H2 Physics 9749 – 2019 A Level Exam

Paper 1

<table>
<tr><td>1</td><td>
Essential Question(s):

What does the unit prefixes represent?

Solution:

nano - 10^{-9}
micro - 10^{-6}
milli - 10^{-3}
centi - 10^{-2}
deci - 10^{-1}
kilo - 10^{3}
giga - 10^{9}

Answer: D
</td></tr>
<tr><td>2</td><td>
Essential Question(s):

What does accuracy ±1% mean?
What does “additional” uncertainty of ±10 mV mean?
When recording value together with its uncertainty, how do we represent the absolute uncertainty and how does the value be represented?

Solution:

The overall absolute uncertainty = 1 % of the value recorded PLUS 10 mV,
$\Delta V = (4.072 \times 0.01) + (10 \times 10^{-3}) = 0.0502V$
$\Delta V = \pm 0.05V$
Rounding up the uncertainty to reflect the full statement of “additional 10 mV”, and to represent absolute uncertainty to 1 significant figure.

Subsequently, the next step is to truncate the value to the same decimal place as the absolute uncertainty,
$V \pm \Delta V = (4.07 \pm 0.05)V$

Answer: D
</td></tr>
<tr><td>3</td><td>
Essential Question(s):

How to construct the equations of motion using the information provided?

Solution:
From Start to (t-1)seconds
$S_1 = ½ a (t-1)^2$ – (1)
From Start to t seconds
$S_2 = ½ a (t)^2$ – (2)

(2) / (1) :
</td></tr>
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	$\frac{S_1}{S_2} = \frac{\frac{1}{2}a(t-1)^2}{\frac{1}{2}a(t)^2}$ $\frac{0.25}{1} = \frac{(t-1)^2}{(t)^2}$ $\frac{1}{2} = \frac{(t-1)}{(t)}$ $t = 2$ **Answer: D** **Examiner's comments:** *Candidates performed well on this question demonstrating string understanding of kinematics*
4	**Essential Question(s):** o How is the speed and acceleration related to the displacement time graph? o How does acceleration changes in a free fall with air resistance? **Solution:** Speed increases. Gradient of the graph is increasing. Speed increases at a decreasing rate because the air resistance is increase but the weight is constant. Resultant force decreases and so acceleration decreases. **Answer: C**
5	**Essential Question(s):** • How is the conservation of linear momentum applied here? **Solution:** Initial momentum is zero. So X being less mass move at higher speed, and Y being higher mass moves at lower speed. But the product of the speed and mass is the same. So the centre of mass remains at the same position. **Answer: A** **Examiner's comments:** *Options **C** or **D** were popular incorrect choices. As the total momentum of the system is zero before the explosion, the centre of gravity cannot move. If it does, this would mean that an external force must have been applied to the system, which is not the case in this question.*
6	**Essential Question(s):** o Since it is inelastic collision, what are the physics concepts to be used? **Solution:** Conservation of linear momentum: mu = mv + 2mv u = 3 v

	$$\frac{[\text{Initial Total KE}] - [\text{Final Total KE}]}{[\text{Initial Total KE}]} = \frac{\frac{1}{2}m(u)^2 - \frac{1}{2}m(v)^2 - \frac{1}{2}m(2v)^2}{\frac{1}{2}m(u)^2}$$ $$= \frac{(3v)^2 - (v)^2 - (2v)^2}{(3v)^2}$$ $$= \frac{9-1-4}{9}$$ $$= \frac{4}{9}$$ **Answer: B**
7	**Essential Question(s):** • What is Hooke's Law? • How to calculate the work done? • **Solution:** Hooke's Law is obeyed when there is a straight line on the F – extension graph. The straight line stop at 20 mm (0.020 m), where the force is 28 N. Work done = ½ (28)(0.020) = 0.28 J **Answer: A**
8	**Essential Question(s):** o How does the change in direction of the force affect the contribution of work done to the Ke and GPE? **Solution:** As the force is applied in the direction of the velocity, as the slope becomes more vertical, more and more of the component of the force is given to the vertical, meaning the GPE increase more and more. Therefore the gain in KE becomes lesser and lesser. **Answer: D** **Examiner's comments:** *Candidates performed well in general. Candidates choosing option A thought that the kinetic energy of the object was decreasing, not realizing that the force was being applied to the object continually*
9	**Essential Question(s):** • What form of energy is given to the water? • What happen for the energy given to be minimum? **Solution:** Power = Energy/ time $Power = \frac{GPE}{time}$ $= \frac{1.3\times10^9 \times 9.81 \times 2}{24\times60\times60}$ $= 295208$ $= 300000$

	Answer: D
10	**Essential Question(s):** o What equation relates ω to R? **Solution:** Rearranging the eqn v = R ω, $\omega = \frac{v}{R}$, with v being constant we can see that $\omega \propto \frac{1}{R}$ → Graph should be a rectangular hyperbola for a graph of ω against R. **Answer: B**
11	**Essential Question(s):** o What equation relates acc, ω and R? **Solution:** Centripetal acc, $a = R\omega^2$ $\omega = \sqrt{\frac{a}{R}} = \sqrt{\frac{20x9.81}{\left(\frac{14}{2}\right)}} = 5.3 \text{ rad s}^{-1}$ **Answer: D**
12	**Essential Question(s):** o What does "escape from planet's gravitational field" mean? [mass goes to infinity where GPE is max and hence a 0 value.] o What is the energy conversion when object goes from surface of planet to infinity? [loss in KE and gain in GPE] **Solution:** By conservation of energy, Energy of object at surface of planet = Energy of object at infinity $KE_{\text{max at surface}} + GPE_{\text{surface}} = KE_{\text{infinity}} + GPE_{\text{infinity, max}}$ $\frac{1}{2}mv^2 + \left(\frac{-GMm}{R}\right) = 0 + 0$ $v = \sqrt{\frac{2GM}{R}}$ **Answer: A**
13	**Essential Question(s):** o How is $C_{r.m.s}$ related to temperature, mass and molar mass? **Solution:** $C_{r.m.s} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3 \times 8.31 \times (30 + 273.15)}{4 \times 10^{-3}}} = 1375 = 1400 \text{ m s}^{-1}$ (2sf) **Answer: C** **Examiner's comments:** *The majority of candidates that responded incorrectly chose option **A** (43 m s^{-1}). This was probably because they did not convert the mass of the helium into kilograms. Since the root-mean-square speed of a typical air molecule is about 500 m s^{-1}, a helium atom is going to be moving more quickly than this.* *Remember to convert the mass of the helium into kilograms*.

14	**Essential Question(s):** o What is internal energy of the air? **Solution:** Internal energy is the sum of molecular KE due to random motion of molecules and the molecular PE due to intermolecular forces of attraction. $N(E_k+E_p)$ **Answer: C**
15	**Essential Question(s):** • Recall the 1st Law of Thermodynamics and the meaning of its symbols. • Be aware that the question is requiring "heat transferred to the surroundings" which is not the definition used for symbol for *Q*. o Need an equation linking these quantities. Then apply the relevant rules to calculate the percentage uncertainty (product-quotient or addition-subtraction rule). **Solution:** From the 1st Law of Thermodynamics $\Delta U = Q + W$ where: ΔU represents the increase in internal energy of the system *Q* represents the heat supplied to the system and *W* represents the work done on the system Therefore from the question, it is defined from the symbols that ΔU is the increase in the internal energy of the gas (the system) and *W* is the work done on the gas (the system) so rearranging the equation, the heat supplied **<u>to the gas</u>** (the system) is $Q = \Delta U - W$ However the question required the heat supplied to the surroundings, in other words the heat supplied **<u>from the</u>** gas, i.e. $-Q = W - \Delta U$ **Answer: B** **Examiner's comments:** *Candidates performed very well in this question. Candidates choosing option* ***C*** *did not consider the direction of heat transfer.*
16	**Essential Question(s):** • Recall the standard information for an object in oscillation. In other words what is the acceleration/velocity/displacement at equilibrium vs amplitude to link it to restoring force/kinetic energy respectively at equilibrium vs amplitude locations. **Solution:** The solution requires very little calculation but a quick recall that $a = -\omega^2 x$ where: *a* represents the acceleration of the object ω represents the angular frequency of the object and

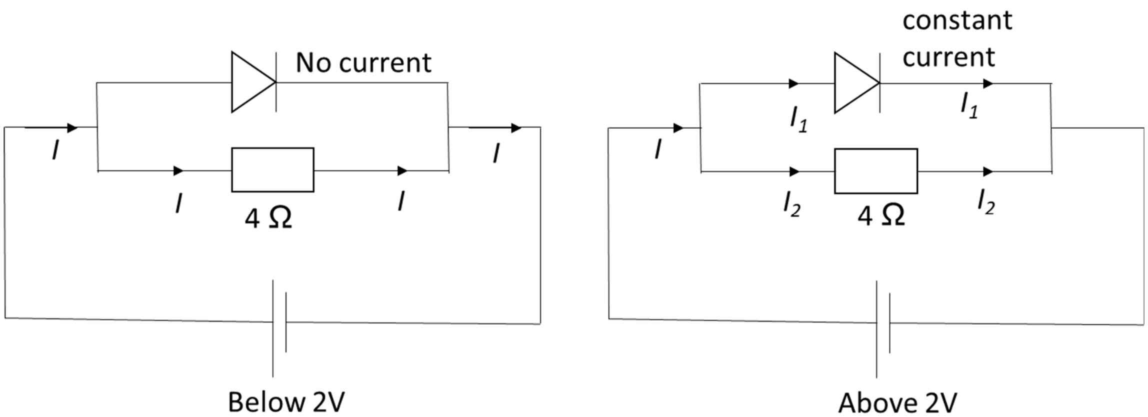
	x represents the displacement of the object from the equilibrium Since $F_{net} = ma = -m\omega^2 x$ Therefore the net force on the object which is the restoring force will be proportional to the acceleration and in turn proportional to the displacement from the equilibrium. So when the object is at displacement = 0 (i.e. equilibrium), $x = 0$ hence Restoring force (F_{net}) = 0 Conversely when the object is at displacement = maximum (i.e. the amplitude), x = maximum hence Restoring force (F_{net}) = maximum With this set of information that eliminates options A and C. The deciding factor will then depend on the velocity and thus kinetic energy at the locations stated. At displacement = 0, the velocity is a maximum, thus kinetic energy is also a maximum. At displacement = maximum, the velocity is 0, thus kinetic energy is zero. This eliminates option D, therefore the answer is B. **Answer: B** **Examiner's comments:** *Candidates found this question relatively easy.*
17	**Essential Question(s):** • Recall the conditions required for constructive and destructive interference to take place when two waves of equal amplitude meet at a point. • Interpret what it means by the resultant amplitude of the two waves at point P is a maximum. The 2 waves • Differ by 2 cycles per 1 s (phase diff = 4π rad) • Differ by 1 cycle per 0.5 s (phase diff = 2π rad) • Differ by ½ cycle per 0.25 s (phase diff = π rad) The 2 waves will be in antiphase whenever phase diff = odd number multiple of π rad, i.e. π rad, 3π rad, 5π rad, 7π rad, … So corresponding values of t at which these occur would be: **0.25 s,** (3x0.25 = **0.75 s**), (5x0.25 = **1.25 s**), (7x0.25 = **1.75 s**), … **Answer: B** **Examiner's comments:** *Most of the candidates who got this question wrong either chose option A or C. Those who chose A were mistaking the times of minimum disturbance for the time of minimum and maximum disturbance, and those who chose C were mistaking times of minimum disturbance for those of maximum disturbance.*
18	**Essential Question(s):** • Recall the scenario of what is the type of wave is formed in this setup. • Understand what the receiver picks up to detect a maximum or minimum voltage.

