PHYS 212-01 & 02
Comprehensive Final
8:00 am - Thursday, May 6, 2004

Name Key
Prob. Session Hour ______ **Prob. Session Instr.** ______

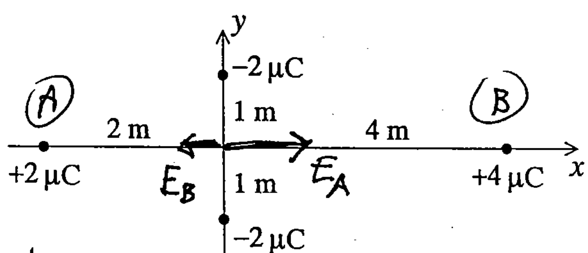
Scores: **Comp** ____ **Lab** ____

<u>Show all work for full credit</u>! Answers must have correct units and appropriate number of significant digits. For all the problems (except for multiple choice questions), start with either (a) a fundamental equation (b) a sentence explaining your approach; or (c) a sketch.

1. (5 pts) Give instructions that are simple and explicit enough for five year olds, telling them how to make an electromagnet that is strong enough to pick up a paper clip using only a battery, a nail, and some wire.

Wrap the wire tightly around the nail many times. Attach one free end of the wire to one end of the battery and the other end of the wire to the other end of the battery

2. (8 pts) The figure shows four charges at various distances from the origin. Calculate the electric field $\vec{E}$ at the origin, due to the four charges shown.



$E = \frac{k|q|}{r^2}$ add as vectors

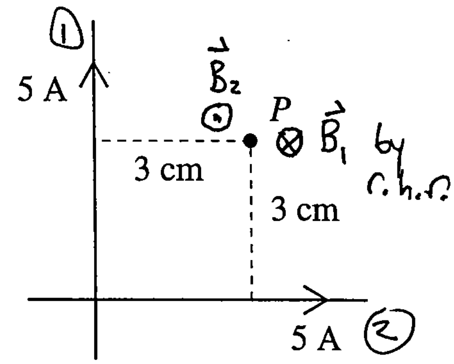
$E_y = 0$ by symmetry

$$E_x = \frac{(9.0\times10^9)(2\times10^{-6}C)}{(2m)^2} - \frac{(9.0\times10^9)(4\times10^{-6}C)}{(4m)^2}$$

$E_x = 4500$ N/C $- 2250$ N/C $= 2250$ N/C

$$\boxed{\vec{E} = 2250 \text{ N/C } \hat{i}}$$

3. (7 pts) The diagram shows two perpendicular wires both carrying a current of 5A. Point P is located a perpendicular distance of 3 cm from each of the wires.



a) Calculate the magnitude of the total magnetic field at point P due to both wires.

Magnitude: $B_{wire} = \frac{\mu_0 I}{2\pi r}$ (assume long, straight wires)

because wires carry same current and P is equidistant, $B_{wire,1} = B_{wire,2}$.

Direction: Right hand rule says $\vec{B}_1$ and $\vec{B}_2$ are opposite, so $\vec{B}_{total} = 0$

b) A charge of 2 C is placed at point P and then released. Ignoring gravity, which is the correct direction for the charge's acceleration upon release? (Circle one.)

↗ ↘ ↙ ↖ ⊙ out of page ⊗ into page (not accelerated)

$\vec{F}_{net} = m\vec{a}$ and $\vec{F} = q\vec{v} \times \vec{B}$, and both $\vec{v}$ and $\vec{B}$ are zero

4. (9 pts) An alpha particle is composed of two protons and two neutrons and has a mass $m = 6.64\times10^{-27}$ kg $= 3.73\times10^{9}$ eV/c^2. The alpha particle is accelerated from rest through an electric potential difference of 10^6 V. Calculate the resulting de Broglie wavelength of the alpha particle. at rest initially

kinetic energy $K = K_f - 0 = W = |q\Delta V| = (2e)(10^6 V) = 2\times10^6 eV$

de Broglie: $\lambda = \frac{h}{p}$ $\quad K = \frac{p^2}{2m} \Rightarrow p^2 = 2mK \quad p = \sqrt{2mK}$

$$\lambda = \frac{hc}{c\sqrt{2mK}} = \frac{hc}{\sqrt{2mc^2K}} = \frac{1240\ eV\cdot nm}{\sqrt{2(3.73\times10^9 eV)(2\times10^6 eV)}}$$

$= \boxed{1.02\times10^{-5}\ nm}$ or 1.02×10^{-14} m

5. (7 pts) Some of the spectral lines of hydrogen are the result of transitions from excited states to the $n = 3$ state. Determine the longest photon wavelength that is the result of such transitions.

