VICTORIA JUNIOR COLLEGE
2022 JC2 PRELIMINARY EXAMINATIONS
Higher 2

Name : ____________________________ CT group : _________________

PHYSICS **9749 / 02**

Paper 2 Structured Questions

8 – 10 am

Candidates answer on the Question Paper. **2 Hours**

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your name and CT group at the top of this page.

Write in dark blue or black pen on both sides of the paper.

You may use a soft pencil for any diagrams or graphs.

Do not use staples, paper clips, highlighters, glue or correction fluid.

The use of an approved scientific calculator is expected, where appropriate.

Answer **all** questions.

At the end of the examination, fasten all your work securely together.

The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use	
1	
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Total (max. 80)	

This question set consists of a total of **16** 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,	$m_e = 9.11 \times 10^{-31}$ kg
rest mass of proton,	$m_p = 1.67 \times 10^{-27}$ 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,	$s = ut + (½)\ at^2$ $v^2 = u^2 + 2as$
work done on/by a gas,	$W = p\Delta V$
hydrostatic pressure,	$p = \rho gh$
gravitational potential,	$\varphi = -\frac{GM}{r}$
temperature	$T / K = T / °C + 273.15$
pressure of an ideal gas	$p = \frac{1}{3}\frac{Nm}{V}\langle c^2 \rangle$
mean translational kinetic energy of an ideal gas molecule	$E = \frac{3}{2}kT$
displacement of particle in s.h.m.,	$x = x_o \sin \omega t$
velocity of particle in s.h.m.,	$v = v_o \cos \omega t$ $= \pm\omega\sqrt{(x_o^2 - x^2)}$
electric current	$I = Anvq$
resistors in series,	$R = R_1 + R_2 + \ldots$
resistors in parallel,	$1/R = 1/R_1 + 1/R_2 + \ldots$
electric potential,	$V = Q/4\pi\varepsilon_0 r$
alternating current/voltage,	$x = x_o \sin \omega t$
Magnetic flux density due to a long straight wire	$B = \frac{\mu_0 I}{2\pi d}$
Magnetic flux density due to a flat circular coil	$B = \frac{\mu_0 NI}{2r}$
Magnetic flux density due to a long solenoid	$B = \mu_0 nI$
radioactive decay,	$x = x_o \exp(-\lambda t)$
decay constant,	$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$

Answer **all** questions in the spaces provided

1(a) A massive truck is parked along the roadside on a flat surface. Adam pushes the truck, and it does not move. He justifies this by saying that the two forces that he and the truck exert on each other are equal and opposite, so they cancel out each other. Using Newton's laws of motion, comment on his explanation and explain why the truck does not move. [4]

(b)(i) State the principle of conservation of momentum. [1]

(ii) In Figure 1.1 below, an 80 kg man is on a ladder hanging from a balloon that has a total mass of 320 kg (including the basket passenger). The balloon is initially stationary relative to the ground. The man on the ladder begins to climb at 2.5 m s^{-1} as seen by an observer on the ground.

Fig. 1.1

(1) Determine the speed and direction that the balloon moves at. [3]

(2) The man decides to stop climbing. State the speed of the balloon. [1]

2(a) Figure 2.1 shows a light spring of a spring constant k = 160 N m^{-1} rests vertically on the bottom of a large beaker of water. A 5.0 kg block of wood, with a density of 650 kg m^{-3}, is connected to the spring, and the block-spring system is allowed to come to a static equilibrium. The block of wood has two-thirds of its volume partially submerged in the water. Density of water is 1000 kg m^{-3}.

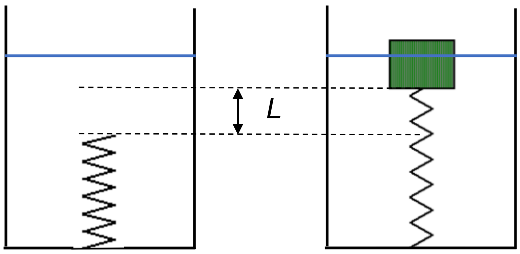
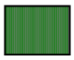


Figure 2.1

(i) Using the figure below, draw and label clearly all the forces exerting on the block of wood. [2]



(ii) Determine L. [3]

(b) A 1200 N uniform boom AC is supported by a cable perpendicular to the boom as shown in Figure 2.2. The cable joins the boom at point B where BC = $\frac{AC}{4}$. The boom is hinged at the bottom, and a 2000 N weight hangs from its top.