	Solution: Between the transmitter and the metal sheet a stationary microwave is formed. And the receiver will pick up the signals as a result of this stationary wave formed. When the receiver detects a maximum voltage it corresponds to an antinode location and when the minimum is detected a nodal location is detected. **It is to be taken note that the sheet of metal is the one that is moving while the receiver is stationary.** Therefore where the metal sheet is first placed the receiver picks up a nodal location. As the metal sheet moves 60 mm from its original location, away from the transmitter, another nodal location is detected at the receiver. And when it is 120 mm from its original location, away from the transmitter, another nodal location is detected. (Take note that the frequency of the transmitter is constant so the stationary wave formed by moving the metal sheet further away is to continue to add "loops" between the transmitter and the receiver) It can thus be stated that the distance between two adjacent nodes is 60 mm and since this is a stationary microwave, the wavelength of the microwave source = 2 x the distance of adjacent nodes = 2 x 60 mm = 120 mm **Answer: C**
19	**Essential Question(s):** • What is the equation used to locate the positions of the principal maxima produced by a diffraction grating? • How can the wavelength of light be determined? • How is the angle of diffraction determined? **Solution:** $d = \frac{1}{4.0 \times 10^5} = 2.5 \times 10^{-6}$ $c = f\lambda ; \lambda = \frac{3.00 \times 10^8}{6.0 \times 10^{14}} = 5.0 \times 10^{-7}$ Using $d \sin\theta = n\lambda$, with n = 3 (third-order diffraction maxima); $\left(2.5 \times 10^{-6}\right) \sin\theta = 3\left(5.0 \times 10^{-7}\right)$ $\theta = 36.9^0$, which is the angle between the incident beam and the third-order diffraction maxima. Therefore, angle between the two third-order diffraction maxima = $2\theta = 74^0$. **Answer: D**
20	**Essential Question(s):** • What is the equation used to locate the position of the first minima for single slit diffraction? • What is the relationship between the wavelength of the wave, angle of diffraction and the gap size? **Solution:** $\sin\theta = \frac{\lambda}{b}$

	To reduce the angle of diffraction θ, the wavelength λ must be decreased and the gap size *b* must be increased. **Answer: C**
21	**Essential Question(s):** • What does a uniform electric field imply about the electric force acting on the electron? • What is the electron's motion under the influence of the constant electric force? • How is a constant acceleration represented on a v-t graph? **Solution:** A uniform electric field means that a constant electric force is acting on the electron. By Newton's Second Law, $F = ma$, and this means that the electron will move under constant acceleration. Thus, the electron will move with a velocity which is increasing at a constant rate (reflected in the form of a constant gradient, since the acceleration is constant). **Answer: B** **Examiner's comments:** *Candidates that gave an incorrect answer in this question did not realise that a charged particle in a uniform electric field undergoes constant acceleration, and the gradient of the v-t graph is constant. Most of these candidates chose the curved graphs (options* ***A*** *or* ***C****), thinking that the graph was an s-t graph or that the acceleration was changing in the field.*
22	**Essential Question(s):** • What is the nature of the electric field between two parallel plates? • How does the value of the electric potential change with the distance from one plate in a uniform electric field? What is the relationship between potential difference and vertical distance? • Given that the potential changes linearly with the vertical distance from one plate (i.e. the potential difference is directly proportional to the vertical distance) due to the uniform electric field, can we determine the potential difference between Points X and Y **Solution:** Given that $E = \frac{\Delta V}{d}$, since the electric field strength is constant (by virtue of the fact that the field between two parallel plate is uniform), we can deduce that the $\Delta V \propto d$, where ΔV is the potential difference between 2 points, and *d* is the vertical distance of separation Since the potential difference is 1000 V for a 10 cm separation between the plates, the change in the electric potential with distance is 100 V per cm. Therefore, two points separated by a vertical distance if 4 cm will have a potential difference of 400 V. **Answer: B**
23	**Essential Question(s):** • What does the non-conducting nature of the diode below 2 V imply about the resistance of diode in that range of p.d.? • Below 2V, how does the current flow through the circuit? What is the value of the overall resistance of the circuit? What does that imply about the shape of the I – V graph? • Above 2V, how does the current flow through the circuit? What is the overall resistance of the circuit? What does this imply about the shape of the I – V graph? **Solution:**

The zero current in the diode under 2 V of p.d. implies that below that threshold, the diode has an effectively infinite resistance.

With that in mind, we can now analyse the circuits in this two ranges of p.d. The diagram on the left shows the circuit in the below 2 V range and the one on the right shows the circuit in the p.d. range above 2 V:



Below 2 V, all the current flows through the resistor, meaning that the circuit is effectively one with just a single resistor. Therefore, the I – V graph is expected to be linear, given that the effective resistance of the circuit is constant with the equation $I = \frac{V}{R} = \frac{V}{4}$

Above 2 V, the diode now maintains a constant current through it, which means that current now flows through both branches of the parallel circuit. However, recalling the fact that the diode's current, I_1 will always be constant, while the current through the resistor I_2 will still vary linearly (due to its constant resistance) this means that the current in the circuit I will vary based on the equation $I = I_1 + I_2$, where I_1 is a constant and $I_2 = \frac{V}{R} = \frac{V}{4}$

This means that the graph will be a linear graph with equation $I = \frac{V}{4} + I_1$, which means that we expect a graph with the same slope as the one below 2 V, but translated vertically by a constant value I_1

Answer: C

Examiner's comments:
All three incorrect options were popular. Candidates had to realise that if the diode had a constant current when V was greater than two volts, then the gradient of the line could not change. There is possibly a misconception here – if two components are connected in parallel and one of them is not conducting, then the other will still conduct.

24 **Essential Question(s):**

- What is the range of values of the effective resistance of the circuit? How can this be determined from the range of resistance of the variable resistor? What happens to the effective resistance when a branch of the parallel circuit has zero resistance?
- What does the voltmeter read? How can that be determined from the effective resistance and the e.m.f of the circuit?

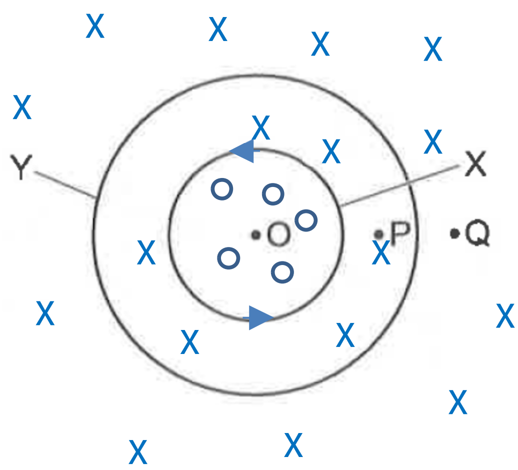
Solution:

	When the variable resistor is 0 Ω, the circuit's effective resistance is: $R_{eff} = 0 + 1.0 = 1.0\,k\Omega$ Do take note that because the variable resistor's resistance is 0, all the current will flow through the lower branch of the parallel circuit, and the resistance is effectively zero for the parallel segment. When the variable resistor is 1.0 kΩ, the circuit's effective resistance is: $R_{eff} = \left(\frac{1}{1.0} + \frac{1}{1.0}\right)^{-1} + 1.0 = 1.5\,k\Omega$ The voltmeter reading is the p.d. across the 1.0 kΩ resistor on the right, and it can be found using the potential divider method: For the first case: $V = \frac{R}{R_{eff}} \times e.m.f = \frac{1.0}{1.0} \times 12 = 12\,V$ For the second case: $V = \frac{R}{R_{eff}} \times e.m.f = \frac{1.0}{1.5} \times 12 = 8\,V$ This means the voltmeter reading will range from 8 – 12 V **Answer: D** **Examiner's comments:** *The majority of candidates who responded incorrectly chose option **C**. They probably did not realise that when the value of the variable resistor is 0 then the resistance of the left-hand side of the circuit is 0, not 1000 Ω.* □.

25	**Essential Question(s):**
	• What is the definition of induced emf?
	• Key information :
	    o magnetic field strength changes at constant rate,
	    o area of conducting loop at right angle to magnetic field and
	    o magnetic field directed into page.
	
	Solution:
	$Induced\ e.m.f. = \frac{\Delta\Phi}{\Delta t} = \frac{\Delta(NBA)}{\Delta t} = \frac{NA\Delta B}{\Delta t}$
	
	$Induced\ e.m.f. = \left\| (1)\left(2\times10^{-2}\right)\frac{\left(-5.0\times10^{-3}\right)-\left(5.0\times10^{-3}\right)}{4} \right\|$
	
	$Induced\ e.m.f. = 5.0\times10^{-5}\ V$
	Answer: B

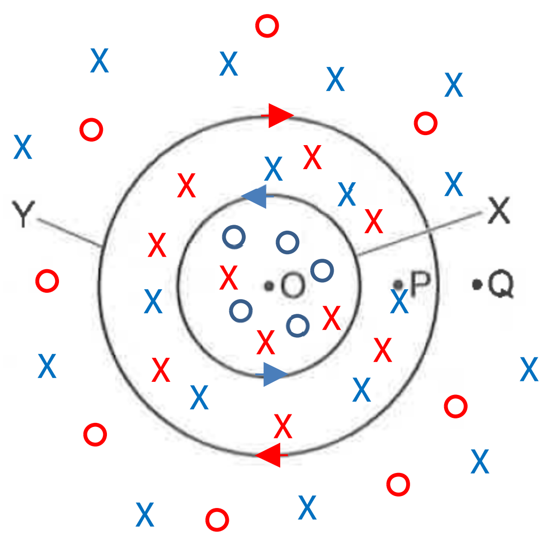
26	**Essential Question(s):**
	• How do you use RH Grip Rule to determine the direction of magnetic flux density in single coil?
	• Key information:
	    o <u>Initially</u> constant current in coil X and no current in coil Y
	    o A small current is <u>now</u> passed through coil Y which decrease magnetic flux density at point O.
	
	Solution:

- Initially constant current in coil X and no current in coil Y
  Assume the current in coil X is flowing in anti-clockwise direction



x, o – magnetic flux density due to current in coil X (using RH Grip Rule)

- Current passed through coil Y to decrease magnetic flux density at point O.
  Current in coil Y must flow in clockwise direction



x, o – magnetic flux density due to current in coil Y (using RH Grip Rule)

From the above diagrams, the magnetic flux density at point P increases and the magnetic flux density at point Q decreases.

Answer: C

Examiner's comments:
The majority of candidates responded correctly to this spatial problem. Most of those who responded incorrectly chose distractor ***B****. The key is that candidates need to realise that the field increases at point P.*

27	**Essential Question(s):** • Recall the turns ratio formula for an ideal transformer. **Solution:** Let N_s be the number of turns on the secondary coil and N_p be the number of turns on the primary coil. Therefore, $\frac{N_s}{N_p} = \frac{V_s}{V_p} = \frac{I_p}{I_s}$ The number of turns on the secondary coil is doubled. Let N'_s be the new number of turns on the secondary coil ie. $N'_s = 2 \times N_s$ Let $\left(\frac{I_p}{I_s}\right)_1$ be the new ratio. Therefore, $\left(\frac{I_p}{I_s}\right)_1 = \frac{N_s'}{N_p} = \frac{2 \times N_s}{N_p} = 2\left(\frac{I_p}{I_s}\right)$ ie. doubles Let $\left(\frac{V_p}{V_s}\right)_1$ be the new ratio. Therefore, $\left(\frac{V_p}{V_s}\right)_1 = \frac{N_p}{N_s'} = \frac{N_p}{2 \times N_s} = \frac{1}{2}\left(\frac{V_p}{V_s}\right)$ ie. Halves. **Answer: B**
28	**Essential Question(s):** • How does the maximum speed of the electrons relate to the wavelength of the emitted X-ray photons? o How does the wavelength of the photon relate to its energy? **Solution:** Through the conversion of energy, Loss of KE_{max} of electron = Energy of photon $\frac{1}{2} m_e v_{max}^2 = \frac{hc}{\lambda_{min}}$ $v_{max}^2 = \frac{2hc}{m_e}\left(\frac{1}{\lambda_{min}}\right)$ $= k\left(\frac{1}{\lambda_{min}}\right)$ where k is a constant. Thus, when the maximum speed of the electrons changes, the minimum wavelength of the emitted photon will change. **Answer: C**
29	**Solution:** This question basically assesses the direct interpretation of the Heisenberg uncertainty. It is a straightforward answer. **Answer: B**
30	**Solution:**

	This question basically assesses the definition of the decay constant. **Answer: A**

Paper 2

				Marks
1	a		**Essential Question(s):** • What does it mean to be in (total) equilibrium? **Solution:** No net force acts on the body and no net moment of force about any pivot acts on the body. **Examiner's Comments:** The majority of candidates gave suitable answers for the two required conditions for equilibrium. A small number gave the condition for rotational equilibrium twice by referring to moments and then torque. In addition, a small number did not sum the clockwise or anticlockwise moments or refer to the resultant or net force.	 **1** **1**
1	b		**Essential Question(s):** ➔ How to apply equilibrium of forces to determine the tensions? **Solution:** Consider horizontal component of the forces $T_1 \cos 20 = T_2 \cos 10$ $0.9397\ T_1 = 0.9848 T_2$ $T_2 = 0.9542\ T_1$ …………(1) Consider vertical component of the forces $T_1 \sin 20 + T_2 \sin 10 = 700$ …………(2) Solving (1) & (2) $T_1 = 1400$ N ; $T_2 = 1300$ N **Examiners' Comments:** A majority of candidates were able to give the equations for the tensions resolved into the horizontal and vertical directions. Many were able to solve these equations and reach the expected answers. A significant number made errors in solving these two equations. There were very few scale drawing used to calculate the tension. Those that drew a sketch and them used the sine rule generally obtained the correct answers.	 **1** **1** **2**
1	c		**Essential Question(s):** • What does it mean to support the pole? o To support the pole, the pole will be in equilibrium. o As there is no translational acceleration ($F_{net} = 0$), we will focus on the condition for rotational equilibrium (net torque =0) • Which point is a good point to take moments? o If we take the base of the pole to be the pivot, the forces at that point will be eliminated in the calculations (this is good, as we are not given any information about the forces at the base of the pole) **Solution:** Taking moments at the base of the pole,	 **1** **1** (calculate sinθ) **1**

