Name:
Student Number:

Physics 200 Midterm #2

November 18, 2009

Questions 1-9: Multiple Choice/Short Answer: 1 point each
Questions 10-12: Show your work

18 points total

MULTIPLE CHOICE ANSWERS:

#1	C
#2	B
#3	C
#4	A
#5	C
#6	A
#7	C
#8	B
#9	D

Formula sheet at back
(you can remove it)

Problem 1

For the statements:

1) Mass can be converted into kinetic energy. → true: e.g. in nuclear fission
2) Kinetic energy can be converted into mass. → true: e.g. creating new particles in accelerators.

A) Only 1 is true.
B) Only 2 is true.
(C) Both 1 and 2 are true.
D) Neither 1 nor 2 are true.

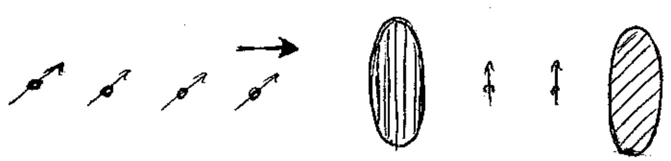
Problem 2

A stable Helium-4 nucleus has two protons and two neutrons. We can conclude that:

Stable ⇒ need to add energy (i.e. do work on system) to separate into parts.

A) $m_{He} = 2m_p + 2m_n$
(B) $m_{He} < 2m_p + 2m_n$
C) $m_{He} > 2m_p + 2m_n$
D) Any of the above may be true.

Problem 3



after going through: will be polarized at 0°
∴ prob $\cos^2(0° - 45°) = \frac{1}{2}$ for passing through second one.

Photons polarized at 45° to the vertical are incident on two polarizers, the first oriented at 0° and the second at 45°. For photons that pass through the first polarizer, we can say that

A) They will definitely pass through the second polarizer.
B) They will definitely not pass though the second polarizer.
(C) On average, half of them will pass through the second polarizer.
D) There is no way to predict the likelihood that these photons will pass through the second polarizer.

Problem 4

A photon is incident on a polarizer oriented at 90° to the vertical. For which initial polarization state can we predict with certainty whether or not the photon will pass through?

eigenstate : definitely absorbed

(A) $|0°\rangle$ → eigenstate : definitely absorbed
B) $|45°\rangle$ → $P = \cos^2(45°) = \frac{1}{2}$ to pass through. But don't know whether any particular photon will go through or not.
C) $1/\sqrt{2}|0°\rangle + 1/\sqrt{2}|90°\rangle$ → same as B $\frac{1}{\sqrt{2}}|0°\rangle + \frac{1}{\sqrt{2}}|90°\rangle = |45°\rangle$
D) All of the above
E) None of the above

Problem 5

In a certain exothermic (i.e. releasing energy) nuclear fusion reaction, deuterium (1 neutron, one proton) and tritium (2 neutrons, one proton) fuse into a Helium nucleus (2 neutrons, 2 protons) and eject a neutron in the process, $D + T \rightarrow He + n$. For this reaction,

D + T → He + n + kinetic energy

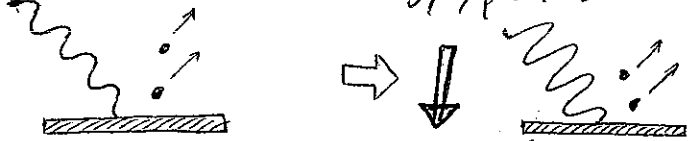
A) $m_D + m_T = m_{He} + m_n$
B) $m_D + m_T < m_{He} + m_n$
(C) $m_D + m_T > m_{He} + m_n$
D) Any of the answers above could be correct depending on what frame of reference we measure the masses in.

more kinetic energy after → comes from mass energy.
$\therefore (m_D + m_T)c^2 > (m_{He} + m_n)c^2$

Problem 6

same wavelength ⇒ same energy / photons

higher amplitude ⇒ higher intensity



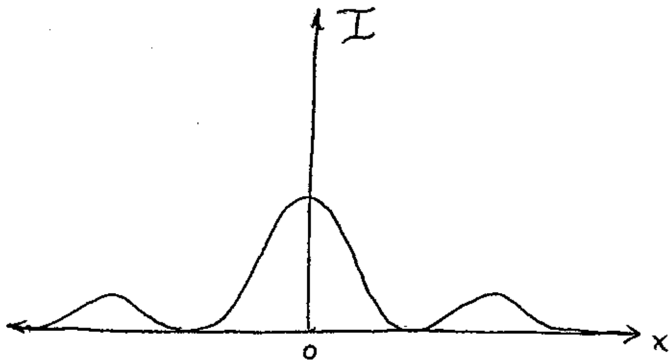
∴ more energy / second
But: same energy / photon
so: more photons / second ⇓ larger # electrons per sec

same max. kinetic energy

Electrons are observed to be emitted when a beam of light is incident on a metal. If we change the light so that the amplitude of the electromagnetic wave is increased but the wavelength remains the same, we will find that

(A) The current of electrons coming out of the metal will increase but their maximum kinetic energy will not change.
B) The current of electron coming out of the metal will stay the same but their maximum kinetic energy will increase.
C) The current of electrons and their maximum kinetic energy will both stay the same.
D) The current of electrons and their maximum kinetic energy will both increase.

