** You may use an exam booklet if you need extra space for long answer questions **

Physics 200 Exam
December 17, 2007

Name: ______________________

Student Number: ______________________

45 points available

Multiple Choice: 20 points

Long Answer: 25 points

#1	#2	#3	#4	#5

#6	#7	#8	#9	#10

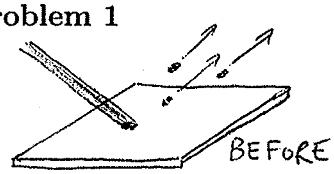
#11	#12	#13	#14	#15

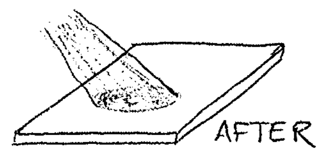
#16	#17	#18	#19	#20

WRITE YOUR MULTIPLE CHOICE ANSWERS HERE!

FORMULA SHEET AT THE BACK

Problem 1

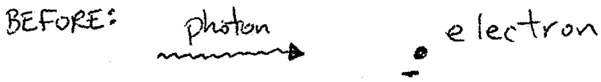




A beam of light incident on a metal has a wavelength such that electrons are emitted via the photoelectric effect. If the beam is adjusted to be more diffuse (keeping the total power fixed), what happens to the current of photoelectrons?

A) it increases
B) it decreases
C) it stays the same

Problem 2



An photon of wavelength λ scatters off an electron that is initially stationary. After the collision, the photon's wavelength will be

A) equal to λ
B) greater than λ
C) less than λ
D) any of the above are possible

Problem 3

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?

A) $|0^\circ\rangle$
B) $|30^\circ\rangle$
C) $|0^\circ\rangle + |90^\circ\rangle$
D) None of the above

Problem 4

The figure above represents the photons in a beam of light with some fixed wavelength and intensity. If size represents photon energy in the picture, which of the pictures below best represents a beam of light with the same wavelength but double the intensity?

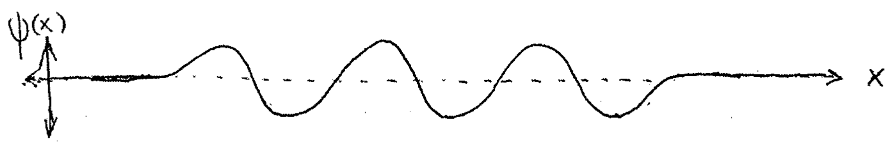
A) 

B) 

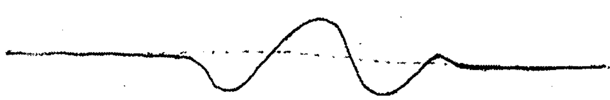
C) 

D) 

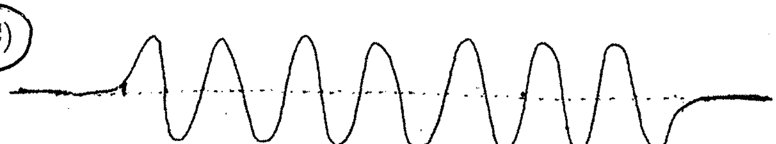
Problem 5



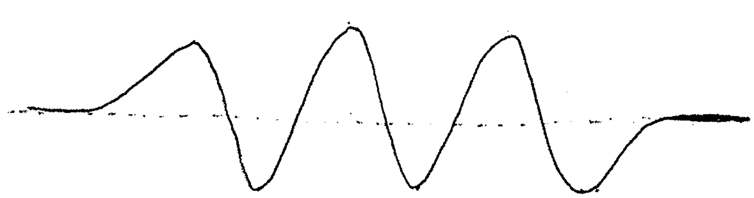
The wavefunction for a traveling electron is described by a wavepacket whose real part is shown above. Which of the following could be the real part of the wavefunction for an electron traveling with double the velocity?