			$(T_{horizontal})(1.2) = (150\cos10)(1.8)$ $(T\sin\theta)(1.2) = (150\cos10)(1.8)$ $T\left(\frac{1.6}{\sqrt{1.2^2+1.6^2}}\right)(1.2) = (150\cos10)(1.8)$ T = 277 N T = 280 N (2sf) **Examiner's Comments:** There were a large number of correct answers achieved by candidates taking moments about the base of the pole. The vast majority were able to determine one of the angles in the triangle formed by the pole, the ground and the support cable.	
2	**a**	**i**	Transverse is a wave in which the **oscillations in the wave** are at **right angles** to the **direction of transfer of the energy** of the wave. Examples of Transverse Wave: • Electromagnetic wave • Vibrations in a guitar string **Examiner's Comments:** *The majority of candidates referred to oscillations being perpendicular to something. Many gave an imprecise description of what the oscillations were perpendicular to. Some candidates used a word like 'motion' or 'propagation' in place of 'oscillation'. The examples of a transverse wave were generally correct; a significant number omitted the statement of an example.*	**1** **1**
		ii	It means that the oscillations in a transverse wave are confined to one direction only, the direction being at right angles to the direction of propagation of the wave energy. **Examiner's Comments:** *Most commonly, candidates simply stated that the vibrations were restricted to one direction or one plane without referring to the direction of energy transfer.*	**1**
2	**b**	**i**	**Essential Question(s):** ➔ What is angle between the incoming vertically plane polarized light and the transmission axis of the first filter? ➔ What is angle between the transmission axes of the first filter and second filter? ➔ Recall Malus' law for the intensity of a polarized light transmitted through a filter. ➔ Recall equation for the amplitude of a polarized light transmitted through a filter. **Solution:** The angle between the incoming vertically plane polarized light and the transmission axis of the first filter, $\theta_1 = 30°$ Let I_1 be the intensity of the polarized light after the first filter, Using Malus's Law, $I_1 = I_0\cos^2\theta_1 = I_0\left(\cos30^o\right)^2 = 0.75I_0$ The angle between the transmission axes of the first filter and second filter, $\theta_2 = 60° - 30° = 30°$	 **1**

Using Malus's Law,

$$I_T = I_1 \cos^2 \theta_2 = 0.75 I_0 \left(\cos 30^\circ\right)^2$$ **1**

$$= 0.56 I_0$$ **1**

Examiners' Comments:
The majority of candidates gave the correct relationship between intensity and polarising angle. A significant number used 60□ for angle between the two polarising filters.

2 b ii

Essential Question(s):

- ➔ What is the relationship between intensity of a wave and its amplitude?

Solution:

Since $Intensity \propto Amplitude^2$,

$$\frac{amplitude\ of\ emerging\ beam\ from\ second\ filter}{amplitude\ of\ beam\ incident\ on\ first\ filter} = \sqrt{\frac{I_T}{I_0}}$$ **1**

$$= \sqrt{\frac{0.56 I_o}{I_0}}$$

$$= 0.748 = 0.75$$ **1**

Examiners' Comments:
The vast majority of candidates gave the correct relationship between intensity and amplitude. Many candidates made a mistake in the denominator of the ratio required by using the amplitude of the beam on the second filter.

2 b iii

Essential Question(s):

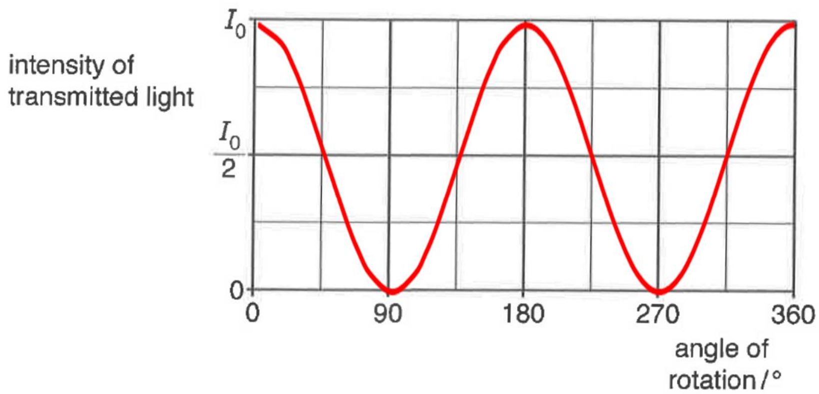
- ➔ What is angle between the incoming vertically plane polarized light and the transmission axis of the first filter when the filter is placed parallel to the plane of polarization of the incoming light?
- ➔ What are the key angles to take note when the transmission axis is rotated through 360°?

Solution:
Use Malus' law, $I_1 = I_0 \cos^2 \theta$
where I_1 is the intensity of transmitted and θ is the angle of transmission axis

when the filter is placed parallel to the plane of polarization of the incoming light, $\theta = 0°$

Some key angles:

θ	0°	30°	45°	60°	90°
I_1	I_0	$0.75I_0$	$0.5I_0$	$0.25I_0$	0

			 **1 mark – correct maximum and minimum intensity** **1 mark – accuracy between maximum and minimum intensity** **Examiners' Comments:** The majority of candidates drew the graph with the correct angles for the maximum and minimum values of intensity. The shape of the curve was often inaccurate in between these points.	**2**
2	**c**	**i**	Sound wave is a longitudinal wave where oscillations in the wave are along the direction of energy transfer. Only transverse wave can be polarized. **Examiner's Comments:** *This question was well answered.*	**1**
2	**c**	**ii**	**Essential question:** ➔ What does an oscilloscope measure? ➔ What does a microphone measure? And how is the measurement reflected on an oscilloscope? ➔ How are period and frequency of a waveform determined from the display of an oscilloscope? ➔ What is a time-base setting on an oscilloscope? **Solution:** Frequency of a sound wave = 740 Hz Therefore, the period is 1/740 = 1.35×10^{-3} s = 1.35 ms Since the distance between two adjacent peaks (which represent one complete oscillation) is 6.8 cm, it means that a complete oscillation of 1.35 ms covers a distance of 6.8 cm on the oscilloscope. Therefore, the time-base setting, Time-based setting = 1.35 / 6.8 = 0.198 = 0.20 ms cm^{-1} **Examiner's Comments:** *The majority of candidates were able to determine the time period of the sound wave. The conversion of the time period to a time-base setting caused problems for many candidates.*	 **1** **1**
3	**a**		**Solution:** The electric potential at a point in an electric field is the work done per unit positive charge by an external agent in moving a point charge from infinity to that point. **Examiner's Comments:**	 **1**

			Many candidates gave imprecise definitions of electric potential, which omitted the term 'positive' charge and the clear statement of work done 'per' unit positive charge.	
3	b	i	**Essential Question(s):** • What information can we get from the keywords “54 protons”? [We can find the total charge of 54 protons.] • How is charge Q of 54 protons related to V and r? **Solution:** Formula for electric potential at distance r away from an isolated point charge is: $V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$ Sub a coordinate from the graph, say (1.3×10^{-10}, 600), $600 = \frac{Q}{4\pi(8.85x10^{-12})(1.3x10^{-10})}$ Q = $+8.6746 \times 10^{-18}$ C Since the charge of each proton is $+1.60 \times 10^{-19}$ C, Number of protons = $\frac{8.6746\ x\ 10^{-18}}{1.60\ x\ 10^{-19}} = 54.2 \approx 54$ protons (shown) **Examiner’s Comments:** *A significant number of candidates gave incomplete working in showing the number of protons stated in the question. Full substitution of the values of all quantities into complete equations were required in this 'show that' question.*	1 1 1
3	b	ii	**Essential Question(s):** ➔ What is the separation between centres of the proton and nucleus as compared to the radius of the proton and nucleus? **Solution:** Diameter of a proton and a nucleus are in the order of 10^{-15} m. A <u>separation</u> of 2 x 10^{-8} m between them is 10^{7} times larger, which is <u>much greater</u> as <u>compared to</u> the diameters of both the proton and nucleus. Therefore the proton and nucleus behave as *point* charges relative to each other. **Examiners’ Comments:** *Do not give imprecise statements. Eg. the word 'size' was used to explain why the proton and nucleus behave as point charges instead of radius or diameter.*	1
3	b	iii	**Essential Question(s):** ➔ How to determine the electric force on the proton? [Recall: Coulomb’s law] ➔ How is electric force related to acceleration? [Recall: N2LM] **Solution:** F $= \frac{1}{4\pi\varepsilon_0}\frac{Qq}{r^2}$ $= \frac{1}{4\pi(8.85x10^{-12})}\frac{(8.6746x10^{-18})(1.60x10^{-19})}{(2.0x10^{-8})^2}$ = 3.12×10^{-11} N	1

			$a = \frac{F}{m}$ $= \frac{3.12x10^{-11}}{1.67x10^{-27}}$ $=1.87 \times 10^{16}$ m s^{-2} **Examiners' Comments:** *A small number of students made errors in their calculations or substituted an incorrect number of charges in the expression for the Coulomb force.*	 **1** **1**
3	**b**	**iv**	**Essential Question(s):** ➔ What is the conversion of energy when object reaches infinity? **Solution:** The proton's final Electric Potential Energy at infinity is defined to be zero. By Conservation of energy, Gain in KE = loss in EPE Loss in EPE = $= \frac{1}{4\pi\varepsilon_0}\frac{Qq}{r} - 0 = \frac{(8.6746x10^{-18})(1.60x10^{-19})}{4\pi(8.85x10^{-12})(2.0x10^{-8})} - 0$ $= 6.24 \times 10^{-19}$ J = gain in KE **Examiners' Comments:** *The explanation of the working was often not so well done. The kinetic energy being zero at infinity or the potential energy increasing when the charge is moved to infinity were given by many candidates.*	 **1** **1** **1**
4	**a**	**i**	**Solutions** The proton, which is positively charged, will experience a magnetic force (F_B) that is directed vertically upwards according to Fleming's Left Hand rule. For the proton to pass through undeflected then the electric field must produce an electric force (F_E) on the proton that acts vertically downwards, opposite direction to F_B, and F_E must equal to F_B in magnitude. Since plate Q has zero potential and the proton is positively charged, the polarity of plate P must be positive in order to produce an electric field that is in the same direction as the electric force on the proton. **Examiner's Comments:** *The majority of candidates gave a good explanation of why the polarity of plate P was positive. The lack of reference to the type of force acting and their directions was common; this was needed to identify one force from the other.*	 **1** **1**
4	**a**	**ii**	**Essential Question(s):** ➔ What does not deviated mean? ➔ How can the proton travel without deviation? ➔ What are the forces acting on the proton? **Solution:** Since the proton is not deviated from its path of travel, there is vertical equilibrium when the proton enters the cross field, (Taking down as positive) $F_{net} = 0$ $F_E = F_B$ $qE = Bqv$ $E = \frac{Bqv}{q}$ $E = Bv$ $= (45 \times 10^{-3})v$	 **1** **1**

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However the kinetic energy of the proton, $\frac{1}{2}mv^2 = 64 \times (1.6 \times 10^{-19})$
$$v = \sqrt{\frac{2 \times \left[64 \times \left(1.6 \times 10^{-19}\right)\right]}{\left[1.67 \times 10^{-27}\right]}}$$
$= 1.11 \times 10^5 \text{ m s}^{-1}$

Therefore the magnitude E is $= (45 \times 10^{-3})(1.11 \times 10^5)$
$= 4980 \text{ N C}^{-1}$

Examiners’ Report:
This was generally well answered. The majority of candidates gave well-presented working to their correct answers. A small minority did not convert the energy in eV to joule or used the mass of an electron instead of the mass of a proton.
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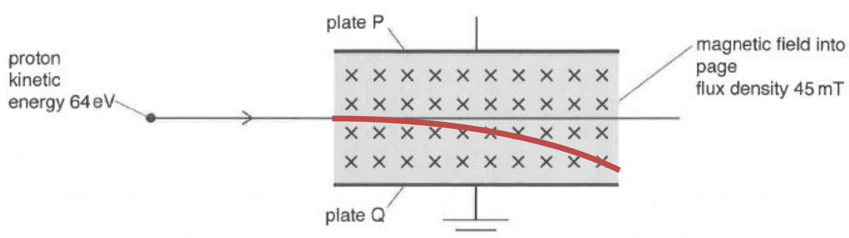
<td>4</td><td>a</td><td>iii</td>
<td>
Essential Question(s):
➔ What does it meant when the kinetic energy is lesser than 64 eV?
➔ Which region should the path be drawn for?

<u>Explanation:</u>
As the proton is now having a lesser kinetic energy, since the proton has a fixed mass, the speed v of the proton decreases. Since the magnetic flux density B and charge q remain constant, the magnetic force F_B directed vertically upwards will now be reduced because $F_B = Bqv$, which means F_B is proportional to v.

On the other hand, the electric force that points vertically downward on the proton is independent of the speed of the proton. So it remains the same as previously. The downward electric force will now be larger in magnitude as compared to the magnetic force pointing upwards causing the proton to deviate downwards towards plate Q.



