1 A stationary wave is formed on a stretched string. Discuss the formation of this wave.
Your answer should include:

- an explanation of how the stationary wave is formed
- a description of the features of the stationary wave
- a description of the processes that produce these features.

The quality of your written communication will be assessed in your answer.

(Total 6 marks)

2 (a) Baryons, mesons and leptons are affected by particle interactions.

Write an account of these interactions. Your account should:

- include the names of the interactions
- identify the groups of particles that are affected by the interaction
- identify the exchange particles involved in the interaction
- give examples of **two** of the interactions you mention.

The quality of your written communication will be assessed in your answer.

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(6)

(b) Draw a labelled diagram that represents a particle interaction.

(3)
(Total 9 marks)

3 A lead ball of mass 0.25 kg is swung round on the end of a string so that the ball moves in a horizontal circle of radius 1.5 m. The ball travels at a constant speed of 8.6 m s^{-1}.

(a) (i) Calculate the angle, in degrees, through which the string turns in 0.40 s.

angle .... degree

(3)

(ii) Calculate the tension in the string.
You may assume that the string is horizontal.

tension .... N

(2)

(b) The string will break when the tension exceeds 60 N.
Calculate the number of revolutions that the ball makes in one second when the tension is 60 N.

number of revolutions ....

(2)

(c) Discuss the motion of the ball in terms of the forces that act on it. In your answer you should:

- explain how Newton's three laws of motion apply to its motion in a circle
- explain why, in practice, the string will not be horizontal.

You may wish to draw a diagram to clarify your answer.

The quality of your written communication will be assessed in your answer.

(6)
(Total 13 marks)

4 (a) Light has a dual wave-particle nature. State and outline a piece of evidence for the wave nature of light and a piece of evidence for its particle nature. For each piece of evidence, outline a characteristic feature that has been observed or measured and give a short explanation of its relevance to your answer. Details of experiments are not required.

The quality of your written communication will be assessed in your answer.

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(6)

(b) An electron is travelling at a speed of 0.890 *c* where *c* is the speed of light in free space.

(i) Show that the electron has a de Broglie wavelength of 1.24×10^{-12} m.

(2)

(ii) Calculate the energy of a photon of wavelength 1.24×10^{-12} m.

answer = ... J

(1)

(iii) Calculate the kinetic energy of an electron with a de Broglie wavelength of 1.24×10^{-12} m.
Give your answer to an appropriate number of significant figures.

answer = ... J

(2)
(Total 11 marks)

5 When light of a certain frequency is shone on a particular metal surface, electrons are emitted with a range of kinetic energies.

(a) Explain

- in terms of photons why electrons are released from the metal surface, and
- why the kinetic energy of the emitted electrons varies upto a maximum value.

The quality of your written communication will be assessed in this question.

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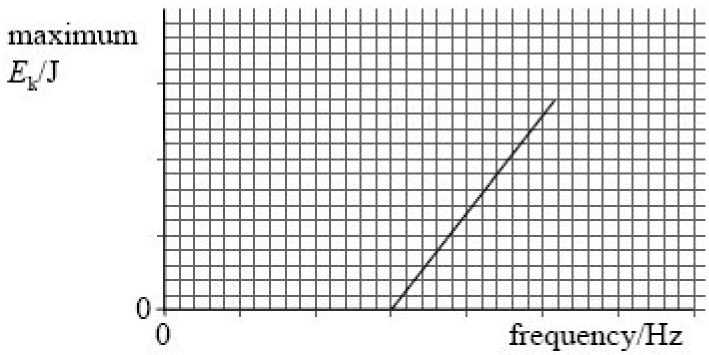
(6)

(b) The graph below shows how the maximum kinetic energy of the electrons varies with the frequency of the light shining on the metal surface.



(i) On the graph mark the *threshold frequency* and label it f_0.

(1)

(ii) On the graph draw a line for a metal which has a higher threshold frequency.

(2)

(iii) State what is represented by the gradient of the graph.

....

(1)

(c) The threshold frequency of a particular metal surface is 5.6×10^{14} Hz. Calculate the maximum kinetic energy of emitted electrons if the frequency of the light striking the metal surface is double the threshold frequency.

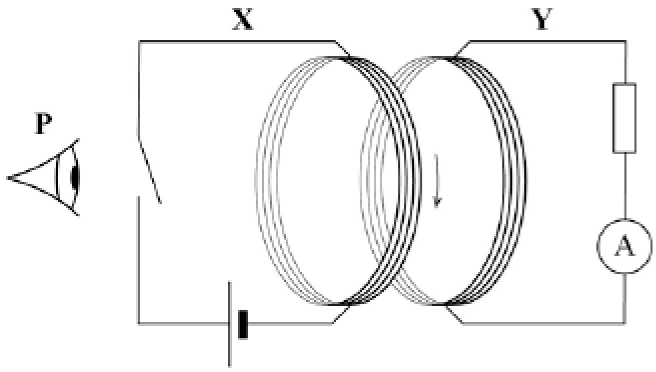
answer = ... J

(3)

(Total 13 marks)

6 **Figure 1** shows an arrangement for investigating electromagnetic induction.

Figure 1



When the switch is closed there is a current in the coil in circuit **X**. The current is in a clockwise direction as viewed from position **P**.

Circuit **Y** is viewed from position **P**.

(a) Explain how Lenz's law predicts the direction of the induced current when the switch is opened and again when it is closed.

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(4)

An ‘Earth inductor’ consists of a 500 turn coil. **Figure 2** and **Figure 3** shows it set up to measure the horizontal component of the Earth’s magnetic field. When the coil is rotated an induced emf is produced.

Figure 2

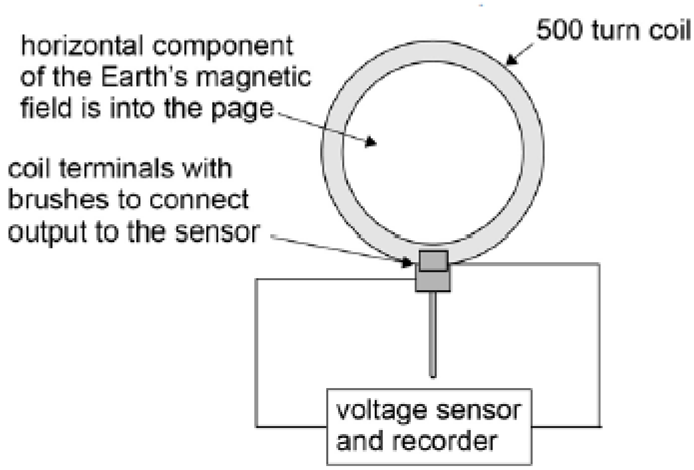
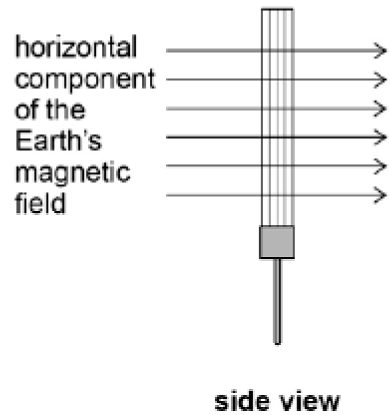
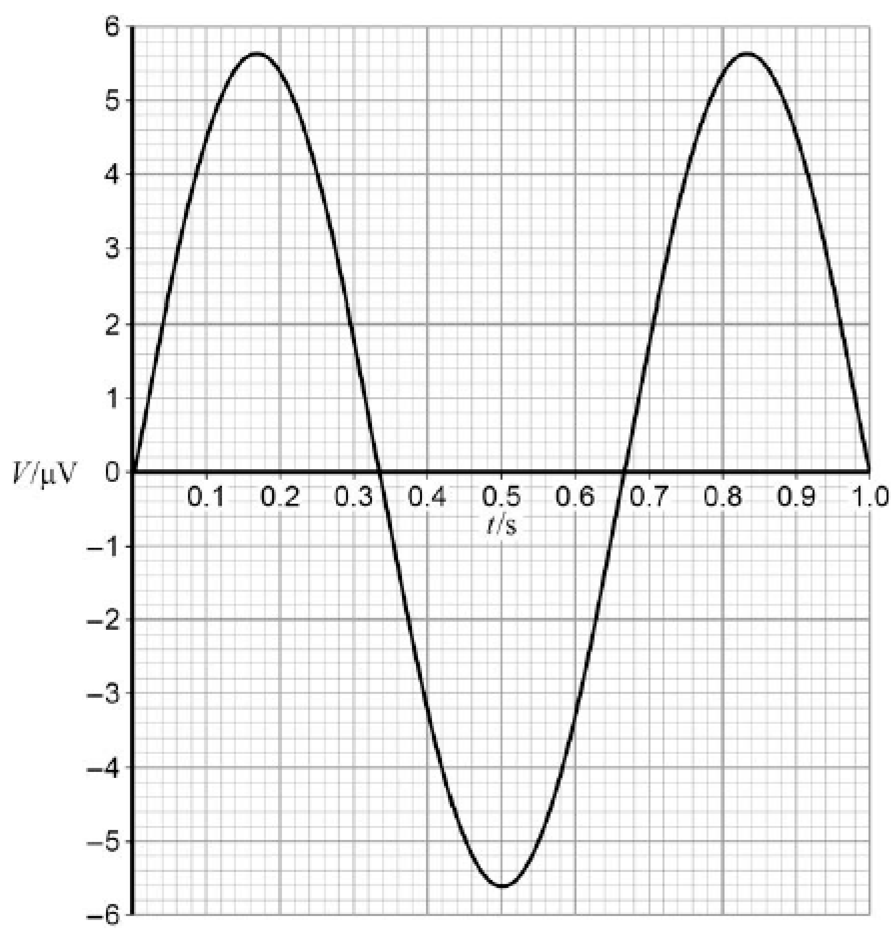


Figure 3



The mean diameter of the turns on the coil is 35 cm. **Figure 4** shows the output recorded for the variation of potential difference V with time t when the coil is rotated at 1.5 revolutions per second.