longest λ from smallest ΔE, since $\Delta E = \frac{hc}{\lambda}$

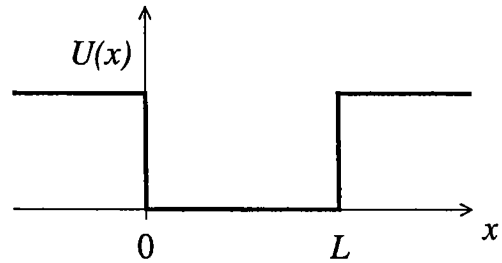
$E_n = -13.6/n^2$ eV for hydrogen $\Rightarrow$ $E_3 = \frac{-13.6}{3^2} = -1.51$ eV

$E_4 = -13.6/4^2 = -0.85$ eV

$\Delta E = 0.66$ eV

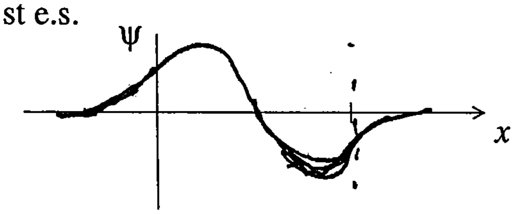
$\lambda = \frac{hc}{\Delta E} = \frac{1240 \text{ eV}\cdot\text{nm}}{0.66 \text{ eV}} = \boxed{1880 \text{ nm}}$

6. (8 pts) A particle is placed in the finite square well illustrated in the diagram.

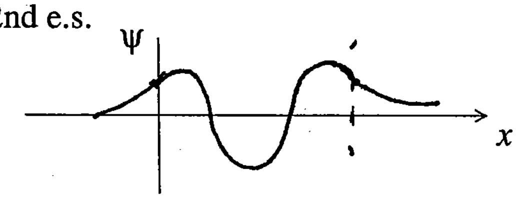


a) In the space provided below, make a qualitatively correct sketch of both the first excited state wavefunction and the second excited state wavefunction.

1st e.s.



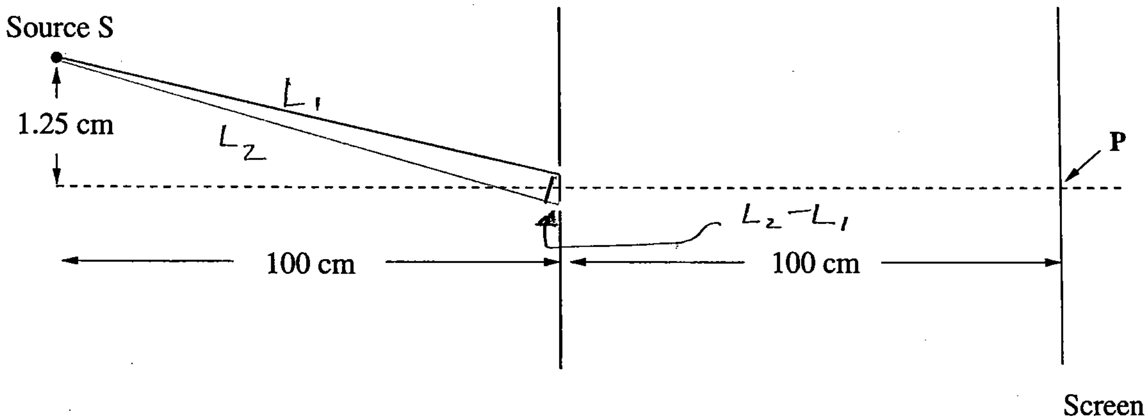
2nd e.s.



b) Your lab assistant prepares the particle so that it is either in the first excited state, or in the second excited state, but does not tell you which. Suppose that you measure the position of the particle and determine that it is exactly $x = L/2$. In which state had your lab assistant prepared the particle?

Second excited state, because $P(x) = |\psi(x)|^2 = 0$ at $x = L/2$ for the 1st excited state.

7. (8 pts) A point source of monochromatic light S illuminates two slits separated by 0.02 mm. Note that the source is *not* on the centerline between the two slits. The wavelength of the light is 500 nm; other dimensions are indicated in the diagram.