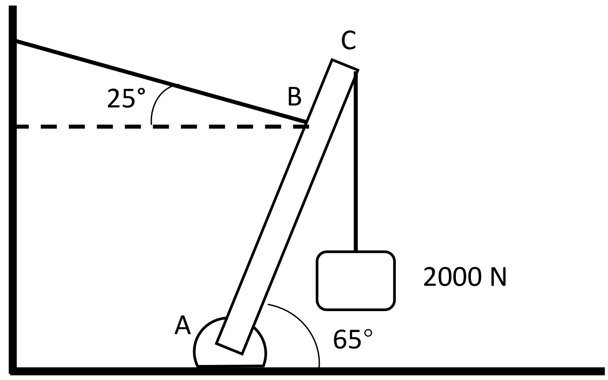


Figure 2.2

(i) Determine the tension in the supporting cable. [3]

(ii) Explain why the force acting on the boom at the hinge is not vertical. [2]

3. 350 g of liquid water at 100 °C is turned into steam at 100 °C at an atmospheric pressure of 1.0×10^5 Pa.
[Density of water = 1000 kg m^{-3};
Mass of one mole of water molecules = 18 g;
Specific latent heat of vaporisation of water = 2.26×10^6 J kg^{-1}]

(a) Assuming that the steam behaves like an ideal gas, calculate its volume. [3]

(b) Calculate the work done by the steam as it expands against the atmosphere. [3]

(c) Calculate the increase in internal energy of the liquid water as it turns into steam. [3]

(d) State the form of energy that the increase in internal energy takes. [1]

4(a) A small ball rests at point P on a curved track of radius r, as shown in Fig 4.1:

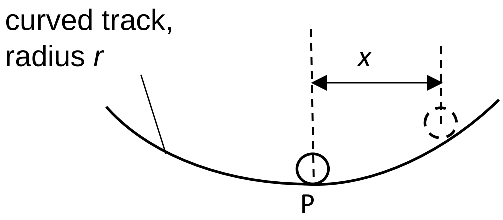


Fig 4.1

The ball is moved a small distance to one side and is then released. The horizontal displacement x of the ball is related to its acceleration a towards P by the expression

$$a = -\frac{gx}{r}$$

where g is the acceleration of free fall.

(i) Explain why the ball will undergo simple harmonic motion. [2]

(ii) The radius r of curvature of the track is 28 cm.
Determine the time interval τ between the ball passing point P and then returning to point P. [3]

(b) The variation with time t of the displacement x of the ball in **(a)** is shown in Fig 4.2.