Figure 4



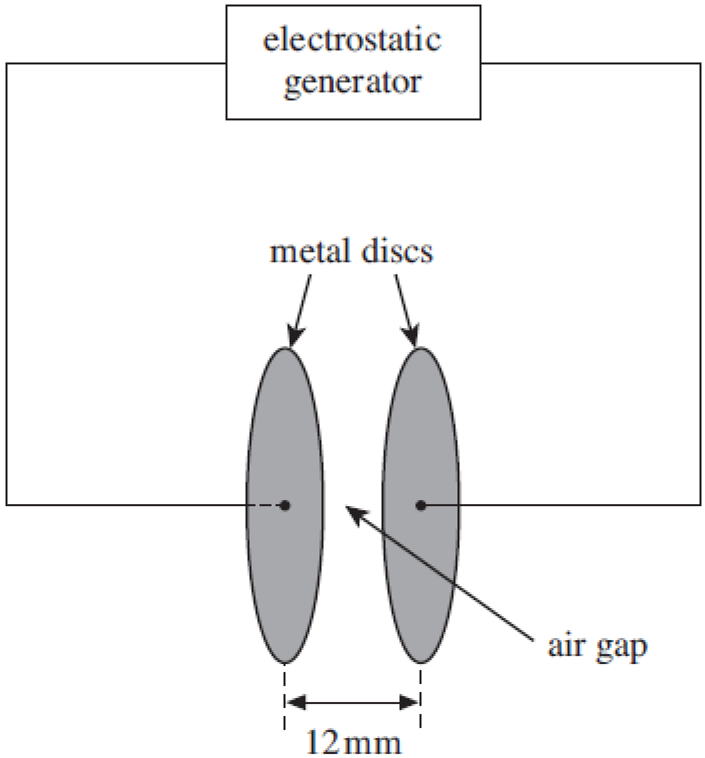
(b) Determine the flux density, B_H, of the horizontal component of the Earth's magnetic field.

horizontal component of flux density = ______________ T

(3)

(Total 7 marks)

7 The diagram below shows an arrangement to demonstrate sparks passing across an air gap between two parallel metal discs. Sparks occur when the electric field in the gap becomes large enough to equal the breakdown field strength of the air. The discs form a capacitor, which is charged at a constant rate by an electrostatic generator until the potential difference (pd) across the discs is large enough for a spark to pass. Sparks are then produced at regular time intervals whilst the generator is switched on.



(a) The electrostatic generator charges the discs at a constant rate of 3.2×10^{-8} A on a day when the minimum breakdown field strength of the air is 2.5×10^{6} V m^{-1}. The discs have a capacitance of 3.7×10^{-12} F.

(i) The air gap is 12 mm wide. Calculate the minimum pd required across the discs for a spark to occur. Assume that the electric field in the air gap is uniform.

pd V

(1)

(ii) Calculate the time taken, from when the electrostatic generator is first switched on, for the pd across the discs to reach the value calculated in part (a)(i).

time .... s

(2)

(b) The discs are replaced by ones of larger area placed at the same separation, to give a larger capacitance.

State and explain what effect this increased capacitance will have on:

(i) the time between consecutive discharges,

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(2)

(ii) the brightness of each spark.

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(2)
(Total 7 marks)

8 (a) When an uncharged capacitor is charged by a **constant** current of 4.5 μA for 60 s the pd across it becomes 4.4 V.

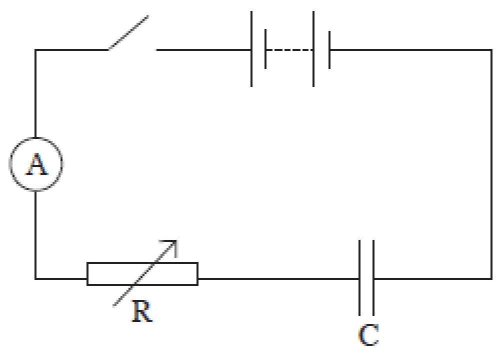
(i) Calculate the capacitance of the capacitor.

capacitance .... F

(3)

(ii) The capacitor is charged using the circuit shown in **Figure 1**. The battery emf is 6.0 V and its internal resistance is negligible. In order to keep the current constant at 4.5 μA, the resistance of the variable resistor R is decreased steadily as the charge on the capacitor increases.

Figure 1



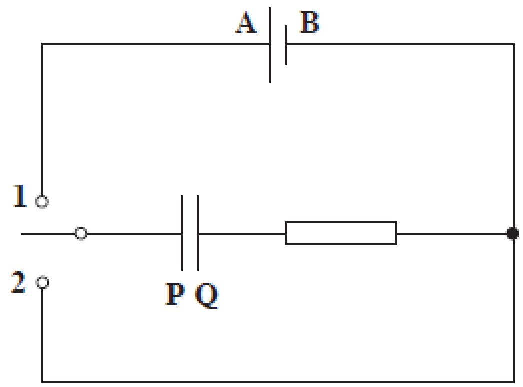
Calculate the resistance of R when the uncharged capacitor has been charging for 30 s.

resistance .... Ω

(3)

(b) The circuit in **Figure 2** contains a cell, an uncharged capacitor, a fixed resistor and a two-way switch.

Figure 2



The switch is moved to position **1** until the capacitor is fully charged. The switch is then moved to position **2**.

Describe what happens in this circuit after the switch is moved to position **1**, and after it has been moved to position **2**. In your answer you should refer to:

- the direction in which electrons flow in the circuit, and how the flow of electrons changes with time,
- how the potential differences across the resistor and the capacitor change with time,
- the energy changes which take place in the circuit.

The terminals of the cell are labelled **A** and **B** and the capacitor plates are labelled **P** and **Q** so that you can refer to them in your answer.

The quality of your written communication will be assessed in your answer.

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(6)
(Total 12 marks)

9 The Large Hadron Collider (LHC) uses magnetic fields to confine fast-moving charged particles travelling repeatedly around a circular path. The LHC is installed in an underground circular tunnel of circumference 27 km.

(a) In the presence of a suitably directed uniform magnetic field, charged particles move at constant speed in a circular path of constant radius. By reference to the force acting on the particles, explain how this is achieved and why it happens.

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(4)

(b) (i) The charged particles travelling around the LHC may be protons. Calculate the centripetal force acting on a proton when travelling in a circular path of circumference 27 km at one-tenth of the speed of light. Ignore relativistic effects.

answer = ... N

(3)

(ii) Calculate the flux density of the uniform magnetic field that would be required to produce this force. State an appropriate unit.

answer = ... unit ....

(3)

(c) The speed of the protons gradually increases as their energy is increased by the LHC. State and explain how the magnetic field in the LHC must change as the speed of the protons is increased.

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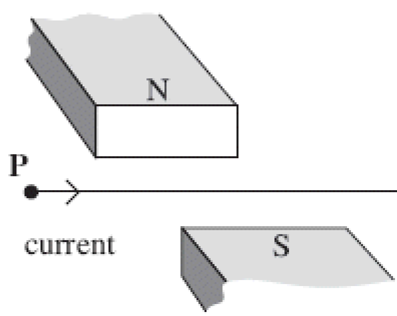
(2)
(Total 12 marks)

10 The figure below shows a horizontal wire, held in tension between fixed points at **P** and **Q**. A short section of the wire is positioned between the pole pieces of a permanent magnet, which applies a uniform horizontal magnetic field at right angles to the wire. Wires connected to a circuit at **P** and **Q** allow an electric current to be passed through the wire.



(a) (i) State the direction of the force on the wire when there is a direct current from **P** to **Q**, as shown in the figure above.

