is also known as an "alpha particle") and one neutron. In the mass number/ atomic number notation, this reaction is

$$ {}^2_1\mathrm{D} + {}^3_1\mathrm{T} = {}^4_2\mathrm{He} + {}^1_0\mathrm{n}. \tag{2} $$

The particles on the left-hand side outweigh the particles on the right-hand side by 18 MeV/c^2 = 0.018 GeV/c^2. Suppose that the original particles are stationary. It may help you to use either ultra-relativistic or non-relativistic approximations in this problem if that is appropriate.

(a) (5 points) What is the total kinetic energy of the final particles in the rest frame of the original particles?

(b) (10 points) The rest mass of a neutron is roughly 1 GeV/c^2, and the helium nucleus has mass about 4 times as large. Are the final particles moving relativistically? Use your answer to estimate the kinetic energy and velocity of each of the final particles. Which final particle moves faster, and by how much?

(c) (10 points) Suppose that a different reaction had occurred that produced the same final particles, with a total kinetic energy of 1 TeV = 10^3 GeV = 10^6 MeV in the rest frame. Estimate the kinetic energy and velocity of each of the final particles.