Government of **Western Australia**
Curriculum Council

PHYSICS

Stage 3

WACE Examination 2011

Marking Key

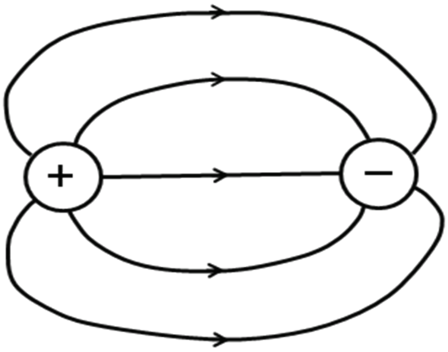
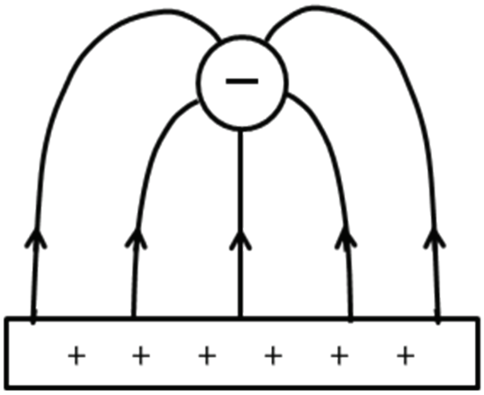
Marking keys are an explicit statement about what the examiner expects of candidates when they respond to a question. They are essential to fair assessment because their proper construction underpins reliability and validity.

When examiners design an examination, they develop provisional marking keys that can be reviewed at a marking key ratification meeting and modified as necessary in the light of candidate responses.

Section One: Short response **30% (54 Marks)**

Question 1 **(3 marks)**

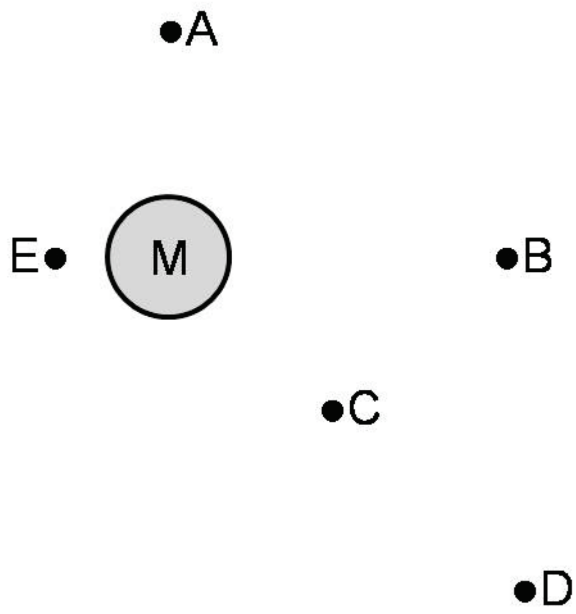
Draw the resultant electric field with at least 5 lines for each of the following situations.

Two opposite but equally-charged spheres	A charged sphere near a charged conductive plate
	

Description	Marks
Field lines are from positive to negative	1
90° entry/exit and no crossing over	1
Evenly distributed across plate	1
	Total 3

Question 2 **(4 marks)**

The diagram below shows five points, labelled 'A' to 'E', in free space around a large mass M. You may wish to use a ruler to help you answer this question.



	Point		Point
Which two points have the same magnitude of gravitational field strength due to M?	**A**	and	**C**

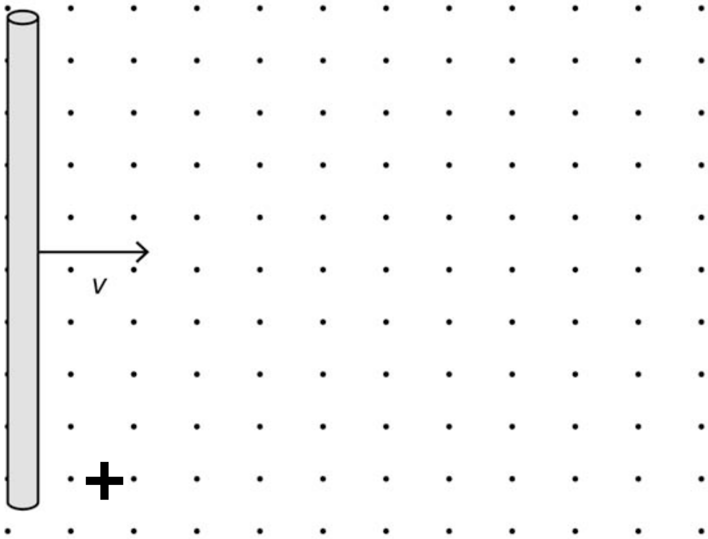
	Point		Point
Which two points experience the same direction of gravitational field due to M (as viewed in this diagram)?	**C**	and	**D**

	Point E		Point B
What is the ratio of the gravitational field strength at E to the gravitational field strength at B?	**9**	**:**	**1**

Description	Marks
A and C	1
C and D	1
9 : 1 (only 1 mark if distance measured to surface, 36 : 1 <u>OR</u> ratio reversed, 1: 9)	1–2
	Total 4

Question 3 **(3 marks)**

A 12.5 cm long piece of copper wire is moved at a constant velocity of 6.56 m s^{-1} through a magnetic field of 0.150 T. Calculate the potential difference between the ends of the wire and indicate on the diagram which end of the wire is positive.

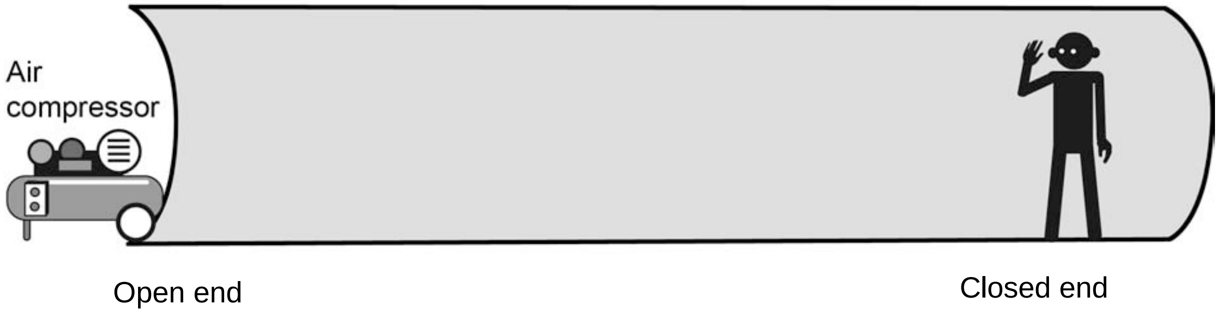


B field out of the page

Description	Marks
emf = $v\ell B$ = 6.56 × 0.125 × 0.150	1
emf = 0.123 V	1
Bottom is positive	1
	Total 3

Question 4 **(2 marks)**

An air compressor is located at the open end of a closed pipe. A maintenance worker walked away from the closed end of the pipe and noticed that the sound from the air compressor was getting louder and quieter as he moved toward the open end of the pipe. The worker found that the sound became louder every 1.50 metres. Calculate the frequency of the sound heard, given that the air was at 25°C.



Description	Marks
$\frac{1}{2}\lambda = 1.50$ m; $\lambda = 3.00$ m	1
$f = v / \lambda = 346/3 = 115$ Hz	1
	Total 2

Question 5 **(4 marks)**

Bathroom scales measure weight (a force) but give the reading in kilograms (mass). A particular scale shows a person's mass as being 70 kg at the Earth's equator. The spinning of the Earth contributes to the scale's reading. What would the scale read at the South Pole, with the same person standing on it? (Circle the correct answer.)

the same less than 70 kg more than 70 kg

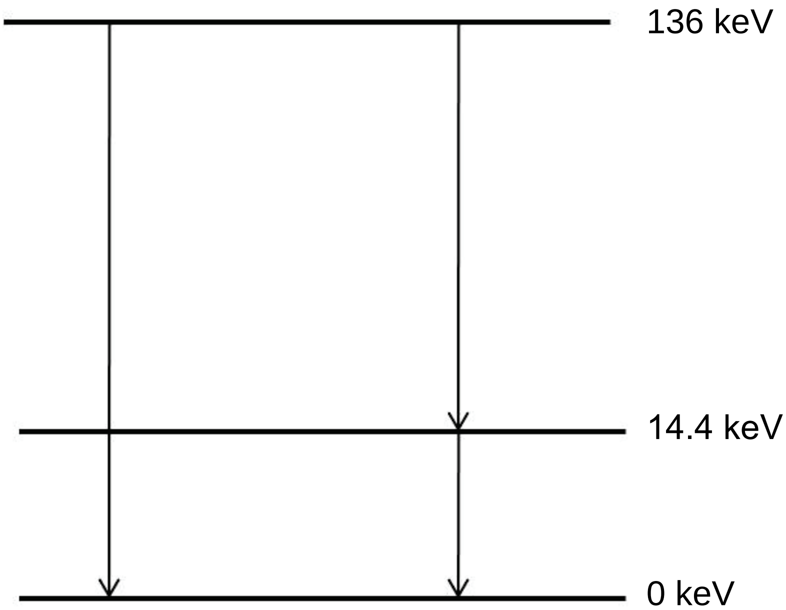
Explain your reasoning:

Description	Marks
'More than 70 kg' circled	1
Part of the gravitational force is used to provide centripetal force at the equator $F_g=F_w+F_c$ The centripetal force is zero at the poles so the weight force is correspondingly larger	1–3
OR The Earth is not spherical. You are slightly closer to the Earth's centre at the poles so the gravitational force is slightly larger at the poles, hence weight is larger at the poles.	1–2
	Total 4

Question 6 **(4 marks)**

When a radioactive isotope undergoes gamma decay, a nucleus in an excited state decays to a lower energy state of the same isotope by the emission of a photon. This decay is similar to the emission of light when an electron in an atom moves from a higher energy level to a lower one. The isotope $^{57}_{26}Fe$ can decay to the ground state in the two ways shown on the energy level diagram below.