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(1)

(ii) In a second experiment, an alternating current is passed through the wire. Explain why the wire will vibrate vertically.

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(3)

(b) The permanent magnet produces a uniform magnetic field of flux density 220 mT over a 55 mm length of the wire. Show that the maximum force on the wire is about 40 mN when there is an alternating current of rms value 2.4 A in it.

(3)

(c) The length of **PQ** is 0.40 m. When the wire is vibrating, transverse waves are propagated along the wire at a speed of 64 m s^{-1}. Explain why the wire is set into large amplitude vibration when the frequency of the a.c. supply is 80 Hz.

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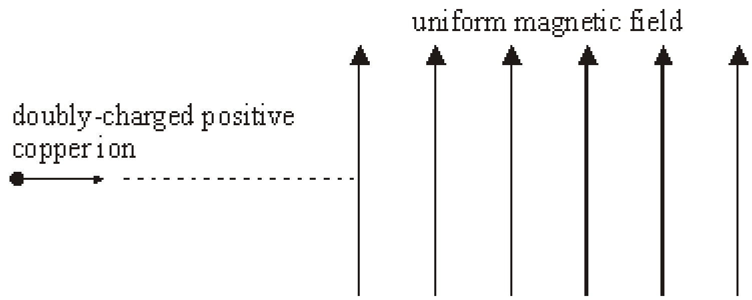
(3)
(Total 10 marks)

11 (a)



The diagram above shows a doubly-charged positive ion of the copper isotope $^{63}_{29}Cu$ that is projected into a vertical magnetic field of flux density 0.28 T, with the field directed upwards. The ion enters the field at a speed of 7.8×10^5 m s^{-1}.

(i) State the initial direction of the magnetic force that acts on the ion.

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(ii) Describe the subsequent path of the ion as fully as you can.
Your answer should include both a qualitative description and a calculation.

mass of $^{63}_{29}Cu$ ion = 1.05×10^{-25} kg

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(5)

(b) State the effect on the path in part (a) if the following changes are made separately.

(i) The strength of the magnetic field is doubled.

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(ii) A singly-charged positive $^{63}_{29}Cu$ ion replaces the original one.

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(3)
(Total 8 marks)

12 A transformer is required to produce an r.m.s. output of 2.0×10^3 V when it is connected to the 230 V r.m.s. mains supply. The primary coil has 800 turns.

(a) Calculate the number of turns required on the secondary coil, assuming the transformer is ideal.

(2)

(b) The transformer suffers from *eddy current* losses.

(i) Explain how *eddy currents* arise.

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(4)

(ii) State the feature of transformers designed to minimise eddy currents.

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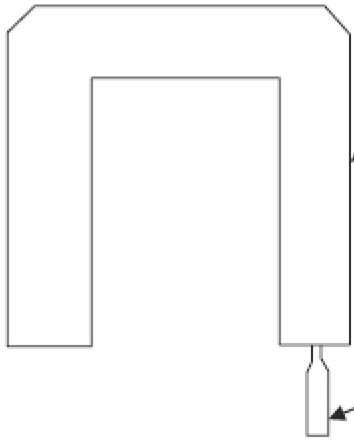
(1)
(Total 7 marks)

13 A life jacket inflates using gas released from a small carbon dioxide cylinder. The arrangement is shown in the following figure**.**



(a) The cylinder initially contains 1.7×10^{23} molecules of carbon dioxide at a temperature of 12 °C and occupying a volume of 3.0×10^{-5} m^3.

(i) Calculate the initial pressure, in Pa, in the carbon dioxide cylinder.

(ii) When the life jacket inflates, the pressure falls to 1.9×10^5 Pa and the final temperature is the same as the initial temperature. Calculate the new volume of the gas.

(iii) Calculate the mean molecular kinetic energy, in J, of the carbon dioxide in the cylinder.

(6)

(b) (i) Explain, in terms of the kinetic theory model, why the pressure drops when the carbon dioxide is released into the life jacket.

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(ii) Explain why the kinetic theory model would apply more accurately to the gas in the inflated life jacket compared with the gas in the small cylinder.

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(6)

(c) Explain, in terms of the first law of thermodynamics, how the temperature of the gas in the system can be the same at the beginning and the end of the process.

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(4)
(Total 16 marks)

14 In a nuclear reactor the mean energy produced by each uranium-235 nucleus that undergoes induced fission is 3.0×10^{-11} J. In one pressurised water reactor, PWR, the fuel rods in the reactor contain 2.0×10^4 kg of uranium-235 and 40% of the energy produced per second is converted to 500 MW of electrical output power. It is assumed that all the energy produced in the reactor core is removed by pressurised water in the coolant system. The pressure of the water is approximately 150 times greater than normal atmospheric pressure. The water enters the reactor at a temperature of 275 °C ad leaves at a temperature of 315 °C. Under the operational conditions of the reactor the mean density of water in the coolant circuit is 730 kg m^{-3} and the specific heat capacity of water is approximately 5000 J kg^{-1} K^{-1}.

normal atmospheric pressure = 1.0×10^5 Pa
molar mass of uranium-235 = 0.235 kg

(a) The equation below gives one induced fission reaction that takes place in a reactor.

$$^{235}_{92}\mathrm{U} + ^{1}_{0}\mathrm{X} \Rightarrow ^{n}_{56}\mathrm{Br} + ^{90}_{p}\mathrm{Kr} + 2^{1}_{0}\mathrm{X}$$

(i) State the name of the particle represented by **X**.

....

(1)

(ii) State the proton and nucleon numbers represented by *p* and *n*.

p ....

n ....

(2)

(b) (i) Calculate the number of fission reactions that occur in the reactor each second.

number of fission reactions per second ....

(2)

(ii) The reactor fuel rods contain 2.0×10^4 kg of uranium-235. Assume that all this uranium-235 could be used.
Calculate the maximum time, in years, for which the reactor could operate.

time ....years

(4)

(iii) Suggest why it is not possible to use all the uranium-235 in the reactor fuel rods.

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(2)

(c) Calculate the force exerted by the pressurised water on each square centimetre of the wall of the reactor.

force ....N

(2)

(d) Calculate, in $m^3\ s^{-1}$, the flow rate of the water through the PWR reactor.
You will need to use data from the passage at the beginning of the question.

flow rate .... $m^3\ s^{-1}$

(4)

(e) In a PWR the cooling water also acts as the moderator in the reactor and boron rods are used to control the power output. Describe the physical processes that take place in the moderator and control rods.

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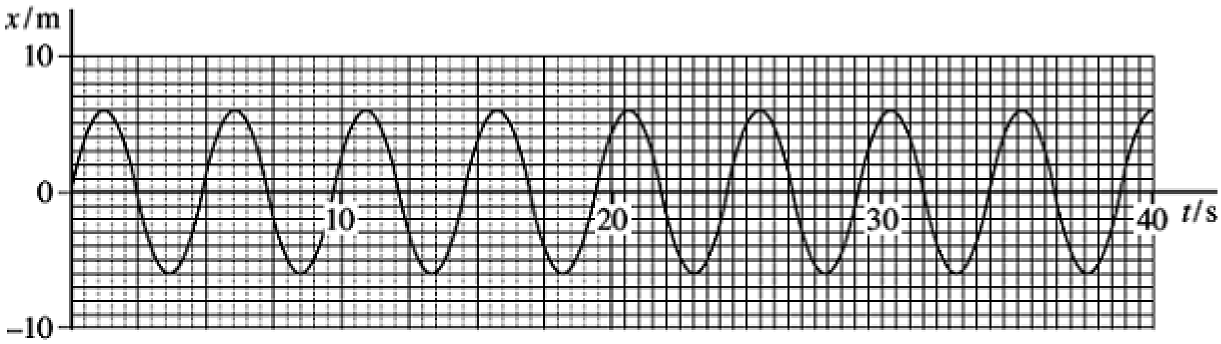
(4)
(Total 21 marks)

15 A pirate ship is a type of amusement park pendulum ride in which a gondola carrying passengers is made to oscillate. The ride can be modelled using a simple pendulum consisting of a mass on a string.

The figure below shows how the displacement x of the mass varies with time *t*.



(a) (i) Define amplitude.

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....

(1)

(ii) Determine the amplitude of the oscillations of the mass.

amplitude .... m

(1)

(iii) Calculate the period of the pendulum.

period .... s

(2)

(b) Another model was constructed using a pendulum of frequency 0.25 Hz with the mass having an initial amplitude of 4.5 m.

(i) Calculate the maximum velocity of the mass.

maximum velocity .... ms^{-1}

(2)

(ii) Calculate the maximum acceleration of the mass.

maximum acceleration .... ms^{-2}

(2)

(iii) Calculate the length of the simple pendulum that has a frequency of 0.25 Hz.

length .... m

(2)

(c) To simplify the driving mechanism of the actual ride it is suggested that the gondola should be pushed each time it reaches the centre moving in one direction.
Explain why this would lead to large amplitude oscillations.

