Name: ____________________________________ Class: 13S __________

VICTORIA JUNIOR COLLEGE
2014 JC2 PRELIMINARY EXAMINATION

PHYSICS **9646/3**
Higher 2
Paper 3

23/9/2014 **1400h – 1600h**
TUESDAY **(2 Hours)**

This paper consists of two sections:

Section A (40 marks) consists of 4 short structured questions. Write your answers in the spaces provided for each question.

Section B (40 marks) consists of 3 long structured questions. Answer ***any*** two questions. Write your answers in the spaces provided for each of the chosen questions.

The intended marks for each question or part question in sections A and B are given in brackets [ ].

N.B. You will hand in the whole question set issued to you at the end of the examination. Do not separate the question set into parts.

For marker's use	
Section A	
Q1	
Q2	
Q3	
Q4	
Section B	
Q5	
Q6	
Q7	
s.f.	
units	
Total (80)	

This question set consists of a total of 19 printed pages.

Data

speed of light in free space,	$c = 3.00 \times 10^{8}$ m s^{-1}
permeability of free space,	$\mu_o = 4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space,	$\varepsilon_o = 8.85 \times 10^{-12}$ F m^{-1} $(1/(36\pi)) \times 10^{-9}$ F m^{-1}
elementary charge,	$e = 1.60 \times 10^{-19}$ C
the Planck constant,	$h = 6.63 \times 10^{-34}$ J s
unified atomic mass constant,	$u = 1.66 \times 10^{-27}$ kg
rest mass of electron,	$m_{\mathrm{e}} = 9.11 \times 10^{-31}$ kg
rest mass of proton,	$m_{\mathrm{p}} = 1.67 \times 10^{-27}$ kg
molar gas constant,	$R = 8.31$ J mol^{-1} K^{-1}
the Avogadro constant,	$N_A = 6.02 \times 10^{23}$ mol^{-1}
the Boltzmann constant,	$k = 1.38 \times 10^{-23}$ J K^{-1}
gravitational constant,	$G = 6.67 \times 10^{-11}$ N m^{2} kg^{-2}
acceleration of free fall,	$g = 9.81$ m s^{-2}

