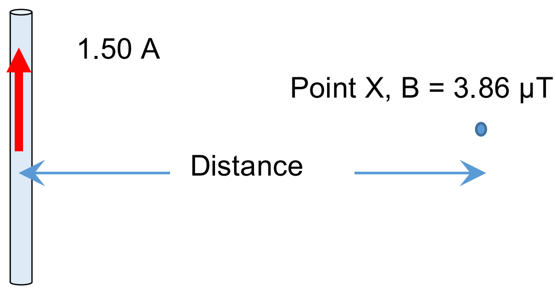
Section One: Short response **30% (54 Marks)**

This section has **12** questions. Answer **all** questions. Write your answers in the space provided. Suggested working time for this section is 50 minutes.

Question 1 **(2 marks)**

A wire is conducting a DC current of 1.50 A. At point X a magnetic flux density of 3.86×10^{-6} T is detected. Calculate the distance between the current carrying wire and point X. You can ignore the effects of the Earth's magnetic field in this question.



$$B = \frac{\mu_0}{2\pi} . \frac{I}{r}$$

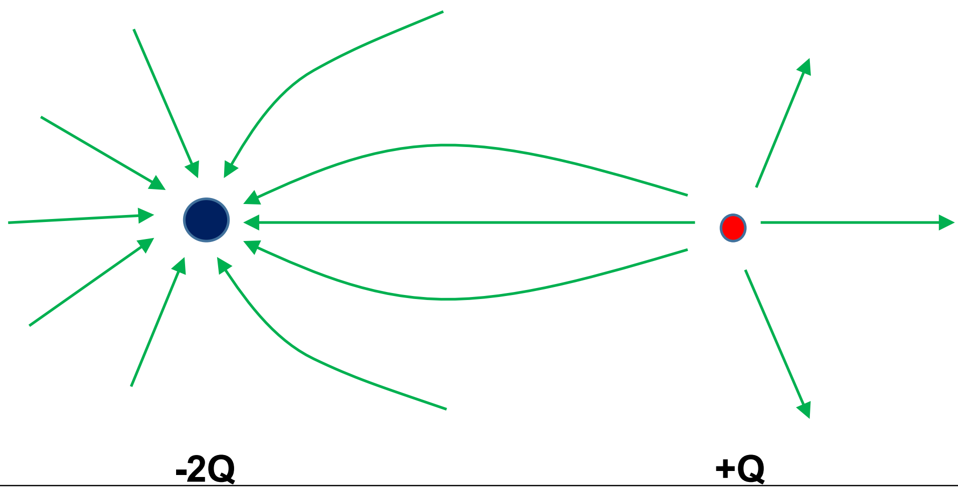
$$3.86 \times 10^{-6} = \frac{4\pi \times 10^{-7}}{2\pi} . \frac{1.50}{r} \checkmark$$

$r = 7.77 \times 10^{-2} m$ ✓

(0.0780 if other constant used)

Question 2 **(2 marks)**

Two point charges are shown in the diagram below. Their relative charges are -2Q and +Q. On the diagram show the relative shape of the net electric field established around and between the point charges. You should draw at least 12 field lines on the diagram.