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(2)

(d) When the force is no longer applied the gondola will naturally come to rest. The time for this to happen will usually be too long to satisfy the ride operators. External dampers are used to reduce the time taken to stop the gondola.
Explain why the gondola would come to rest naturally and what feature of an energy efficient ride design would make this a lengthy process.

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(3)
(Total 15 marks)

Mark schemes

1 **The student's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.**

The student's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria.

Answers may cover some of the following points:

- *(1) a wave and its reflection / waves travelling in opposite directions meet / interact / overlap / cross / pass through etc*

  point (1) must be stated together i.e it should not be necessary to search the whole script to find the two parts namely the directions of the waves and their meeting
- *(2) same wavelength (or frequency)*
- *(3) node − point of minimum or no disturbance*

  points (3) may come from a diagram but only if the node is written in full and the y-axis is labelled amplitude or displacement
- *(4) antinode − is a point of maximum amplitude*

  point (4) may come from a diagram but only if the antinode is written in full and the y-axis is labelled amplitude or displacement
- *(5) node - two waves (always) cancel / destructive interference / 180° phase difference / in antiphase [out of phase is not enough] (of the two waves at the node) [not peak meets trough]*
- *(6) antinode − reinforcement / constructive interference occurs / (displacements) in phase*
- *(7) mention of <u>superposition</u> [not superimpose] of the two waves*
- *(8) energy is not transferred (along in a standing wave)*.

  if any point made appears to be contradicted elsewhere the point is lost − no bod's

High Level (Good to excellent): 5 or 6 marks
The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.

6 marks: points (1) ***AND*** *(2)* ***with*** *4 other points which must include point (4) or the passage must indicate that the wave is oscillating at an antinode*

5 marks: points (1) ***AND*** *(2)* ***with*** *any three other points*

although point (1) may not be given as a mark the script can be searched to see if its meaning has been conveyed as a whole before restricting the mark and not allowing 5 or 6 marks

Intermediate Level (Modest to adequate): 3 or 4 marks
The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate.

4 marks: (1) ***OR*** *(2)* ***AND*** *any three other points*
3 marks: any three points

Low Level (Poor to limited): 1 or 2 marks
The information conveyed by the answer is poorly organised and may not be relevant or

coherent. There is little correct use of specialist vocabulary.
The form and style of writing may be only partly appropriate.

2 marks: any two points
1 marks: any point or a reference is made to both nodes and antinodes

[6]

2 (a) **The student's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.**

The student's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria.

High Level (Good to excellent): 5 or 6 marks
The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.

Student names strong, weak and electromagnetic interactions. Identifies that only hadrons experience the strong interaction but hadrons and leptons experience weak interaction. Charged particles experience electromagnetic interaction. Is able to identify all exchange particles such as gluons, W+ and W- and virtual photons. Gives examples of two of the interactions i.e. electrons repelling, electron capture, beta decay.

Intermediate Level (Modest to adequate): 3 or 4 marks
The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate.

Student names strong, weak and electromagnetic interactions. Identifies that only hadrons experience the strong interaction but hadrons and leptons experience weak interaction. Charged particles experience electromagnetic interaction. Is able to identify some exchange particles such as gluons, W^+ and W^- and virtual photons.

Low Level (Poor to limited): 1 or 2 marks
The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate.

Student names strong, weak and electromagnetic interactions. Identifies that only hadrons experience the strong interaction. Identifies one exchange particle.

The explanation expected in a competent answer should include a coherent selection of the following points concerning the physical principles involved and their consequences in this case.

Names of interactions – strong, weak and electromagnetic
hadrons experience strong
hadrons and leptons experience weak
charged particles experience electromagnetic
identify exchange particles
give examples of various interactions e.g. electron capture
(either weak interaction or electromagnetic or strong interaction)
first mark conservation at left hand junction of charge, baryon and lepton number ✓
second mark conservation at right hand junction of charge, baryon and lepton number ✓
third mark for correct exchange particle ✓

ignore any reference to gravity
ignore any Feynman diagrams electrostatic not allowed as alternative for electromagnetic

Properties of interactions

- *correct exchange particle (W $^{(+/-)}$boson / Z_0 boson, (virtual) photon, gluon / pion) NB sign on W not required*
- *correct group of particles affected (strong: baryons andmesons, weak: baryons, mesons and leptons, electromagnetic: charged particles)*
- *example of the interaction*

Lower band

1 mark – two interactions OR one interaction and one property for that interaction

2 marks – two interactions and one property for one interaction

Middle band

3 marks – two interactions plus two properties

4 marks – two interactions plus minimum of four properties (e.g. 3 props plus 1 OR 2 props plus 2), if three interactions quoted then properties can be spread between the 3 e.g. one property for each (3) plus one additional

Top band

5 marks – 3 interactions plus two properties for each

6 marks – must give first two properties for all three interactions AND correctly state two examples of interactions e.g. electron capture example of weak, strong nuclear responsible for binding protons / neutrons / baryons together

A table may help:

	strong	weak	EM
property 1			
property 2			
property 3			

(b)

if exchange particle not identified but baryon and lepton numbers conserved on both sides − 1 mark
ignore orientation of line showing exchange particle or any arrows on exchange particle line when awarding first two marks

if arrows on incoming and outgoing interacting particles in wrong direction then lose mark

if lines do not meet at a junction lose 1 mark
***with third mark** orientation of exchange particle line must be consistent with exchange particle shown and no arrow required*

if exchange particle line is horizontal (for weak) then must be a correct arrow
arrow overrides slope

3

[9]

3

(a) (i) $\omega\left(=\frac{v}{r}\right)=\frac{8.6}{1.5}$ (= 5.73 rad s^{-1}) ✓

$\theta(=\omega t)$ = 5.73 × 0.40 = 2.3 (2.29) (rad) ✓

$= \frac{2.29}{2\pi}$ × 360 = 130 (131) (degrees) ✓

[**or** $s((=vt)$ = 8.6 × 0.40 (= 3.44 m) ✓

$\theta = \frac{3.44}{2\pi \times 1.5}$ × 360 ✓ = 130 (131) (degrees) ✓]

Award full marks for any solution which arrives at the correct answer by valid physics.

3

(ii) tension $F(=m\omega^2 r)$ = 0.25 × 5.73^2 × 1.5 ✓ = 12(.3) (N) ✓

[**or** $F\left(=\frac{mv^2}{r}\right) = \frac{0.25\times 8.6^2}{1.5}$ ✓ = 12(.3) (N) ✓]

Estimate because rope is not horizontal.

2

(b) maximum $\omega \left(= \sqrt{\frac{F}{mr}} \right) = \sqrt{\frac{60}{0.25 \times 1.5}}$ (= 12.6) (rad s^{-1}) ✓

maximum $f \left(= \frac{\omega}{2\pi} \right) = \frac{12.6}{2\pi}$ = 2.01 (rev s^{-1}) ✓

[**or** maximum $v = \sqrt{\frac{Fr}{m}} = \sqrt{\frac{60 \times 1.5}{0.25}}$ (= 19.0) (m s^{-1}) ✓

maximum $f \left(= \frac{v}{2\pi r} \right) = \frac{19.0}{2\pi \times 1.5}$ = 2.01 (rev s^{-1}) ✓]

Allow 2 (rev s^{-1}) for 2nd mark.

Ignore any units given in final answer.

2

(c) **The student's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.**

The student's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria.

High Level (Good to excellent): 5 or 6 marks

The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.

The student appreciates that the velocity of the ball is not constant and that this implies that it is accelerating. There is a comprehensive and logical account of how Newton's laws apply to the ball's circular motion: how the first law indicates that an inward force must be acting, the second law shows that this force must cause an acceleration towards the centre and (if referred to) the third law shows that an equal outward force must act on the point of support at the centre. The student also understands that the rope is not horizontal and states that the weight of the ball is supported by the vertical component of the tension.

*A **high level** answer must give a reasonable explanation of the application of at least two of Newton's laws, and an appreciation of why the rope will not be horizontal.*

Intermediate Level (Modest to adequate): 3 or 4 marks

The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate.

The student appreciates that the velocity of the ball is not constant. The answer indicates how at least one of Newton's laws applies to the circular motion. The student's understanding of how the weight of the ball is supported is more superficial, the student possibly failing to appreciate that the rope would not be horizontal and omitting any reference to components of the tension.

*An **intermediate level** answer must show a reasonable understanding of how at least one of Newton's laws applies to the swinging ball.*

Low Level (Poor to limited): 1 or 2 marks
The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate.
The student has a much weaker knowledge of how Newton's laws apply, but shows some understanding of at least one of them in this situation. The answer coveys little understanding of how the ball is supported vertically.