A) 

B) 

C) 

D)



Problem 6

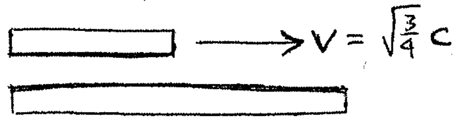
An unstable particle has an average lifetime of 10^{-7} seconds in its rest frame. A beam of these particles is produced with speed 4/5c. How far on average do the particles travel before decaying?

A) 24m
B) 40m
C) 14.4m
D) 30m

$\gamma = \frac{5}{3}$

$10^{-7}s \cdot \gamma \cdot \frac{4}{5} c = 10^{-7} \frac{5}{3} \frac{4}{5} 3 \cdot 10^{8} = 40m$

Problem 7

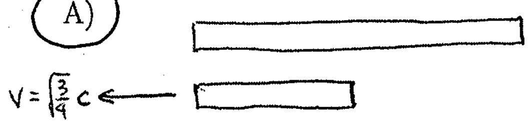


$\gamma = \frac{1}{\sqrt{1-3/4}} = 2$

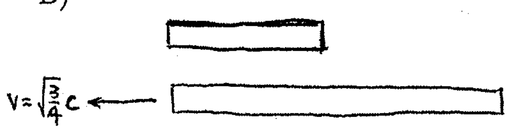
SAME PROPER LENGTH!

The picture above shows two rods, as observed in the frame of the lower rod. Which of the pictures below represents an observation of the same rods in the frame of the upper rod?

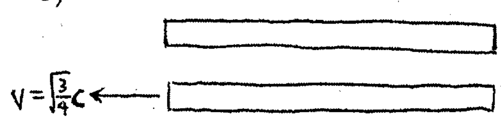
A)



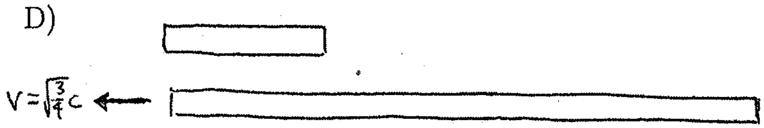
B)



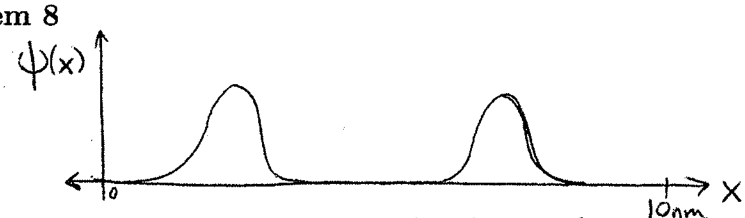
C)



D)



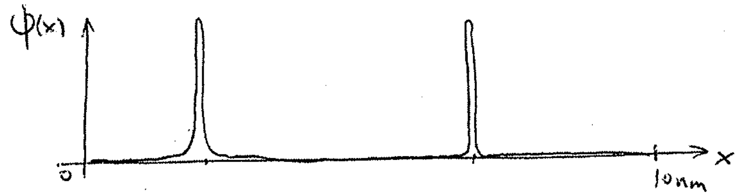
Problem 8



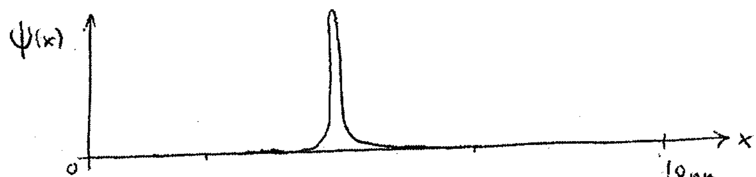
For an electron in a state represented by the wavefunction shown, a measurement of position is performed. Which of the following best represents a possible wavefunction immediately after the measurement?

assume all wavefunctions are normalized.