Problem 7



The graph shows a plot of intensity versus position on the screen for an interference pattern produced in a double slit experiment with light. If we send four individual photons through the same apparatus, which of the following statements is correct? each photon has prob. $\frac{1}{2}$ of hitting region $x>0$.

A) Two of the photons will hit the screen at $x<0$ and two of the photons will hit the screen at $x>0$.
B) Each photon will hit the screen directly behind one of the slits.
(C) The number of photons hitting the screen at $x>0$ could be anything between 0 and 4, but is most likely 2.
D) Since the photons are identical, each photon distributes its energy onto the screen in the same way, with the energy distribution matching the classical intensity pattern.

Problem 8

An electron is in a state $3/5|x_1\rangle - 4/5|x_2\rangle$. If we do a measurement of position, we are most likely to find the electron at

Probability ∝ squared coefficient
$\left(\frac{4}{5}\right)^2 > \left(\frac{3}{5}\right)^2 \therefore x_2$ most likely.

A) x_1
B) x_2
C) $3/5\ x_1 - 4/5\ x_2$
D) $9/25\ x_1 + 16/25\ x_2$
E) All positions between x_1 and x_2 are equally likely.

Problem 9

If we perform the measurement of problem 8 a large number of times on electrons with the same initial state, the average value of the position measurements will be

get x_1 w. probability $\left(\frac{3}{5}\right)^2 = \frac{9}{25}$
get x_2 w. probability $\left(\frac{-4}{5}\right)^2 = \frac{16}{25}$
Average value: $\frac{9}{25} x_1 + \frac{16}{25} x_2$

A) x_1
B) x_2
C) $3/5\ x_1 - 4/5\ x_2$
(D) $9/25\ x_1 + 16/25\ x_2$
E) $1/2\ (x_1 + x_2)$

Problem 10

A certain metal is found to emit electrons with maximum kinetic energy 5eV when it is illuminated with 200nm light. What is the maximum wavelength light that will cause electrons to be emitted? (3 points)

We have $E^k_{max} = hf - W$ and $f = \frac{c}{\lambda}$, so:

$$E^k_{max} = \frac{hc}{\lambda} - W$$

Then:

$$5eV = \frac{hc}{200nm} - W$$

$$\Rightarrow W = \frac{hc}{200nm} - 5eV$$

$$= \frac{1.24 \times 10^3 eV \cdot nm}{200 nm} - 5eV = 1.2 eV$$

Now the largest wavelength for which electrons are emitted occurs when the photon energy is just equal to the work function. So:

$$E_{min} = W$$

$$\frac{hc}{\lambda_{max}} = W$$

$$\Rightarrow \lambda_{max} = \frac{hc}{W}$$

$$= \frac{1.24 \times 10^3 eV \cdot nm}{1.2 eV} \approx 1.03 \times 10^3 nm.$$

Problem 11

A particle of mass M travels at velocity v in the $+\hat{x}$ direction. At some time, it decays into two photons, one with energy 8 MeV traveling in the $+\hat{x}$ direction, and one with energy 2MeV traveling in the $-\hat{x}$ direction. Determine the velocity v and the mass M of the original particle.

(give v as a fraction of c and M in units of MeV/c^2).

(4 points)

Energy conservation $\Rightarrow$ $E_{before} = E_{after}$

$$\gamma M c^2 = 10 \text{MeV} \quad (1)$$

Momentum conservation $\Rightarrow$ $p_{before} = p_{after}$

$$\gamma M v = -\frac{2\text{MeV}}{c} + \frac{8\text{MeV}}{c}$$

(recall $|\vec{p}| = \frac{E}{c}$ for light)

$$\Rightarrow \gamma M v = \frac{6\text{MeV}}{c} \quad (2)$$

Dividing (2) by (1), we get:

$$\boxed{v = \frac{3}{5} c}$$

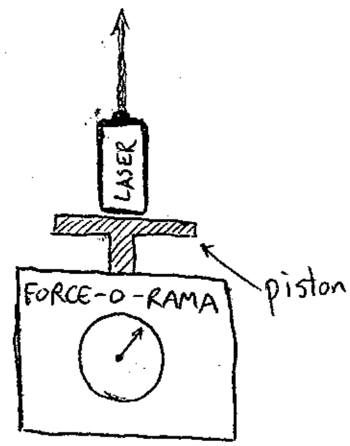
This gives $\gamma = \frac{5}{4}$, so from (1) we get