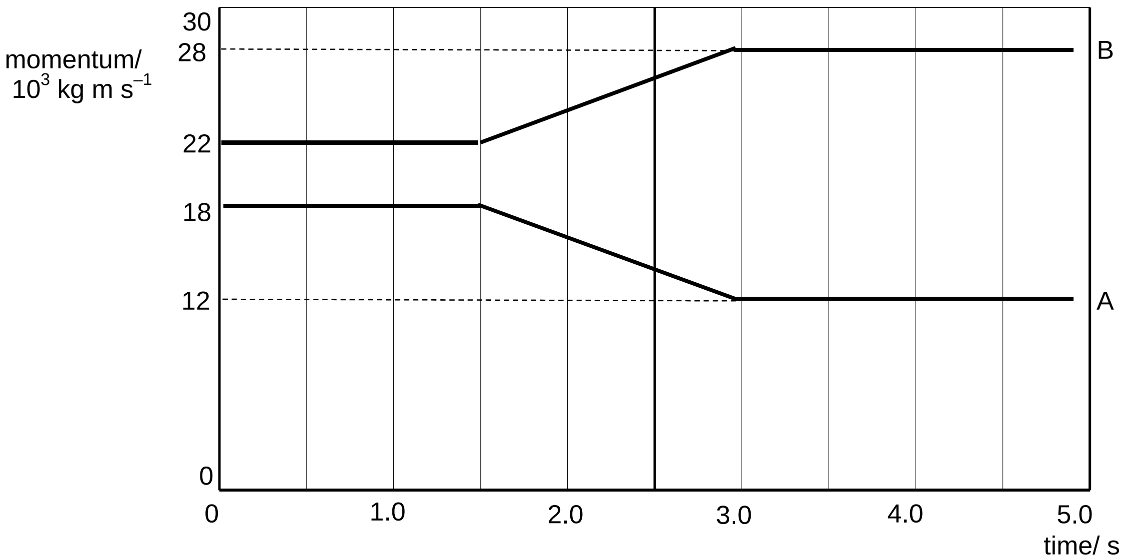
Formulae

uniformly accelerated motion,	$s = ut + \frac{1}{2} at^2$ $v^2 = u^2 + 2as$
work done on/by a gas,	$W = p\Delta V$
hydrostatic pressure,	$p = \rho gh$
gravitational potential,	$\phi = -\frac{GM}{r}$
displacement of particle in s.h.m.,	$x = x_o \sin \omega t$
velocity of particle in s.h.m.,	$v = v_o \cos \omega t$ $= \pm \omega \sqrt{(x_o^2 - x^2)}$
mean kinetic energy of a molecule of an ideal gas	$E = \frac{3}{2} kT$
resistors in series,	$R = R_1 + R_2 + \ldots$
resistors in parallel,	$1/R = 1/R_1 + 1/R_2 + \ldots$
electric potential,	$V = \frac{Q}{4\pi\varepsilon_0 r}$
alternating current/voltage,	$x = x_o \sin \omega t$
transmission coefficient,	$T \propto \exp(-2kd)$ where $k = \sqrt{\frac{8\pi^2 m(U-E)}{h^2}}$
radioactive decay,	$x = x_o \exp(-\lambda t)$
decay constant,	$\lambda = \frac{0.693}{t_{\frac{1}{2}}}$

Section A

Answer **all** the questions in this section.

1 The graph below shows the momentum against time graphs for two colliding lorries A and B.



The masses of lorries A and B are 2.0 x 10^3 kg and 4.0 x 10^3 kg respectively.

(a) State what the gradients of the graphs during the collision represent. [1]

(b) Explain why the gradients of the graphs during the collision have *opposite* signs. [1]

(c) Calculate the force acting on lorry B during the collision. Hence, or otherwise, calculate the force acting on lorry A during the collision. [2]

(d) Use Newton's laws of motion to explain whether momentum is conserved in this collision. [3]

(e) Calculate the *change* in the kinetic energy of the system and hence deduce whether the collision is elastic or inelastic. [3]

2(a) Distinguish between electrical resistance and resistivity. [4]

(b) The Nile fish (*Gnathonemus*) is capable of producing an electric field in the water around itself (refer to the figure below). This field causes current to flow in the conducting seawater. As the fish swims, it passes near objects that have resistivities different from that of seawater, which in turn causes the current to vary. Cells in the skin of the fish are sensitive to this changing current.

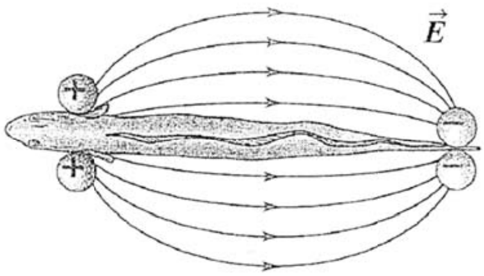


Figure 2. The electric field created around a Nile fish

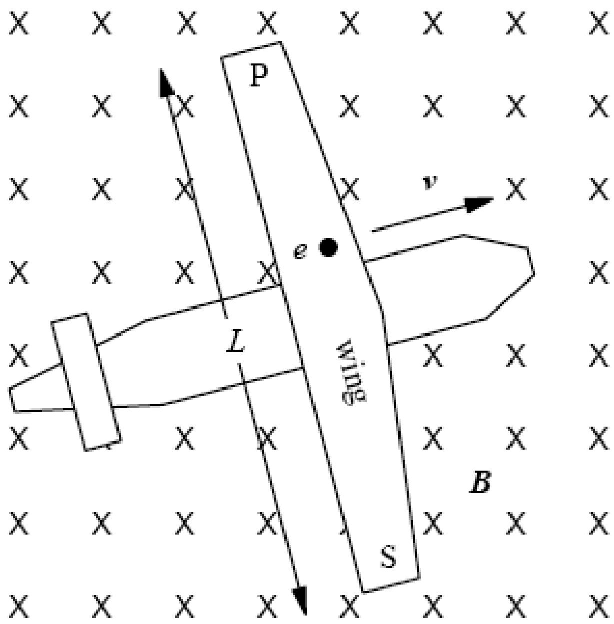
We can model the seawater through which that electric field passes as a conducting tube of cross-sectional area 1.0 cm^2 and having a potential difference of 3.0 V across its ends. The length of a Nile fish is about 20 cm, and the resistivity of seawater is 0.13 Ω m.

(i) Show that the resistance of the conducting tube of seawater is 260 Ω. [1]

(ii) Calculate the current through the tube of seawater. [1]

(iii) Suppose the fish swims next to a cylindrical object that is 10 cm long and 1.0 cm^2 in cross-sectional area and has half the resistivity of seawater. This object replaces the seawater for half the length of the original tube. Calculate the current through this new tube now. [3]

3 A jet aeroplane is flying with velocity ***v*** at right angles to the Earth's magnetic field ***B*** near the North pole of the Earth, as shown in the plan view below. The plane's wingspan (distance between wingtips) is *L*. The wingtips are labelled P (port) and S (starboard).