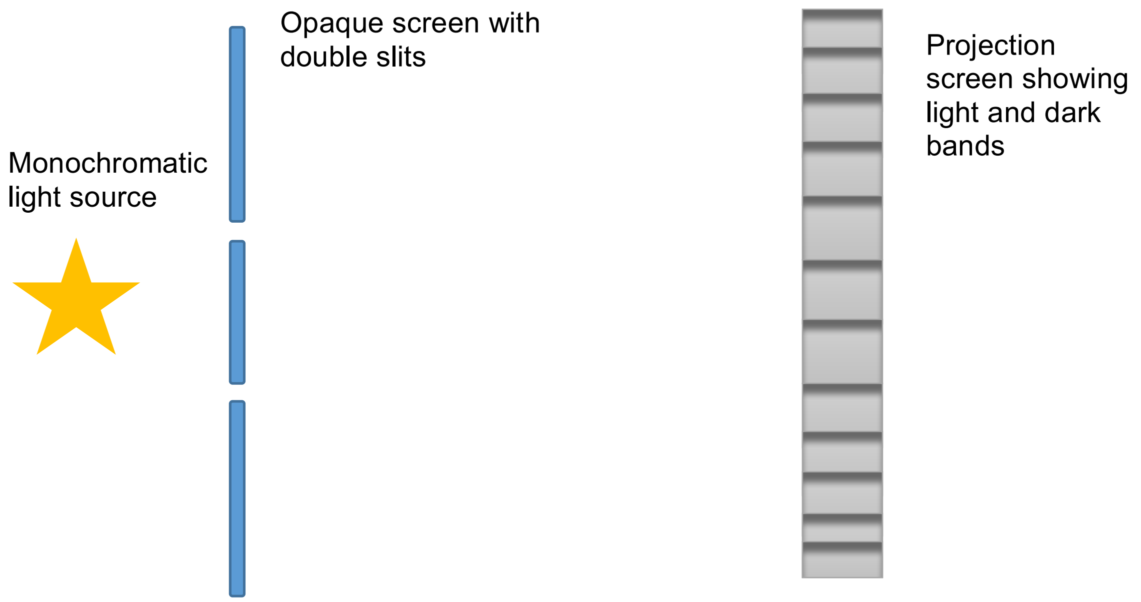


General shape way from positive at least 12 lines ✓

Higher density around -2Q ✓

Question 3 **(4 marks)**

Young's double slit experiment produces a series of light and dark bands on a screen when monochromatic light is passed through both slits and shone onto a screen. With reference to the diagram below explain how the light bands and the dark bands are formed.

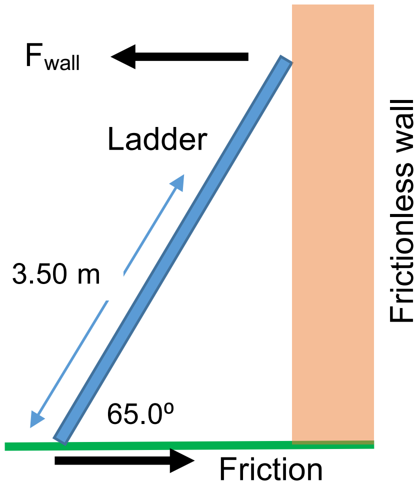


Light travels in waves and diffracts with circular wavefronts from each slit. ✓
The two waves undergo superposition at locations beyond the double slits. ✓
At locations on the screen where constructive interference occurs a bright spot is formed. ✓
At locations on the screen where destructive interference occurs a dark spot is formed.✓

Question 4 **(7 marks)**

The diagram shows a uniform ladder of mass 20 kg and length 5.00 m resting on firm ground and against a frictionless wall. Friction acts at the base of the ladder from the ground as shown to stop the ladder collapsing. The force from the wall (**F_{wall}**) and friction both act in the horizontal and are in equilibrium. A person of mass 80.0 kg is standing on the ladder 3.50 m from the base. A normal reaction force at the base of the ladder and the two weight forces act in the vertical direction on the ladder.

The ladder makes an angle of 65.0º with the ground.



a) Calculate the force of friction acting on the ladder in the position shown.

(4 marks)

Select base of ladder as fulcrum and take moments, ΣM = 0

Moment = r.F.sin θ

Σacwm = Σcwm correct concept

(5 x F_{wall} x sin 65) ✓ = (3.5x80x9.8xsin25) + (2.5x20x9.8xsin 25) ✓

F_{wall} = 301.6 N ✓

F_{wall} = $F_{friction}$ = 302 N ✓ (acting to the right at the base)

b) If the angle that the ladder makes to the horizontal is changed to 45º how would this change the magnitude of friction required to maintain equilibrium. The friction would:

Increase Stay the same Decrease Insufficient data to determine

Circle a response and explain your choice:

(3 marks)

Increase ✓

Σacwm = Σcwm

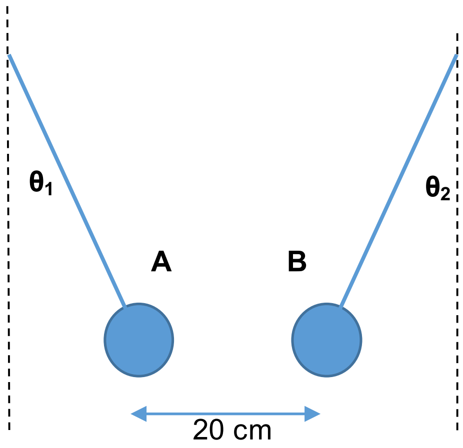
(5 x F_{wall} x sin 45) = (3.5x80x9.8xsin45) + (2.5x20x9.8xsin 45)