*A **low level** answer must show familiarity with at least one of Newton's laws, but may not show good understanding of how it applies to this situation.*

References to the effects of air resistance, and/or the need to keep supplying energy to the system would increase the value of an answer.

The explanation expected in a competent answer should include a coherent selection of the following points concerning the physical principles involved and their consequences in this case.

- *First law:* ball does not travel in a straight line, so a force must be acting on it
- although the ball has a constant speed its velocity is not constant because its direction changes constantly
- because its velocity is changing it is accelerating
- *Second law*: the force on the ball causes the ball to accelerate (or changes the momentum of it) in the direction of the force
- the acceleration (or change in momentum) is in the same direction as the force
- the force is centripetal: it acts towards the centre of the circle
- *Third law*: the ball must pull on the central point of support with a force that is equal and opposite to the force pulling on the ball from the centre
- the force acting on the point of support acts outwards
- *Support of ball*: the ball is supported because the rope is not horizontal
- there is equilibrium (or no resultant force) in the vertical direction
- the weight of the ball, mg, is supported by the vertical component of the tension, $F \cos \theta$, where θ is the angle between the rope and the vertical and F is the tension
- the horizontal component of the tension, $F \sin \theta$, provides the centripetal force $m \omega^2 r$

Credit may be given for any of these points which are described by reference to an appropriate labelled diagram.

A reference to Newton's 3 rd law is not essential in an answer considered to be a high level response. 6 marks may be awarded when there is no reference to the 3rd law.

max 6

[13]

4 (a) **The candidate's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.**

The candidate's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria.

High Level (Good to excellent): 5 or 6 marks

The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.

The candidate provides a comprehensive and coherent answer that includes a stated property of light such as interference or diffraction that can only be explained in terms of the wave nature of light and a <u>stated property</u> such as photoelectricity that can only be explained in terms of the particle nature of light. In each case, a relevant specific <u>observational feature</u> should be referred to and should be accompanied by a <u>coherent explanation</u> of the observation. Both explanations should be relevant and <u>logical</u>.

For full marks, the candidate may show some appreciation as to why the specific feature of either the named wave property cannot be explained using the particle nature of light or the named particle property cannot be explained using the wave nature of light.

Intermediate Level (Modest to adequate): 3 or 4 marks

The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate.

The candidate provides a logical and coherent explanation that includes a stated property of light such as interference or diffraction that can only be explained in terms of the wave nature of light ***and*** *a stated property such as photoelectricity that can only be explained in terms of the particle nature of light.*

For 4 marks, the candidate should be able to refer to a relevant specific observational feature of each property, at least one of which should be followed by an adequate explanation of the observation. Candidates who fail to refer to a relevant specific observational feature for one of the properties may be able to score 3 marks by providing an <u>adequate</u> explanation of the observational feature referred to.

Low Level (Poor to limited): 1 or 2 marks

The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate.

The candidate provides some relevant information relating to two relevant stated properties for 1 mark. Their answer may lack coherence and may well introduce irrelevant or incorrect physics ideas in their explanation.

Points that can be used to support the explanation:

Wave-like nature property

- property is either interference **or** diffraction
- observational feature is either the bright and dark fringes of a double slit interference pattern or of the single slit diffraction pattern (or the spectra of a diffraction grating)
- explanation of bright or dark fringes (or explanation of diffraction grating spectra) in terms of path or phase difference
- particle/corpuscular theory predicts two bright fringes for double slits or a single bright fringe for single slit or no diffraction for a diffraction grating

Particle-like nature

- property is photoelectricity
- observational feature is the existence of the threshold frequency for the incident light **or** instant emission of electrons from the metal surface
- explanation of above using the photon theory including reference to photon energy *hf*, the work function of the metal and '1 photon being absorbed by 1 electron'
- wave theory predicts emission at all light frequencies **or** delayed emission for (very) low intensity

6

(b) (i) m (= m_o (1 - v^2 / c^2)$^{-0.5}$ = 9.11 × 10^{-31} (1 - 0.890^2)$^{-0.5}$)

(= 1.998 × 10^{-30} kg) = 2.0(00) × 10^{-30} kg ✓

$$\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{2.0(0) \times 10^{-30} \times 0.89(0) \times 3.0(0) \times 10^{8}} \checkmark$$

(= 1.2(4) × 10^{-12}m)

2

(ii) $$E_{Ph} = \left(hf = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{1.24 \times 10^{-12}} \right) = 1.6(0) \times 10^{-13} \text{ J} \checkmark$$

1

(iii) $E_K = (m - m_o)\,c^2$

$= (1.998 \times 10^{-30} - 9.11 \times 10^{-31}) \times (3.0 \times 10^8)^2$

$= 9.78 \times 10^{-14}$ J ✓ 3 sf only ✓

2

[11]

5 (a)

QWC	descriptor	mark range
good-excellent	The candidate provides a comprehensive and logical explanation which recognises that light consists of photons of energy *hf* and that an electron at or near the metal surface can only gain the energy of a single photon when it interacts with a photon. In addition, the candidate should recognise the significance of the work function (of the metal) in this context in relation to the maximum kinetic energy that an emitted electron can have. The candidate should also provide some indication of why the kinetic energy of an emitted electron may be less than the maximum kinetic energy. Although the term 'work function' might not be defined or used, the candidate's explanation should clearly state that each electron needs a minimum amount of energy to escape from the metal.	**5-6**
modest-adequate	The candidate provides a logical and coherent explanation which includes the key ideas including recognition that light consists of photons of energy *hf* and that an electron at or near the metal surface can only gain the energy of a single photon when it interacts with a photon. In addition, the candidate should be aware that each electron needs a minimum amount of energy to escape from the metal. They should appreciate that the kinetic energy of an emitted electron is equal to the difference between the energy it gains from a photon and the energy it needs (or uses) to escape from the metal. However, the explanation may lack a key element such as why the kinetic energy of the emitted electrons varies.	**3-4**
poor-limited	The candidate provides some correct ideas including recognition that light consists of photons of energy *hf* and that electrons in the metal (or at its surface) absorb photons and thereby gain energy. Their ideas lack coherence and they fail to recognise or use in their explanation the key idea that one photon is absorbed by one electron.	**1-2**

The explanations expected in a good answer should include most of the following physics ideas

energy is needed to remove an electron from the surface

work function φ (of the metal) is the minimum energy needed by an electron to escape from the surface

light consists of photons , each of energy $E = hf$

one photon is absorbed by one electron

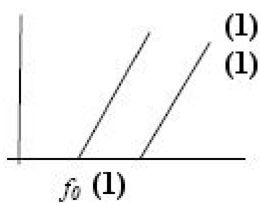
an electron can escape (from the surface) if $hf > \varphi$

kinetic energy of an emitted electron cannot be greater than $hf - \varphi$

an electron below the surface needs to do work/uses energy to reach the surface

kinetic energy of such an electron will be less than $hf - \varphi$

(b) (i)



(ii) parallel line, higher threshold frequency **(1)(1)**

(iii) Planck's constant **(1)**

4

(c) (use of $hf_0 = \phi$)

$hf = 6.63 \times 10^{-34} \times 2 \times 5.6 \times 10^{14}$ **(1)**

$\phi = 3.7(1) \times 10^{-19}$ J **(1)**

$E_k = 2 \times 3.7 \times 10^{-19} - 3.7 \times 10^{-19} = 3.7 \times 10^{-19}$ J **(1)**

3

[13]

6 (a) Induced current such as to opposes the change producing it✓

Switch on current increases the flux through Y✓

Current opposite direction / anticlockwise to create opposing flux✓

Switch off flux thorough Y due to X decreases so current travels clockwise to create flux to oppose the decrease✓

one marks for Lenz's law statement

two for explaining what happens at switch on ***OR*** *switch off adequately*

one for completing the argument for switch on and off adequately

4

(b) Determines correctly in the calculation two of V_{pk}(5.6±1 μV) , *A* (0.096 m^2) and *ω*(9.4 rad s^{-1})β✓

Substitutes all three in $v = BAn\omega$ ignoring powers of 10 and calculation errors for *A* and / or ω provided they have been attempted with working shown✓

B_H = 12.4 nT✓

Allow 2 or 3 sf

3

[7]

7 (a) (i) required pd (= 2.5 × 10^{6} × 12 × 10^{-3}) = 3.0(0) × 10^4 (V) ✓

1

(ii) charge required *Q (= CV)* = 3.7 × 10^{-12} × 3.00 × 10^4 ✓

(= 1.11 × 10^{-7} C)

Allow ECF from incorrect V from (a)(i).

$$\text{time taken } t\left(=\frac{Q}{I}\right)=\frac{1.11\times10^{-7}}{3.2\times10^{-8}}=3.5\ (3.47)\ (\text{s})\ ✓$$

