SOLUTIONS

Name (please print):
Signature:
Student number:

FACULTY OF PURE AND APPLIED SCIENCE
YORK UNIVERSITY
DEPARTMENT OF PHYSICS AND ASTRONOMY

PHYS 1420 06 – Physics with Applications to Life Sciences
F/W 2009-2010

Final examination

Instructions:

1. Print your name and student number on this page in the upper left corner.
2. Check that your exam contains 7 questions.
3. The total number of marks is 84.
4. Calculators are allowed as aid.
5. Answer all questions in the space provided on this test paper.
6. Formulae are provided on the last page of this paper.

1.	
2.	
3.	
4.	
5.	
6.	
7.	
TOTAL	
%	

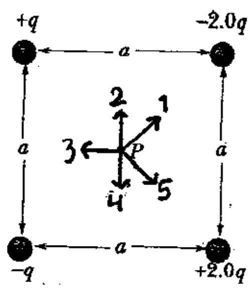
1. (24 marks, 2 marks for each question).

Answer the following twelve multiple-choice questions. Circle the correct answer in the answer table provided below.

a.	1	2	3	4	5
b.	1	2	3	4	5
c.	1	2	3	4	5
d.	1	2	3	4	5
e.	1	2	3	4	5
f.	1	2	3	4	5
g.	1	2	3	4	5
h.	1	2	3	4	5
i.	1	2	3	4	5
j.	1	2	3	4	5
k.	1	2	3	4	5
l.	1	2	3	4	5

a. The direction of the electric field at the center of the square is given by the following vector.

1. 1
2. 2
3. 3
4. 4
5. 5

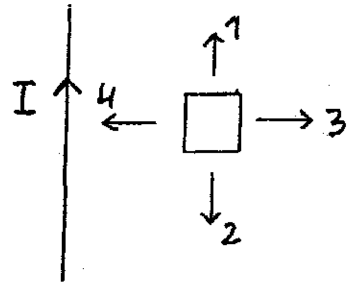


b. If three unequal capacitors are connected in series across a battery, which of the following statements is true?

1. The equivalent capacitance is greater than any of the individual capacitances.
2. The largest voltage appears across the capacitor with the smallest capacitance.
3. The capacitor with the largest capacitance has the greatest charge.
4. The capacitor with the smallest capacitance has the smallest charge.
5. None of the statements is true.

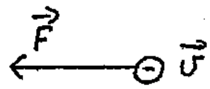
c. A constant current I is passed through the straight wire shown below. In which direction should a rectangular metal loop be pulled so that the induced current in it is clockwise?

1. 1
2. 2
3. 3
4. 4
5. 1 or 2



d. A negatively charged particle has velocity perpendicular to the page, into the page, when a magnetic field (perpendicular to velocity) is switched on at the location of the particle. The magnetic force on the particle is to the left of the page. The direction of the magnetic filed is

1. ↑
2. ←
3. →
4. ↓
5. the force is zero



e. A proton (q = e, m = 1u) and an alpha particle (q = 2e, m = 4u) with the same kinetic energy enter a region of uniform magnetic field **B**, moving perpendicular to **B**. The ratio of the radii of their circular paths, r_p/r_α , is

1. 1/4
2. 1/8
3. 4
4. 8
5. 1

f. Two fields, electric and magnetic, are applied in the same region of space. The electric field is in the positive direction of the x-axis, while the magnetic field is in the positive direction of the y-axis. An electron can move in a straight line in these two mutually perpendicular fields if its velocity (of an appropriate magnitude) is

1. in the positive direction of the z -axis
2. in the negative direction of the z -axis
3. in the negative direction of the x -axis
4. in the positive direction of the y -axis
5. in any direction in the xz plane.

g. What happens to a light wave when it travels from air into glass?