Calculate the wavelength of the photon emitted in the transition from the level with energy of 136 keV to the level with energy of 14.4 keV.



Description	Marks
Energy of photon 136 keV – 14.4 keV = 121.6 keV	1
Convert to J 121.6 keV × 1000 × 1.6 ×10^{-19} C = 1.95 × 10^{-14}J	1
$\lambda = \frac{hc}{E} = \frac{6.63\times10^{-34}\times3\times10^{8}}{1.95\times10^{-14}}$	1
λ = 1.02 × 10^{-11} m	1
	Total 4

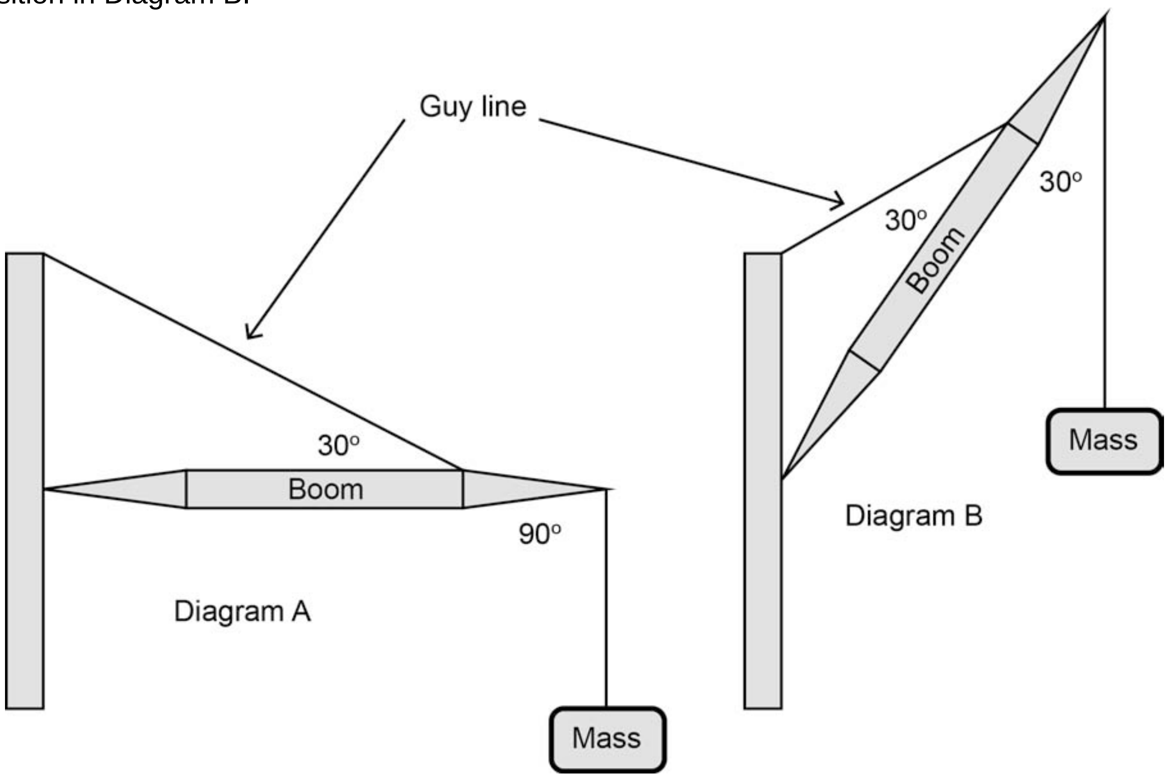
Question 7 **(5 marks)**

Mick is watering the lawn and wants to estimate the initial velocity of the water coming from the hose. Use information from the photograph to estimate the magnitude of the initial velocity of the water. Express your answer to an appropriate number of significant figures.

Description	Marks
Estimate initial height 1.5 m Estimate distance = 1.5 m (accept 1–2 m as 1 sig fig)	1
$s = ut + ½ at^2$ (1 mark using an appropriate formula with $u_v = 0$)	1
$1.5 = 0t + ½\ 9.8t^2$ $t = \sqrt{(2 \times 1.5/9.8)} = 0.55$ s (accept 0.45 s to 0.63 s)	1
$v = s/t = 1.5/0.55 = 2.7$ m s^{-1} (2.2 to 3.1 acceptable)	1
(1 mark answer sig fig/direction)	1
	Total 5

Question 8 **(4 marks)**

A crane (Diagram A) lifts a mass by raising its boom (Diagram B). Explain how this affects the tension in the guy line as the crane shifts the mass from its initial position in Diagram A to its position in Diagram B.



Description	Marks
The tension in Diagram B is less	1
The guy wire doesn't change its orientation to the boom (r × sin30° = constant)	1
The mass exerts a constant force, downwards, but the θ changes (90° to 30°)	1
τ = rFsinθ = rFsin30° which is half torque, so half the tension.	1
	Total 4

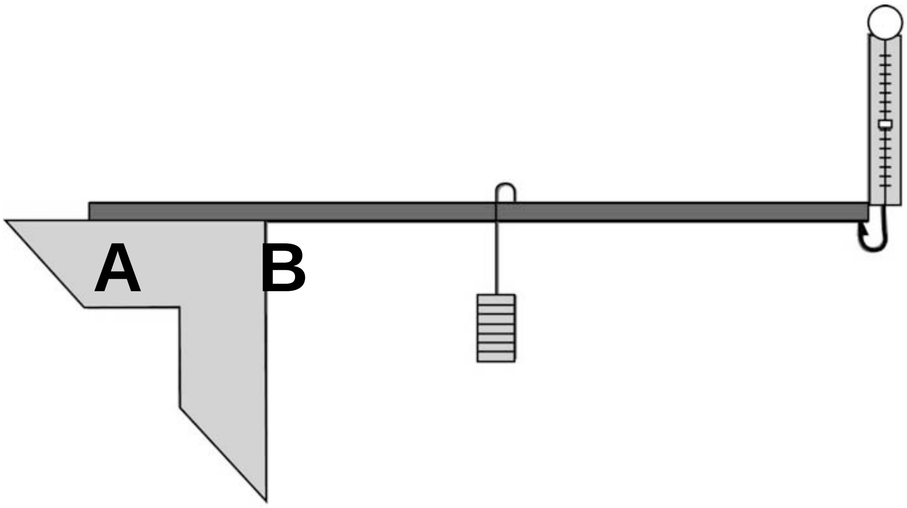
Question 9 **(4 marks)**

Describe briefly how Edwin Hubble's observations of the redshifts of galaxies were used to formulate Hubble's Law and explain how Hubble's Law is used to support the Big Bang theory.

Description	Marks
All moving objects have a Doppler effect in their spectrum showing the relative speed to the observer, Redshift means the object is moving away.	1
The more the redshift the faster the object is moving	1
Hubble's Law states the more distant the object, the faster it is moving –	1
this means there is a common origin, e.g. all started from an original point in a "big bang"	1
	Total 4

Question 10 **(4 marks)**

A uniform 100 gram, metre-long ruler is placed on a table, with most of its length overhanging the edge. A 350 gram slotted mass is placed at the ruler's 500 mm mark, and a spring balance holds it up at one end, as shown in the diagram below.



The ruler is just lifted using the spring balance so that it touches the table in only one place. At this point the spring balance reads 2.20 N. Indicate on the diagram the fulcrum, or pivot point, for this action and label it 'A'.

The ruler is then lowered slightly, changing the position of the fulcrum.

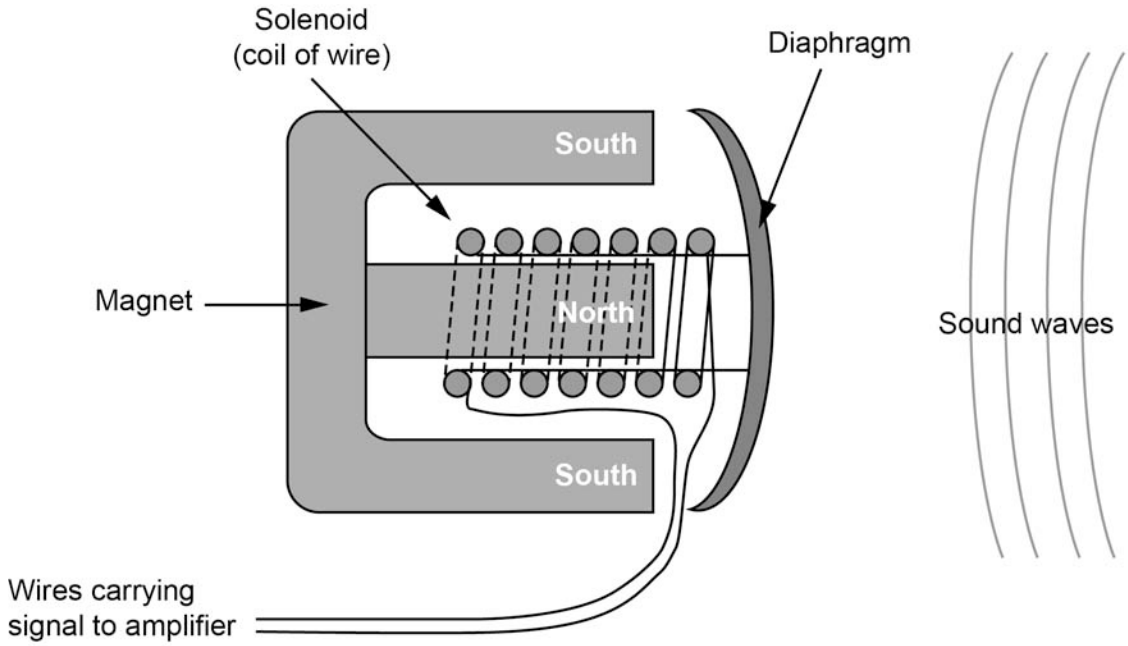
Label this new fulcrum, or pivot point, 'B'.