NOTE: Figure not drawn to scale.

a) Calculate the path length difference for the light that travels from the source to the upper slit and the light that travels from the source to the lower slit.

$$L_2 - L_1 \approx d \sin\theta \qquad \sin\theta \approx \frac{1.25\,\text{cm}}{100\,\text{cm}} = 0.0125$$

$$= 0.02 \times 0.0125$$

$$= 2.5 \times 10^{-4}\ \text{mm}$$

$$= 2.5 \times 10^{-7}\ \text{m}$$

b) Is there a bright spot or a dark spot at the point **P** at the center of the screen? Justify your answer with quantitative calculations.

$$\Delta\varphi_{total} = \Delta\varphi_L$$

$$= 2\pi \frac{\Delta L}{\lambda}$$

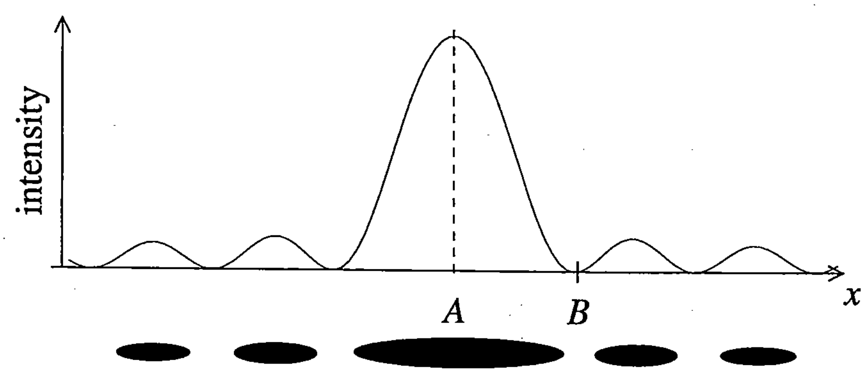
$$= 2\pi \times \frac{2.5\times10^{-7}}{500\times10^{-9}}$$

$$= \pi$$

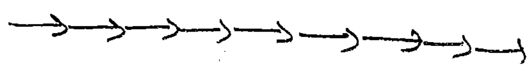
← No path length difference from slits to screen; Only path length difference is ΔL calculated in a).

⇒ Destructive interference ⇒ Dark Spot

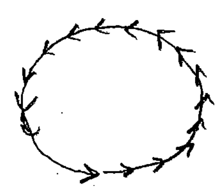
8. (6 pts) Light hits a **single** slit at normal incidence, and the illustrated diffraction pattern is observed on a screen which is 0.5 m away from the slit.



a) Sketch the appropriate phasor diagram for light that hits the screen at point *A*.



b) Sketch the appropriate phasor diagram for light that hits the screen at point *B*.



Individual phasors infinitesimally small.

9. (8 pts) For each of the following terms identify the appropriate descriptions. **More than one may apply.**

Baryon A, C, E
Messenger B, D, F
Lepton C, F
Meson A, B, D
~~Messenger~~ ______

a) Feels the strong force
b) Is a boson
c) Is a fermion
d) Has integer spin
e) Is made up of three quarks
f) Contains no quarks or antiquarks

10. (7 pts) The cosmic microwave background radiation is made up of photons that stopped interacting with matter at some point after the Big Bang.

a) What was the scale of the photons' energy at the time that they stopped interacting with matter? (Circle one)

3   (10 eV)   0.5 MeV   1 GeV   100 GeV 10^{17} MeV

b) Calculate the approximate time after the Big Bang when this occurred.

4   $E \approx \frac{10^6\ \mathrm{eV \cdot s^{1/2}}}{\sqrt{t}} \Rightarrow t = \frac{10^{12}\,\mathrm{eV}}{E^2} = \boxed{10^{10}\ \mathrm{s}}$

others: 0.5 MeV → 4 s; 1 GeV → 10^{-6} s; 100 GeV → 10^{-10} s

10^{17} MeV = 10^{23} eV → $t = 10^{-34}$ s.

11. (6 pts) Sound from two speakers is detected by a microphone. When speaker 1 is on alone, the detected pressure in the sound wave is

$$P_1 = 2.0\times10^{-8}\cos(270t)\ \mathrm{N\cdot m^{-2}}$$

and when speaker 2 is on alone the detected pressure is

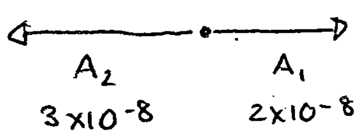
$$P_2 = 3.0\times10^{-8}\cos(270t + 3\pi)\ \mathrm{N\cdot m^{-2}}$$

where t is in seconds. Calculate the amplitude of the total pressure wave at the microphone when both speakers are on.

$$P_{tot} = P_1 + P_2 = 2\times10^{-8}\cos(270t) + 3\times10^{-8}\cos(270t + 3\pi)$$
$$= 2\times10^{-8}\cos(270t) - 3\times10^{-8}\cos(270t).$$
$$= -1\times10^{-8}\cos(270t)$$