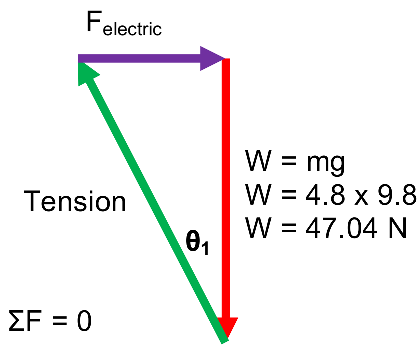
Σcwm increases due to change in angle from 25º to 45º ✓

Σacwm must match this increase but 5sin 45º is less than 5sin 65º so F_{wall} must increase and therefore $F_{friction}$ must increase. ✓

Question 5 **(7 marks)**

The diagram shows two charged spheres. Each sphere has a mass of 4.8 kg. Sphere A has a charge of +2.50 μC and sphere B has a charge of -2.50 μC. They are separated by 20.0 cm between their effective point charge locations. Each sphere is suspended from a fine string whose mass can be ignored. In this situation $\theta_1 = \theta_2$ which is the angle each string makes to the vertical.





a) Determine the angle θ_1

(5 marks)

W = mg = 4.80 x 9.8 = 47.04 N ✓

$$F_{electric} = \frac{1}{4\pi\,\varepsilon_0}\cdot\frac{q_1 q_2}{r^2} = \frac{1}{4\pi\,\varepsilon_0}\cdot\frac{2.5\times10^{-6}\times-2.5\times10^{-6}}{0.20^2}$$ ✓

$$F_{electric} = 1.405\ N$$ ✓

$$Tan\ \theta = \frac{F_{electric}}{mg} = \frac{1.405}{47.04}$$ ✓

θ = 1.71° N ✓

b) If the charge of sphere A is changed to +1.00 μC and sphere B is changed to -6.25 μC, explain what will happen to the values of angle θ_1 and θ_2.

(2 marks)

Consider the electric force in this situation

$$F_{electric} = \frac{1}{4\pi\,\varepsilon_0}\cdot\frac{q_1 q_2}{r^2} = \frac{1}{4\pi\,\varepsilon_0}\cdot\frac{1\times10^{-6}\times-6.25\times10^{-6}}{0.20^2}$$

$$F_{electric} = 1.405\ N$$ ✓

The force acting on each sphere is the same so the angles will not change✓

Question 6 **(3 marks)**

A proton has been accelerated to 95% of the speed of light in the Large Hadron Collider. Calculate its energy.

m = 1.67x 10^{-27} kg v = 0.95 x 3.00 x 10^{8} m s^{-1} ✓

$$E = \frac{m.c^2}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$E = \frac{1.67 \times 10^{-27} \times (3 \times 10^8)^2}{\sqrt{1 - \frac{0.95^2}{1}}}$$ ✓

E = 4.81 x 10^{-10} J ✓

Question 7 **(4 marks)**

An artificial satellite has been put into a circular polar orbit around the planet Venus. Venus has a radius of 6,052 km. The satellite is at an altitude of 1,050 km and orbits the planet every 1 hour and 50 minutes. Calculate the mass of Venus based on this data.

m = ? r = 6 052 000 + 1 050 000 = 7 102 000 m ✓

T = 110 x 60 = 6600 s ✓

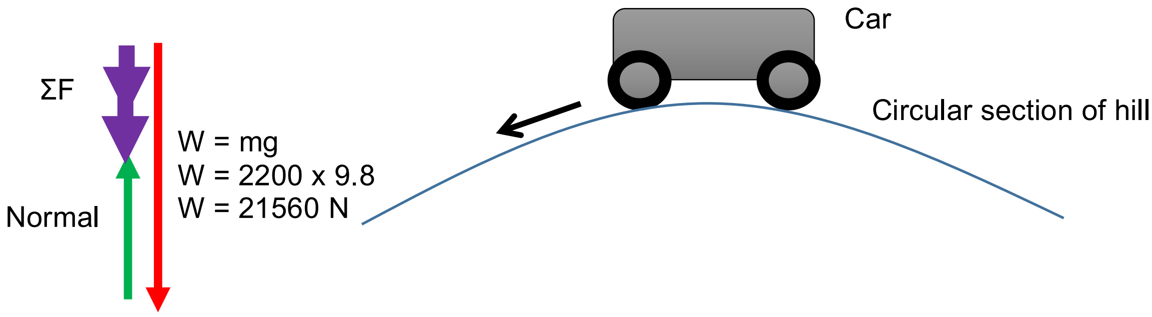
$$T^2 = \frac{4\pi^2}{GM} r^3$$ by rearrangement $$M = \frac{4\pi^2 r^3}{GT^2}$$

$$M = \frac{4 \times \pi^2 \times 7\,102\,000^{\,3}}{6.67 \times 10^{-11} \times 6600^2}$$ ✓