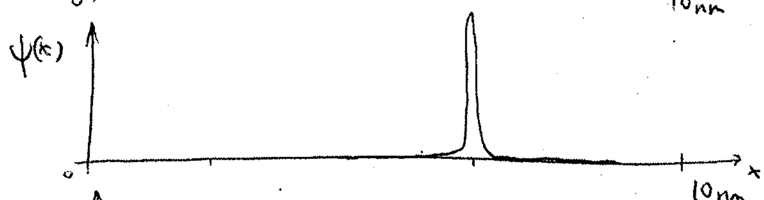
A)



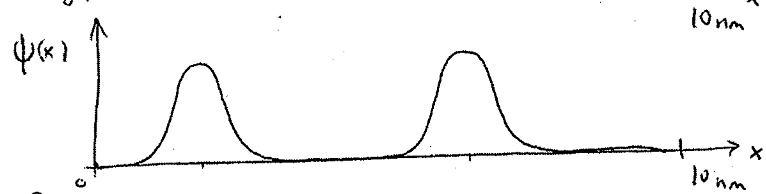
B)



C)



D)



Problem 9

In a double slit experiment with electrons, what happens to the interference pattern if we double the velocity of the electrons?

A) It stays the same.
B) The fringes get further apart.
C) The fringes get closer together.

Problem 10

A nucleus of mass M decays into another nucleus of mass M' by emitting an α-particle. The original mass M is

UNSTABLE!

A) less than $M' + m_\alpha$
B) equal to $M' + m_\alpha$
C) greater than $M' + m_\alpha$

Problem 11

Six photons polarized at 45° to the vertical are incident on a vertical polarizer. How many of the photons will pass through?

A) 0
B) 3
C) 6
D) Any of the above are possible

Problem 12

An electron and a positron (each with mass $0.511\text{MeV}/c^2$) traveling with equal relativistic speeds in opposite directions collide to produce a new particle of mass M. The mass M must be

A) equal to $1.022\text{MeV}/c^2$.
B) greater than $1.022\text{MeV}/c^2$.
C) less than $1.022\text{MeV}/c^2$.

Problem 13

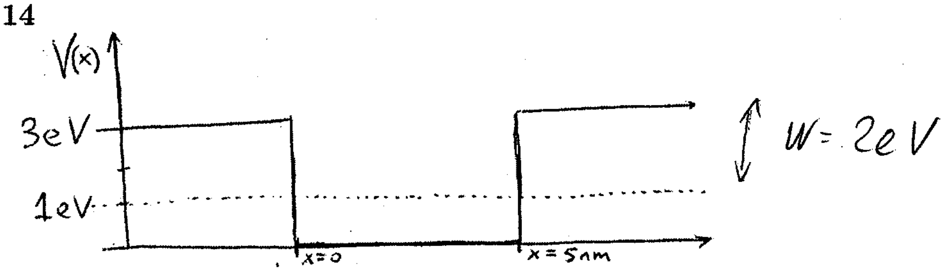
$(10^{-8}c)^2 - 4^2 = 3^2 - 4^2 < 0$

In a certain frame of reference, two small firecrackers explode at times 10^{-8}s apart at locations separated by 4 meters. Which of the following is true:

SPACELIKE

A) There is a frame of reference in which both firecrackers explode at the same time.
B) There is a frame of reference in which both firecrackers explode at the same location.
C) Both A and B are true
D) Neither A nor B are true

Problem 14



The potential energy as a function of x is shown for an electron in a short wire, where $x = 0$ and $x = 5nm$ represent the ends of the wire. If the electron is in a bound state with energy 1eV (corresponding to the dotted line shown), for which photon wavelengths would a photon be capable of liberating the electron from the wire?

A) $\lambda < hc/(1\text{eV})$
B) $\lambda < hc/(2\text{eV})$
C) $\lambda < hc/(3\text{eV})$
D) A photon of any wavelength has some probability of liberating the electron.