1. Its speed remains the same.
2. Its speed increases.
3. Its wavelength decreases
4. Its wavelength remains the same.
5. Its frequency decreases.

h. Unlike transverse waves, longitudinal waves cannot

1. interfere.
2. diffract.
3. be reflccted.
4. be polarized.
5. produce beats.

i. Some materials are optically active. It means that these materials:

1. absorb light completely.
2. absorb only electric field (but not the magnetic field) of the electromagnetic wave.
3. rotate the plane of polarization of the wave.
4. polarize light.
5. refract light.

j. A student sits in the park measuring sound intensity levels when one radio is playing alone and when two identical radios are playing together (tuned to the same station). By how many dBs is the intensity level larger when both radios are playing together as compared to the case when one radio is on?

1. 3
2. log2
3. 1.3
4. 2
5. 10

h

$10 \log 2 = 3$

k. A double slit is illuminated by light emitted by hydrogen gas contained in a discharge tube. The pattern of colour fringes observed on the screen (taking as a reference the zero order fringe) is

1. red, green, blue, violet
2. violet, red, green, blue
3. green, red, blue, violet
4. blue, red, violet, green
5. violet, blue, green, red

l. When the nucleus of Kr-95 (Z = 36) undergoes beta decay, does the daughter nucleus (Rb) contains

1. 58 neutrons and 37 protons
2. 58 protons and 37 neutrons
3. 54 neutrons and 41 protons
4. 59 neutrons and 36 protons
5. 55 neutrons and 40 protons.

${}^{95}_{36}Kr \longrightarrow {}^{95}_{37}X + {}^{0}_{-1}e$

2. (10 marks).

a. Calculate the electric potential established by the nucleus of a hydrogen atom at the average distance of the circulating electron ($r = 5.29 \times 10^{-11}$ m).

b. What is the electric potential energy of the hydrogen atom (in J and in eV)?

c. Show that the kinetic energy of the hydrogen atom is $KE = ke^2/2r$, where k is the Coulomb's constant and e is the elementary charge $e = 1.6 \times 10^{-19}$ C.

d. What is the total energy (in eV) of the hydrogen atom?

a) $$V = k\frac{q}{r} = \left(9.0\times10^{9}\,\frac{Nm^2}{C^2}\right)\frac{(+1.6\times10^{-19}C)}{5.29\times10^{-11}m} = 27.2\ V.$$

b) $$PE = k\frac{q_1 q_2}{r} = \left(9.0\times10^{9}\,\frac{Nm^2}{C^2}\right)\frac{(+1.6\times10^{-19}C)(-1.6\times10^{-19}C)}{5.29\times10^{-11}m} =$$

$$PE = -4.35\times10^{-18}\,J$$

$$PE = \left(-4.35\times10^{-18}J\right)\left(\frac{1\,eV}{1.6\times10^{-19}C}\right) = -27.2\ eV.$$

c)

$$F = m\frac{v^2}{r}$$

$$k\frac{e^2}{r^2} = m\frac{v^2}{r}$$

$$k\frac{e^2}{r} = mv^2$$

$$KE = \frac{1}{2}mv^2 = \frac{ke^2}{2r}$$

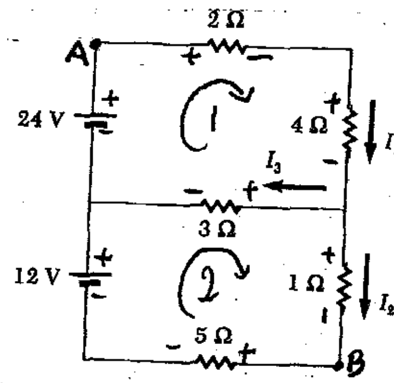
d)

$$\text{TOTAL ENERGY} = PE + KE = (-27.2\,eV) + \left(\frac{27.2\,eV}{2}\right) = -13.6\,eV.$$

3. (10 marks).

For the circuit shown below calculate:

a. the current in all three branches in the circuit.
b. the potential difference between points A and B.
c. the amount of energy released in 4 Ω resistor. IN 1 MINUTE.