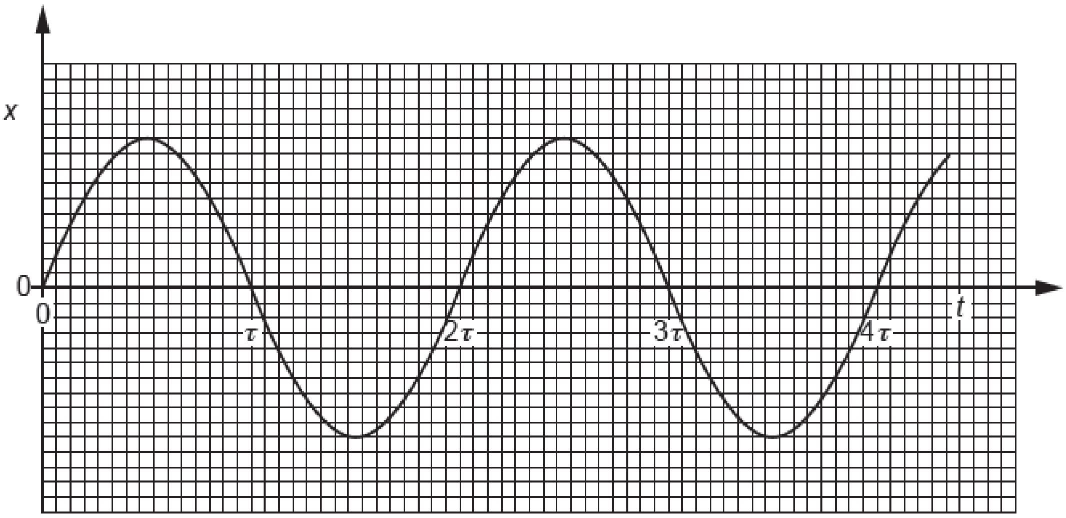


Fig 4.2

Some moisture now forms on the track, causing the ball to come to rest eventually.

On the axes of Fig 4.2, sketch the variation with time t of the displacement x of the ball for the first two periods after the moisture has formed. Assume the moisture forms at $t = 0$. [2]

5. The pick-up on an electric guitar produces an electrical signal from the vibrations of the guitar strings. The pick-up consists of a small coil of insulated wire wound round a small cylindrical magnet as illustrated in Fig. 5.1.

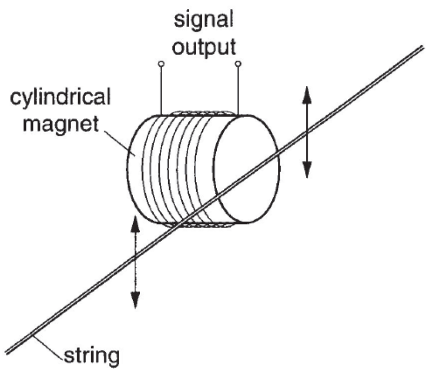


Fig. 5.1

The strings of the electric guitar are made of steel. When a string vibrates, an electrical signal is generated between the terminals of the coil.

(a)(i) State Faraday's law of electromagnetic induction. [1]

(ii) Use Faraday's law to explain why an electric signal is generated between the terminals of the coil. [3]

(iii) Suggest why nylon strings cannot be used for an electric guitar. [1]

(b) Consider a guitar string which is stretched between two fixed clamps 64.0 cm apart. The wire is set vibrating at its fundamental (lowest) frequency and the speed of the waves propagating along the string is 300 m s^{-1}.

Show that the string is vibrating at a frequency of 230 Hz. [2]

(c) Assume that the magnet (seen in Fig. 5.1) produces a uniform magnetic flux density of 4.50 mT over a 2.00 cm segment of the string. (The magnetic field over the rest of the string is negligible.) The section of the string in the magnetic field vibrates with an amplitude of 1.50 cm and in a direction that is perpendicular to the field. This means that, besides the e.m.f. induced in the pick-up coil, there is also an e.m.f. induced between the ends of the string.

Using your answer from (b), calculate the maximum e.m.f. induced between the ends of the string. (Ignore the e.m.f. induced in the pick-up coil.) [3]

6(a) Isotope X undergoes radioactive decay to form isotope Y. The half-life of isotope X is 2.0×10^5 years. The activity of a pure sample of isotope X extracted from an ore is measured to be 1.1×10^7 Bq.

(i) Explain why the measured activity of the sample X is relatively constant. [2]

(iii) It is discovered that isotope Y undergoes radioactive decay to form isotope Z. The half-life of isotope Y is 1.5 hours.

1. Calculate the decay constant of Y. [1]

2. The number of isotope Y in the sample is found to be constant. Explain how this is possible. [1]

3. Hence, calculate this constant number of nuclei of Y. [2]

b(i) Th-232 decays by alpha-emission with a decay constant of 4.95×10^{-11} yr^{-1}. This is the beginning of a decay chain which eventually ends in Pb-208. A sample of rock is found to contain both Th-232 and Pb-208 such that the ratio of the number of nuclei of Th-232 to Pb-208 is 5:1.