2

(b) (i) time increases ✓

(larger *C* means) more charge required (to reach breakdown pd)

Mark sequentially *i.e. no explanation mark if effect is wrong.*

or $t=\dfrac{CV}{I}$ **or** time ∝ capacitance ✓

2

(ii) spark is brighter (**or** lasts for a longer time) ✓

more energy (**or** charge) is stored **or** current is larger

Mark sequentially.

or spark has more energy ✓

2

(Total 7 marks)

8 (a) (i) $Q(= It)$ 4.5 × 10^{-6} × 60 **or** = 2.70 × 10^{-4} (C) ✓

$C\left(=\frac{Q}{V}\right)=\frac{2.70\times10^{-4}}{4.4}$ ✓ = 6.1(4) × 10^{-5} = 61 (μF) ✓

3

(ii) since V_C was 4.4V after 60s, when t = 30s V_C = 2.2 (V) ✓

[**or** by use of $Q = It$ and $V_C = Q / C$]

∴ pd across R is (6.0 – 2.2) = 3.8 (V) ✓

$R\left(=\frac{V}{I}\right)=\frac{3.8}{4.5\times10^{-6}}$ = 8.4(4) × 10^{5} (Ω) ✓ (=844 kΩ)

In alternative method,

$Q = 4.5 \times 10^{-6} \times 30 = 1.35 \times 10^{-4}$ (C)

$V_C = 1.35 \times 10^{-4} / 6.14 \times 10^{-5} = 2.2$ (V)

(allow ECF from wrong values in (i)).

3

(b) **The candidate's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.**
The candidate's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria.

High Level (Good to excellent): 5 or 6 marks
The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.

The candidate gives a coherent and logical description of the flow of electrons taking place during the charging and discharging processes, indicating the correct directions of flow and the correct time variations. There is clear understanding of how the pds change with time during charging and during discharging. The candidate also gives a coherent account of energy transfers that take place during charging and during discharging, naming the types of energy involved. They recognise that the time constant is the same for both charging and discharging.

*A **High Level** answer must contain correct physical statements about at least **two** of the following for **both** the charging and the discharging positions of the switch:-*

- *the direction of electron flow in the circuit*
- *how the flow of electrons (or current) changes with time*
- *how V_R and / or V_C change with time*
- *energy changes in the circuit*

Intermediate Level (Modest to adequate): 3 or 4 marks
The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate.

The candidate has a fair understanding of how the flow of electrons varies with time, but may not be entirely clear about the directions of flow. Description of the variation of pds with time is likely to be only partially correct and may not be complete. The candidate may show reasonable understanding of the energy transfers.

*An **Intermediate Level** answer must contain correct physical statements about at least **two** of the above for **either** the charging or the discharging positions of the switch.*

Low Level (Poor to limited): 1 or 2 marks
The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate.

The candidate is likely to confuse electron flow with current and is therefore unlikely to make effective progress in describing electron flow. Understanding of the variation of pds with time is likely to be quite poor. The candidate may show some understanding of the energy transfers that take place.

*A **Low Level** answer must contain a correct physical statement about at least **one** of the above for **either** the charging or the discharging positions of the switch.*

Incorrect, inappropriate or no response: 0 marks

No answer, or answer refers to unrelated, incorrect or inappropriate physics.

The explanation expected in a competent answer should include a coherent selection of the following points concerning the physical principles involved and their consequences in this case.

Charging

- electrons flow from plate **P** to terminal **A** and from terminal **B** to plate **Q** (ie. from plate **P** to plate **Q** via **A** and **B**)
- electrons flow in the opposite direction to current
- plate **P** becomes + and plate **Q** becomes –
- the rate of flow of electrons is greatest at the start, and decreases to zero when the capacitor is fully charged
- V_R decreases from E to zero whilst V_C increases from zero to E
- at any time $V_R + V_C = E$
- time variations are exponential decrease for V_R and exponential increase for V_C
- chemical energy of the battery is changed into electric potential energy stored in the capacitor, and into thermal energy by the resistor (which passes to the surroundings)
- half of the energy supplied by the battery is converted into thermal energy and half is stored in the capacitor

Discharging

- electrons flow back from plate **Q** via the shorting wire to plate **P**
- at the end of the process the plates are uncharged
- the rate of flow of electrons is greatest at the start, and decreases to zero when the capacitor is fully discharged
- V_C decreases from $-E$ to zero and V_R decreases from E to zero
- at any time $V_C = -V_R$
- both V_C and V_R decrease exponentially with time
- electrical energy stored by the capacitor is all converted to thermal energy by the resistor as the electrons flow through it and this energy passes to the surroundings
- time constant of the circuit is the same for discharging as for charging

Any answer which does not satisfy the requirement for a Low Level answer should be awarded 0 marks.

max 6

[12]

9 (a) (magnetic) field is applied perpendicular to path

or direction **or** velocity of charged particles ✓

(magnetic) force acts perpendicular to path

or direction **or** velocity of charged particles ✓

force depends on speed of particle **or** on B [or $F \propto v$ or $F = BQv$ explained] ✓

force provides (centripetal) acceleration towards centre of circle

[**or** (magnetic) force is a centripetal force] ✓

$BQv = \frac{mv^2}{r}$ **or** $r = \frac{mv}{BQ}$ shows that r is constant when B and v are constant ✓

4

(b) (i) radius r of path = $\frac{\text{circumference}}{2\pi} = \frac{27 \times 10^3}{2\pi}$ = 4.30×10^3 (m) (allow 4.3km) ✓

centripetal force $\left(= \frac{mv^2}{r}\right) = \frac{1.67 \times 10^{-27} \times (3.00 \times 10^7)^2}{4.30 \times 10^3}$ ✓ $= 3.50 \times 10^{-16}$(N) ✓

3

(ii) magnetic flux density $B \left(= \frac{F}{Qv}\right) = \frac{3.50 \times 10^{-16}}{1.60 \times 10^{-19} \times 3.00 \times 10^7}$ ✓

$= 7.29 \times 10^{-5}$ ✓ T ✓

3

(c) magnetic field must be increased ✓

to increase (centripetal) force **or** in order to keep r constant ✓

[**or** otherwise protons would attempt to travel in a path of larger radius]

[**or**, referring to $r = \frac{mv}{BQ}$, B must increase when v increases to keep r constant]

2

[12]

10 (a) (i) (vertically) downwards **(1)**

1

(ii) force F is perpendicular to both B and I [**or** equivalent correct explanation using Fleming LHR] **(1)**

magnitude of F changes as size of current changes **(1)**

force acts in opposite direction when current reverses
[**or** ac gives alternating force] **(1)**

continual reversal of ac means process is repeated **(1)**

max 3

(b) appreciation that maximum force corresponds to peak current **(1)**

peak current = 2.4 × $\sqrt{2}$ = 3.39 (A) **(1)**

F_{max} (= $B\ I_{pk}\ L$) = 0.22 × 3.39 × 55 × 10^{-3} **(1)** (= 4.10 × 10^{-2} N)

3

(c) wavelength (λ) of waves = $\left(=\frac{c}{f}\right)=\frac{64}{80}$ = 0.80 (m) **(1)**

length of wire is λ/2 causing fundamental vibration **(1)**

[**or** λ of waves required for fundamental (= 2 × 0.40) = 0.80 m **(1)**

natural frequency of wire $\left(=\frac{c}{\lambda}\right)=\frac{64}{0.80}$ = 80 (Hz) **(1)**]

wire resonates (at frequency of ac supply) [**or** a statement that fundamental frequency (or a natural frequency) of the wire is the same as applied frequency] **(1)**

3

[10]

11 (a) (i) out of plane of diagram **(1)**

(ii) circular path **(1)**
in a horizontal plane [or out of the plane of the diagram] **(1)**

$BQv = \frac{mv^2}{r}$ **(1)**

radius of path, $r \left(\frac{mv}{BQ}\right) = \frac{1.05 \times 10^{-25} \times 7.8 \times 10^5}{0.28 \times 2 \times 1.6 \times 10^{-19}}$ **(1)**

= 0.91(4) m **(1)**

max 5

(b) (i) radius decreased **(1)**
halved **(1)**
[or radius is halved **(1) (1)**]

(ii) radius increased **(1)**
doubled **(1)**
[or radius is doubled **(1) (1)**]

max 3

[8]

12 (a) $\frac{N_S}{N_P} = \frac{V_S}{V_P}$

C1

7000 (6960)

A1

(2)

(b) (i) changing magnetic field

B1

emf or changing magnetic field is in the core

B1

e.m.f. induced (due to changing magnetic field) not back emf

B1

current flows as core is made from a conducting material

B1

(4)

(ii) laminated core

B1

(1)

[7]