Problem 15

An electron in a hydrogen atom is in a state given by a superposition of the two lowest energy eigenstates

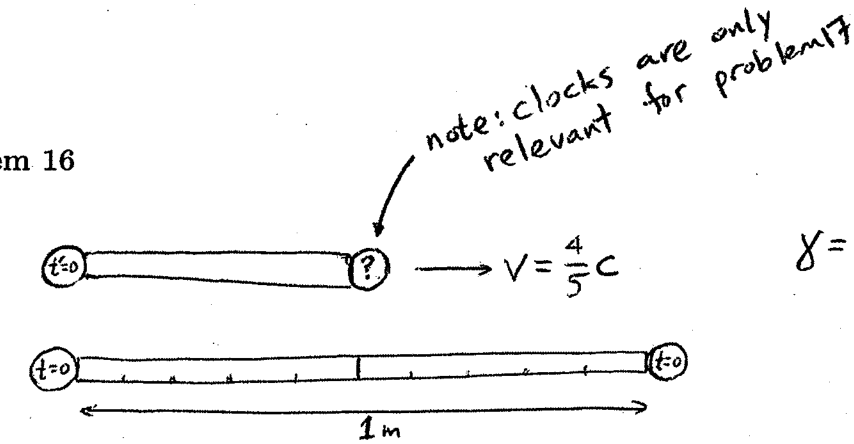
$$\psi(\vec{x}) = \frac{1}{2}\psi_1(\vec{x}) + \frac{\sqrt{3}}{2}\psi_2(\vec{x}) \,.$$

ψ_1 - 1/4
ψ_2 - 3/4 → E_2

where ψ_1 and ψ_2 are the wavefunctions for the states with energies $E_1 = -13.6eV$ and $E_2 = -3.4eV$ respectively. If a measurement of energy is made, the most likely result is

A) -13.6eV
B) -3.4eV
C) $\frac{1}{4}$(-13.6eV) + $\frac{3}{4}$(-3.4eV)
D) either -13.6eV and -3.4eV are equally likely

Problem 16



$\gamma = \frac{5}{3}$

The picture above shows two rods (not necessarily identical) as observed in the frame of the lower rod at $t = 0$. What is the proper length of the upper rod (i.e. the length in its own frame)?

A) 1m
B) $\frac{5}{6}$m
C) $\frac{1}{2}$m
D) $\frac{3}{10}$m

$(\frac{1}{2}m)(\frac{5}{3}) = \frac{5}{6}\ m$

Problem 17

For the picture in the previous problem, what is the clock at the right of the upper rod observed to read if the two clocks on the upper rod are synchronized in the frame of the upper rod?

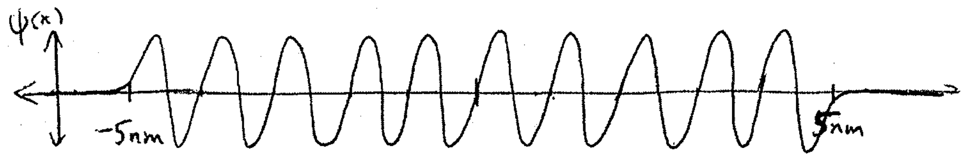
A) 2.22ns
B) -2.22ns
C) 1.4ns
D) -1.4ns

$x = 0.5m \qquad t = 0$

$\tilde{t} = \gamma(t - \frac{xv}{c^2}) = \frac{5}{3}(0 - \frac{0.5 \cdot 4/5}{3 \cdot 10^8})$

$= \frac{0.4 \cdot 5}{9 \cdot 10^8} s = \frac{20}{9} \cdot 10^{-9} s$

Problem 18



The graph above shows the real part of a one-dimensional wavepacket for an electron traveling in a thin wire. For this electron, the uncertainty in position is closest to

Δx

A) 0.5nm
B) 5nm
C) 0
D) $\hbar$

Problem 19

For the electron in the previous problem, the momentum is approximately

A) 6.6×10^{-25} kg m/s
B) 6.6×10^{-26} kg m/s
C) 1.3×10^{-25} kg m/s
D) 1.3×10^{-20} kg m/s