(a) Consider an electron of charge magnitude *e* in the metal wing of the plane at the point shown by a dot in the figure.

(i) Draw a vector on the diagram to represent the magnetic force that this electron will experience due to its motion in the magnetic field. Label the force as *F*. [1]

(ii) State an expression for the magnitude of the force on the electron in this situation. [1]

(iii) Hence explain why an electric field will be formed across the wing, and draw a vector in the diagram to show its direction. Label the field as *E*. [2]

(b) While the plane is flying steadily in the magnetic field, the electrons in the wing experience the magnetic force in a(ii) but do not move along the wing; such motion is opposed by the *electric* field in a(iii) arising in the wing.

(i) Explain why the electric force on the electron is **exactly** equal to the magnetic force, in this situation. [2]

(ii) If the plane is flying at a speed of 720 km h^{-1} and the magnetic flux density of the earth B is 5.0 x 10^{-5} T, calculate the electric field that will be set up in the wings of the aeroplane. [2]

4(a) A source of ultra-violet radiation illuminates a zinc plate and is placed beneath a piece of gauze as shown in Fig 4.1.
Photoelectrons are attracted to the gauze because of the potential difference between the plate and the gauze.
When V is varied, it is found that the photo current varies as shown in Fig 4.2.
When the intensity of light is I_1, graph A is obtained. When the intensity is increased to I_2, graph B is obtained.

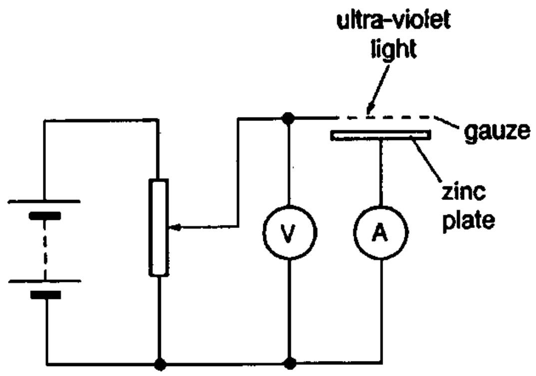


Fig 4.1

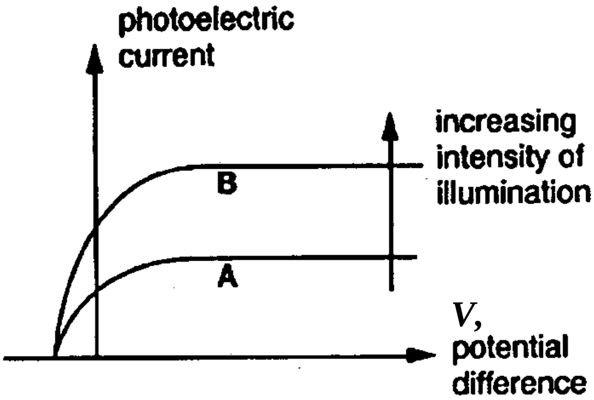


Fig 4.2

(i) Explain why curve A has a lower maximum value of photoelectric current than curve B. [2]

(ii) The battery connections are now reversed such that the potential difference is made negative. Explain why the photocurrent diminishes to zero as the potential difference is made more negative. [2]

(iii) Explain why the negative value of V where the photocurrent is zero remains the same for both curve A and curve B. [2]

(iv) Given that the work function of the zinc plate is 4.3 eV and the wavelength of light used is 1.0×10^{-8} m, calculate the value of the negative potential difference that is required to reduce the photocurrent to zero. [2]

(b) It has been shown that using a suitable crystal lattice, the diffraction of particles such as electrons can be observed.

(i) Calculate the kinetic energy of an electron that has been accelerated through a potential difference of 2500 V. [1]