When the ruler is in this position, the spring balance reads 1.65 N. Determine the distance between the points 'A' and 'B'. Note that the angle that the ruler makes with the horizontal has not changed significantly and should not be considered in your calculations.

Description	Marks
Diagram labelled correctly	1
For point 'B' (radii correct) Anticlockwise torque = Clockwise torque Turning point chosen and radii determined	1
(s – 1.00) × 1.65 = (s – 0.50) × (0.350+0.100) × 9.8	1
s = 0.201 m	1
	Total 4

Question 11 **(4 marks)**

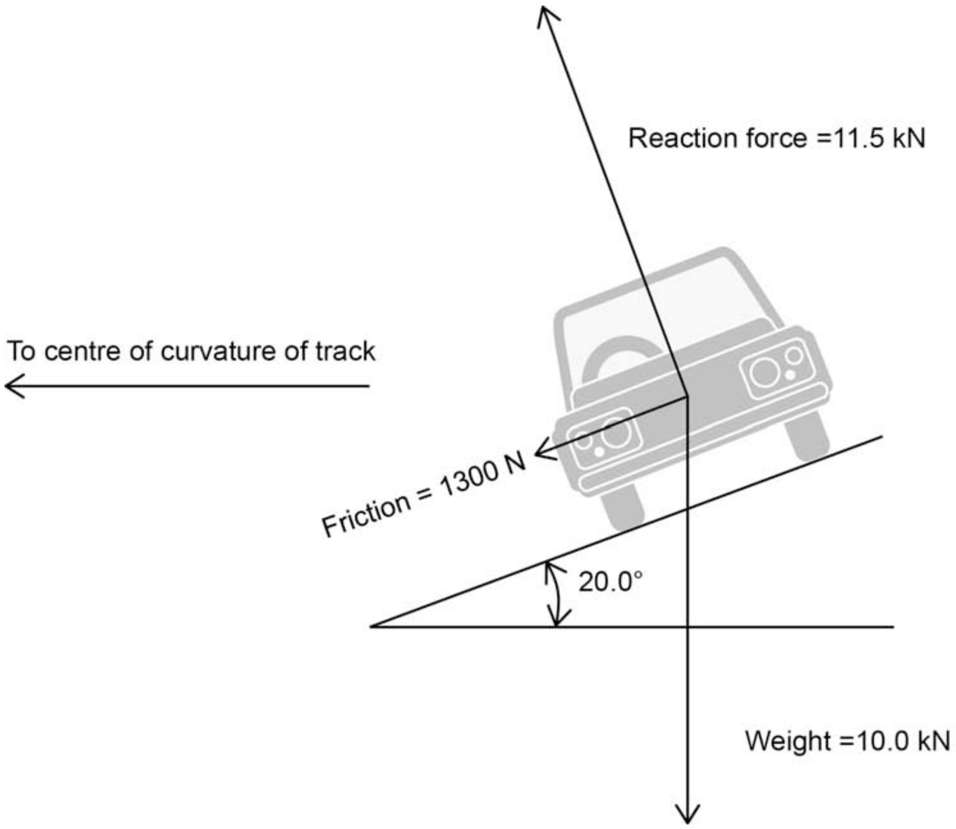
The diagram below shows a cross-section of a simple dynamic microphone. Describe how a musical note played near the diaphragm of the microphone can be detected by an amplifier. Your description should include an explanation of how the sound is converted to an electrical signal.



Description	Marks
Moving air particles cause the diaphragm to vibrate	1
The diaphragm causes the coil to move over the magnet which results in a changing flux through the coil.	1
By Faraday's Law the rate of change of flux produces an emf.	1
This causes a current to flow in the wires to the amplifier.	1
	Total 4

Question 12 **(5 marks)**

The diagram below shows the forces acting on a car following a curve on a banked track. The car is travelling at 17.0 m s^{-1} without slipping. Calculate the radius of the track.



Description	Marks
Centripetal force = (11.5 × 10^3 N × sin20°) + (1300N × cos20°) = 3933 N + 1222 N = 5155 N (1 mark each component)	1–2
Convert weight to mass m = W/g = 10000/9.8 = 1020 kg	1
Rearrange and substitute $r = \frac{mv^2}{F} = \frac{1020 \times 17^2}{5155}$	1
r = 57.2 m	1
	Total 5

Question 13 **(5 marks)**

Earthquakes cause seismic waves to travel through the Earth. These waves are detected by seismometers around the Earth. Two types of seismic waves are P and S waves. P waves are longitudinal and travel at a speed of 5.57 km s^{-1}. S waves are transverse and travel at a speed of 3.56 km s^{-1}.

Give **one** example of a transverse wave and **one** example of a longitudinal wave that you have studied (**not** P and S waves).

Transverse:

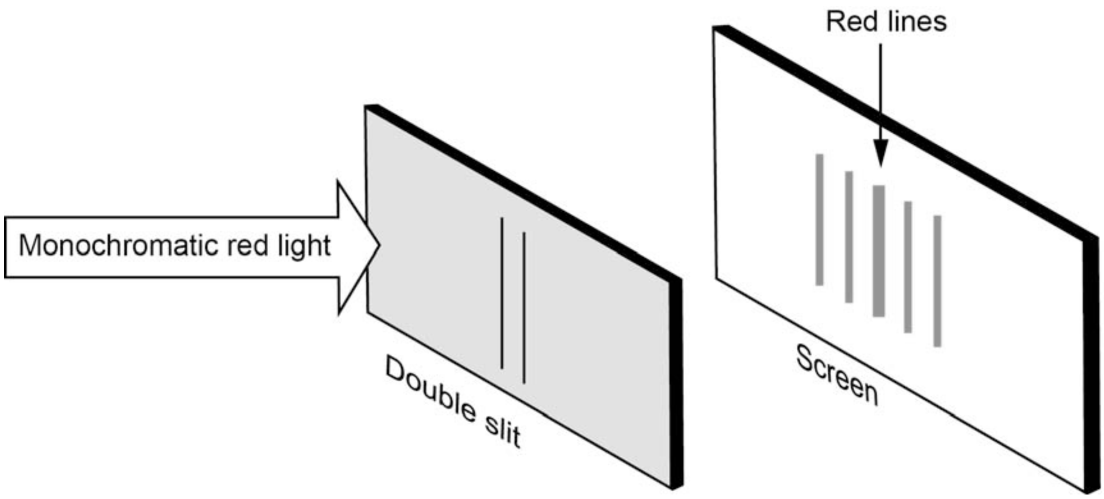
Longitudinal:

A seismometer records an earthquake. The P waves arrive 13.5 s before the S waves. Calculate the distance between the seismometer and the point of origin of the earthquake waves.

Description	Marks
Transverse wave examples: water surface waves, light (EM), string, 'Mexican'. Any one valid example.	1
Longitudinal: sound, traffic jam, crowd/mosh pit. Any one valid example. Note: if "slinky spring" is used, context must be clear	1
t = s/v so $s/v_P - s/v_S$ = time difference	1
s/3.56 – s/5.57 = 13.5	1
133 km away	1
	Total 5

Question 14 **(3 marks)**

The pattern observed when monochromatic light passes through a piece of cardboard with twin slits close together is often considered evidence for the wave theory of light. A diagram of an experiment set up in a classroom is provided below.



Explain how the pattern of red lines is formed on the screen and why this is considered to be evidence for the wave theory of light.

Description	Marks
diffraction spreads the light sideways	1
Interference: dark where destructive, light where constructive	1
only wave theory explains interference pattern formed	1
	Total 3

End of Section One

Section Two: Problem-solving **50% (90 Marks)**

Question 15 **(10 marks)**

An uncharged drop of oil is given 7 excess electrons. It is then introduced into the space between two horizontal plates 25.0 mm apart with a potential difference between them of 1.50 kV. The drop of oil remains stationary.