$\lambda = 1$ nm

$p = h/\lambda = \frac{6.6\ 10^{-34}}{10^{-9}}$

Problem 20

For the electron in the previous two problems, the minimum uncertainty in momentum is closest to

A) 10^{-24} kg m/s
B) 10^{-25} kg m/s
C) 10^{-26} kg m/s
D) $\hbar/2$

$\Delta p \sim \frac{\hbar}{2} \frac{1}{\Delta x} = \frac{10^{-34}}{2} \frac{1}{5 \cdot 10^{-9}}$

$= 10^{-34} \cdot 10^{8} = 10^{-26}$

Long Answer Questions: explain your work

Problem 21

Please answer the following as concisely as possible (a couple sentences is sufficient).

a) What is wrong with the classical picture of a Hydrogen atom as an electron orbiting a proton? (2 points)

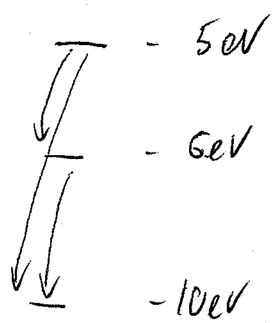
- IT'S UNSTABLE SINCE AN ACCELERATING e^- SHOULD RADIATE & LOSE ENERGY
- IT'S SPECTRUM (EMISSION & ABSORBTION LINES) ARE NOT EXPLAINED

b) How does quantum mechanics resolve the problem? (2 points)

- AN ATOM IN ITS QUANTUM GROUND STATE IS STABLE - NO LOWER STATE TO DECAY TO
- SPECTRAL LINES CAN BE COMPUTED FROM ENERGY LEVELS, WHICH YOU GET FROM TIME-INDEP SCHRÖDINGER EQUATION

Problem 22

The imaginary element Kryptonite is made up of atoms which have three possible bound states, with energies -5eV, -6eV, and -10eV. Which wavelengths are present in the emission spectrum of hot Kryptonite gas? (4 points)



∴ 1 eV
5 eV
4 eV

$$\lambda = c/f = \frac{c}{\Delta E / h} = \frac{hc}{\Delta E}$$

$\Delta E = 1\,eV \Rightarrow \lambda = 1281\ nm$

$\Delta E = 4\,eV \Rightarrow \lambda = 310\ nm$

$\Delta E = 5\,eV \Rightarrow \lambda = 248\ nm$

Problem 23

An electron in a thin wire has a one-dimensional wavefunction given by (don't worry that ψ isn't continuous; assume that this is an approximation to a continuous wavefunction):

$$\psi(x) = \begin{cases} 0 & x < 0 \\ Ae^{\frac{-x}{a}} & x \geq 0 \end{cases} \qquad a = 1\,\text{nm}$$

a) What must the constant A be? (2 points)

$$1 = \int |\psi|^2\, dx = |A|^2 \int_0^\infty e^{-2x/a}\, dx$$

$$= |A|^2 \frac{a}{2}$$

$$\therefore |A|^2 = 2/a = 2\,\text{nm}^{-1}$$

$$A = \left(\sqrt{2\,\text{nm}^{-1}}\right) \times (\text{ARBITRARY PHASE})$$

$$e^{i\theta} \quad \theta \in \mathbb{R}$$

b) If we make a measurement of the electron's position, what is the probability that we will find it in the region $x > 1nm$? (2 points)

$$\int_{1nm}^{\infty} |\psi|^2 \, dx = |A|^2 \int_{1nm}^{\infty} e^{-2x/a} \, dx$$

$$= (2\,nm^{-1}) \frac{a}{2} e^{-\frac{2 \cdot 1nm}{a}}$$

$$= (2\,nm^{-1})(\tfrac{1}{2} 1nm)(e^{-2})$$

$$= e^{-2} = 0.135$$

c) If we do the position measurement a large number of times, with the same initial wavefunction each time, what is the average value of position that we will obtain? (2 points)

$$\langle x \rangle = \int |\psi|^2 x = |A|^2 \int_0^\infty e^{-2x/a} x \, dx$$

$$= \frac{2}{a} \left(\left(-\frac{a}{2}\right) e^{-2x/a} x \Big|_0^\infty - \left(-\frac{a}{2}\right) \int_0^\infty e^{-2x/a} dx \right)$$

$$= \frac{2}{a} \left(\frac{a}{2}\right) \left(\frac{a}{2}\right) = \frac{a}{2} = 0.5 \text{ nm}$$