Examiners’ Report:
A number of candidates drew lines that were not sufficiently precise. The start of the deflection was often a long distance from where the proton entered the field, or the line stopped before the proton had exited the field. The correct direction of the deflection was shown by the vast majority of candidates.
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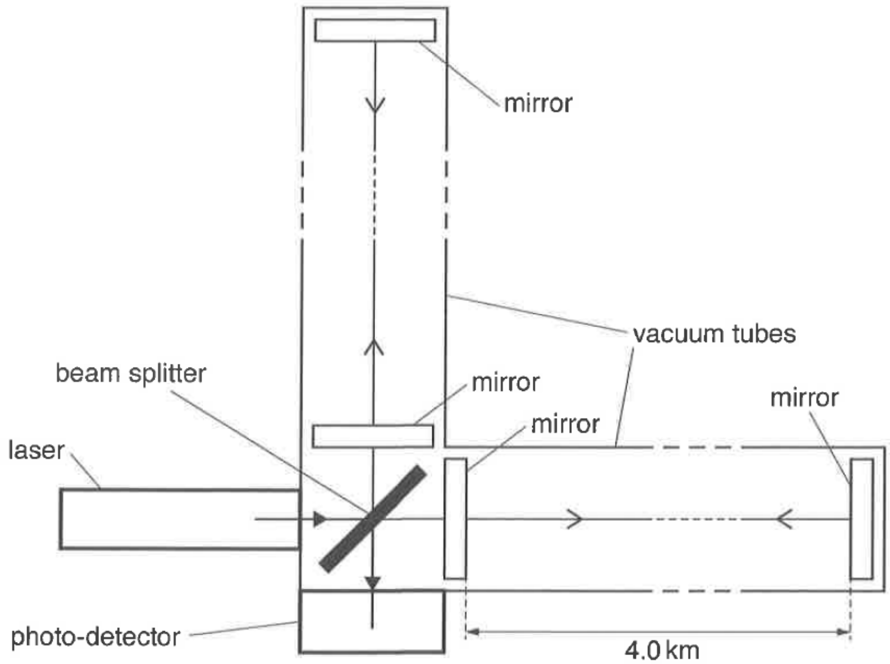
				1
			Examiners' Comments: *A number of candidates drew lines that were not sufficiently precise. The start of the deflection was often a long distance from where the proton entered the field, or the line stopped before the proton had exited the field. The correct direction of the deflection was shown by the vast majority of candidates.*	
4	**b**		**Essential Question(s):** • What is the direction of the magnetic field around each wire? How do we determine that? What is the magnetic flux density at a certain distance from a straight current carrying conductor? • How do we determine the direction and magnitude of the magnetic force acting on a straight current carrying conductor?	
			Solution:	
			Using the right hand grip rule on Wire Y, we can determine at Wire X, the magnetic field due to Y is acting into the plane of the paper.	
			The magnetic flux density of the field due to wire Y at X is given by: $B_Y = \frac{\mu_o I_Y}{2\pi d}$	1
			The force on X due to a magnetic field B_Y is given by: $F_X = B_Y I_X L = \frac{\mu_o I_Y I_X}{2\pi d} L$	
			Therefore, the force per unit length will be:	
			$\frac{F_X}{L} = \frac{\mu_o I_Y I_X}{2\pi d} = \frac{(4\pi \times 10^{-7})(5.5)(8.4)}{2\pi(0.12)}$	1
			$= 7.7 \times 10^{-5}\ Nm^{-1}$	1
			By Fleming's Left Hand Rule, since the B field is pointing into the paper and the current is downwards, the force is towards the right (or Wire Y).	1
			Examiners' Comments: Many candidates obtained the correct answer, including the direction of the force.	
5	**a**		**Essential Question(s):** ➔ How can e.m.f. of a source be defined in terms of energy changes? ➔ Which formula can be used to derive the meaning of e.m.f.?	

			Solution: The electromotive force (e.m.f.) of a source is the amount of energy transferred per unit charge from some other forms of energy into electrical energy, when the charge is driven round a complete circuit. **Examiner's Comments:** *Some candidates provided a generally imprecise explanation of the meaning of e.m.f.. There were references to work done instead of energy transferred. Some candidates provided the energy transfer in the wrong direction as electrical energy to other forms, while others missed the statement of energy transfer per unit charge.*	**1**
5	**b**	**i**	**Essential Question(s):** ➔ How does the current in the circuit flow when the switch is open? ➔ How does the current in the circuit flow when the switch is closed? ➔ What is the difference between e.m.f. of a source and terminal p.d.? **Solution:** When the switch is open; The circuit is incomplete. There is no current flowing through r. Hence, there is no potential drop across r. Thus terminal p.d. = e.m.f. = 12.0 V. When the switch is closed; The voltmeter reads the terminal p.d. of the entire circuit. Effective resistance of resistors S and T: $\left(\frac{1}{200}+\frac{1}{300}\right)^{-1}$ = 120 Ω Applying the potential divider principle: $\frac{120}{r+120}\times 12.0 = 10.8$ V r = 13.3 Ω **Examiners' Comments:** Many candidates were able to calculate the total resistance of resistors S and T in parallel.	**1** **1** **1** **1** **1**
5	**b**	**ii**	**Essential Question(s):** ➔ How is energy dissipated in the power supply? ➔ How does the current in the circuit flow when the switch is closed? **Solution:** When the switch is closed; Current I flows through the internal resistance. $I = \frac{V}{120} = \frac{10.8}{120} = 0.090$ A $E = I^2rt$ = $(0.090)^2(13.3)(5.0 \times 60)$ = 32 J	**1** **1**

5	**b**	**iii**	**Essential Question(s):** ➔ *What is an NTC thermistor?* ➔ *How does the change in total resistance of the entire circuit affect the flow of current?* ➔ *What is the relationship between the e.m.f. of source and the potential drop across the various components?*	
			Solution: *An NTC thermistor* is a thermistor with a negative temperature coefficient. When the temperature of the thermistor is increased, its resistance decreased. The total effective resistance of the NTC thermistor and resistor S in parallel thus decreased.	**1**
			Total resistance of entire circuit decreased. Current I flowing through r increased since E remains constant. There is a greater drop in potential (Ir) across r.	**1**
			Using $V = E - Ir$;	
			Terminal p.d. V thus decreased.	**1**
			Examiners' Comments: *Many candidates were able to give the correct decrease in total resistance for the thermistor and resistor S. However, only few candidates were able to give the effect of this resistance change on the p.d. across r and hence the p.d. reading on the voltmeter.*	
6			**Gravitational Waves**	
			In 1916, Albert Einstein predicted the existence of **gravitational waves**.	
			➔ What does "gravitational waves" mean? ➔ "Waves" suggests a propagation of energy from a source into a region of space ➔ "Gravitational" might suggest either potential energy or field strength at this stage.	
			Charge particles that are accelerating emit **electromagnetic waves**. Einstein thought that masses that are accelerating would emit **gravitational waves**. The **Laser Interferometer** Gravitational-wave Observatory (LIGO) detectors in the Louisiana and Washington states of America have recently confirmed the existence of these waves. The two detectors are 3002 km apart.	
			➔ At 'A' level content knowledge, o In EM waves, the electric field strength vector oscillates. (Wave Topic) o E-field and G-field have parallel. Therefore, G-field wave at this stage might suggest gravitational field strength oscillating as the wave travels. (E-field and G-field properties) ➔ "Interferometer" comes from the stem word, "interfere". Similar to any"-meter", like a voltmeter and ammeter, laser interferometer would suggest a device that allows laser light to interfere and to measure certain quantity. ➔ Laser is a light source. If they are to interfere, there must be two paths of light. Hence, by mentioning the detectors are "3002 km apart" would suggest a possibility of a path differences, hinting possibility of a geometry analysis (straight lines, Superposition Topic) ➔ At this point would be a possible confusion between gravitational waves and why a laser light interfering. What is the relationship between these two?	
			As a gravitational wave passes through the universe, it stretches and compresses space so that it is stretched in one direction and compressed in	

			a perpendicular direction. As a gravitational wave passes through an object, the **<u>object will change shape</u>** from the viewpoint of an outside observer. ➔ This paragraph attempts to describe properties of a “gravitational wave”. ➔ From previous paragraph, it is implied that gravitational field strength oscillates as the wave propagate. ➔ At some point in space, gravitational field strength is larger and at some point, it is smaller. ➔ In an object where different parts experience different gravitational field strength, the object can be stretch. Imagine a very long spring. If we strength with different forces along the spring, the spring would have different extension and compression. Gravitational forces are very weak. Only the gravitational waves emitted by very massive bodies, such as black holes and neutron stars, are currently detectable. ➔ Consistent with knowledge at ‘A’ level. The gravitational forces between two people are negligible because our masses are small. ➔ Furthermore, we are looking at oscillation (variation) of gravitational field strength over a distance ($1/r^2$ law), that source must be very massive. The first gravitational waves detected were emitted during the collision of two black holes, about 1.3×10^9 **<u>light-years</u>** from Earth. The black holes had masses of 29 and 36 solar masses, respectively. The two black holes collided to form one single black hole of 62 solar masses in a time of 20 ms. ➔ Source of gravitational wave is described as a collision of two black holes. Consistent the analogy so far with EM waves. When electrons collide with a target metal, X-rays (EM waves) are formed (Bremsstrahlung). ➔ Collision of two masses, 29 + 36 = 65 solar mass, but the single black hole only has a mass of 62 solar masses. Analogy to mass defect, any energy released due to the collision must be due to the missing mass. Still analogous to the idea that gravitational waves propagate energy and the energy comes from the massing mass. A LIGO detector is an interferometer built away from human activity. It consists of two straight vacuum tubes, each about 40 km long, arranged as shown in Fig. 6.1.	



A beam of leaser light, wavelength 1064 nm and power 200 W, is split into two coherent beams. Each beam is directed along a different tube of the interferometer. The two beams have a phase difference of π radian.

➔ As implied in first paragraph, the interferometer allows the laser light to interfere with itself – one path is towards the right while one is towards the top of page.
➔ "Beam splitter" in the diagram, together with the "split" in the text suggest one beam separated into two path.
➔ There are two types of arrow head – a solid one and a skeleton one. The solid arrow head suggests the path when two beams are combined as one, while the skeleton arrow head is when one beam is split into two individual paths.
➔ The skeleton arrows points in two directions. With mirrors in each tubes suggest that the light in each path is reflected multiple times along the same path. It is not immediately known to the reader at this time the purpose of the mirror, but the reader would need to trust that the description of the mirrors will be known, or perhaps suggested by the candidates.
➔ The two beams have a phase difference of π radian, suggesting that if the paths of the light beams taken in two arms are the same, the photo-detector will observe a minima (Superposition topic)

The light going along each tune is reflected 140 times from each mirror. The mirrors are 4.0 km apart. The distance between the mirrors in each tube is measured to a precision of one thousandth of a mm. These mirrors are designed to be isolated from vibrations and to minimize the effect of the light radiation pressure on them. Hence, the distance between the mirrors is only sensitive to changes caused by gravitational waves.

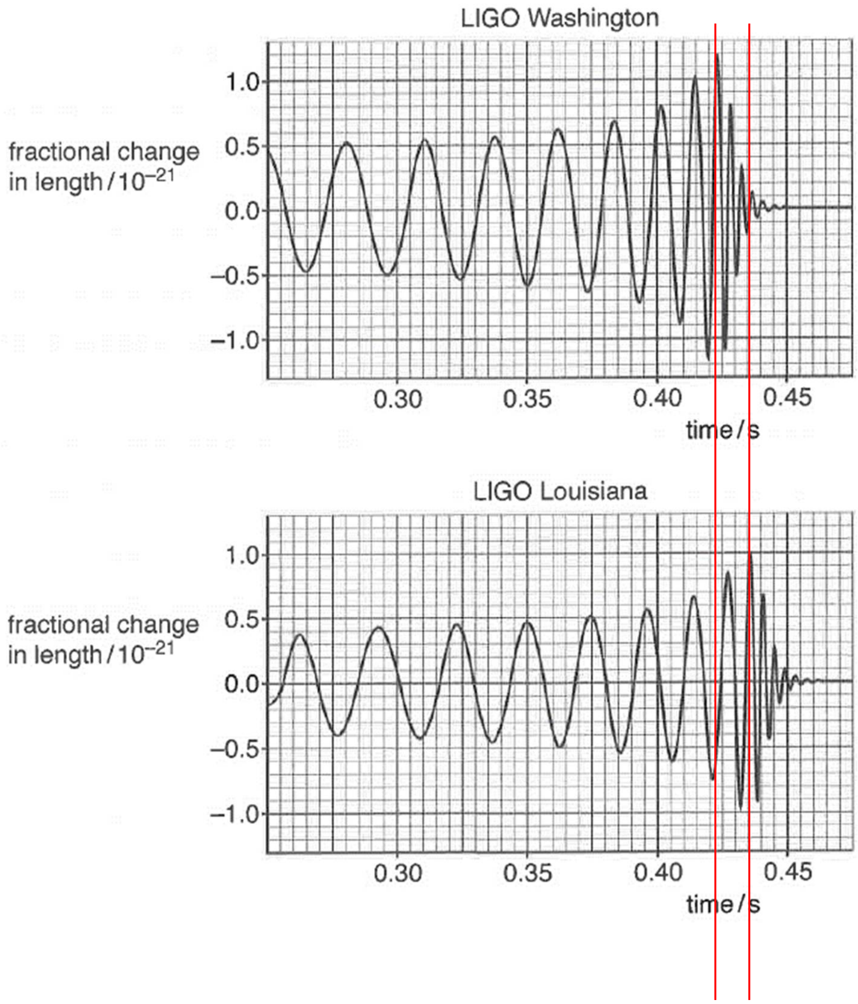
➔ It is unknown how 140 times reflection is done, but need to have the faith that it is indeed this number. The diagram is simplified and does not show how 140 times reflections are achieved. It seems that the mirror will reflect the light indefinitely. What is also assumed is that these mirrors are only partially opague, something like a two way mirror. If not, there is no chance that the light beam can enter the tube from the back of the mirrors.
➔ 140 times and placed 4.0 km apart. Total path taken is about 1120 km.