(a) Calculate the magnitude of the electric field strength between the plates. (2 marks)

Description	Marks
$E = V / d = 1500/0.025$	1
$E = 6.00 \times 10^{4}$ V m^{-1}	1
	Total 2

(b) Is the top plate positive or negative? Explain your reasoning. (2 marks)

Description	Marks
The top plate is positive.	1
This is because gravity is providing a downwards force on the drop since the drop is stationary the electric force must be upwards.	1
	Total 2

(c) Calculate the magnitude of the electric force acting on the oil drop. (3 marks)

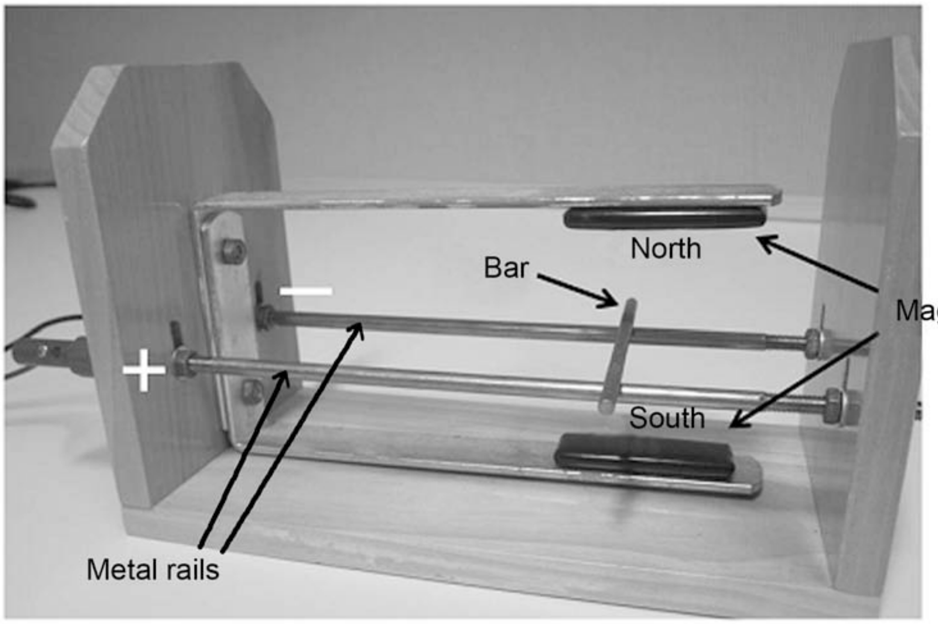
Description	Marks
$F = Eq = 6.00 \times 10^{4} \times 7 \text{ x } 1.6 \times 10^{-19}$	1–2
$F = 6.72 \times 10^{-14}$ N NB: penalise 1 mark for incorrect or no units.	1
	Total 3

(d) Calculate the mass of the oil drop. (3 marks)

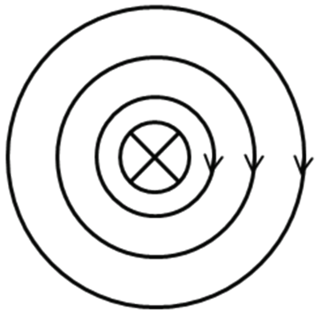
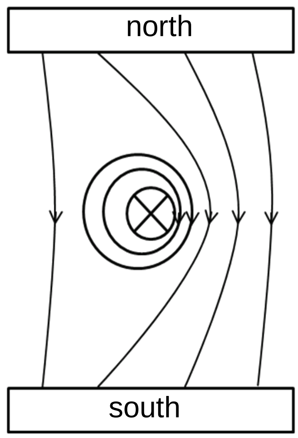
Description	Marks
If oil drop is stationary then electric force = gravitational force $F_e = mg$	1
$m = F_e / g = 6.72 \times 10^{-14} / 9.8$	1
$m = 6.86 \times 10^{-15}$ kg NB: penalise 1 mark for incorrect or no units.	1
	Total 3

Question 16 **(10 marks)**

An apparatus that demonstrates the interactions between a current and a magnetic field is shown below. There are two metal rails on which a metal bar is free to roll. Contact between the rails and bar allows a current to flow through them from the power pack attached to the metal rails. Two magnets provide a uniform magnetic field around the bar.



(a) Draw the magnetic fields associated with the following situations. (4 marks)

The bar carrying current into the page		The current carrying bar in a uniform magnetic field
		

Description	Marks
LH diag. Field directions shown and magnitude changes with distance	1–2
RH diag. Field direction of both shown and field interaction with a higher density on the right	1–2
	Total 4

(b) The rails are 8.50 cm apart and the magnetic field strength due to the magnets is $B = 1.50 \times 10^{-3}$ T.

Calculate the magnitude of the force acting on the bar when an electric current of 5.00 A is passed through the bar.

Draw and label on the photograph on page 18 the direction of the force and current. (4 marks)

Description	Marks
$F = BI\ell$ $F = 1.5 \times 10^{-3} \times 15 \times 10.085$	1
$F = 6.375 \times 10^{-4}$ N	1
Current direction chosen correctly (into page)	1
Direction shown on the diagram correctly (to the left)	1
	Total 4

(c) The apparatus in the photograph is then tilted at a small angle to the horizontal by lifting the left side when the current is flowing. The bar rolls toward the right-hand side, away from where the power supply is connected, due to the effects of gravity acting on the bar.

Describe two changes that could be made, either to the circuit or apparatus, to enable the force due to the current's interaction with the magnetic field to hold the bar stationary. (2 marks)

Description	Marks
Any two of the following Increase potential difference across the circuit (to increase current) Get bigger/stronger magnets Move magnets closer to bar	1–2
	Total 2

Question 17 **(12 marks)**

The planet Jupiter has a mass of 1.90 × 10^{27} kg, a radius of 71 500 km and many moons.

The closest moon, Metis, has a mass of 9.56 × 10^{16} kg and a mean orbital radius of 1.28 × 10^{5} km. Metis has an average planetary radius of 21.5 km.

(a) Calculate the gravitational force of attraction between Jupiter and Metis. (3 marks)

Description	Marks
$F_g = \frac{GM_J m_M}{r^2}$	1
$F_g = \frac{6.67 \times 10^{-11} \times 1.90 \times 10^{27} \times 9.56 \times 10^{16}}{(1.28 \times 10^{8})^2}$	1
F = 7.39 × 10^{17} N	1
	Total 3

(b) Calculate the time it takes in hours for Metis to orbit around Jupiter. (4 marks)

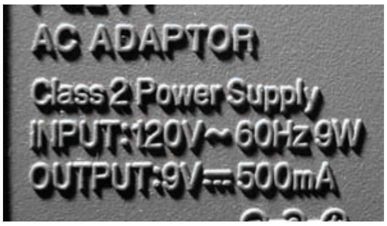
Description	Marks
$F_c = \frac{mv^2}{r}$ and v =2πr/t Substitute for v in F_c $F_c = \frac{m\left(\frac{2\pi r}{t}\right)^2}{r} = \frac{4\pi^2 mr}{t^2}$	1
Rearrange for t and substitute values in $t = \sqrt{\frac{4\pi^2 mr}{F_c}} = \sqrt{\frac{4\pi^2 \times 9.56 \times 10^{16} \times 1.28 \times 10^{8}}{7.39 \times 10^{17}}}$ Note: if Kepler's Law recalled correctly and all values are shown correctly but calculated answer is incorrect, 3 marks out of 4.	1
t = 25568 seconds or 2.56 × 10^{4} s	1
Convert to hours 25568 s /3600 = 7.10 hours	1
	Total 4

(c) Calculate the magnitude and direction of the net gravitational force acting on a 1.00 kg mass resting on the surface of Metis that faces Jupiter. (5 marks)

Description	Marks
(1 mark for two forces) $F_{gnet} = \frac{GM_J 1kg}{r_J^{\ 2}} - \frac{GM_M 1kg}{r_M^{\ 2}}$ where towards Jupiter is positive	1
(1 mark for numbers in) $F_{gnet} = \frac{6.67\times10^{-11}\times1.90\times10^{27}\times1}{(1.28\times10^{8}-21.5\times10^{3})^{2}} - \frac{6.67\times10^{-11}\times9.56\times10^{16}\times1}{(21.5\times10^{3})^{2}}$	1
(1 mark for realising opposite directions) $F_{g\ net}$ = 7.736-0.0138	1
(1 mark for answer with units) $F_{g\ net}$ = 7.72 N	1
(1 mark for direction given somewhere) Towards Jupiter	1
	Total 5

Question 18 **(13 marks)**

This photograph shows the information on a compliance plate on the outside of a small transformer used in a house in another country.



(a) Determine the ratio of windings of primary:secondary coils in the transformer. (2 marks)

Description	Marks
$V_p:V_s = N_p:N_s$	1
120:9 or 40:3 or 13.3:1	1
	Total 2

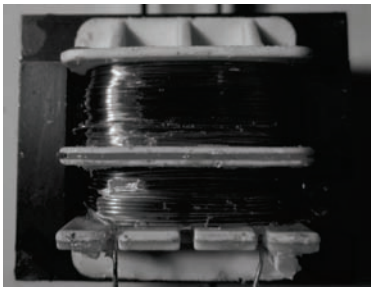
(b) Using the information on the compliance plate, calculate the power output of the transformer and use this information to determine the percentage efficiency of the transformer. (3 marks)

Description	Marks
$P_s = VI = 9 \times 0.500$	1
$P_s = 4.5$ W	1
efficiency = $\frac{4.5}{9}\times100 = 50\%$	1
	Total 3

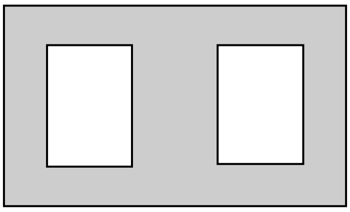
(c) Explain why the input voltage must consist of an alternating current rather than of direct current. (2 marks)

Description	Marks
There is no changing voltage/current with DC so no changing flux	1
To induce a current in the secondary coil there should be a changing flux	1
	Total 2

(d) The following photograph shows the coils and core inside the transformer case.



For small commercial transformers, the coils are placed around the centre pillar of the core, which is shaped like this:

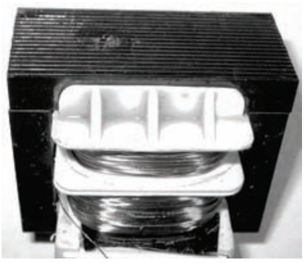


Describe the purpose and properties of the core. (2 marks)

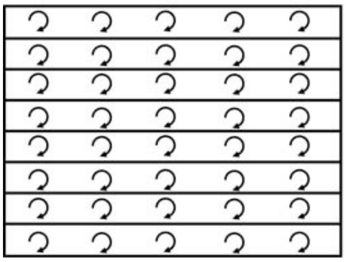
Description	Marks
Purpose: Direct and strengthen the flux	1
Properties: Soft (non-permanent ferromagnetic) material and laminated	1
	Total 2

(e) The photograph below shows the laminae (a number of thin iron sheets separated by non-electrically conductive material, such as plastic) that make up the core. These laminae are used to reduce ‘eddy currents’ or ‘back emf’ and make transformers more efficient.