JUNCTION RULE : $I_1 = I_2 + I_3$

LOOP 1 : $24 - 2I_1 - 4I_1 - 3I_3 = 0 \Rightarrow 24 - 6I_1 - 3I_3 = 0$

LOOP 2 : $12 + 3I_3 - 1I_2 - 5I_2 = 0 \Rightarrow 12 + 3I_3 - 6I_2 = 0$

$$\begin{cases} I_1 = I_2 + I_3 \\ 24 - 6I_1 - 3I_3 = 0 \\ 12 + 3I_3 - 6I_2 = 0 \end{cases}$$

SOLVING SIMULTANEOUSLY

$I_1 = 3.5 A$
$I_2 = 2.5 A$
$I_3 = 1.0 A$.

b) $V_A - 24 - 12 + 5I_2 = V_B \Rightarrow V_A - V_B = 36 - 5(2.5) = 23.5 V$.

OR

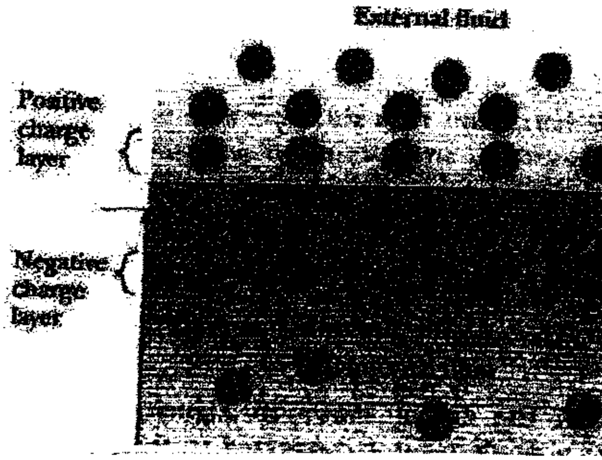
$V_A - 2I_1 - 4I_1 - 1I_2 = V_B \Rightarrow V_A - V_B = 6(3.5) + (2.5) = 23.5 V$

c) $E = I(\Delta V)(\Delta t) = I(IR)\Delta t = I^2 R \Delta t$

$E = (2.5 A)^2 (5 \Omega)(60 s) = 1875 J.$

4. (10 marks).

A neuron can be modeled as a as parallel plate capacitor, where the membranes serves as a dielectric (k = 3.0) and the oppositely charged ions are the charges on the "plates", as shown below.



a. Find the capacitance of neuron assuming that the membrane is 10.0 nm thick and its area is $1.0\text{x}10^{-10}$ m^2.

$$C = \frac{k \varepsilon_o A}{d}$$

$$C = \frac{(3.0)(8.85\times10^{-10}\ \frac{Nm^2}{C^2})(1.0\times10^{-10}\ m^2)}{10.0\times10^{-9}\ m}$$

$$C = 2.7\times10^{-11}\ F$$

b. How many ions (singly charged) are required to establish a potential difference of -70.0 mV across this capacitor?

$$C = \frac{Q}{\Delta V}$$

$$Q = C\Delta V = (2.7\times10^{-11}\ F)(70\times10^{-3}\ V) = 1.9\times10^{-12}\ C$$

$$N = \frac{Q}{e} = \frac{1.9\times10^{-12}\ C}{1.6\times10^{-19}\ C} = 1.2\times10^{7}\ \text{IONS}$$

c. How much net positive charge must flow through the cell membrane (through ion channels) to reach the excited state of +30 .0 mV (from the resting state of -70.0 mV)? How many singly charged ions such as Na^+ is this charge equivalent to?

$$Q = C\Delta V = (2.7\times10^{-11}F)(30-(-70))\,mV$$

$$Q = (2.7\times10^{-11}F)(100\times10^{-3}\ V) = 2.7\times10^{-12}\ C$$

$$N = \frac{Q}{e} = \frac{2.7\times10^{-12}\ C}{1.6\times10^{-19}\ C} = 1.7\times10^{7}\ \text{IONS}$$