			➔ Error of one thousandth of a mm suggest that every reflection will have an error of one thousandth of an mm. Total absolute uncertainty = 1.4 x 10^{-4} mm ➔ Isolated for vibration is consistent with previous paragraph that talked about "away from human activities". For example, transportation cause vibration of the ground. ➔ "Light radiation pressure" suggest a force on the mirror. Every reflection of light photon has a change in momentum of the photon, causing a force on the mirror by the photon (Quantum physics, de Broglie's principle, Newton's 2^{nd} law) ➔ All the considerations are to account for the change in the space measured to be only due to gravitational waves, and not by vibrations or caused by the light force. The light travels 280 times along each tube before being recombined at a photo-detector. Under normal conditions, the resultant signal upon recombination has zero amplitude. In the presence of a gravitational wave, one tube of the interferometer lengthens and shortens, and the other tube shortens and lengthens. The tubes will change length in this way for as long as it takes the wave to pass. This results in a further difference in phase between the two light beans and a corresponding change of amplitude at the photo-detector where the two beams are recombined. LIGO detectors can detect a change in tube length as small as 10^{-19} m. ➔ Reflection of 140 means the light beam travels 280 times. Consistent with problem description earlier. ➔ Normal conditions, resultant signal is has zero amplitude. Consistent with earlier paragraph of phase difference of π, same path length by both beam (hence no path difference) ➔ One tube lengthens and shortens, the other tube shortens and lengthen. Just like a squeeze ball. If we squeeze the ball in one direction, the ball will lengthen in the perpendicular direction. No wonder Fig. 6.1 shows the paths perpendicular to one another. ➔ Change in phase corresponding to change of amplitude (consistent with 'A' level syllabus on Superposition, just like in the young double slit experiment along the screen.)	
6	**a**		**Essential Question(s):** ➔ What is the characteristic (quantity) of the source that can emit detectable gravitational waves? ➔ How do we know that in our solar system, there is no "source" that has that physical quantity? **Solution:** **Explanation:** In the 4^{th} paragraph, gravitational waves emitted by very massive bodies, such as black holes and neutron stars are detectable. The first gravitational waves detected are from masses of 29 to 36 solar masses and a single black hole of 62 solar masses. In our solar system, our sun is 1 solar mass. All planets are lesser than 1 solar mass. **Answer:** The masses of a source in the solar system, with sun as the heaviest with 1 solar mass, is not as high for gravitational waves to be observed, compared with black hole of 29 to 32 solar mass.	**1**

			Examiner's Comments: *A large number of candidates did not apply the information given in the text to the objects in the Solar System. Imprecise terms were used for the objects in the Solar System such as 'too small', 'not large' or 'heavy enough', rather than comparing the mass of the objects in the Solar System with the mass of a neutron star or black hole.*	
6	**b**	**i**	**Essential Question(s):** ➔ What does the graphs in Fig. 6.2 show? ➔ What does fractional change mean? ➔ How do we read off the maximum fractional change of length in the LIGO tube? **Solution:** From LIGO Washington, the largest fractional change in length is 1.2 x 10^{-21} Therefore the maximum change in length, $\Delta L = 1.2 \times 10^{-21} \times 4000 = 4.8 \times 10^{-18}\,m$ **Examiner's Comments:** *A large number of candidates confused the fractional change in length obtained from the graph with the actual change in length asked for in the question.*	**1**
6	**b**	**ii**	**Essential Question(s):** ➔ If the intensity detected by the photodetector is to increase from zero to the first maximum, what will its path difference be? ➔ Will the maximum change in length account for the path difference? Why and why not? **Solution:** As the wavelength of the light is 1064 nm and to have the first maxima, it requires a path difference of 532 nm which is 5.32 x 10^{-7} m, just a change in length of 4.8 x 10^{-18} is too small to have an observable change in the intensity at the detector. Each reflection increases the maximum path difference two times of the value obtained in (b)(i). In order to have an observable change in intensity detected, beams are reflected multiple times to increase the path difference which would increase the phase difference, which will produce a greater change in the resultant amplitude and intensity of the recombined beam, leading to a smaller percentage uncertainty in measurement. **Examiner's Comments:** *A large number of candidates gave incomplete answers referring to the reduction in the uncertainty or improving the accuracy. This is only true because the path difference has been increased.*	**1** **1**
6	**b**	**iii**	**Essential Question(s):** ➔ During interference, what are the criteria that resulted in the superposition of light to have amplitude zero? **Solution:** The two light beams are π radians out of phase at the point of splitting. And in the absence of gravitational waves, each beam travels the same distance, hence there is no path difference between the two light beams. Therefore the two beams meet at the detector with phase difference of π radians (antiphase) and undergo destructive interference. Assuming that the beam splitter splits the beam with equal intensity, each light beam will have the same amplitude. Therefore, during complete destructive interference, the resultant amplitude is zero.	**1** **1**

			Examiner's Comment: *This was generally well answered. A significant number gave the incorrect answer of zero amplitude due to the gravitational waves not being present and therefore no change in length.*	
6	c	i	**Essential Question(s):** ➔ What is power? ➔ What is a photon? And how do we quantify power due to photon? ➔ How to calculate the energy of one photon? **Solution:** Power is the rate of transfer of energy with respect to time, $P = \frac{E}{t} = \frac{Nhf}{t} = \frac{Nhc}{\lambda t}$ Where the energy of a photon is E = hf = hc/λ, and Nhf represents the total energy passing through a point in time t. If time t is 1s, $N = \frac{P\lambda t}{hc} = \frac{(100)(1064 \times 10^{-9})(1)}{(6.63 \times 10^{-34})(3.00 \times 10^{8})}$ $N = 5.349 \times 10^{20} \approx 5.35 \times 10^{20}$ **Examiner's Comment:** *This was generally well answered. The majority of candidates were able to link the energy of a photon with the power of the beam and calculate the number of photons passing a point each second.*	1 1 1
6	c	ii	**Essential Question(s):** ➔ What is a force? How can a force be exerted? ➔ How can a photon reflected by the mirror exert a force on the mirror? ➔ How is the number of photons in (c)(i) contribute to the "average" force exerted by the light beam? ➔ What does completely reflected back suggest about the number of photons reflected? ➔ What does the phrase "along its original path" suggest about the change in momentum of the photon? **Solution**: Momentum of a 1064 nm photon, $p = \frac{h}{\lambda}$ When a photon is reflected along its original path, it has the same magnitude of momentum but in the opposite direction. Therefore, the change in momentum of one photon, $\Delta p = -p - p = -2p$ As there are N photon changing its momentum over a period of 1 s, the rate of change of momentum, $\left\lvert \frac{\Delta P}{\Delta t} \right\rvert = \frac{N\Delta p}{\Delta t} = \frac{N\left(2\frac{h}{\lambda}\right)}{\Delta t} = \frac{(5.35 \times 10^{20})\left(2\frac{6.63 \times 10^{-34}}{1064 \times 10^{-9}}\right)}{1}$ $\langle F \rangle = 6.67 \times 10^{-7} N$ **Examiner's Comments:** *Candidates did not perform well in this question. A small number of candidates were able to link the momentum change of the photons with the force exerted by the light beam. Some only treated the momentum change assuming the photon stopped rather than being reflected.*	1 1 1

6	c	iii	**Essential Question(s):** ➔ When the photon is absorbed and ceased to exist, what happens to its final momentum? And what is the change in momentum of that photon? **Solution:** When a photon is absorbed (rather than reflected), its final momentum is zero and hence the change in momentum for the absorbed photon is half that of the reflected photon (lesser at p rather than 2p). As the change in momentum for some of the photons in the light beam is smaller than that in (c)(ii), the average force is also smaller than that in (c)(ii). **Examiner's Comment:** *Candidates did not perform well in this question. A minority of candidates gave a correct response with the correct explanation. A significant number stated the change in the force without any explanation. A number of candidates explained the reduction in the force as due to a reduction in the number of photons.*	
6	d	i	**Essential Question:** ➔ Where does that energy come from? ➔ A hint is provided – 1.0 Solar Mass = 2.0 x 10^{30} kg. How is mass related to energy? ➔ During the analysis above, there is a reducing in mass when the black holes collide. Which topic tells us about a reduction in mass give rise to an energy release? **Solution:** By Einstein's mass-energy equivalence, mass loss give rise to energy released, $E = \Delta m.c^2$ $E = (29+36-62)(2.0\times10^{30})(3.00\times10^8)^2$ $E = 5.4\times10^{47}\,J$ **Examiner's Comments:** *This was well-answered by the majority of candidates. A small minority did not square the velocity of light in their final calculation after correctly stating the formula.*	 1 1
6	d	ii	**Essential Question(s):** ➔ What's the quantity that is the same as power per unit area? **Solution:** As the distance between the source and the Earth is large, the source appears as a point source to the Earth. Hence the energy travels uniformly in all directions, implying spherical wavefronts. Therefore, the intensity received at Earth, $I = \frac{P}{4\pi r^2}$ $I = \frac{5.4\times10^{47}}{(20\times10^{-3})(4\pi)(1.3\times10^9\times9.5\times10^{15})^2}$ $I = 0.01408 \approx 0.014 Wm^{-2}$ **Examiner's Comments:**	 1 1 1 1

			*A minority of candidates obtained the correct answer. A significant number were unable to give the area for a spherical surface as the area through which the waves passed. Some used the energy calculated in **(i)** as the power or tried to calculate the time for the waves to travel to the Earth for the time in which the energy was emitted during the collision of the black holes.*	
6	**e**	**i**	**Essential Question**: ➔ How different is the two graphs for the two LIGO detectors? ➔ How do we see time differences from the two graphs? Solution:  Taking the largest positive fractional changes of the respective LIGO detector, the timing is about **0.015 s**. Examiner's Comments: *A minority of candidates gave a correct response. Many candidates were not able to interpret the two graphs correctly.*	**1**
6	**e**	**ii**	**Essential Question(s):** ➔ How to determine speed? **Solution:** Speed is the total distance travelled divided by the time taken, $v=\frac{s}{t}=\frac{3002\times10^{3}}{0.015}=2.0\times10^{8}ms^{-1}$	**1**

			Examiner's Comments: *There were many correct answers. A few candidates used the length of the tubes instead of the separation of the detectors.*	
6	e	iii	**Essential Question(s):** ➔ How is the distance of 3002 km determined? ➔ If EM waves' speed can be altered when going through different "medium", what kind of "medium" will change the speed of gravitational wave? **Solution:** The actual path taken by the gravitational wave is affected by the gravitational field of the Earth and the solar system such that it is actually longer than the distance on the Earth surface. **Examiner's Comment(s):** *There were very few correct suggestions.*	1
6	f		**Essential Question(s):** ➔ How is space different from on Earth surface? **Solution:** Any two of the following: • While LIGO is physically bound to 4.0 km arms, space-based detectors can form vast interferometers spanning millions of kilometers. This dramatically multiplies the instrument's overall sensitivity to faint cosmic signals. • The Earth vibrates continuously from human activity, ocean waves, and seismic shifts. Placing detectors in free-floating satellites in space eliminates these background disturbances completely, opening the door to detecting low-frequency gravitational waves. • Low-frequency waves have enormous wavelengths (spanning from light-years to astronomical units). To accurately measure them, the detector must be a substantial fraction of the wavelength. Earth-based detectors like LIGO can only measure lengths on the kilometer scale, making them blind to these stretched-out signals. Whereas space-based detectors can span much larger distance and hence able to measure the ultra-long wavelengths. **Examiner's Comments:** *There were very few correct responses.*	2