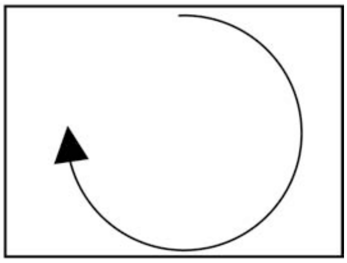
Use the following diagrams representing the centre pillar of the transformer and any relevant formula to explain why a transformer with a laminated core is more efficient than a transformer with a solid core. (4 marks)



Laminated core



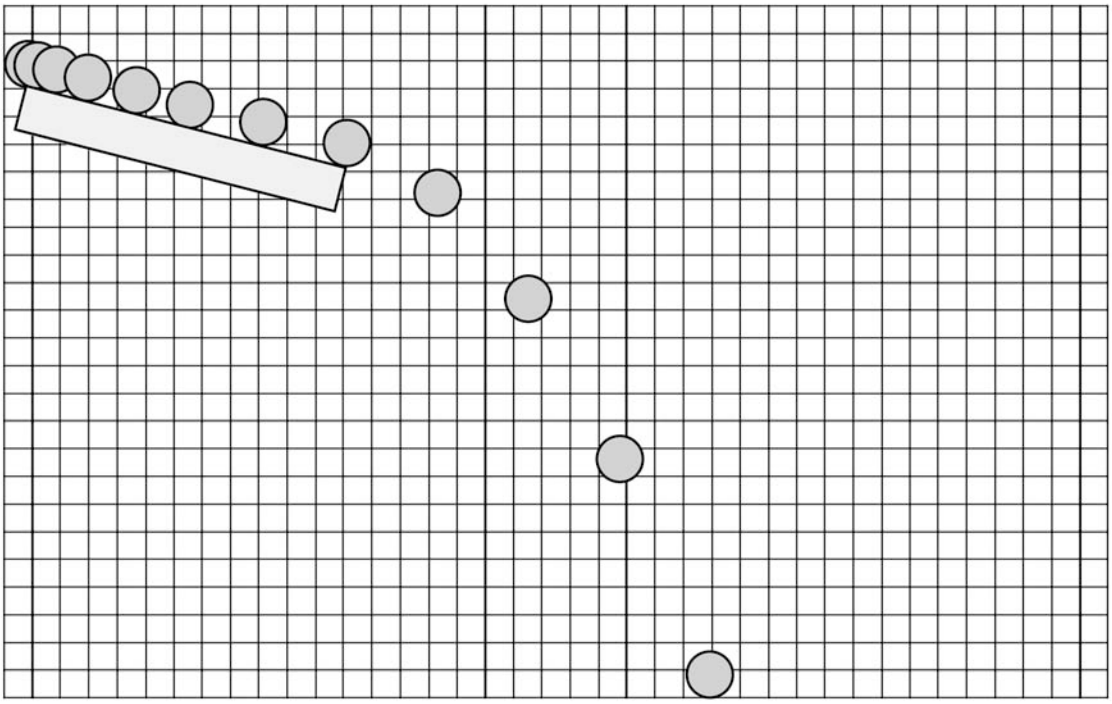
Solid core



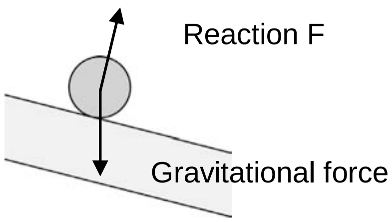
Description	Marks
Changing magnetic field induces emf in the iron core, large current if not laminated.	1
Relates induced/eddy current to cross sectional area	1
A laminated core increases the efficiency of transformer by *reducing* induced or eddy currents	1
Uses the diagram to show a difference in sizes current (eg little loops vs big loops)	1
	Total 4

Question 19 **(19 marks)**

Below is a diagram of a photograph taken using a strobe light flashing at 10.0 Hz. The camera is able to take multiple photographs of a single ball moving down a frictionless inclined plane over a short period of time. Each square on the background grid measures 5.0 cm × 5.0 cm. Ignore air resistance unless instructed otherwise.



(a) Draw and label the force(s) acting on the ball while it is on the inclined plane below. (2 marks)



Description	Marks
Normal, perpendicular to surface shown and labelled	1
Gravitational force acting downwards NB maximum 1 mark if friction or resultant force shown and labelled	1
	Total 2

(b) As the ball leaves the inclined plane its motion changes. (2 marks)

(i) Describe the horizontal and vertical accelerations when the ball has left the inclined plane.

Description	Marks
Horizontally – acceleration changes to 0	1
Vertically – increases to 9.8 m s^{-2}	1
	Total 2

(ii) How would each of these accelerations be affected if air resistance was considered?

Description	Marks
Horizontally – becomes a negative acceleration	1
Vertically – decreases to less than 9.8 m s^{-2}	1
	Total 2

(c) Use the diagram to determine the horizontal velocity of the ball after it has left the inclined plane. Express your answer to an appropriate number of significant figures. (3 marks)

Description	Marks
A displacement and time value accurately determined e.g. s = 0.64 m, t = 0.4 s	1
v = s/t =0.64/0.4 v = 1.6 m s^{-1}	1
Value within ±0.2, sig fig important	1
	Total 3

(d) The angle of the plane to the horizontal is 14°. Determine the component of gravitational acceleration that acts along the inclined plane. (2 marks)

Description	Marks
$\text{Sin}14^o = a_{Slope}/ 9.8$	1
$a_{Slope} = 2.37$ m s^{-2}	1
	Total 2

(e) Calculate the horizontal component of the ball's acceleration. Given that the ball starts from rest on the first strobe light flash and reaches the end of the inclined plane on the eighth flash, use the horizontal component of acceleration to determine the ball's horizontal velocity component as it leaves the inclined plane. (5 marks)

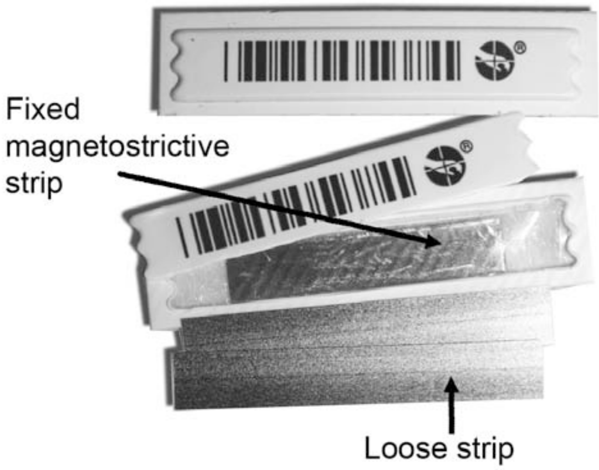
Description	Marks
t = 0.70 s (8-1 flashes × $^1/_{10}$ of a second)	1
$\cos14^o = a_H / a_{Slope}$	1
$a_H = 2.30$ m s^{-2}	1
v = u + at = 0 + 2.30 × 0.70	1
v = 1.61 m s^{-1}	1
	Total 5

(f) Use the motion of the ball to calculate the length of the inclined plane. (3 marks)

Description	Marks
Sorry markers, a number of methods exist for this one. Give credit where physics calculations and reasoning exists. Example below. (1 mark only if length measurements from graph are used)	
a_{Slope} = 2.37 m s^{-2}; t= 0.7 s from (e) or graph (uses appropriate values)	1
s = 0t + 0.5 × 2.37 × 0.7^2 (calculation appropriate)	1
s = 0.58 m (answer close to value)	1
	Total 3

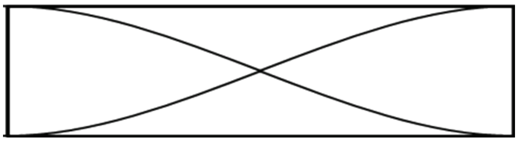
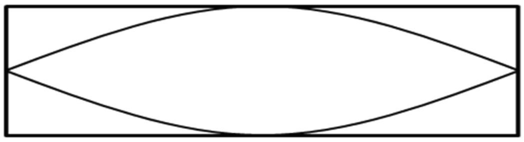
Question 20 **(7 marks)**

Acousto-magnetic tags (pictured) are commonly used in stores for security purposes. A radio transmitter near the front door emits an electromagnetic pulse of 58.0 kHz. A fixed metal strip made of magnetostrictive material (metal that shrinks when in a magnetic field) contained in a tag vibrates at this frequency due to the changing magnetic field.



When the magnetostrictive strip vibrates it causes loose metal strips in the tag to vibrate and produce a sound. The frequency of the transmitter corresponds to the resonant frequency of the metal strips in the tag. A nearby receiver, on detecting a sound of 58.0 kHz frequency shortly after the transmitter has finished sending the electromagnetic pulse, activates the alarm.