⇒ Amplitude = 1×10^{-8} Nm^{-2}

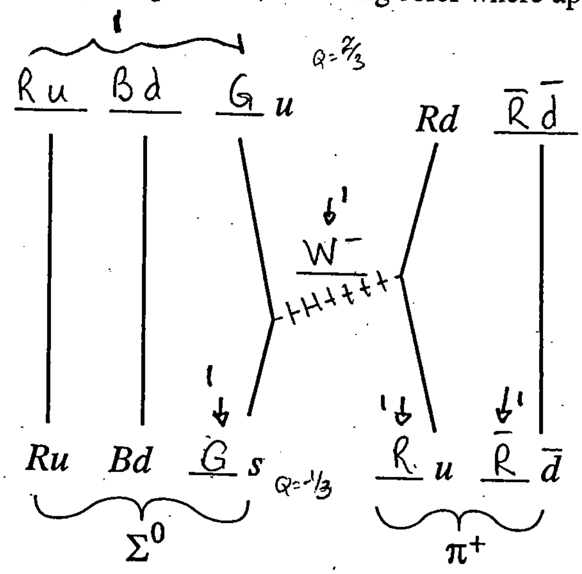
OR use phasors:



resultant has magnitude 1×10^{-8} Nm^{-2}

12. (10 pts)

a) Fill in the missing parts of the following reaction diagram. Include all information necessary to specify fully the particles, including color where appropriate.



2) b) What force is involved in the illustrated interaction? (Circle one.)

Strong Electromagnetic Weak Gravitational Force in Direction of Motion

c) Identify a possible baryon produced in this reaction.

udu ⇒ Q=1 B=1 S=0 ⇒ proton

13. (6 pts) Find the quark content of the following particles.

Q=0 , S=-2 , B=1

a) Ξ^0

u ss

b) Θ^+ pentaquark, with $Q = 1$, $B = 1$, and $S = 1$

dd uus̄

14. (12 pts) The wavefunction of a particle is given as

$$|\psi\rangle = \frac{2}{3}|a\rangle + \frac{1}{3}|b\rangle - \frac{2}{3}|c\rangle,$$

where $|a\rangle$ is a state with energy $E_a = -4\,\text{eV}$, $|b\rangle$ is a state with energy $E_b = -1\,\text{eV}$, and $|c\rangle$ is a state with energy $E_c = 3\,\text{eV}$.

a) Calculate the expectation value for the energy $\langle E \rangle$ of the particle prepared in state $|\psi\rangle$.

$$\langle E \rangle = a_a^2 E_a + a_b^2 E_b + a_c^2 E_c$$
$$= \left(\frac{2}{3}\right)^2(-4\,\text{eV}) + \left(\frac{1}{3}\right)^2(-1\,\text{eV}) + \left(-\frac{2}{3}\right)^2(3\,\text{eV}) = \boxed{-\frac{5}{9}\,\text{eV}}$$

b) If you measure the energy of a particle prepared to be in the state $|\psi\rangle$ given above, what is the probability that you will find the energy to be equal to the expectation value $\langle E \rangle$ you calculated in part b)?

$\boxed{\text{Prob} = 0}$ can only measure $-4\,\text{eV}, -1\,\text{eV}, 3\,\text{eV}$

c) If you measure the energy of a particle prepared to be in the state $|\psi\rangle$ given above, what is the probability that you will find the energy to be 3 eV?

$$\text{Prob} = |a_c|^2 = \left(-\frac{2}{3}\right)^2 = \boxed{4/9}$$

d) If you measure the energy of a particle prepared to be in the state $|\psi\rangle$ given above and find the energy to be 3 eV, what is the probability that a second measurement of the same particle's energy done immediately after the first will yield a value of -1 eV?

State collapses to $|c\rangle$,

So prob of finding $|b\rangle$ is

$\boxed{\text{ZERO}}$

15. (5 pts) The following three decays all occur. Order them from fastest to slowest.

(A) $\pi^+(\bar{d}u) \rightarrow \mu^+ + \nu_\mu$ WEAK - Leptons

(B) $\Sigma^{*0}(sud) \rightarrow \Sigma^+(suu) + \pi^-(\bar{u}d)$ STRONG

(C) $\Sigma^+(usu) \rightarrow n(udd) + \pi^+(\bar{d}u)$ WEAK - Hadrons

Fastest B C A Slowest

16. (8 pts) For each of the reactions below list all of the conservations laws that are **violated,** and determine if the reaction can occur.

Reaction	Violated Conservation Laws	Can Occur? (Yes/No)
$\Delta^+ \rightarrow n + \mu^+ + \bar{\nu}_\mu$	Lepton-μ #	NO
$\Sigma^- \rightarrow \pi^- + n$	Strangeness	YES (weak