Paper 3
Section A

				Marks
1	a	i	**Essential Question(s):** ➔ What is the direction of air resistance acting on the object? ➔ Do you need to know the magnitude of air resistance? No. ➔ What will be the maximum height reach when there is no air resistance? Will this height be greater than 1100 m? **Solution:** As the object travels vertically upwards, both the weight and air resistance acts opposite in direction to the object. Assuming negligible air resistance, weight is then the only the force acting , in opposite direction, to the object, and the magnitude of the acceleration of the ball is constant at g.	1

			Take upwards as positive, $u = 160\ m\ s^{-1}$, $a = -g = -9.81\ m\ s^{-2}$, at maximum height, $v = 0$ Using $v^2 = u^2 + 2as$ $0 = (160)^2 + 2(-9.81)s$ $s = 1300\ m$ Since the calculated height is 1300 m > 1100 m, the actual height, it can be concluded that air resistance acting on the object is not negligible. When both the weight and air resistance acts opposite in direction to the object, the object experiences an average deceleration of magnitude greater than g, causing the object to slow down at a greater rate and thus reach a height of 1100 m instead of 1300 m. **Examiner's comments:** There were several correct routes by which the question could be answered. The majority chose to calculate the height to which the object rose, assuming no air resistance and then to compare this to the actual height. A significant number used an equation for constant acceleration to determine a value for the deceleration on the upward motion, without mentioning that this is an average or that the equation is not really valid.	 **1** **1**
1	**a**	**ii**	**Essential question:** ➔ Apply conservation of energy Solution: When the object reaches the maximum height, Applying conservation of energy, Loss in K.E. = Gain G.P.E + Energy lost due to air resistance $\frac{1}{2}mu^2 - 0 = mg\Delta h$ + Energy lost due to air resistance Energy lost due to air resistance $= \frac{1}{2}(0.92 \times 10^{-3})(160)^2 - (0.92)(9.81)(1100)$ $= 1.848 = 1.85\ J$ **Examiner's comments:** This was generally completed accurately by reference to the actual height reached and the height assuming no air resistance.	 **1** **1**
1	**b**		**Essential Question(s):** ➔ What law can be applied to find acceleration/deceleration? **Solution:** Take upwards as positive, Let R be the air resistance acting on the object at the initial speed, W be the weight of object and a is the acceleration of object. Apply Newton 2^{nd} Law, $F_{net} = ma$ $-R - W = ma$	

$(-3.4 \times 10^{-3}) - (0.92 \times 10^{-3} \times 9.81) = (0.92 \times 10^{-3}) \times a$ **1**

$a = -13.5 \text{ m s}^{-2}$ **1**

Examiner's comment(s):
A common error was to give as an answer the deceleration produced alone by the air resistance. Some candidates subtracted this value from the acceleration of free fall.

1 c

Essential Question(s):

➔ If force F_A due to air resistance is proportional to the square of the speed v at speed greater than 80 m s^{-1}, how will the calculated value of constant of proportionality at each speed, changes?

➔ How do you choose the values of v and FA to calculate the value of constant of proportionality?

Solution:

For speed greater 80 m s^{-1}, the ratio of $\frac{F_A}{v^2}$ is calculated as follows:

No.	v / m s^{-1}	F_A / N	v^2 / m^2 s^{-2}	Ratio = $\frac{F_A}{v^2}$
1	100	1.35×10^{-3}	1.00×10^{4}	1.350×10^{-7}
2	120	1.90×10^{-3}	1.44×10^{4}	1.319×10^{-7}
3	140	2.60×10^{-3}	1.96×10^{4}	1.327×10^{-7}
4	160	3.40×10^{-3}	2.56×10^{4}	1.328×10^{-7}

1

From the above table,

maximum deviation of the ratio = $(1.35 - 1.319) \times 10^{-7}$
$= 0.031 \times 10^{-7}$

maximum deviation of the ratio in percentage $\frac{0.031 \times 10^{-7}}{1.319 \times 10^{-7}} \times 100\% = 2.35\ \%$ **1**

Since the deviation of the calculated ratio is less than 3% for speed greater 80 m s^{-1}, the ratio $\frac{F_A}{v^2}$ is almost constant.

It can then be concluded that the force F_A due to air resistance is proportional to the square of the speed *v.* **1**

Examiner's comments:
Stronger responses used two points whose co-ordinates were well-spaced out along the graph line. Most candidates did realise that, where a 'constant' of proportionality was determined for each point, two significant figure answers would be inadequate for drawing any conclusion.

2 a

Essential question:

➔ What equation must we begin this derivation from?

Solution:

The gravitational force, F_G, on the satellite provides its centripetal force, **1**

$$F_G = F_C$$

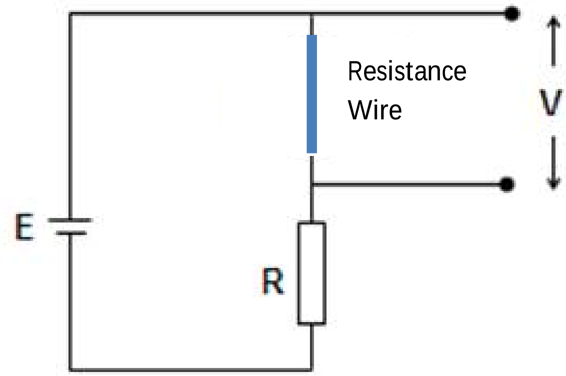
1

			$\frac{GMm}{(R+h)^2} = \frac{mv_s^2}{(R+h)}$ where m is the mass of the satellite $v_s^2 = \frac{GM}{(R+h)}$ therefore, $v_s = \sqrt{\frac{GM}{(R+h)}}$ **Examiners' Comments:** *In general, answers were satisfactory. Where symbols are stated in the question, stronger candidates tended to use these symbols in their answers.*	1
	b		**Essential Question(s):** ➔ What concept must we make use of to solve this question? ➔ What equation must we use to arrive at the derivation from? By the law of conservation of energy, Total intial energy = Total final energy $GPE_{initial} + KE_{initial} = GPE_{final} + KE_{final}$ As the rock starts from rest at an infinite distance away, $GPE_{initial} = 0$ and $KE_{initial} = 0$ So, $0 + 0 = GPE_{final} + KE_{final}$ $0 = -\frac{GMm_1}{(R+h)} + \frac{1}{2}m_1V^2$ (where m_1 is the mass of the rock) $\frac{1}{2}m_1V^2 = \frac{GMm_1}{(R+h)}$ $V = \sqrt{\frac{2GM}{(R+h)}}$ **Examiners' Comments:** *Most candidates derived the expression correctly. However, quite a number of candidates did not explain clearly the energy changes.*	1 1 1
	c		**Essential Question(s):** ➔ What conditions are there for the object to be in orbit? For the object to be in orbit the speed of the object has to be equal to $\sqrt{\frac{GM}{(R+h)}}$. However the speed of the rock when it arrives at the planet is $\sqrt{\frac{2GM}{(R+h)}}$. If the speed of the object is higher than that required to be in orbit it thus means that the gravitational force is insufficient to provide the centripetal force required for the object to be in orbit. Therefore it will travel off into space. Coincidentally the speed that the rock arrives at the planet is the escape speed so the rock has enough kinetic energy to travel and reach infinity again. **Examiners' Comments:**	1 1

			With few exceptions, answers were based correctly on the expressions derived in (a) and (b).	
3	**a**	**i**	**Essential Question(s):** ➔ *How can the ideal gas equation pV = nRT be used to derive the relationship between volume and temperature of a gas at constant pressure?* ➔ *What are the units for the volume and temperature of the gas?* Solution: Using *pV = nRT, since p, n and R are constants,* $\frac{V_A}{T_A} = \frac{V_B}{T_B}$ $\frac{2800 \times 10^{-6}}{315} = \frac{7600 \times 10^{-6}}{T_B}$ T_B = 860 K	 **1** **1**
3	**a**	**ii**	**Essential Question(s):** ➔ *What is the formula used to determine work done by gas?* ➔ *Graphically, how is Fig. 3.1 used to calculate the work done by the gas?* **Solution:** External work done by the gas = area under the pressure-volume graph from A to B. $W = p_A(V_B - V_A) = (3.5 \times 10^5)(7600 \times 10^{-6} - 2800 \times 10^{-6})$ = 1700 J **Examiners' Comments:** *Most candidates were able to answer this part of question correctly. There were some power-of-ten errors made by few candidates.*	 **1** **1**
3	**b**		**Essential Question(s):** ➔ How does temperature vary with internal energy of the ideal gas? ➔ How is the first law of thermodynamics applied in the various stages of the process? **Solution:** stage | increase in internal energy / J from point B to point C | 0 from point C to point A | -2520 from point A to point B | +2520 From point A to point B; Net change in internal energy of the gas is zero since the gas returns to its original state in the cyclic process. Thus, change in internal energy has to be +2520 J. From point B to point C; Internal energy of the ideal gas $U = \frac{3}{2}nRT$. Since the temperature of the gas remains constant, there is no change in internal energy.	 **1** **1**

			<u>From point C to point A;</u> There is no change in volume. Thus, there is no work done on gas. By first law of thermodynamics, $\Delta U = Q = -2520$ J. **Examiners' Comments:** *Most candidates were able to answer correctly for the change in internal energy from point C to point A. Only few candidates realized that there would be no change in internal energy from point B to point C. For most candidates, the answer for the change in internal energy from point A to point B usually led to the total change as being zero.*	1
4	a	i	**Essential Question(s):** • What forces are acting on the tube when immersed in water? What are the directions of these forces? • When the tube is displaced downwards, how do the forces acting on the tube change? Why? • Why does the tube oscillate vertically? What provides for the net force required for the oscillation? • How do we find the equations for the upthrust and the weight? What does the upthrust depend on? • How do we find the resultant force acting on tube when displaced downwards? What is the direction of this resultant force? Why is it in that direction? **Solution:** Before the tube is displaced downwards, it is floating, and by the Principle of Floatation, its weight, *Mg* is equals to the upthrust acting on it, *U*. (*U* = *Mg*) When the tube is displaced downwards, more fluid is displaced by the tube, and thus the upthrust increases. Let this new upthrust be *U'*. At this point, the forces acting on the tube is the upwards upthrust, *U'* and the downwards weight *Mg*. Taking upwards as positive, the resultant force is therefore: $F = U' - Mg.$ Since *Mg* = *U*, therefore: $F = U' - U$, which is the change in upthrust when the tube was displaced downwards. This change in upthrust, Δ*U* is given by the weight of the additional fluid displaced by Archimedes Principle, and so: $F = U' - U = \Delta U = \Delta V \rho g = Ax\rho g$ where ΔV is the volume of the additional fluid displaced. **Examiner's comments:** *In the majority of answers, it was not made clear that the resultant force would be the difference between the weight and the upthrust. In most cases, answers were not explained clearly and amounted to a statement of the expression.*	1 1 1
4	a	ii	**Essential Question(s):** • How is the resultant force related to the acceleration of the tube? • What is the direction of the resultant force? Why does a negative sign emerge in the expression? **Solution:** By Newton's Second Law, and taking upwards as positive, the acceleration is given by:	1

			$$a = \frac{F}{M} = \frac{A(-x)\rho g}{M} = -\left(\frac{\rho A g}{M}\right)x$$ The negative sign arises from the fact that the displacement is downwards (negative direction), while the acceleration is upwards (positive direction). **Examiner's comments:** *Most answers included the correct final expression. Comparatively few included a statement regarding the directions of the displacement and the acceleration in order to show how the negative sign arose.*	**1**
4	**(b)**		**Essential Question(s):** • What is the defining equation of a simple harmonic motion? What does $\left(\frac{\rho A g}{M}\right)$ equate to when comparing the derived equation to the SHM equation? • How can we find frequency from the angular frequency of a SHM? **Solution:** The SHM equation is: $a = -\omega^2 x$ where ω is the angular frequency Comparing with: $a = -\left(\frac{\rho A g}{M}\right)x$, we can see that $\left(\frac{\rho A g}{M}\right) = \omega^2$ Since $\omega = 2\pi f$, then $(2\pi f)^2 = \left(\frac{\rho A g}{M}\right)$ Rearranging and solving for *f:* $$f = \sqrt{\left(\frac{\rho A g}{4\pi^2 M}\right)} = \sqrt{\frac{(1.2\times10^3)(5.3\times10^{-4})(9.81)}{4\pi^2(0.13)}} = 1.1Hz$$ **Examiner's comment(s):** *Most answers were correct.*	**1** **1** **2**
5	**a**		Essential question: ➔ How to calculate **extension using Hooke's Law?** **Solutio**n: Extension = Force / Spring constant = 27 / 1.8 x 10^4 = 1.5 x 10^{-3}m	**1** **1**
	b		**Essential Question(s):** ➔ How to calculate resistance using the resistivity formula? **Solution:** $$\Delta R = \frac{\rho \Delta l}{A} = \frac{3.2\times10^{-8}\times1.5\times10^{-3}}{2.0\times10^{-7}}$$ $= 2.4\times10^{-4}\Omega$	**1** **1**
	c		**Essential Question(s):** ➔ What kind of circuit does a resistance result in a change in the voltage?	