(a) The metal strips are 37.0 mm long. In the rectangle below draw the fundamental harmonic representing the wave formed in the metal strip and calculate the speed of sound in the metal. (3 marks)


or


Description	Marks
Fundamental harmonic shown (either displacement or pressure (density) type)	1
L = ½ λ λ = 74 mm or 7.4×10^{-2} m	1
v = f λ = 58000 × 0.074 = 4.29×10^{3} m s^{-1}	1
	Total 3

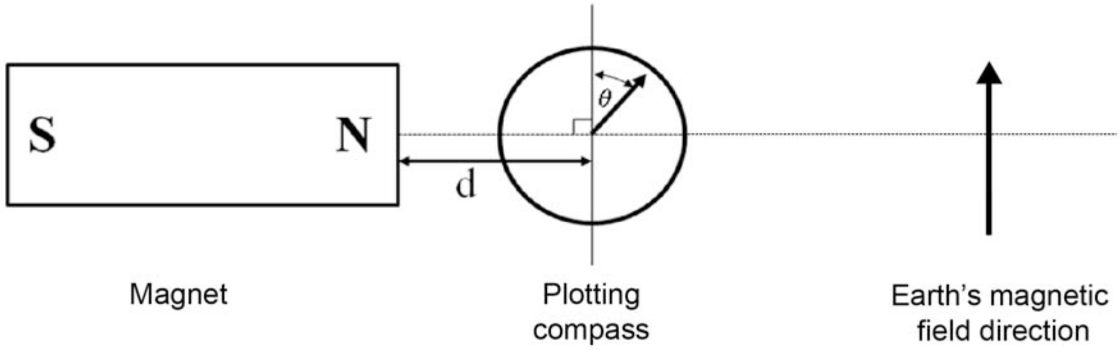
(b) All radio frequencies cause the magnetostrictive material to vibrate at the same frequency as the radio signal. Explain why only a frequency of 58.0 kHz will activate the alarm. (4 marks)

Description	Marks
Resonance must occur	1
Energy is transferred to the metal strips by the vibrating magnetostrictive material	1
The vibration corresponds to the natural frequency of vibration of the metal strips, reinforcing the vibration and storing energy (causing larger amplitude of vibration)	1
Metal strips continue to vibrate at harmonic frequency after forcing vibration has stopped, which is detected causing alarm to sound	1
	Total 4

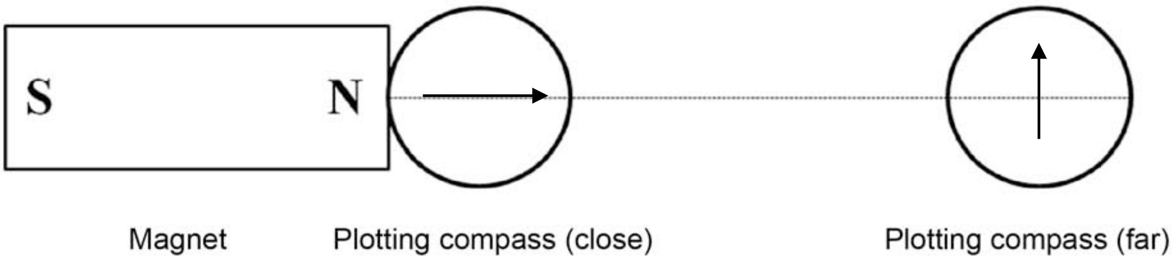
Question 21 **(19 marks)**

A student performed an experiment to investigate how the magnetic field strength of a bar magnet varied with distance from the magnet along a line through the long axis of the magnet. She measured the angle θ between the pointer of a plotting compass and geographic north, as she moved the plotting compass to various distances (d) away from the magnet. She measured the angle θ at intervals of 3.0 cm, as shown in Diagram A.

Diagram A

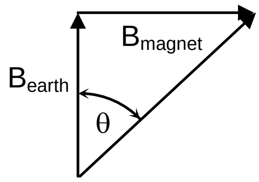


(a) On Diagram B, draw arrows on each of the plotting compasses to indicate the angle you would expect the needle of the compass to make when it is close to, and when it is far (more than 50 cm) from, the bar magnet. (2 marks)



Description	Marks
Arrow is very close to horizontal →	1
Arrow is closely aligned to north ↑	1
	Total 2

(b) Both the Earth's magnetic field and the bar magnet's magnetic field affect the compass. Draw a vector diagram that shows these two magnetic fields and the resultant magnetic field experienced by the plotting compass shown in Diagram A. Use your diagram to derive a relationship between the Earth's magnetic field, the magnet's magnetic field and the angle θ. (3 marks)

Description	Marks
Diagram has B fields at right angles θ correctly indicated (arrows in correct directions) 	1–2
$\tan\theta = \dfrac{B_{magnet}}{B_{Earth}}$	1
	Total 3

(c) Calculate the strength of the magnetic field due to the bar magnet at a point on the axis, 10.0 cm from the end of the bar magnet, if the value of θ at this point is 82°, and the Earth's magnetic field strength is 2.0×10^{-5} T. (2 marks)

Description	Marks
$B_{magnet} = B_E \times \tan\theta = 2.0\times10^{-5} \times \tan(82°)$	1
$B_{magnet} = 1.4 \times 10^{-4}$ T	1
	Total 2

Parts (d), (e) and (f) of this question assess your understanding of uncertainty in measurements, interpretation of graphs and use of appropriate significant figures.

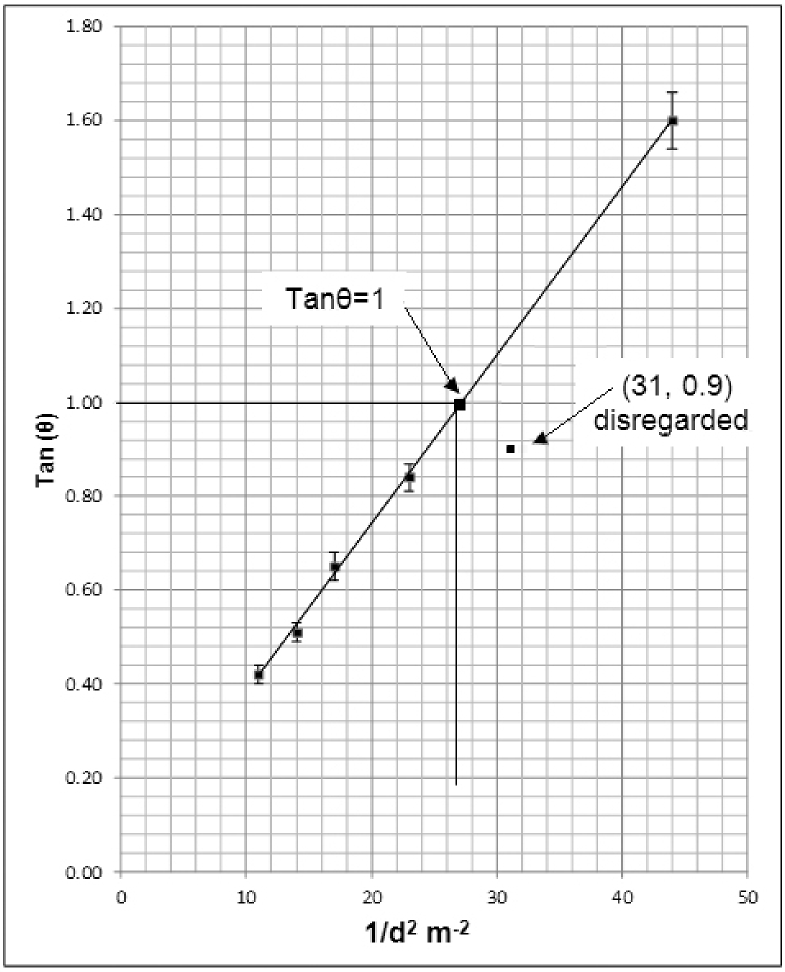
The compass that the student used to measure the angle θ was marked in divisions of 1°. The student could see when the needle was between divisions but could not judge accurately how close to a division it was. The student decided to express all her measurements of θ with an uncertainty of ± 1°. The student was confident that she placed the centre of the compass on the ruler accurately so decided not to express her measurements of d with any uncertainty.
The student's results are shown in the table below.

Distance from magnet (m)	$\dfrac{1}{d^2}$ **(m^{-2})**	**θ (°)**	**Tan θ**
0.15	**44**	58 ± 1	1.60 ± **0.06**
0.18	**31**	42 ± 1	0.90 ± 0.03
0.21	**23**	40 ± 1	0.84 ± 0.03
0.24	**17**	33 ± 1	0.65 ± 0.02
0.27	**14**	27 ± 1	0.51 ± 0.02
0.30	**11**	23 ± 1	0.42 ± 0.02

(d) Complete the table by filling in the values for $\frac{1}{d^2}$ and the uncertainty range for the value of tan θ for θ = 58°. You must show your calculation for determining the uncertainty range. (3 marks)

Description	Marks
Correctly complete table for $\frac{1}{d^2}$ to 2 sig figs	1
58.0° ± 1 = is 57° to 59°; tan 57° = 1.54 to tan 59° = 1.66	1
(1.66-1.54)/2 = ± 0.06	1
	Total 3

(e) Plot the graph of tan θ versus $\frac{1}{d^2}$ on the following graph paper. Include error bars and a line of best fit. (5 marks)



Description	Marks
Axes labelled correctly with units	1
Data points correct	1
Error bars included	1
Line of best fit drawn	1
Outlier left out of line of best fit (tan1→27) (tan1→28+ with outlier included)	1
	Total 5

(f) Mark and label the point on your graph where the strength of the Earth's magnetic field is equal to the strength of the magnetic field of the bar magnet. Use this point to determine the distance from the magnet where these fields are equal. (4 marks)

Description	Marks
When $B_{earth} = B_{magnet}$ $\tan\theta = 1$	1
Point indicated and labeled	1
from graph this occurs at when $1/d^2 = 27\ m^{-2}$	1
d = 19 cm	1
	Total 4

Section Three: Comprehension **20% (36 Marks)**

Question 22 **(19 marks)**
Muons and Relativity

Muons are subatomic particles that were discovered in 1936 by researchers studying cosmic radiation. The researchers noticed some particles whose paths in a magnetic field curved in a direction indicating negative charge, with path curvature indicating a mass between a proton mass and an electron mass.