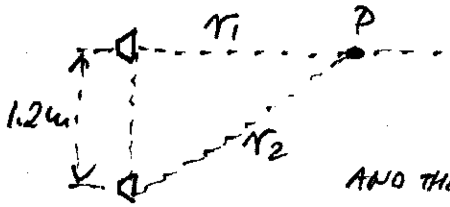
d. If it takes 2.0 ms for the ions to enter the axon, what is the average current in the axon wall in this process?

$$I = \frac{\Delta Q}{\Delta t} = \frac{2.7\times10^{-12}\ C}{2.0\times10^{-3}\ S} = 1.4\times10^{-9}\ A$$

5. (10 marks)

A pair of speakers separated by 1.2 m are driven by the same signal generator at a frequency of 750 Hz. An observer originally positioned at one of the speakers begins to walk along a line perpendicular to the line joining the speakers.

a. How far must the observer walk before reaching a maximum in sound intensity?



$r_2 - r_1 = m\lambda$, $m = 1$, $\lambda = \frac{v}{f}$

$\sqrt{r_1^2+(1.2)^2} - r_1 = \frac{343 \text{ m/s}}{750 \text{ Hz}}$

TAKING r_1 TO THE OTHER SIDE OF THE EQUATION AND THEN SQUARING BOTH SIDES OF THE EQUATION

$r_1^2 + 1.44 = r_1^2 + 0.915 r_1 + 0.209$

$0.915 r_1 = 1.23$

$r_1 = 1.34 \text{ m}$.

b. The observer stops at the position where the sound intensity is maximum. Then the frequency of the sound is slowly increased. At what frequency will the observer hear sound of the minimum intensity?

$r_2 - r_1 = (m + \frac{1}{2})\lambda$, $\lambda = \frac{v}{f}$

$r_2 = \sqrt{r_1^2 + (1.2)^2} = \sqrt{(1.34)^2 + (1.2)^2} = 1.80 \text{ m}$

$1.80 - 1.34 = (m + \frac{1}{2}) \frac{343}{f}$

$f = \frac{(m + \frac{1}{2})(343)}{0.46}$

for $m = 0$, $f = 372.8$ Hz

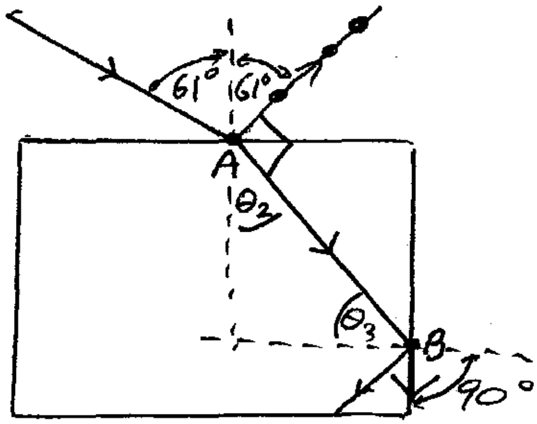
FOR $m = 1$, $f = 1118.5$ Hz.

c. Describe what the observer hears when the two speakers are driven by two different signal generators at frequencies 750 Hz and 755 Hz.

BEATS. (PULSATING SOUND)

6. (10 marks).

Unpolarized red light is incident on a glass plate in the form of a rectangular prism at point A at the Brewster angle of 61^0.



a. Determine the index of refraction of the glass plate.

$n_1 \sin 61^\circ = n_2 \sin \theta_2$

$n_1 = 1.0, \quad \theta_2 = 90 - 61^\circ = 29^\circ$

$1.0 \sin 61^\circ = n_2 \sin 29^\circ$

$n_2 = 1.8$

b. What is the direction of the electric field in the reflected ray of light? Explain.

THE ELECTRIC FIELD IS PERPENDICULAR TO THE REFLECTED RAY OF LIGHT AND PARALLEL TO THE REFLECTING SURFACE

c. Is the Brewster angle for red light the same as for green light? Explain.