M = 4.87 x 10^{24} kg ✓

Question 8 **(7 marks)**

A car of mass 2200 kg is moving over a hill which has a profile that is a section of a circle. The radius of the circle is 29.0 m and the car is moving at 54.0 km hr^{-1} at the top of the hill.



a) Construct a vector diagram in the box above. Show the forces acting on the car and the net force.

(2 marks)

Vectors head to tail ✓ ΣF shown from start to finish✓

b) Calculate the normal reaction force on the car from the hill.

(3 marks)

$V = 54 / 3.6 = 15 \text{ m s}^{-1}$

Net force towards centre = Weight - Normal

$\Sigma F = mv^2/r = mg - N$

$N = mg - mv^2/r$ ✓ (correct analysis)

$N = (2200 \times 9.8) - (2200 \times 15^2)/29$ ✓

$N = 4.49 \times 10^3$ N ✓ (up)

c) The apparent weight is equal to the magnitude of the normal reaction force experienced by the car. If the car goes over the top of hill at a slower speed the apparent weight will: (circle a response)

Increase Stay the same Decrease Impossible to determine

Explain your response. You should refer to your vector diagram.

(2 marks)

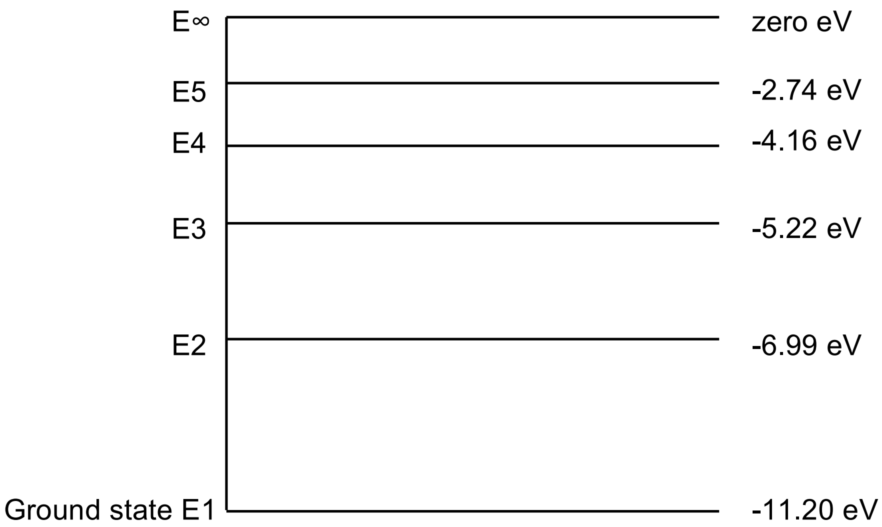
Increase ✓

$N = mg - mv^2/r$ (refer to vector diagram)

So if v decreases mv^2/r decreases, mg is constant so N increases. ✓

Question 9 **(6 marks)**

The energy level diagram for a simple atom is shown below.



a) An atomic electron in energy level E2 absorbs a photon which excites it to E5. Calculate wavelength of this photon.

(4 marks)

E (eV) = 6.99 -2.74 = 4.25 eV ✓

E (J) = 4.25 x 1.60 x 10^{-19} = 6.80 x 10^{-19} ✓

$$E = \frac{h.c}{\lambda}$$

$$6.80\times10^{-19} = \frac{6.63\times10^{-34}\times3\times10^{8}}{\lambda}$$ ✓

$\lambda = 2.93\times10^{-7}\ m$ ✓ (= 293 nm)

b) It is possible that an atomic electron at E5 can de-excite to E1(the ground state), explain how energy is conserved when this happens.

(1 mark)

The reduction in potential energy is converted to photon energy. ✓

c) It is possible for an atomic electron in the ground state (E1) to absorb a 14.0 eV photon. Explain how energy is conserved in this case.