Researchers first thought these particles were hadrons (heavy particles made of quarks). Hadrons such as protons and neutrons consist of three quarks and are called baryons. The new particles were thought to be mesons, that is, hadrons containing two quarks. Hadrons may emit either a neutrino or an antineutrino when they decay.

Further investigation showed that muons emit both a neutrino and an antineutrino when they decay, indicating that muons are leptons – fundamental particles that are not made of quarks. The most familiar lepton is the electron. Muon decay can be summarised as

muon → electron + neutrino + antineutrino

Most naturally-occurring muons are created when cosmic rays collide with atoms in the upper atmosphere, approximately 10 km above the Earth. A muon has a rest mass of $\frac{106\ \text{MeV}}{c^2}$, a charge of -1 and an average lifetime of 2.2×10^{-6} s.

(a) The table below contains information about some subatomic particles. Complete the last column of the table by writing baryon, meson or lepton to indicate the group of particles to which the individual particle belongs. (4 marks)

Particle	Quark structure	Decay products	Baryon, meson or lepton
Lambda	charm, up, down	proton, pion, kaon	
Tau		tau neutrino, electron, electron anti-neutrino	
Kaon+	strange, charm	muon and muon neutrino	
Xi	up, strange, strange	lambda and pion	

Description	Marks
Baryon	1
lepton	1
meson	1
baryon	1
	Total 4

(b) Muons travel at almost the speed of light. Calculate the average distance that a muon created in the upper atmosphere would travel before it decayed. Assume that its speed is equal to c and that there are no relativistic effects. (2 marks)

Description	Marks
s = v/t = $3 \times 10^8 \times 2.2 \times 10^{-6}$	1
s = 6.6×10^2 m [0.66 km]	1
	Total 2

(c) Muons created by cosmic rays in the upper atmosphere can be detected by detectors on the Earth's surface. This means that the muons have travelled much further than expected. An explanation of this phenomenon involves the effects of relativity.

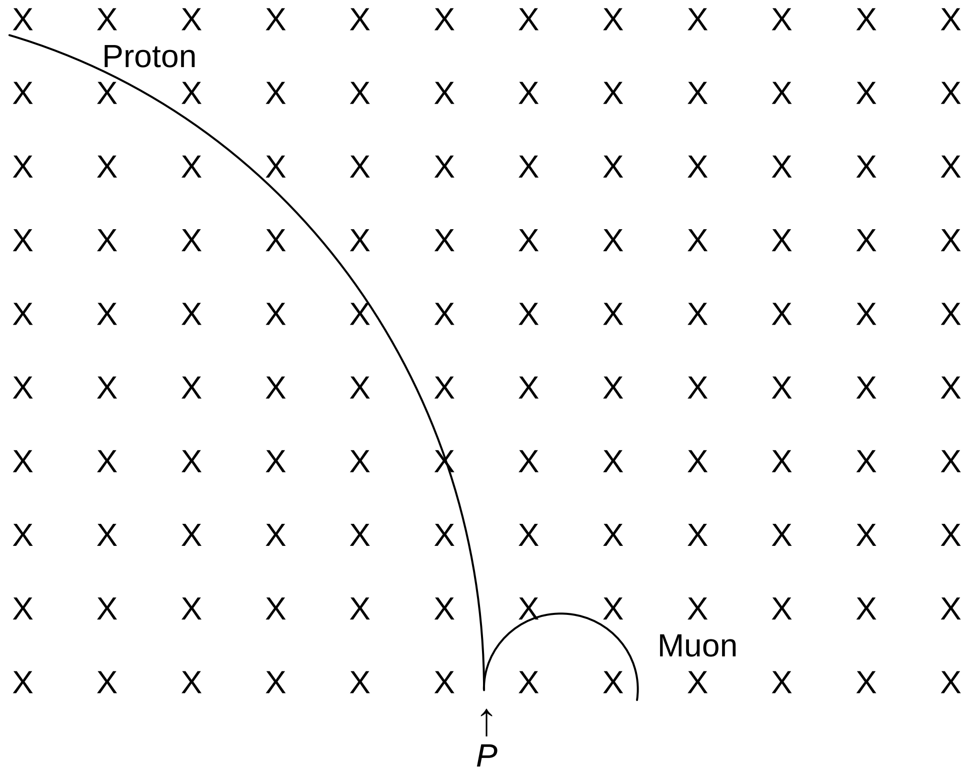
Explain how relativity affects the muons and enables them to travel over a greater distance than that calculated in (b). (3 marks)

Description	Marks
Time measured on Earth depends on the speed of the observer and the object being viewed	1
As the speed increases the time [dilation] increases (either frame reference of muon or Earth is valid) (correct length contractional , so valid)	1
Muons last longer since they travel so fast	1
	Total 3

(d) Express the rest mass of a muon in kilograms, and compare this to the rest mass of a proton. (3 marks)

Description	Marks
106 $\frac{\text{MeV}}{\text{C}^2}$ to mass $= \frac{106 \times 10^6 \times 1.6 \times 10^{-19}}{(3 \times 10^8)^2}$	1
= 1.88×10^{-28} kg	1
Proton to muon ~ 9x larger	1
	Total 3

(e) On the diagram below sketch and label two lines representing the paths you would expect a proton and a muon to follow in the given magnetic field. Assume both particles are injected into the field at P with the same velocity. (3 marks)



Description	Marks
The curve with the larger radius moves to the left = proton	1
The smaller curve moves to the right = muon	1
Scale of curve ~1/9th the size	1
	Total 3

(f) Injecting and directing a charged particle using magnetic and electric fields is a commonly-used phenomenon. It is used in old (cathode ray tube) television technology as well as in high technology applications such as the CERN Large Hadron Collider.

Using formulae from your Formulae and Constants Sheet, show the derivation of the formula below that determines a particle's velocity from its mass (m) and charge (q), having been accelerated through a potential difference (V). You must show all steps. (4 marks)

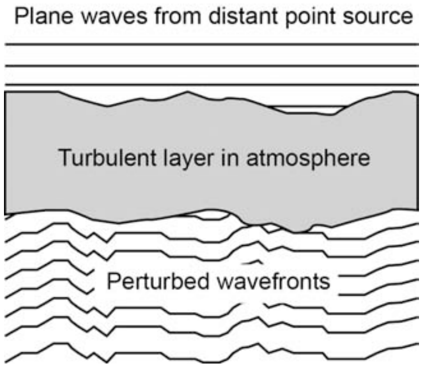
$$v = \sqrt{\frac{2Vq}{m}}$$

<table>
<tr><th colspan="2">Description</th><th>Marks</th></tr>
<tr><td colspan="2">Accelerated through Electric field E or over a potential difference V</td><td>1</td></tr>
<tr><td>F = Eq or Vq/d = ma</td><td>W = Vq = E_k</td><td>1</td></tr>
<tr><td>a = Vq/md and
$v^2 = u^2 + 2as$, where u = 0</td><td>$E_k = ½mv^2 - ½mu^2$, where u = 0</td><td>1</td></tr>
<tr><td>v^2 = 2Vqs/md (s = d) so v^2 = 2Vq/m
$v = \sqrt{\frac{2Vq}{m}}$</td><td>v^2 = 2Vq/m
$v = \sqrt{\frac{2Vq}{m}}$</td><td>1</td></tr>
<tr><td colspan="2"></td><td>Total 4</td></tr>
</table>

Question 23 **(17 marks)**

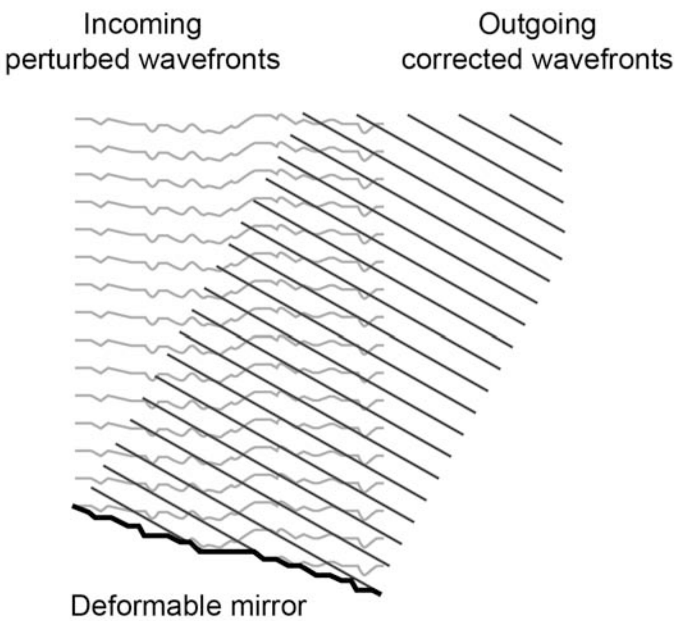
Adaptive Optics and Laser Guide Star

Telescopes with very large mirrors can gather a lot of light to allow viewing of dim, distant astronomical objects. As light waves pass through the atmosphere, tiny variations in the refractive index of the atmospheric gases distort the light's path, causing stars to appear to change position and twinkle. Large-diameter mirrors with fixed focal points thus suffer from image distortion when the position of an astronomical object seems to be in many different places when viewed from different places on the mirror.



Optical wave fronts from an astronomical object may be distorted by a layer of turbulence in the atmosphere. The amount of distortion has been exaggerated.

Adaptive optics is a technology used to improve the performance of large telescopes by reducing the effect of wavefront distortions caused by atmospheric distortion. Adaptive optics works by measuring the distortions in a wavefront and compensating for them with a deformable mirror. This requires a wavefront reference source to allow the telescope to correct the distortion of light caused by turbulence in the atmosphere. Turbulence changes the refractive index of the atmosphere in unpredictable ways. Monitoring the apparent motions of a bright star with known optical characteristics can provide a reference for adaptive optics. When the atmosphere's effects are subtracted, using a deformable tip-tilt mirror, the astronomical image produced is steady and clear.