When the rock was formed, there was no Pb-208 present in the sample. Estimate the age of the rock in years. [2]

(ii) State the assumption made in **(b)(i)** regarding the intermediate product nuclei. [1]

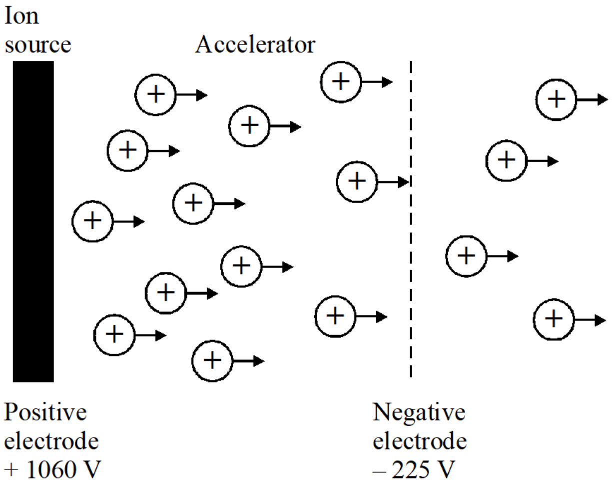
(iii) State with a reason, whether your answer in **(b)(i)** is an overestimate or an underestimate of the age of the rock if the assumption in **(b)(ii)** is not valid. [1]

7. This question examines two ways to propel a spacecraft: using an ion engine and using a solar sail.

Using an ion engine: Deep Space 1

In 1998 NASA launched the probe called Deep Space 1. It was designed to test new technologies for future deep space and interplanetary missions. Once in orbit, this probe was the first to use an ion engine to propel it on its mission.

The diagram below simplifies the main features of the ion engine.



Atoms of xenon were ionised by the loss of a single electron and then accelerated until they were ejected out of the rear of the probe, providing the means of propulsion. The mass of a xenon ion is 2.2×10^{-25} kg. The positive and negative electrodes were operating at +1060 V and –225 V respectively.

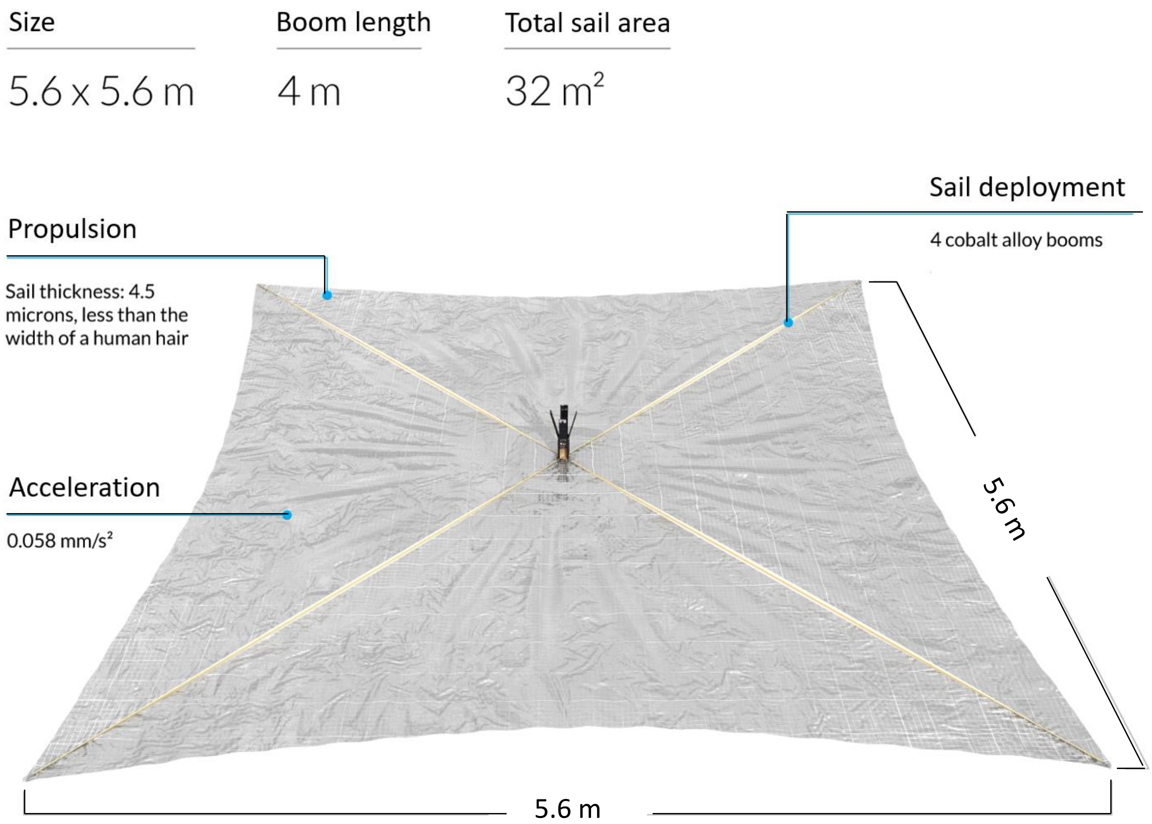
The ion engine used only a very small amount of xenon at a time. It may take 4 days or more just to use up 1 kg of xenon. For its whole mission, Deep Space 1 used about 74 kg of xenon to accelerate to a speed of about 4.3 km s^{-1}. At that time, this was greater than any spacecraft had ever been able to change its speed. The ion engine thrusted for 678 days, far longer than any propulsion system had ever been operated.