NO, THE INDEX OF REFRACTION DEPENDS ON THE WAVELENGTH OF LIGHT (DISPERSION)

d. If the refracted ray of light falls on the side of the prism at point B, will it undergo a total internal reflection? Show calculations.

$\theta_3 = 90 - \theta_2 = 90 - 29^\circ = 61^\circ.$

θ_3 MUST BE GREATER THAN THE CRITICAL ANGLE, WHICH IS FOUND FROM THE FOLLOWING CONDITION

$1.8 \sin \theta_3 = 1.0 \sin 90^\circ$

$\sin \theta_3 = \frac{1.0}{1.8} = 0.555$

$\theta_3 = 33.7^\circ$

$61^\circ > 33.7^\circ \rightarrow$ TOTAL INTERNAL REFLECTION OCCURS AT B.

7. (10 marks).

A patient swallows a drug containing phosphorus-32 (A = 32, Z = 15), which is an electron emitter with half-life of 14.3 days. The initial activity of the sample is 1.31 x10^6 Bq. The kinetic energy of the emitted electron is 700 keV.

a. Determine thc activity after 10-day period.

$$R = R_0 e^{-\lambda t}, \quad R_0 = 1.3\times10^6 \text{ Bq}, \quad \lambda = \frac{\ln 2}{T_{1/2}} = \frac{\ln 2}{14.3 \text{ DAYS}}$$

$$t = 10.0 \text{ DAYS}$$

$$R = (1.31\times10^6 \text{ Bq})\, e^{-\frac{(\ln 2)(10.0 \text{ DAYS})}{(14.3 \text{ DAYS})}} = 0.8\times10^6 \text{ Bq}.$$

b. What was the initial number of phosporus-32 in the sample?

$$R_0 = \lambda N_0, \quad \lambda = \frac{\ln 2}{T_{1/2}}$$

$$T_{1/2} = (14.3 \text{ DAYS})\left(\frac{24 \text{ HR}}{1 \text{ DAY}}\right)\left(\frac{60 \text{ MIN}}{1 \text{ HR}}\right)\left(\frac{60 \text{ s}}{1 \text{ MIN}}\right) = 1235520 \text{ s}$$

$$N_0 = \frac{R_0}{\lambda} = \frac{(1235520 \text{ s})(1.31\times10^6 \text{ Bq})}{\ln 2} = 2.3\times10^{12} \text{ NUCLEI}$$

c. Determine the number of electrons emitted in a 10-day period.

THE ACTIVITY AFTER 10 DAYS IS $R = 0.8\times10^6$ Bq

$$N = \frac{R}{\lambda} = \frac{(0.8\times10^6 \text{ Bq})(1235520 \text{ s})}{\ln 2} = 1.4\times10^{12} \text{ NUCLEI}$$

OR

$$N = N_0 e^{-\lambda t} = (2.3\times10^{12})\, e^{-\frac{(\ln 2)(10)}{14.3}} = 1.4\times10^{12} \text{ NUCLEI}$$

$$N_0 - N = 2.3\times10^{12} - 1.4\times10^{12} = 0.9\times10^{12} \text{ NUCLEI}.$$

d. What is the total energy absorbed by the patient?

$$E = (N_0 - N)(700 \text{ keV}) = (0.9\times10^{12})(700\times10^3 \text{ eV})$$

$$E = 6.3\times10^{17} \text{ eV} = (6.3\times10^{17} \text{ eV})\left(\frac{1.6\times10^{-19} \text{ J}}{1 \text{ eV}}\right) = 1.0\times10^{-1} \text{ J} = 0.1 \text{ J}.$$

e. What is the dose (in rads ~~and in rems~~) if the mass of the patient is 70.0 kg.

$$\text{DOSE} = \frac{E}{m} = \frac{0.1 \text{ J}}{(70.0 \text{ kg})} = 1.4\times10^{-3} \text{ Gy} =$$

$$= (1.4\times10^{-3} \text{ Gy})\left(\frac{1 \text{ RAD}}{10^{-2} \text{ Gy}}\right) = 14 \text{ RAD}.$$

THE END.