13 (a) (i) $PV = NkT$ **(1)**

223×10^5 Pa **(1)**

2

(ii) pV = const or repeat calculation from (i) **(1)**

3.5×10^{-3} m^3 **(1)**

2

(iii) kinetic energy = 3/2 kT **(1)**

$5.9(0) \times 10^{-21}$ J **(1)**

2

(b) (i) volume increase **(1)**)
time between collisions increases **(1)**)
speed constant as temp constant **(1)**)
rate of change of momentum decreases **(1)**)

max 3

(ii) volume smaller in cylinder **(1)**

molecules occupy significantly greater proportion of the volume **(1)**

molecules closer so intermolecular forces greater **(1)**

3

(c) internal energy stays the same **(1)**

gas does work in expanding so W is negative **(1)**

gas must be heated to make U positive **(1)**

U and W equal and opposite **(1)**

4

[16]

14 (a) (i) neutron

B1

1

(ii) p = 36

B1

n = 144

B1

2

(b) (i) total energy produced = $\frac{500 \times 100}{40}$ MJ each second

C1

number of reaction = 4.2×10^{19} per second

A1

2

(ii) 1 kg contains $(1000/235) \times 6.02 \times 10^{23}$ atoms of uranium

C1

total number of fissions = $(1000/235) \times 6.02 \times 10^{23} \times 2 \times 10^{4}$ (5.1×10^{28})

C1

time = total fissions available/number per second or 1.2×10^{9}s

C1

38.7(39) years

A1

4

(iii) too few neutrons produced to maintain the chain reaction

B1

probability of a neutron colliding with a uranium nucleus too low

B1

more absorption of neutrons in non–fission capture

B1

2

(c) pressure = 150×10^{5} (Pa) or $F = PA$

C1

force on 1 cm ^{2} = 1500N

A1

2

$E = \frac{500 \times 100}{40}$ MJ = 1.25×109 J or $E = mc\Delta\theta$

C1

$1.25 \times 10^9 = m\ 5000 \times 40$

C1

mass per second = 6250 kg

C1

volume per second = 8.6(8.56) m^3

A1

4

(e) **control rods**

neutrons are absorbed

B1

by the nucleus of the boron/atoms

B1

moderator

neutrons are slowed down

B1

when colliding with the protons/hydrogen nucleus

B1

4

[21]

15 (a) (i) Maximum **displacement** (of carriage/pendulum from rest position)

B1

1

(ii) 6.0 (m)

B1

1

(iii) Clear evidence of what constitutes period

C1

4.8–4.9 (s)

A1

2

(b) (i) Use of $v = 2\pi fA$

C1

7.07 (ms^{-1})

A1

2

(ii) Use of $a = 4\pi^2 f^{\,2} A$

C1

11.1 (ms^{-2}) ecf

A1

2

(iii) Substitution into or rearrangement of $T = 2\pi\sqrt{l/g}$

C1

3.98 (m)

A1

2

(c) Applied frequency = natural frequency

B1

Mention or clear description of resonance

B1

2

(d) Resistive/frictional/damping/air resistance forces

C1

due to friction in named place (eg in bearings)/air resistance acting on named part (allow ride/gondola here)

A1

low friction/large mass or inertia /streamline/smooth surface etc.

B1

3

[15]

Examiner reports

1 Almost all students made a good effort at answering this question and almost all of those knew that standing waves are constructed from two waves. This being the case it was appropriate that this question was the basis of the quality of written communication assessment in this examination. Weaker students often spent too long setting the scene. They gave details of the apparatus and explained how the string was plucked or vibrated before the bullet points were addressed. Often at this stage these were answered with very brief responses that gave very little detail. The middle ability group of students fared much better. They could describe what nodes and antinodes were and how they came about in terms of the interference of two waves. What was often missing was the fact that the two waves that superpose have the same frequency or wavelength. Many of this group and a large percentage of the top ability group understood that an antinode was a maximum of the motion but they referred to the maximum displacement rather than the maximum amplitude. A couple of points separated this top group from the middle students as well as the quality of the structure of their writing and spelling. First they referred to the waves superposing unlike the majority who thought the waves superimposed on each other. Secondly, they sometimes included a point about the lack of energy transmission in a standing wave.

2 (a) assessed the quality of written communication and it has often proved to be the case that student answers were much more confident than when they are asked to provide an extended answer to a question based on a topic from the electricity part of the specification. Some very good answers were seen with students clearly identifying three interactions. Weaker students did confuse the properties of these interactions and it was not uncommon to see an incorrect exchange boson linked to an interaction, for example the W^+ with the strong interaction. There was a tendency for students to be a little vague when discussing the weak interaction. A common example of this was statements linking the weak interaction to leptons but not hadrons even though examples of interactions involving both of these classes of particles were then given.

The Feynman diagram in (b) generated some good answers with over half the students scoring full marks. The commonest examples seen were electron capture and the repulsion of two electrons.

3 The rubric for the paper requires students to show their working and it is generally wise for a student to do so since otherwise credit cannot be given when an incorrect answer is obtained. This usually involves showing any equation used and the substitution of numerical values into it. When these steps are not shown, marks may not be gained even when the final answer is numerically correct and this led to some of the more careless students failing to gain some of the marks in part (a). There were several successful routes to the answer in part (i), using angular speed, linear speed and / or time period or frequency. The main causes of weaker answers were thinking that an answer in radians was the final answer in degrees, or not showing how a conversion from radians to degrees had been carried out.

The majority of answers for the tension in part (a)(ii) were correct, arrived at by the use of either $m\omega^2 r$ or mv^2 / r. Part (b), the maximum frequency of rotation, was also usually addressed successfully.

The final part of the question required an explanation of the mechanics of the rotated ball in terms of Newton's laws and an explanation of why the supporting string would not be horizontal. This part was used to assess the quality of the students' written communication by applying a standard 6-mark scheme. The understanding of circular motion traditionally presents difficulties for many, and the students in 2015 were no exception. It was at least satisfying to see a greater proportion of them attempting to address the bullet points than has often been the case previously. In order to achieve an intermediate level grading (3-4 marks) it was necessary for the answer to show knowledge and understanding of how at least one of Newton's laws applies. For a high level grading (5-6 marks) this was required for at least two of the laws, together with some understanding of the non-horizontal string. On the whole the students showed some familiarity with Newton's laws, particularly the second law and the third law. How they apply to circular motion was more demanding. Fundamental to any satisfactory explanation is the observation that although the speed of the ball is constant its velocity is not. It is therefore accelerated at right angles to the path and this requires a force to act in this same direction. Common misconceptions were that the ball continues at constant *speed* because no overall force acts on it (supposedly Newton I), or that the ball is in equilibrium in an orbit of constant radius because equal and opposite radial forces are acting (supposedly Newton III). The most able students were able to apply all of the laws correctly to the rotated ball and to explain the non-horizontal string by considering the weight of the ball being balanced by the vertical component of the tension.

4 In part (a) it was pleasing to see some well-written accounts that covered most if not all the relevant facts. Many students failed to support a reasonable or good account of one of the two properties with a similar account of the other property. Many students who were able to supply a reasonable 'wave' explanation of the double slits experiment often gave a limited account of photoelectricity as a particle property with little more than a statement of the meaning of the threshold frequency. Explanations often lacked depth as many students failed to link the threshold frequency to the work function and the photon energy equation. However, a significant number of students did provide a brief outline of why interference fringes could not be accounted for using corpuscular theory or why the threshold frequency could not be explained using wave theory.

In part (b)(i), many students did not realise the relativistic mass needed to be calculated even though the speed of the electron was given in terms of the speed of light. In (ii) and (iii), whereas most students were able to calculate the photon energy in (ii), only the best students were able to calculate the kinetic energy in (iii). Frequent errors included the use of $\frac{1}{2}mv^2$, some with the correct mass of the electron and some with its rest mass. A significant number of students did calculate the total energy correctly but then failed to subtract the rest energy.

5 Part (a) was not answered well and there was much confusion as to the processes involved in the photoelectric effect. However, a significant number of candidates confused the effect with excitation and line spectra. Only a minority of candidates were able to explain why the kinetic energy of the emitted electrons varied. A common response referred to the photons having a variety of energies even though the question stated that the light had a certain frequency. Most answers lacked significant detail such as the idea that a photon interacts with one electron and how threshold frequency and work function are related.

This question assessed quality of written communication and it was clear that most candidates appreciated that their answers needed a logical structure. However, few candidates were able to give a coherent and comprehensive answer.

Part (b) generated better answers although a significant minority of candidates did not appreciate the fact that the gradient of the maximum kinetic energy against frequency graph is the Planck constant.

Part (c) proved more difficult than expected and a number of candidates calculated the energy of the photon using the threshold frequency and failed to calculate the work function.