Using a solar sail: LightSail 2

LightSail® is a crowdfunded project from The Planetary Society to demonstrate that solar sailing is a viable means of propulsion. The LightSail 2 spacecraft, launched on June 25, 2019, uses sunlight alone to change its orbit, and is currently operating under an extended mission to further advance solar sailing technology.

A solar sail, simply put, is a spacecraft propelled by sunlight. Whereas conventional rockets are propelled by the combustion of rocket fuel, a solar sail is pushed forward by light from the Sun. A solar sail does this by capturing the momentum of photons with sheets of large, reflective material such as Mylar.

The picture below shows the LightSail 2 spacecraft.



The sail is 4.5 μm thick and its total area is 32 m^2. The picture also suggests that the spacecraft experiences an acceleration of 0.058 mm s^{-2}.

LightSail 2 is currently orbiting Earth with an orbital radius of about 7020 km. The solar radiation flux (intensity) at that altitude is about 1400 W m^{-2}. The mass of Earth is 6.0×10^{24} kg.

(a) Show that the speed of a xenon ion after being accelerated is about 4.3×10^4 m s^{-1}. [3]

(b)(i) Show that the maximum mass of xenon ejected by the engine per second is 2.9×10^{-6} kg. [2]

(ii) Calculate the maximum thrust (the force of propulsion) on Deep Space 1. [2]

(c) Assuming that the mass of Deep Space 1 remains constant, estimate its mass. [2]

(d) Simply firing xenon ions into space would leave Deep Space 1 negatively charged. Suggest a reason why this would lead to reduced thrust. [1]

(e) Chemical rockets eject their propellant at about a tenth of the velocity achieved by ion engines but produce much greater thrust by ejecting more than a thousand kilograms per second. Suggest why ion engines may be preferable for missions extending over long distances and periods of time. [2]

(f)(i) Show that the energy E and momentum p of a photon are related by the expression $E = pc$, where c is the speed of light. [2]

(ii) For LightSail 2, show that the total momentum of the photons striking 1 m^2 of sail in one second is 4.7×10^{-6} N s. Assume that the photons strike the sail at right angles. [2]

(iii) Hence, find the force exerted on the whole sail if it is completely reflective. [2]

(iv) Explain how this force in (iii) will change if the whole sail is completely non-reflective so that all of the incident light is absorbed. [2]

(g) Discuss whether the centripetal acceleration of LightSail 2 can be 0.058 mm s^{-2}. [2]

(h) Comparing the solar sail with the ion engine, suggest one advantage and one disadvantage of the solar sail. [2]

End of paper