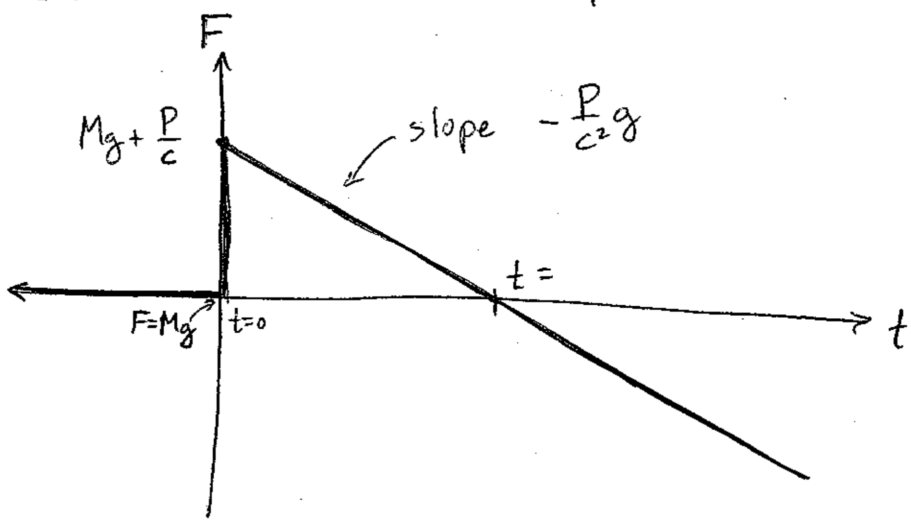
$$\boxed{M = 8 \text{MeV}/c^2}$$

Problem 12

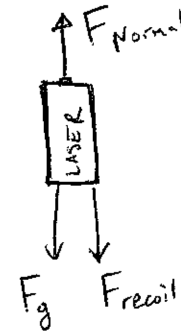
A battery-powered laser with power P has mass M. The laser is placed pointing upwards on a scale that exactly measures the downward force on the piston (initially the scale will read Mg). If the laser is turned on at time t=0, sketch on the graph below what the scale will read in the region t>0. Explain your result, and if possible, give quantitative expressions for any features of your graph (e.g. slope). (2 points)

we'll assume the battery doesn't die (see next page for graph taking that into account)





force diagram:



Once the laser is on, its mass will start decreasing by energy conservation:

$$\frac{d}{dt}\left(E_{laser} + E_{light}\right) = 0$$

$$\Rightarrow c^2 \frac{dM}{dt} + P = 0$$

$$\Rightarrow \frac{dM}{dt} = -\frac{P}{c^2}$$

∴ force of gravity on laser decreases w. time.

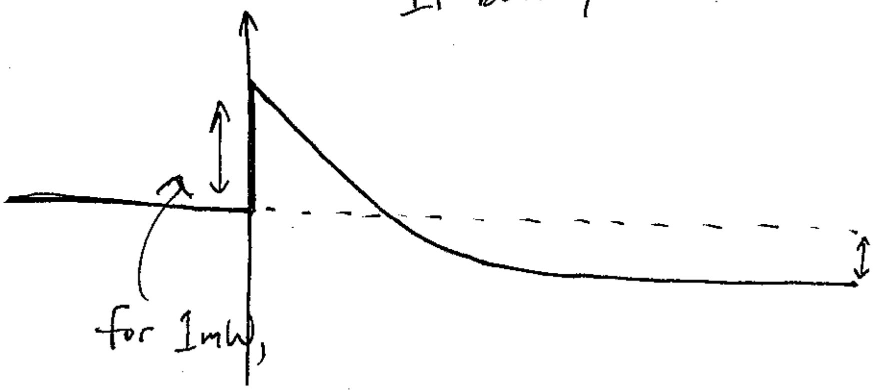
But, there is also a force of "recoil" while the laser is turned on:

Newton's 3rd Law ⇒ $F_{on\ laser} = -\left(\frac{dp_{Light}}{dt}\right) = -\frac{1}{c}\frac{dE_{light}}{dt} = -\frac{P}{c}$

Net force on Laser = force of gravity + recoil force from light + normal force $= 0$ ∴ $|F_{on\ piston}| = |F_{normal}| = g\left(M - \frac{P}{c^2}t\right) + \frac{P}{c}$

scrap

If battery dies:



$$\frac{P}{c} \sim \frac{10^{-3}\,W}{c}$$

In reality: energy stored by battery $\times \frac{g}{c^2}$

$$\approx \frac{1kJ \times 10\,m/s^2}{c \times 3\times10^{8}\,m/s}$$

$$\sim \frac{3\times10^{-5}\,W}{c}$$