A deformable mirror can correct distorted incoming wavefronts.

Many parts of the sky lack stars bright enough to use for judging atmospheric conditions. This limits the effectiveness of adaptive optics that use natural guide stars. A laser guide star is an artificial star-like light source created by shining a laser into the upper atmosphere. Such an artificial 'star' can be positioned anywhere that the astronomer wishes to observe, allowing any part of the sky to be viewed using adaptive optics.

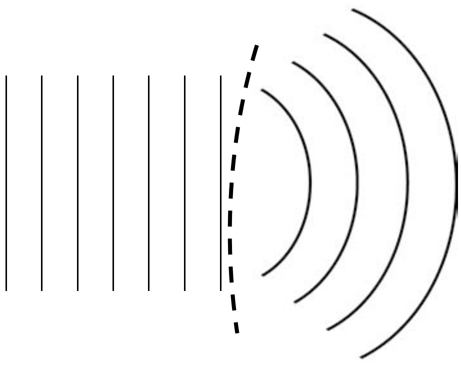
The bright line is a laser beam visible only because of atmospheric scattering.

A 'sodium beacon' is one type of laser guide star. It is created by shining a laser tuned to 589 nm (nanometres) into the upper atmosphere, exciting a naturally-occurring layer of sodium atoms at an altitude of about 90 km. The excited sodium atoms quickly decay, re-emitting the 589 nm light and giving the appearance of a glowing star.

Often, the laser is pulsed and the light from the laser guide star is measured a very short time after the pulse is emitted. This eliminates errors from scattered light at ground level, so that only light that has travelled down from the sodium layer is actually detected. The light returning from the sodium beacon, having travelled through most of the atmosphere, appears to have moved around in the sky in the same way as the light from astronomical objects.

(a) The following diagram shows light wavefronts moving from more dense air, where it moves slower, to less dense air, where it travels faster. Complete the diagram by sketching four more wave fronts in the less dense air.

(2 marks)



More dense 'slow' air Less dense 'fast' air

Description	Marks
Wave fronts are spread out (further apart) (wavelength is larger)	1
Wave paths diverge/curved wavefronts	1
	Total 2

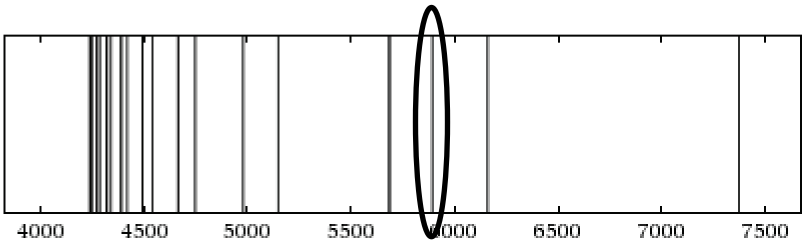
(b) Calculate the time taken for a pulse from a laser to reach the sodium layer and for the re-emitted light to return to the Earth's surface. Assume that the decay time of excited sodium atoms is negligible. (3 marks)

Description	Marks
Data from article s = 90 km × 2 = 1.8×10^5 m	1
c = 3×10^8 m s^{-1} $t = \frac{s}{v}$ = $1.8 \times 10^5 / 3 \times 10^8$	1
t = 6.0×10^{-4} s	1
	Total 3

(c) Calculate the energy in electron volts of a photon of light produced by the sodium beacon laser. (3 marks)

Description	Marks
E = hc/ λ = $6.63 \times 10^{-34} \times 3 \times 10^8 / 589 \times 10^{-9} = 3.38 \times 10^{-19}$	1
E = $3.38 \times 10^{-19} \div 1.6 \times 10^{-19}$	1
= 2.11eV	1
	Total 3

(d) When white light is shone through a gas consisting of sodium atoms and then passed through a prism, the white light's visible spectrum has several dark lines appear, as shown below. The scale is in angstroms ($\times 10^{-10}$ m). (4 marks)



(i) What type of spectrum is this considered to be? **Line absorption**

(ii) Circle the part of the spectrum that corresponds to the light emitted by a sodium beacon laser.

(iii) Astronomers observe light that has passed through gases, such as in a nebula (a gas cloud in space) or a planet's atmosphere. Explain how the characteristics of this light are used to determine the composition of the gases.

Description		Marks
(i)	line absorption	1
(ii)	line at 5890 angstroms circled	1
(iii)	for a photon to be absorbed, the photon's energy must correspond to an energy level difference of the atom	1
	each element has a unique set of energy level differences, identifying the gas	1
		Total 4

Fluorescent angiography is a technique for examining the circulation of blood in the retina of the eye using a dye-tracing method. It involves the injection of sodium fluorescein, which circulates through the whole body, including the eye. The eye is then illuminated using blue light of wavelength 490 nm. The sodium fluorescein fluoresces, emitting yellow-green light that is photographed to create an angiogram.

(e) Using the energy level diagrams below, determine and draw on the diagrams the photon absorption and emission transitions for:

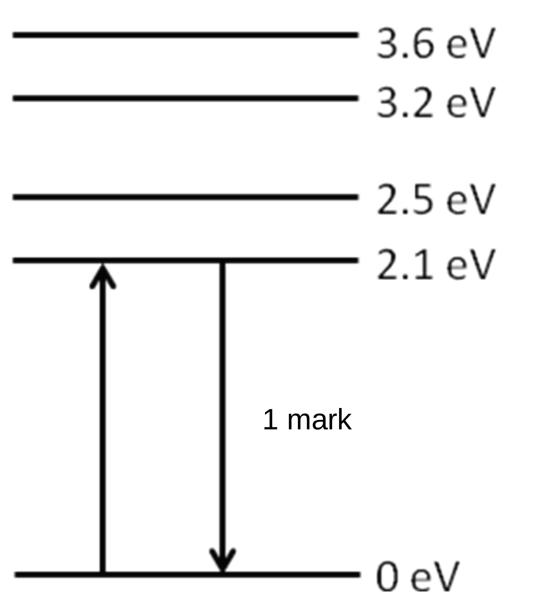
A the sodium beacon laser guide star

and

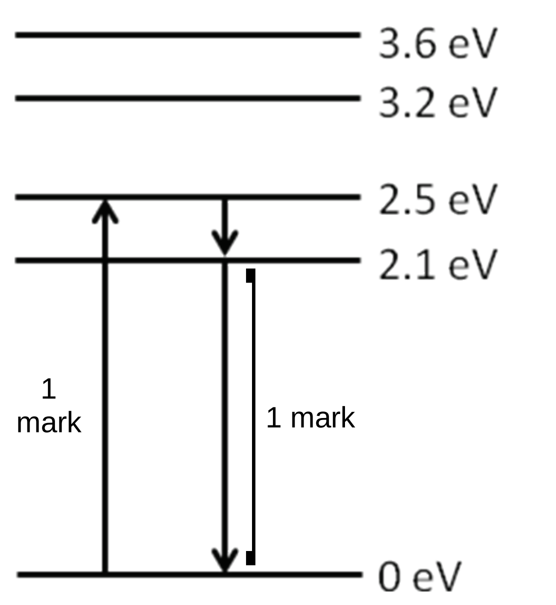
B the fluorescent angiography. You must show the calculations used for determining the absorption transition.

The energy level diagrams are simplified. A sodium atom has many energy level transitions available and therefore not all energy levels are shown. (5 marks)

A Laser guide star transitions



B Fluorescent angiography transitions



Description	Marks
Diagram A	
Line upwards from 0 eV to 2.1 eV then return 2.1 eV to 0 eV	1
Diagram B	
$E = hc/\lambda = 6.63 \times 10^{-34} \times 3 \times 10^{8}/490 \times 10^{-9} = 4.06 \times 10^{-19}$ J	1
$E = 4.06 \times 10^{-19}$ J $/ 1.6 \times 10^{-19} = 2.53$ eV	1
Line upwards from 0 eV to 2.5 eV	1
Line downwards from 2.5 eV to 2.1 eV, then 2.1 eV to 0 eV (or any two smaller steps if calculation not present)	1
	Total 5

ACKNOWLEDGEMENTS

Section One:
Question 7 Photograph of boy with hose. Use with kind permission of the examining panel.

Section Two:
Question 16 Photograph of current and magnetic field. Use with kind permission of the examining panel.

Question 18 Photograph of compliance plate. Use with kind permission of the examining panel.

Question 18(d) Photograph of transformer coils and core. Used with kind permission of the examining panel.

Question 18(e) Photograph of laminates in transformer coil. Used with kind permission of the examining panel.

Question 20 Photograph of acousto magnetic tags. Used with kind permission of the examining panel.

Section Three:
Question 22 Text adapted from: *Muon*. (2011, July 26). Retrieved July, 2011, from http://en.wikipedia.org/wiki/Muon. Text is available under the Creative Commons Attribution-ShareAlike 3.0 Unported License.

Question 23 Adapted from: Gringer. (2008, December 29). *Atmos_struct_imaging* [Diagram]. Retrieved January 21, 2011, from: http://en.wikipedia.org/wiki/File:Atmos_struct_imaging.svg.

Adapted from: Tubbs, B. *Adaptive optics correct* [Diagram]. (2007, September 9). Retrieved January 21, 2011, from: http://en.wikipedia.org/wiki/File:Adaptive_optics_correct.png.

Adapted from: *Laser guide star system installed at the Very Large Telescope (European Southern Observatory) in Chile* [Photograph]. Retrieved January 21, 2011, from http://en.wikipedia.org/wiki/Laser_guide_star.

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