(1 mark)

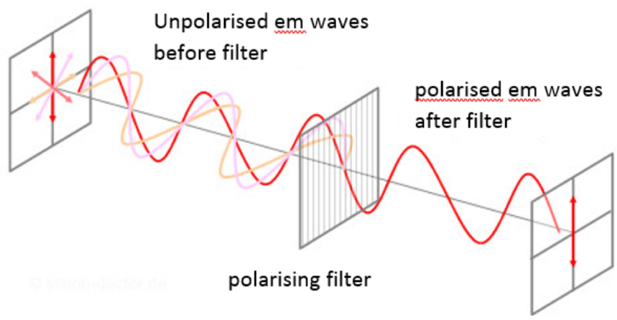
11.20 eV is used to ionize the atom, the balance (14 – 11.2 = 2.80 eV) is in the form of kinetic energy of the ionized electron. ✓

Question 10 **(4 marks)**

Passing unpolarised light through a polarising filter allows the intensity of a light beam to be reduced. In Polaroid sunglasses, this phenomenon is used to reduce glare.

Explain whether polarisation of light indicates that it is behaving as a particle or a wave and with reference to a simple diagram explain how light intensity is reduced by passing it through a polarising filter.

Light is behaving as a wave. ✓
For unfiltered electromagnetic waves, the plane of oscillation of the electric field can be in any direction. ✓
Only transverse waves whose electric field plane of oscillation matches the orientation of the polarizing material can pass through. ✓
Simple diagram that conveys this idea. ✓ for example



Question 11 **(4 marks)**

A telecommunications company want to put an artificial satellite into a circular orbit at a fixed altitude around the Earth. The owner of the company wants the satellite to a have a range of orbital speeds. Explain why this is not possible. You must refer to physics principles and equations that consider gravitational field strength and centripetal acceleration.

For a satellite to be in a stable circular orbit, the centripetal acceleration of the satellite must match the gravitational field strength at the altitude of this orbit. ✓

Mathematically

$G\frac{M}{r^2} = \frac{v^2}{r}$ ✓ and by rearrangement $v = \sqrt{\frac{GM}{r}}$ ✓

As G, M and r are fixed quantities there can only be one value of orbital speed v. ✓

(Or any other acceptable explanation)

Question 12 **(4 marks)**

The de Broglie wavelength of a proton used in a diffraction experiment is 3.42 x 10^{-10} m.

a) Calculate the speed of the proton. Recall from ATAR Physic Unit 2 that momentum is defined as the product of mass and velocity.

(2 marks)

m = 1.67 x 10^{-27} kg λ = 3.42 x 10^{-10} m

$$\lambda = \frac{h}{mv}$$

$$3.42 \times 10^{-10} = \frac{6.63 \times 10^{-34}}{1.67 \times 10^{-27} \times v} \checkmark$$

$$v = 1160\ m\ s^{-1} \checkmark$$

b) Is it possible to achieve an interference pattern by diffracting protons? Explain briefly.

(2 marks)

Yes, particles can behave as waves if they are in motion ✓

Waves are required to produce an interference pattern. ✓

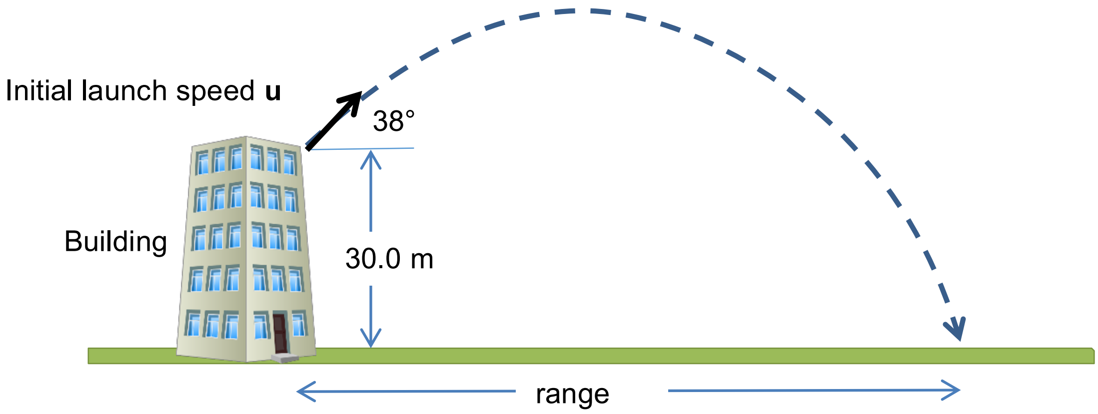
End of Section One

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

This section has **seven (7)** questions. You must answer **all** questions. Write your answers in the space provided. Suggested working time for this section is 90 minutes.