7 Very few candidates experienced any difficulty in (a)(i), where the product of field strength and plate separation readily led to 30,000 V. In the other parts of Question 2 the principal failing of many of the candidates' attempts was to resort to time variations that were exponential. Part (a) puts this question clearly in the context of a charging current that is constant, so any references to exponential changes or time constants showed misunderstanding and were irrelevant. Arithmetical slips sometimes caused the loss of marks in part (a)(ii), but $Q = CV$ and $t = Q / I$ were usually applied correctly to arrive at 3.5 s.

In part (b) it was essential for candidates to realise that both the charging current and the breakdown pd remain constant at their original values when the capacitance is changed. The majority of candidates could see in part (b)(i) that the time between discharges would increase. Many also gave an acceptable explanation, either by stating that the charge stored would have to be larger before the breakdown pd was reached, or by reference to $t = CV / I$, where V and I are both unchanged. A common misconception in part (b)(ii) was to think that the brightness of the spark would be unchanged because the breakdown pd would be the same as it had been originally. It was expected that candidates would know that increased capacitance at the same pd would mean that the energy stored by the capacitor would be greater, so each spark would transfer more energy and would therefore be brighter. Alternatively, explanations in terms of the greater charge stored were also accepted.

8 The capacitance calculation in part (a)(i) rewarded most students with full marks. Answers to part (a)(ii) made a distinct contrast, because relatively few students were able to progress. Correct answers were rare. The circuit in Figure 1 is one in which the *current is maintained constant* by reducing the resistance as the capacitor is charged. Consequently the large number of attempted solutions that introduced exponential decay equations were totally inappropriate. An understanding of the principle that in a series circuit the sum of the voltages across components is equal to the applied voltage was essential. Many of the efforts progressed as far as establishing that the pd across the capacitor at 30 s would be 2.2V, but then went on to find what is effectively "the resistance of the capacitor" by dividing 2.2V by the current.

The final question in this examination, part (b), concerned a *C-R* circuit is which *R* is constant and charging / discharging *are* exponential processes. Apart from testing this subject content, the question was also used to assess the communications skills of the students. The guidance given in the bullet points helped most students to organise their answers systematically. A very good spread of marks was seen, ranging from students who clearly knew everything that happens during charging and discharging to ones who understood little or nothing about capacitors. A large number of correct statements about the factors listed in the bullet points for both charging and discharging constituted a high level answer (5 / 6 marks). Fewer correct statements about either charging or discharging put answers into the intermediate level (3 / 4 marks) whilst even fewer correct statements put answers into the low level (1 / 2 marks). Contributing also to the overall assessment was examiners' consideration of the incorrect statements made in the answers, and how satisfactorily the answers had been had been written. There were many instances of answers in which it was stated that electrons passed directly from plate **Q** across the gap to plate **P** – these tended to condemn the knowledge of the student concerned. A common misapprehension concerning this circuit was that the reduction in current is caused by an increase in the *resistance of the capacitor* rather than by a decrease in the net potential difference as the capacitor charges or discharges. A large proportion of the students chose to ignore the advice given to refer in their answers to points **A**, **B**, **P** and **Q** in the circuit. This omission usually made their answers somewhat more difficult to assess.

9 It was rare for all four marks to be awarded in part (a). The essence of this question was well understood, but poor use of English and an inability to write logically limited the mark that could be given. An alarming proportion of answers made no reference at all to the magnetic field; these students appeared to be answering a more general question about circular motion. Many of the students evidently thought that the purpose of the magnetic force (presumably acting outwards) was to balance the centripetal force, rather than to *provide* it. Relatively few correct solutions were seen that used $r = mv / BQ$ to show that r is constant when B and v are constant.

The common error in part (b)(i) was failure to deduce the radius of the path of the protons from the 27 km circumference of the LHC. This only meant the loss of one of the three marks, however, provided the principles of the rest of the calculation were correct. Careless arithmetic such as failure to square v, and/or forgetting to convert km to m, was also a frequent source of loss of marks. $F = BQv$ was usually applied successfully in part (b)(ii), where the unit of magnetic flux density was quite well known. Almost inevitably, there was some confusion between *flux density* and *magnetic flux.*

The fact that had to be appreciated in part (c) was that in the LHC the radius of the path of the charged particles must remain constant as they are accelerated. A large proportion of students thought that it was necessary to maintain a constant centripetal force for this to happen, whereas it ought to have been clear to them that F must increase as v increases if r is to be constant.

10 Most candidates were able to use Fleming's left hand rule in order to give the correct force direction in part (a) (i). Sometimes a candidate's answer was contradictory and went unrewarded, for example 'downwards towards the S pole'. Most answers to part (a) (ii) were reasonably good when explaining why the wire would vibrate, but rarely explained why these vibrations are vertical. An explanation by reference to the mutually perpendicular field, current and force directions was required in a complete answer. The reversal of force direction with change of current direction was well understood.

Fewer candidates made reference to the continuous current reversals brought about by ac causing the process to repeat, or to the fact that the size of the current affects the magnitude of the magnetic force.

It was evident that a large number of candidates had made a second, more enlightened, attempt at part (b) once they had realised that direct substitution of I = 2.4 A into $F = BIL$ did not lead to the value of force (about 40 mN) they had been asked to show. Once they realised that the maximum force is caused by the peak current, it became a straightforward matter to secure three marks.

The final part of the question, part (c), involved the resonance effect observed when the wire is supplied with ac current at the frequency of its fundamental vibration. Resonance was usually mentioned, but fewer candidates used the values provided in the question together with $c = f\lambda$ to give a wholly convincing account of why the wire would vibrate in its fundamental mode at 80 Hz.

A large number of candidates had forgotten that the fundamental condition would be $L = \lambda/2$ (this should be studied in unit 2). After using $c = f\lambda$ with $\lambda = 0.40$ m, they concluded that the frequency of waves on the wire would be 160 Hz. These candidates then attempted to argue that resonance would occur at 80 Hz because 80 is one half of 160, not understanding that if 160 Hz was the fundamental frequency, no frequency lower than 160 Hz could possibly set the wire into resonance.

11 Students are much more accustomed to diagrams which show magnetic fields acting at right angles to the plane of a diagram, than magnetic fields acting in the plane of a diagram. Consequently the seeds of confusion were sown at the start of part (a) for a large proportion of the candidates, many evidently treating the question as though it referred to an electric field. Therefore the path of the ion in part (ii) was stated to be parabolic, and not circular, in a large number of the scripts. Perhaps the aim of the required calculation was a little obscure, but a question about a circular path ought to have triggered ‘radius’ in the minds of the candidates. Many calculated this radius very successfully, the principal error being a wrong value for the charge of the doubly-charged ion.

In part (b) it was not possible to award any marks to candidates who were convinced that the path was parabolic; they tended to write about curves that were ‘steeper’ or ‘with a bigger slope’, etc.

12 (a) Most candidates used the correct equation but a surprisingly large number rearranged it incorrectly and gave an answer indicating that there would be fewer turns on the secondary coil than on the primary coil. Significant figure penalties were common here.

(b) (i) This explanation was not well done. Few candidates made it clear that the induction was taking place in the core and very few mentioned that the core was an electrical conductor. Many candidates made weak references to back e.m.f’s and a large number seemed to be trying to explain what happened in the secondary coil. Questions of this type are often asked and candidates would be well advised to practice making sequential explanations.

(ii) Many candidates knew about laminations. A few forgot to specify that it was the core that should be laminated. Some wanted to laminate the coils.

14 The neutron was identified by most students in part (a) (i).

There were many correct answers to part (a) (ii) but less able students did not take account of the two 'X' particles on the right hand side of the equation so obtained *n*= 145.

Most made some progress with part (b) (i). Obtaining the total energy produced by the reactor proved difficult for less able students.

There were a good proportion of correct answers in part (b) (ii). Some progress was made by a majority of the students.

Few were able to make a sensible comment in part (b) (iii).

Most were able to gain one of the two available marks in part (c) but the conversion from cm^2 to m^2 was the downfall of many students.

Whilst many were able to gain credit in part (d) for making some progress, relatively few could correctly complete the problem.

Most showed an appreciation of the different roles of the moderator in part (e) and the control rods but the majority gave inadequate detail of the processes.

15 Many students failed to define amplitude precisely in part (a)(i). Many described displacement not amplitude and the word 'maximum' was frequently omitted. Most students gained the mark for part (a)(ii) but 12 was a relatively common incorrect response. Most students used multiple oscillations to allow the period to be calculated reasonably precisely in (a)(iii) – a minority tried to use the simple pendulum formula using the amplitude as the length.

All parts of (b) were almost invariably done well. A minority of students failed to square the 2π factor in part (b)(iii).

Most students recognised that part (c) was a resonance situation and either stated this or else described the effect in terms of energy transfer.

The effects of friction at the moving parts or air resistance acting on the gondola were usually mentioned in part (d); most students went on to explain that lubrication or a streamline shape reduced these factors and increased the time that the gondola would naturally come to rest in.