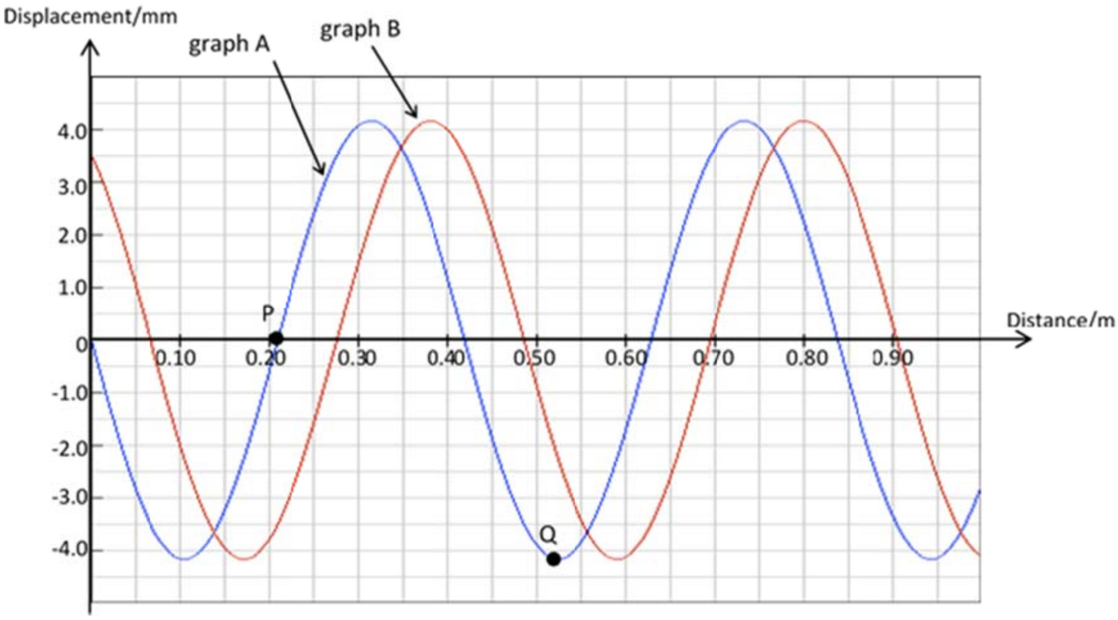
(ii) Calculate the de Broglie wavelength of the electron in part(i) [2]

(iii) Hence explain why, for an electron that has been accelerated through a potential difference of 2500 V, a diffraction pattern cannot be observed with a typical diffraction grating of 300 lines per mm. [2]

Section B

Answer **two** questions from this section.

5(a) Graph A shows the displacement at time $t = 0$ at different points on a longitudinal progressive sound wave that is travelling to the right. Positive displacement is taken to be to displaced to the right. Graph B shows the wave at $t = 0.20$ ms.



(i) Explain what is meant by longitudinal progressive wave. [2]

(ii) Mark on graph B

1. a point C where it is a region of compression (high pressure).
2. a point N where it is a region of normal pressure. [2]

(iii) Use graphs A and B to determine, for the wave [6]

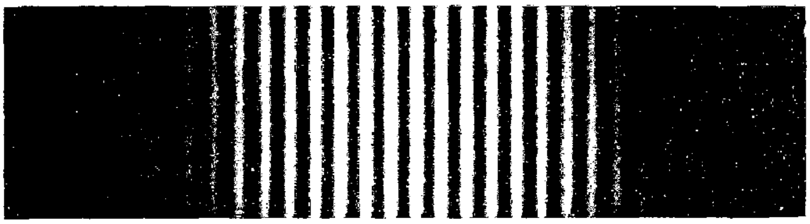
1. the wavelength

2. the wave speed

3. the frequency of the wave

4. the phase difference between points P and Q marked on graph A.

(b) The diagram below shows a full-scale photograph of an interference pattern produced when monochromatic light falls on a pair of slits 0.30 mm apart. The pattern was produced on a screen 1.5 m from the slits.



(i) State the principle of superposition and use this principle to explain why such an interference pattern is produced when light falls on a pair of closely spaced slit. [3]

(i) Use the photograph to obtain a value for the fringe spacing. Show your working clearly. [2]

(iii) Calculate the wavelength of the light used. [2]

(iv) Explain why the fringes near the centre of the photograph are brighter than those near the edges of the photograph. [2]

(v) Sketch the pattern which would be obtained on the screen if one of the slits were covered up. [1]

6 When a neutron is captured by a Uranium-235 nucleus, it causes the nucleus to undergo fission. The large amount of energy released in such a nuclear fission reaction has made it possible for neutron-induced fission to be used as a source of useful energy.