Question 13 **(13 marks)**

A stone of mass 520 g is thrown from a building of height 30 m. The stone is launched with an angle of elevation of 38.0º above the horizontal. It takes a time of 3.15 s for the stone to reach ground level. You can ignore air resistance for this question.



a) Calculate the initial launch speed **u** of the stone.

(4 marks)

$s_y = -30.0$ $u_y = u.\sin 38$ $a_y = -9.80\ m/s^2$

$u_x = s_x / t_f$ $u_x = u.\cos 38$ $t_f = 3.15\ s$

$s_y = u_y t_f + \frac{1}{2} a_y t_f^2$

$-30 = u_y \times 3.15 - 4.9 \times (3.15^2)$ ✓

$18.6205 = u_y \times 3.15$

$u_y = 5.91119\ s$ ✓

$u_y = u.\sin 38 = 5.91119$ ✓

$u = 9.60\ m/s$ ✓

For the following calculations use a numerical value of 9.60 m s^{-1} for the initial launch speed of stone if it is required.

b) Calculate the horizontal range of the stone.

(2 marks)

$u = 9.60$ m s^{-1} $t_f = 3.15$ s $u_x = s_x / t_f$

$u_x = u.\cos 38$

$u_x = 9.60 \times \cos 38 = 7.5649$ m s^{-1} right ✓

$s_x = u_x \times t_f = 7.5649 \times 3.15 = 23.8$ m ✓

c) Calculate the velocity of the stone after 2.50 s of flight. You must give a magnitude and direction.

(5 marks)

$u = 9.60$ m s^{-1} $u_x = u \cos \theta = +7.5649$ m s^{-1} right

$u_y = u.\sin \theta = +5.91$ m s^{-1}

In the vertical

$u_y = u.\sin \theta = +5.91$

$v_y = u_y + at = 5.91 + (-9.8 \times 2.5)$ ✓

$v_y = -18.59$ ✓

$$v = \sqrt{{v_y}^2 + {v_x}^2}$$

$v = \sqrt{-18.59^2 + 7.5649^2} = 20.1\ m\ s^{-1}$ ✓

Angle of descent, $\theta = \tan^{-1}(18.59 / 7.5649)$ ✓

$\theta = 67.9^o$ ✓

d) Calculate the work done on the stone by the Earth's gravitational field in the motion from launch to reaching ground level.

(2 marks)