$\bar{v} = \frac{\Delta x}{\Delta t}$, $v = \frac{dx}{dt}$, $a = \frac{\Delta v}{\Delta t}$, $a = \frac{dv}{dt}$

$\sum \vec{F} = m\vec{a}$, $a = \frac{v^2}{r}$

$F = k\frac{q_1 q_2}{r^2}$, $k = 9.0 \times 10^9 \frac{Nm^2}{C^2}$, $\vec{E} = \frac{\vec{F}}{q}$, $E = k\frac{q}{r^2}$

$E = \frac{Q}{\varepsilon_0 A}$, $\varepsilon_0 = 8.85 \times 10^{-12} \frac{C^2}{Nm^2}$,

$\Delta PE = -qE\Delta x$, $\Delta V = \frac{\Delta PE}{q}$, $\Delta V = -E\Delta x$, $V = k\frac{q}{r}$

$PE = \pm k\frac{q_1 q_2}{r}$

$C = \frac{Q}{\Delta V}$, $C = \frac{k\varepsilon_0 A}{d}$, $E = \frac{1}{2}Q\Delta V = \frac{1}{2}C(\Delta V)^2 = \frac{Q^2}{2C}$

$q = Q_0(1 - e^{-t/RC})$, $q = Q_0 e^{-t/RC}$, $\tau = RC$

$C_{eq} = \sum C_i$, $\frac{1}{C_{eq}} = \sum \frac{1}{C_i}$

$I = \frac{\Delta Q}{\Delta t}$, $Q = Ne$, $e = 1.6 \times 10^{-19} C$, $\Delta V = IR$

$R = \rho\frac{l}{A}$, $P = (\Delta V)I$, $P = \frac{E}{\Delta t}$, $R_{eq} = \sum R_i$, $\frac{1}{R_{eq}} = \sum \frac{1}{R_i}$

$B = \frac{\mu_0 I}{2\pi r}$, $B = \frac{\mu_0 I}{2R}$, $B = \frac{\mu_0 N I}{L}$, $\mu_0 = 4\pi \times 10^{-7}\ Tm/A$

$F_B = qvB\sin\theta$, $\vec{F}_B = q\vec{v} \times \vec{B}$, $F_B = BIL\sin\theta$, $\vec{F}_B = I\vec{L} \times \vec{B}$

$\mathcal{E} = -N\frac{d\Phi}{dt}$, $\Phi = BA\cos\theta$, $\Phi = \vec{B}\cdot\vec{A}$

$v = \lambda f$, $v = \sqrt{\frac{F}{\mu}}$, $v = \sqrt{\frac{B}{\rho}}$, $I = \frac{P}{A}$, $I = \frac{P}{4\pi r^2}$, $V = 343\ m/s$

$\beta = 10\log\frac{I}{I_0}$, $I_0 = 1.0 \times 10^{-12} \frac{W}{m^2}$

$r_2 - r_1 = n\lambda$, $r_2 - r_1 = (n + \frac{1}{2})\lambda$, $n = 0, 1, 2, \ldots$, $E = hf$

$h = 6.63 \times 10^{-34} J\cdot s$

$n = \frac{c}{v}$, $n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\sin\theta_m = \frac{m\lambda}{d}$, $\sin\theta_m = \frac{(m + \frac{1}{2})\lambda}{d}$

$R = \frac{\Delta N}{\Delta t} = \lambda N$, $N = N_0 e^{-\lambda t}$, $R = R_0 e^{-\lambda t}$, $T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$

$DOSE = \frac{ENERGY}{MASS}$, DOSE IN REM = (DOSE IN RAD) × (RBE).

$1u = 931.5\ MeV$ DOSE IN SV = (DOSE IN GY) × (RBE)