One such reaction is: $^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{144}_{56}\mathrm{Ba} + {}^{90}_{36}\mathrm{Kr} + 2\mathrm{X}$

(a) (i) Identify the particle represented by the symbol X. [1]

(ii) The binding energy per nucleon of Uranium-235 is approximately 7.5 MeV and that of Barium-144 and Krypton-90 is approximately 8.5 MeV. Determine the energy released in this nuclear reaction. [2]

(b) In a nuclear power station, 25% of the energy released in the fission process is converted into electrical energy. Assume that 230 MeV of energy is released from the fission of each Uranium-235 nucleus. Calculate, for the fission of 1.0 kg of Uranium-235,

(i) the number of nuclei in 1.0 kg of Uranium-235, [2]

(ii) the electrical energy generated, [2]

(iii) the average power output of the power station if the uranium is fissioned in a time of 24 hours. [2]

(iv) The energy released in a fission reaction occurs partly as kinetic energy of the fission products and of the neutrons. Suggest one other mechanism by which energy is released in a fission reaction. [1]

(c) The fission products are usually radioactive and give rise to a series of radioactive decay products. Each decay product has its own half-life, but eventually a stable nuclide is reached. Two such fission products with their decay products and half-lives are shown below.

$$^{99}_{42}\text{Mo} \xrightarrow{\text{67 hours}} {}^{99}_{43}\text{Tc} \xrightarrow{2\times10^{5}\text{ years}} {}^{99}_{44}\text{Ru (stable solid)}$$

$$^{140}_{54}\text{Xe} \xrightarrow{\text{16 seconds}} {}^{140}_{55}\text{Cs} \xrightarrow{\text{1.1 minutes}} {}^{140}_{56}\text{Ba} \xrightarrow{\text{13 days}} {}^{140}_{57}\text{La} \xrightarrow{\text{40 hours}} {}^{140}_{58}\text{Ce (stable solid)}$$

(i) If the original amount of $^{99}_{42}\text{Mo}$ undergoes a certain number of decays in one second today, calculate how long it will take the same source to undergo the same number of decays 30 days later. [3]

(ii) Consider equal numbers of atoms of the two fission products, $^{99}_{42}\text{Mo}$ and $^{140}_{54}\text{Xe}$. Explain why there are very different problems for the storage of this nuclear waste and suggest ways to overcome these problems. [4]

(d) The function of a moderator in a fission reactor is to slow down fast neutrons. The neutrons collide with the nuclei of the moderator and transfer some of their kinetic energy to them. This process can be modelled by considering a neutron of mass *m* colliding elastically with a moderator nucleus of mass *M*. The fraction *F* of the initial kinetic energy of the neutron transferred to the moderator nucleus is given by

$$F = \frac{4m}{M}\left(1+\frac{m}{M}\right)^{-2}.$$

Both deuterium ($^{2}_{1}\mathrm{H}$) and carbon ($^{12}_{6}\mathrm{C}$) are used in moderators. State which of these nuclei would be expected to be the more efficient in slowing down neutrons. Explain your answer. [3]

7(a)

The energy diagram shows the simplified representation of the 5 lowest energy levels of the outermost electrons in the sodium atom.

(i) By considering the transitions between these energy levels, state how many spectral emission lines might be produced by transitions among these levels. [1]

(ii) Electrons moving at a speed of 1.09×10^{6} m s^{-1} are now introduced into a sample of sodium atoms at ground state. Calculate the possible frequencies of light visible in the emission spectra. [3]

(iii) Energy level 2 is actually made up of two closely spaced sub levels (such that they appear as a single line on the diagram). Two bright yellow lines are visible in the emission spectra of sodium at 589.0 and 589.6 nm. Calculate the energy difference between these two sub levels and state the other energy level which is involved in the production of the two bright lines. [2]

(iv) A young astronomer proposes that the Sun contains sodium vapour in its atmosphere. Suggest a simple method to verify his hypothesis using line spectra. [2]

(b) A pulse of gamma radiation lasts for 1.0×10^{-4} s. A photon of gamma radiation may be assumed to be at any point within the pulse, although the location is unknown.

(i) Calculate the uncertainty in the position of the photon. [2]

(ii) Hence calculate the uncertainty in the momentum of the photon. [3]

(c) The scanning tunnelling microscope (STM) is widely used in both industrial and fundamental research to obtain atomic-scale images of metal surfaces. It provides a three-dimensional profile of the surface which is very useful for characterising surface roughness, observing surface defects, and determining the size and conformation of molecules and aggregates on the surface.

(i) Describe the application of quantum tunnelling to the probing tip of a scanning tunnelling microscope (STM) and how it is used to obtain atomic-scale images of sample surfaces. (You should only describe one of the operating modes) [4]

(ii) In a particular case study, the ability of an electron to tunnel across a 4.0 eV potential barrier of width d is being investigated. When electrons of energy 1.0 eV approach the gap (barrier), the probability of successful tunnelling is T. If the width d of the gap is increased by 10 %, determine the new value of the energy E' of the electrons such that the probability of successful tunnelling remains at the same value T. [3]

End of paper