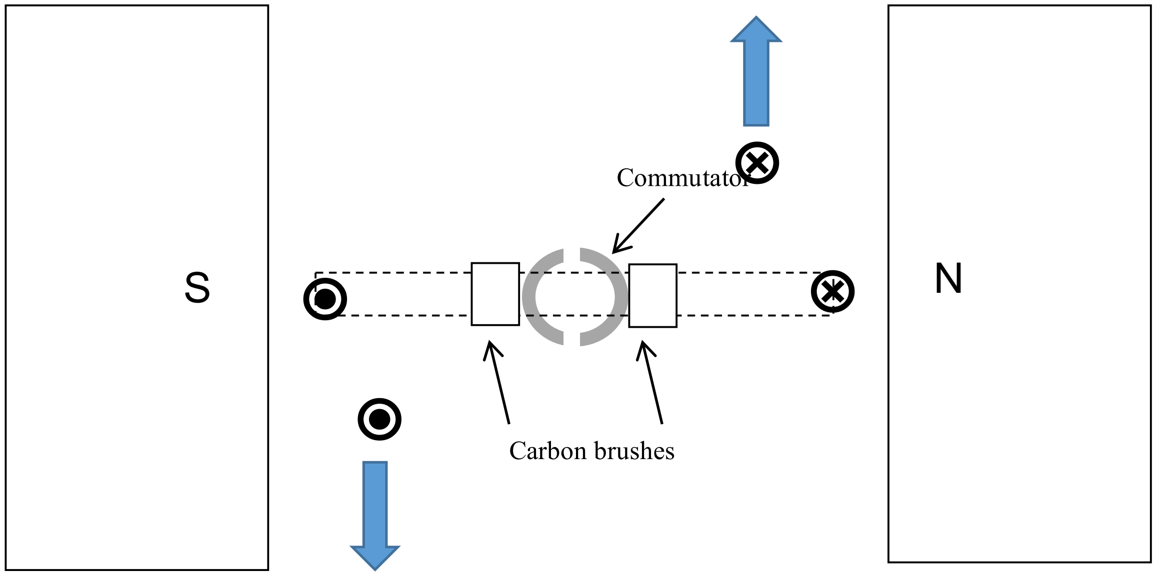
$W = m.g.\Delta h$

$W = 0.520 \times 9.8 \times 30$ ✓

$W = 153$ J ✓

Question 14 **(13 marks)**

The diagram shows the side view of a DC electric motor. A square coil is placed flat in the uniform magnetic field between the North and South magnetic poles. Current direction in the coil is shown on the sides adjacent to the magnetic poles. The commutator and carbon brushes are also shown.



a) Which direction will the coil turn from this start position?

(1 mark)

Anti-clockwise or otherwise correctly indicated ✓

b) Explain the function of the brushes and the function of the commutator.

(3 marks)

Transfer current from external source of emf ✓ into the coil and ensure switching such that the coil next to each magnetic pole experiences a force in a uniform direction. ✓
This ensures a constant direction of torque and rotation. ✓

c) On the diagram above, use the symbols ⦿ and ⊗ to sketch the location of the coil sides adjacent to the magnetic poles after 30° of rotation from this start position. Put arrows on your symbols to indicate the direction of magnetic force acting on them.

(2 marks)

As above, approx 30° ✓ Force arrows correct ✓

d) At this new position after 30º of rotation from the start position; determine the torque value of the motor as a percentage of maximum torque.

(2 marks)

Angle between lever arm and force = (90 – 30 = 60º) ✓
Torque = r.F.sin θ
Sin 60 = 0.866 therefore torque = 86.6% of maximum ✓

e) A single 120 mm length of wire, adjacent to one of the magnetic poles, experiences a 0.0280 N magnitude of force when a current of 5.30 A is present. Calculate the magnetic flux density between the poles.

(2 marks)

$F = I \ell B$

0.028 = 5.30 x 0.12 X B
B = 4.40 x 10^{-2} T or Wbm^{-2}

f) After the motor is switched on its rate of rotation increases. As this happens the net current in the coil decreases. Clearly explain why this happens.

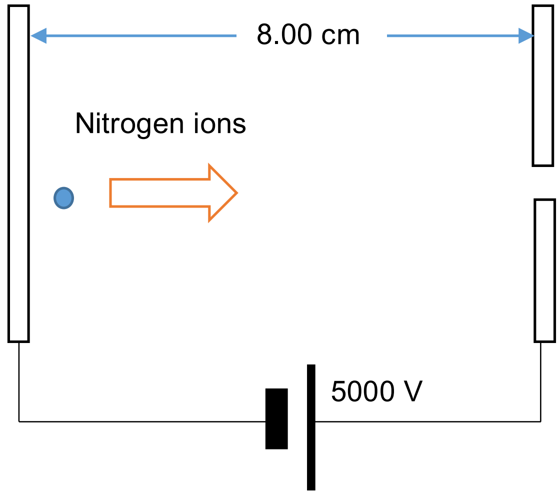
(3 marks)

The charge in the coil is now cutting through magnetic flux such that an emf is produced according to Faraday's Law. (or Lenz's Law explanation – as flux within coil changes an emf is induced whose current establishes a magnetic field to oppose the change) ✓

This induced emf opposes the external emf supplying the motor so the net emf is reduced. ✓
A reduction in emf means a reduction in current ✓

Question 15 **(14 marks)**

Nitrogen-14 ions (**N^{3-}**) of mass 2.33 x 10^{-26} kg and triple negative charge are accelerated from rest in a potential difference established between 2 charged parallel plates. The parallel plates have a potential difference of 5000 V across a gap of 8.00 cm. You can ignore the effects of gravity and air resistance in this question.



a) Calculate the electric field strength between the parallel plates.

(2 marks)

E = V / d
E = 5000 / 0.08 ✓
E = 62 500 V m^{-1} (or N C^{-1}) ✓

b) Calculate the magnitude of the electric force that acts on the Nitrogen ions in this electric field.