			Solution:  **Examiner's comments:** *In general, candidates performed poorly on this question. Only a minority showed clearly the wire in series with a resistor and the cell. Frequently, the resistance wire could not be distinguished from the connecting wires. It was common to find that the voltmeter was connected across the cell.*	
6	**a**	**i**	**Essential Question(s):** • What are the quantities used in the formula for the magnetic flux density in the middle of the coil? Take note of the units used in the diagram. **Solution:** $B=\mu_0 nI$ $=(4\pi\times10^{-7})\left(\frac{900}{46\times10^{-2}}\right)(2.4)$ $=5.9\times10^{-3}$ T **Examiner's Comments:** *Correct answers were in a minority. Many answers were based on an incorrect expression for the flux density. Where the correct expression was stated, the major problem was the value for n.*	
		ii	**Essential Question(s):** • How does the pattern look at the centre and at the ends of the solenoid? • What does the pattern imply for the magnitude of the magnetic flux density? **Solution:** The magnetic field lines at the centre of the solenoid are parallel to each other and are equally spaced out. However, the field lines are more spread out at the ends of the solenoid. The difference in the patterns is due to the magnetic flux density at the ends being half that at the centre. This is because the magnetic flux density at the ends of the solenoid is due to current to one side of that end, whereas the magnetic flux density at any point in the centre is contributed by currents on two sides. **Examiner's Comments:** *Most answers included a correct statement regarding the magnitude of the flux density at the two positions. Relatively few attempted an explanation in terms of the spreading of field lines at the ends of the solenoid. A significant*	**B1** **B1**

			number of answers attributed any change to the flat coil at the centre of the solenoid.	
	b	**i**	**Solution:** Faraday's law of electromagnetic induction states that magnitude of the electromotive force (e.m.f.) induced in a conductor is directly proportional to the rate of change of magnetic flux linkage of the conductor. **Examiner's Comments:** *With few exceptions, an adequate statement was given.*	**B1** **B1**
		ii	**Essential Question(s):** • How does magnitude of the magnetic flux density at the solenoid relate to the emf induced in the flat coil? o How does the value calculated in (a)(i) help in the calculation? • How does the I-t graph used in the calculation of the emf? **Solution:** $\lvert E \rvert = \left\lvert -\frac{d\Phi}{dt} \right\rvert$ $= \frac{d(NBA)}{dt}$ $= NA\frac{dB}{dt}$ At t = 1.5 ms, the current flow in the solenoid is 0 A, thus the $B_{t=1.5s}$ = 0 T. Therefore, $E = NA\frac{dB}{dt}$ $= NA\frac{B_{t=0}-B_{t=1.5\text{ ms}}}{1.5\times10^{-3}}$ $= 95\times\left[\pi\times\left(\frac{1.6\times10^{-2}}{2}\right)^2\right]\left(\frac{5.9\times10^{-3}-0}{1.5\times10^{-3}}\right)$ $= 0.075\text{ V}$ **Examiner's Comments:** *Most answers were correct, when based on the answer in **(a)(i)**.*	**B1** **B1**
		iii	**Essential Question(s):** • How is the I-t graph related to the E-t graph? • What are the important points in the graph that need to be indicated? • What is the value of the induced emf at 3.0 ms? **Solution:**	

$= -\left(N_{coil}A_{\text{of coil intercepting field}}\mu_0 n_{solenoid}\right)\times(\text{gradient of the } I\text{-t graph})$

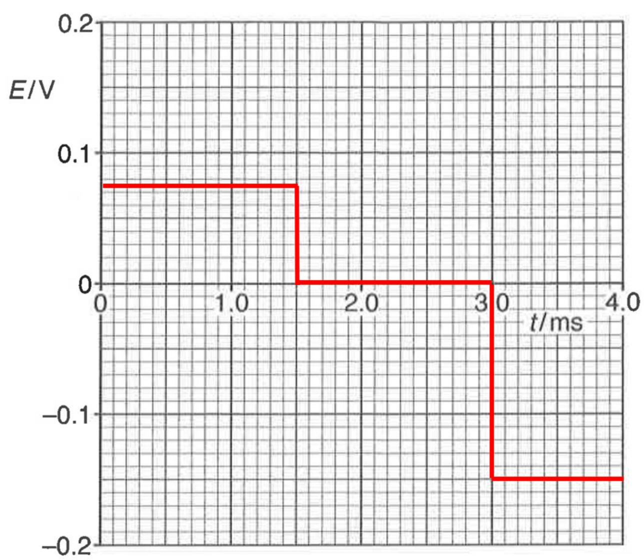
Thus, the shape of the E-t graph is **proportional** to the gradient of the I-t graph.

Repeat calculations in (b)(ii) for time t = 3.0 ms to t = 4.0 ms, or,
Use proportionality between gradient of the I-t graph and E to calculate E for t = 3.0 ms to t = 4.0 ms:

$$E_{t=3.0\text{ ms}} = \frac{E_{t=1.5\text{ ms}}}{\text{grad}_{t=0\text{ ms}\rightarrow t=1.5\text{ ms}}}\left(\text{grad}_{t=3.0\text{ ms}\rightarrow t=4.0\text{ ms}}\right)$$

$$= \frac{0.075}{-2.4/1.5\times10^{-3}}\left(3.2/1.0\times10^{-3}\right)$$

$$= -0.15\text{ V}$$



1 mark:
Correct shape (3 horizontal lines) at the correct time intervals.
Correct positive and negative regions, corresponding to gradient of Fig. 6.2.

1 mark:
Correct value of E at t = 1.5 to 3.0 ms.

1 mark:
Correct value of E at t = 3.0 to 4.0 ms.

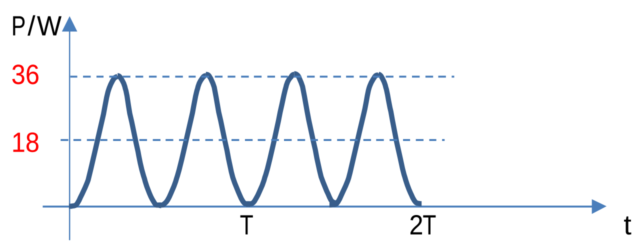
Examiner's Comments:
Most did show constant and zero e.m.f in the correct time intervals. The most common error was on the ratio for the magnitudes of the e.m.f. Some candidates also did not indicate a change in polarity.

7 a

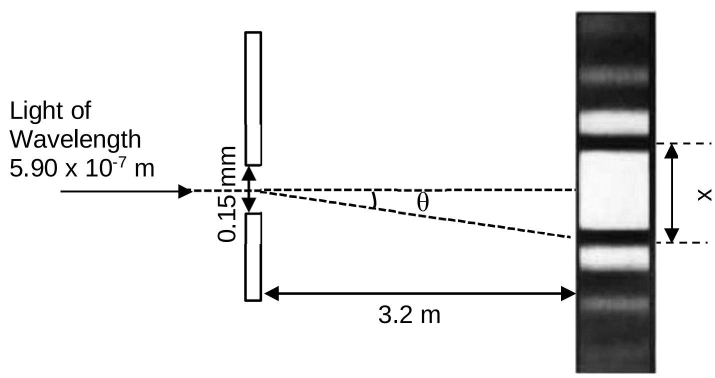
Essential Question(s):
➔ Define r.m.s. in terms of heating effect.

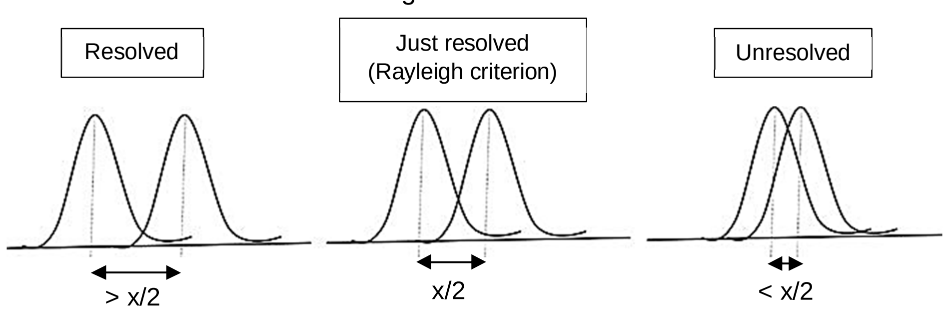
Solution:
The r.m.s. value of an a.c. is the value of a steady direct current that will dissipate heat at the rate as the alternating current in a given resistor. **2**

Examiner's comments:

			The main problem with answering this was lack of precision. Reference was made to same heating rather than rate of energy transfer. Same heating may or may not be time dependent	
7	**b**	**(i)**	**Essential Question(s):** ➔ Relate r.m.s. p.d. to peak p.d. **Solution:** R.M.S. p.d. = $V_o / \sqrt{2} = 24 / \sqrt{2} = 17$ V **Examiner's comments:** *This question was completed with few difficulties.*	**1**
7	**b**	**(ii)**	**Essential Question(s):** ➔ Relate frequency to angular frequency ➔ Given V = 24 sin 440t what is the angular frequency? **Solution:** Frequency = $\varpi / 2\pi = 440 / 2\pi = 70$ Hz **Examiner's comments:** *This question was completed with few difficulties.*	**1**
7	**(c)**	**(i)**	**Essential Question(s):** ➔ Relate mean power to V_{rms} and R **Solution:** Mean power = $V_{rms}^2 / R = 17^2 / 16 = 18$ W **Examiner's comment:** *Most students used the r.m.s. p.d. calculated in* ***(b)(i)***	**2**
7	**c**	**(ii)**	**Essential Question(s):** ➔ How does instantaneous power vary with time? ➔ How is max power related to mean power? ➔ What is the max and min power? ➔ What is the period of V ➔ What is the period of T? **Solution:** Max power = 2 x mean power = 2 x 18 = 36 W Min power = 0 W Period of p.d. = T Period of instantaneous power = T/2  **Examiner's comments:** *Most curves were sinusoidal with the troughs on the time axis. Many had the same period as the alternating voltage. Equally, either the peak power was not labellel or it was made equal to the r.m.s. power.*	**3**

Section B

8	a	i	A *photon* is a quantum of electromagnetic radiation energy. Its energy is equal to the product of Planck's constant and the frequency of the radiation.	1 1
8	a	ii	Two light waves are *coherent* if the phase **difference** between them remains constant. *Note: 'Itacised' words in the question are the words you need to focus on explaining, i.e. no need to explain what are light waves; focus on explaining coherence.*	1
8	b	i	**Essential question(s):** • Which sub-topic under Superposition is this on? ➔ **Single-slit diffraction** • How does the pattern on the screen look like?] ➔ Alternating maxima & minima intensity fringes, with the central maximum fringe being about twice the width of the higher orders maxima fringes ***Tip: Draw a diagram to aid your analysis!*** **Solution:**  Using single-slit diffraction equation: b sin θ = m λ were m: order of intensity *minima* $(0.15 \times 10^{-3}) \sin\theta = (1)(5.90 \times 10^{-7})$ θ = 0.22535° From diagram above, $\tan\theta = \dfrac{\frac{x}{2}}{3.2}$ $\tan 0.22535° = \dfrac{\frac{x}{2}}{3.2}$ x = 0.025174 m = 0.025 m (2 s.f.) **Examiners' Comments:**	1 1 1 1

			The majority of answers were correct. The most common error was to determine the half-width.	
8	b	ii	Rayleigh's criterion states that the images of two sources are ***just*** distinguishable if the **central maximum** of **one diffraction pattern** lies on the **first minimum** of the **other diffraction pattern**. **Examiner's" Comments:** *Most answers included a reference to the central maximum and the first minimum. Very few attributed these to **diffraction patterns** but instead, to 'waves' or 'images'.* ***Note:** Compare this question with the question asked in N2017/P3/5bi: "Explain what is meant by *Rayleigh criterion* for the resolution of the two pattern." → The Examiners' Report in N2017 did not stress the importance of mentioning 'diffraction patterns' probably because it was already mentioned in the question itself. Hence to safeguard yourself, **it is recommended that you always include 3 main points:** **➔ just distinguishable [do not use 'just resolved']** **➔ diffraction pattern [preferred over 'image']** **➔ central maximum of one lies on first minimum of the other**	1 1
8	b	iii	**Essential Question(s):** • To check if the 2 diffraction patterns due to the double slits are distinguishable using Rayleigh criterion, we need to know the separation between the central maxima of the 2 diffraction patterns…how can we know this? → What information is given in the question & what have we derived in the earlier part(s)? ➔ Separation between the 2 central maxima equals to the separation of the double slits = 2.3 mm ➔ What is the distance between the central maximum of one & the first minimum of the other? → Draw out the 2 diffraction patterns as shown below to visualise. → distance equals HALF the width of the central maximum fringe found in (b)(i) = x/2 = 0.025174 m / 2 = 12.6 mm ➔ So are the 2 diffraction patterns distinguishable? → No, because 2.3 mm is less than 12.6 mm. The 2 diffraction patterns overlap to a large extent and hence not distinguishable.  where x: width of the central maximum of a single slit diffraction pattern, calculated in (b)(i) Solution: Using (b)(i), **distance between the central maximum of one diffraction pattern and the first minimum of the other equals to 0.025174 m / 2 = 12.6 mm**. The **separation between the central maxima of the two slits' diffraction patterns in Fig. 8.1 is 2.3 mm**.	 1 1

<table>
<tr><td></td><td></td><td></td><td>The separation of 2.3 mm is <u>very much smaller than</u> the separation of 12.6 mm required for the two diffraction patterns to be distinguishable by Rayleigh criterion. The two diffraction patterns overlap to too large an extent and will <u>not</u> be seen as being separate.