$\therefore$ AVERAGE x = 0.5 nm

★ QUESTION LOOKS WRONG TO ME...

REPLACE 5000 m/s → 500,000 m/s ?

10 000 m/s → 1,0 00,000 m/s

DOESN'T WORK EITHER

Problem 24

A beam of light of wavelength 400nm is incident on a metal, and photo-electrons are observed with maximum velocity 5000m/s. The same sample of metal is illuminated with a new light source, but this time electrons are observed with maximum velocity 10000m/s. What is the wavelength of the new light source? (4 points)

$\lambda = 400\ nm \Rightarrow E = hf = \frac{hc}{\lambda} = 3.10\ eV$

$E_{KIN}^{MAX} = \frac{1}{2} m_e (5000\ m/s)^2 = E - W$

$7 \cdot 10^{-5}\ eV$ - TOO TINY! ★

AS WRITTEN, THE ANSWER WOULD BE 400nm SINCE THE KINETIC ENERGIES ARE TINY COMPARED TO hf

Problem 25

A photon with energy 100MeV is incident on a stationary particle of mass 200MeV/c^2. If the photon is completely absorbed to form a new particle, what is the speed of this new particle (relative to the speed of light)? (4 points)

100 MeV   200 MeV/c^2

$E = 100\text{ MeV} + 200\text{ MeV} = 300\text{ MeV}$.

$p = 100\text{ MeV}/c$

$E = M\gamma c^2$
$p = M\gamma v$
) AFTER COLLISION

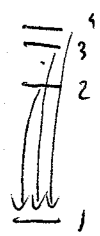
$$v/c = \frac{pc}{E} = \frac{100\text{ MeV}}{300\text{ MeV}} = 1/3$$

$v = 1/3\ c$.

Problem 26

Astronomers observe a cloud of hot atomic hydrogen moving directly away from the Earth at a large velocity. The observed emission spectrum has the usual pattern of spectral lines, but the observed wavelengths are shifted such that the Lyman series (light emitted in transitions to the ground state i.e. $n = 1$) is observed to have lines with wavelengths 320nm, 270nm, 256nm, ... How fast is the hydrogen cloud travelling relative to the Earth? (3 points)

HYDROGEN (IN ITS REST FRAME) HAS ENERGIES $-\frac{13.6\,eV}{n^2}$, SO THE FIRST THREE LYMAN LINES ARE



$\Delta E = 13.6\,eV\,(1 - \frac{1}{4}) = 10\,eV \Rightarrow \lambda = \frac{hc}{\Delta E} = 124\,nm$

$\Delta E = (13.6\,eV)(1 - \frac{1}{9}) = 12.1\,eV \Rightarrow \lambda = 102\,nm$

$\Delta E = (13.6\,eV)(1 - \frac{1}{16}) = 12.75\,eV \Rightarrow \lambda = 97\,nm$

$\lambda' = \underbrace{\gamma\,(1 + V/c)}_{\equiv X}\,\lambda$

$320 = X\,(124) \Rightarrow X = 2.64$

$270 = X\,(102) \Rightarrow X = 2.65$

$256 = X\,97 \Rightarrow X = 2.64$

$X = 2.64 = \gamma(1 + V/c) = \sqrt{\frac{1+V/c}{1-V/c}}$, SQUARE IT!

$6.97 = \frac{1+V/c}{1-V/c} \Rightarrow V/c = \frac{5.97}{7.97} = 0.75$

$V = 0.75\,c$