Examiners' Comments:
Many attempted a purely qualitative argument and thus, did not make any progress. A minority did calculate some angles but generally these were not defined.
➔ Quantitative values are required to justify the qualitative argument.</td><td>1</td></tr>
<tr><td>8</td><td>b</td><td>iv</td><td>Essential Question(s):
• Is this question on diffraction fringes or double-slit interference fringes?
➔ Question talks about 'diffraction through the uncovered double slits'…hence potentially confusing for students. However, key word her is 'double slits'. Basically, the 2 waves need to diffract through each slit first before they can overlap and hence interfere to produce the double slit interference fringes.
➔ Hence use Young's double slit equation: x = λD/a

Solution:

$x = \frac{\lambda D}{a} = \frac{(5.90\,x\,10^{-7})(3.2)}{(2.3\,x\,10^{-3})}$

= 8.2087 x 10^{-4} = 8.2 x 10^{-4} m

Examiners' Comments:
The relevant expression was known by most candidates. It was common to find that the slit separation was not given as 2.3 mm but rather, either 3.15 mm or 2.45 mm.</td><td>1

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<tr><td>8</td><td>b</td><td>v</td><td>Essential Question(s):
• How to relate (b)(i) and (v)?
➔ Recall that the double slit interference maxima fringes are NOT uniformly intense due to diffraction through NON-infinitesimally small double slits.
➔ Recall the following diagram from your Module Notes:</td><td></td></tr>
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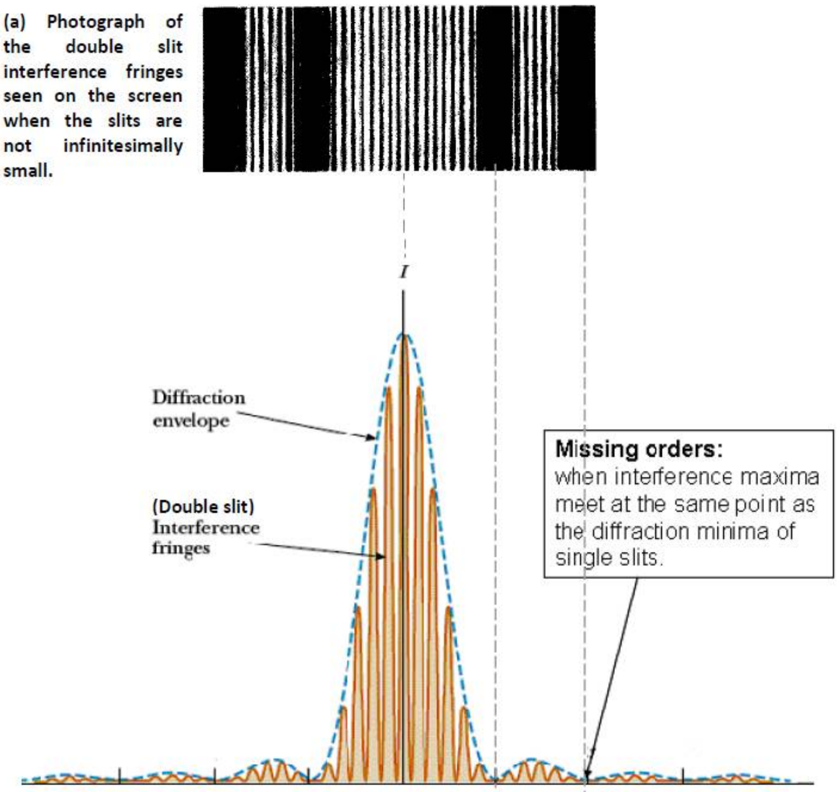
(a) Photograph of the double slit interference fringes seen on the screen when the slits are not infinitesimally small.



(b) Plot of intensity against distance from the central maxima.
The figure shows the combined effects of double slit interference and single slit diffraction. Notice how the diffraction pattern acts as an 'envelope' and controls the intensity of the regularly spaced interference maxima.

- Is the question asking for number of bright fringes or dark fringes or both? → both.

Solution:

Total number of bright & dark fringes within the central maximum diffraction envelope = 0.025174 / 8.2087 x 10^{-4} = **<u>30 (1 s.f.)</u>**

Examiners' Comments:
Many did not give the answer to one significant figure or rounded up the answer, rather than rounded down.

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<td>8</td>
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Essential question(s):

- Which sub-topic under Superposition is this on?
- → **Diffraction grating**
- Which angles of diffraction will produce a maxima on the screen?
- → Find the highest ***order*** of maxima that can form on the screen by using θ = 90°.
- → Once we know which orders can be formed on the screen, we can find their corresponding angles of diffraction.

Solution:

d sin θ = nλ   where n: order of maxima --- (1)

To find the highest ***order*** of maxima that can form on the screen, sub θ = 90°:

$$\frac{1\ x\ 10^{-3}}{750}\sin 90° = n\ (5.90\ x\ 10^{-7})$$

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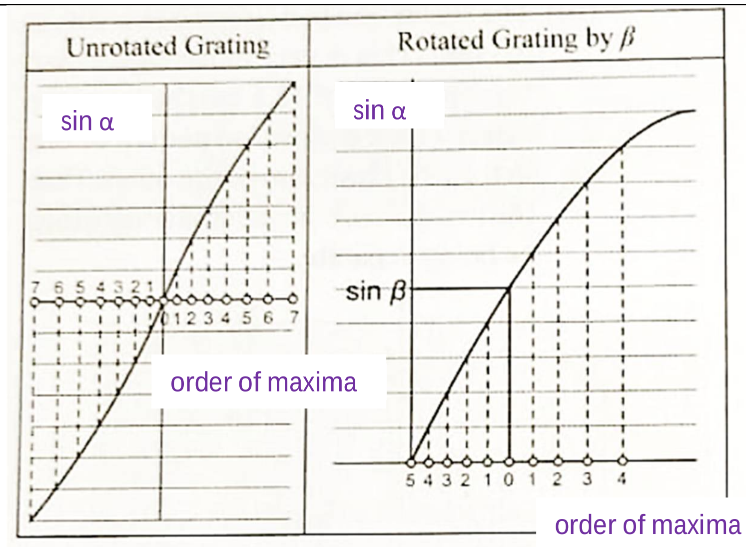
			n = 2.26 → highest order seen = 2 → orders that are seen include n = 0, 1, 2 From (1), For n = 0, θ = 0° For n = 1, $\frac{1\,x\,10^{-3}}{750}\sin\theta\ =\ (1)(5.90\,x\,10^{-7})\ \rightarrow\ \theta\ =\ 26.3°$ For n = 2, $\frac{1\,x\,10^{-3}}{750}\sin\theta\ =\ (2)(5.90\,x\,10^{-7})\ \rightarrow\ \theta\ =\ 62.3°$ Final answer**: <u>0°, 26.3°, 62.3°</u>** ➔ MUST include the zero order! **Examiners' Comments:** *Most answers did give the angle for the first and second orders, but some did not include the zero order.*	 1 1
		ii	**Essential question(s):** • What possible aspects of the pattern *could* change? ➔ Fringe separation & width, intensity, position of fringes **Solution:** Positions on the screen which are further away from the diffraction grating have fringes that are further apart and broader. Fringe separations were previously increasing with order on both sides of the central maximum, but with the grating rotated, the fringe separations increase with order one side (where screen is further away from grating), and decrease with order on the other side (where screen is closer to grating). **Your answer must state the significant **change** clearly.* Additional notes: To get a sense for the 2nd paragraph, why is it that when the grating was not rotated the fringe separations were not uniform but increases with order on both sides: From the diffraction grating equation, d sin θ = nλ ➔ When n doubles from 1 to 2, for example, sin θ doubles, but θ more than doubles. [Consider graph of sin θ against θ for 0° to 90°, due to the curvature of the graph, when the y-axis value doubles, x-axis value more than doubles.] Theory of rotating grating (NOT in A-level syllabus): If the incident beam makes an angle β with the grating normal, the condition for maxima is given by: $d\,(\sin\alpha - \sin\beta) = n\lambda$ where n = 0, ±1, ±2, ….. The following graphs of sin α against n can be obtained:	 1 1

			 **Examiners' Comments:** *Most answers concentrated on any possible changes in intensity of the orders, rather than any differences that would occur in the angles at which the orders would be seen.*	
9	a		**Solution:** Radioactive decay – It is the spontaneous and random decay of a less stable nucleus into a more stable one with the emission an alpha particle or a beta-particle, and usually accompanied by the emission of a gamma ray photon. Nuclear fission – It is the splitting of a nucleus of high nucleon number into smaller nuclei of approximately equal mass with the release of energy. Nuclear fusion – It is the building up of a larger nucleus from two nuclei of low nucleon number, with the release of energy. **Examiner's Comments:** *Statements often included incorrect terms and also lacked clarity between the concept of a nucleus, a nuclide and a neutron. Vague adjectives such as 'larger' or smaller' were used. Stronger responses referred to nucleon number or to 'massive nuclei'.*	**1** **1** **1** **1**
9	b	i	**Essential Question(s):** Keywords: Energy associated Change in mass, reaction Determine the change in mass of the total reactants and products Use mass-energy equivalence relation **Solution:** Total mass of reactants = 14.003074 u + 4.002604 u = 18.005678 u Total mass of products = 16.999130 u + 1.007825 u = 18.006955 u	**1** **1**

			Change in mass = 0.001277 u Energy associated = 0.001277 x 1.66 x 10^{-27} x (3.0 x 10^{8})^{2} = 1.91 x 10^{-13} J **Examiner's Comments:** *This was completed correctly with very few arithmetical errors.*	**1** **1**
9	**b**	**ii**	**Essential Question(s):** How can a nuclear reaction take place? Spontaneously or requiring energy? What is the significance of the energy associated with the change in energy in (b)(i)? With reference to the kinetic energy stated in this part? **Solution**: The nuclear reaction would require at least 1.91 x 10^{-13} J to take place. The energy of the incident alpha particle is less than this amount. Therefore, the reaction will not take place. **Examiner's Comments:** *Most answers included a comparison of the energies with a realisation that energy would be required to initiate the reaction.*	**1** **1**
9	**c**	**i**	**Essential Question(s):** What is the relation between wavelength and photon energy? **Solution:** $E = hf = \frac{hc}{\lambda}$ $\lambda = \frac{hc}{E} = \frac{(6.63 \times 10^{-34})\ (3.00 \times 10^{8})}{1.16 \times 10^{6} \times 1.60 \times 10^{-19}}$ $\lambda = 1.07 \times 10^{-12}\ m$ **Examiner's Comments:** *Both parts of this section were completed with little difficulty.*	**1** **1** **1**
9	**c**	**ii**	**Essential Question(s):** What is the relation between wavelength and photon momentum? **Solution:** $p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}}{1.07 \times 10^{-12}} = 6.19 \times 10^{-22}\ Ns$ **Examiner's Comments:** *Both parts of this section were completed with little difficulty.*	**1** **1**

9	**d**	**i**	**Essential Question(s):** Keywords: Stationary nucleus Recoil kinetic energy If the emitted photon has a momentum and the nucleus was stationary where the photon was emitted, what conclusion can we make on the momentum of the recoil nucleus? What conservation law(s) can be used here? **Solution:** Using conservation of linear momentum, The momentum of the nucleus is opposite but equal in magnitude to the photon's momentum. Recoil kinetic energy = $\frac{p^2}{2m}$ = $\frac{6.19 \times 10^{-22^2}}{2\ x\ 60\ u}$ = $\frac{6.19 \times 10^{-22^2}}{2 \times 60 \times 1.66 \times 10^{-27}}$ = $1.92 \times 10^{-18}\ J$ **Examiner's Comments:** *Rather than use directly the expression energy = $p^2/2m$, the majority chose the longer route by determining the speed and then using the expression energy = ½ mv^2*	 **1** **1** **1** **1**
9	**d**	**ii**	**Essential Question(s):** Compare the kinetic energy of the recoil nucleus to the emitted photon **Solution:** Recoil kinetic energy =$1.92 \times 10^{-18}\ J$ Emitted photon energy = 1.856×10^{-13} J The energy of the photon energy is much greater than the recoil kinetic energy of the nucleus, therefore it is usually not thought to be an important factor. **Examiner's Comments:** *Stronger candidates made a comparison between the answer in **(d)(i)** and the photon energy. Some answers were full; others merely stated that the kinetic energy is 'small'.*	 **1**