(2 marks)

E = F / q
F = E x q = 62 500 x 3 x 1.60 x 10^{-19} ✓
F = 3.00 x 10^{-14} N ✓

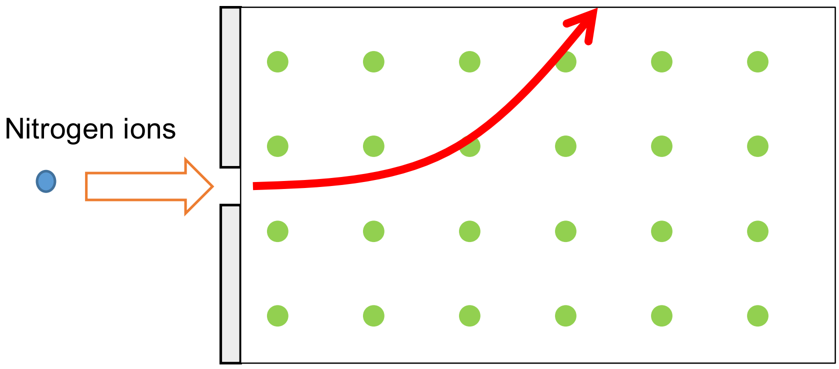
c) Calculate the maximum speed reached by the Nitrogen ions as they move between the parallel plates.

(3 marks)

q= -4.80 × 10^{-19} C v = ?
mass of Nitrogen ion = 2.33 × 10^{-26} kg
W_d = V.q Work done = ΔKE = final KE – initial KE (initial = 0)
$\frac{1}{2}$ m v^2 = V.q
($\frac{1}{2}$ 2.33 × 10^{-26} x v^2) ✓= 5000 x 4.80 × 10^{-19} ✓
v = 453 881 = 4.54 × 10^5 m s^{-1} ✓

Or $a = \frac{F}{m}$ Followed by $v^2 = u^2 + 2as$

The nitrogen ions are fed into a uniform magnetic field within a mass spectrometer. The ions enter at a speed of 4.54×10^5 m s^{-1}. The magnetic field has a uniform flux density of 123 mT. The set up and the direction of the magnetic field is shown in the diagram below.



Vacuum chamber of mass spectrometer – magnetic field indicated

d) Draw an arrow on the diagram to show the general direction that the nitrogen ions will follow.

(1 marks)

As above (curving upwards) ✓

e) Calculate the radius of the path taken by the nitrogen ions in the mass spectrometer.

(3 marks)

B = 0.123 T ✓

$$r = \frac{mv}{qB}$$

$$r = \frac{2.33 \times 10^{-26} \times 4.54 \times 10^{5}}{4.80 \times 10^{-19} \times 0.123} \checkmark$$

$$r = 0.179\ m \checkmark$$

f) Explain what is causing the nitrogen ions to go into circular motion. You must refer to physics principles and equations in the formulae and data booklet.

(3 marks)

Any charged mass moving through a magnetic field experiences a magnetic force given by
F = q.v.B ✓ (where v is the component of velocity perpendicular to the magnetic field)
The force is perpendicular to the motion ✓ so in the absence of other forces it acts as a centripetal force putting the charge into circular motion. ✓ Or similar.

Question 16 **(13 marks)**

A spacecraft of rest mass 90.0 tonnes is moving away from the Earth at a constant speed.

a) The crew of the spacecraft determine that it takes them 1.10 years to reach the star Alpha Centauri. Observers on Earth state that it took the spacecraft 4.50 years to complete the journey. Determine the speed of the spacecraft in the reference frame of Earth.

(3 marks)

v = ? rest time t_0 = 1.10 yrs t = 4.50 yrs

$$t = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}} \qquad 4.50 = \frac{1.10}{\sqrt{1-\frac{v^2}{c^2}}} \checkmark \qquad \sqrt{1-\frac{v^2}{c^2}} = \frac{1.10}{4.50}$$

$$1-\frac{v^2}{c^2} = \frac{1.10^2}{4.50^2} \qquad 1-\frac{1.10^2}{4.50^2} = \frac{v^2}{c^2} \qquad 0.9402469136\, c^2 = v^2 \checkmark$$

$$v = 0.970c \quad or\ 2.91 \times 10^8\ m\ s^{-1} \checkmark$$

b) The crew of the spacecraft argue that time recorded on their clocks was correct but they could reach Alpha Centauri in a time of 1.10 years for a different reason. How is the journey time explained in the reference frame of the spacecraft? Explain with reference to physics principles, no calculation is required.

(2 marks)

In the reference frame of the spacecraft, the dimension of space in the direction of Alpha Centauri is moving past the spacecraft ✓
According to Einstein's Special Relativity this length contracts at relativistic speeds✓

c) As the spacecraft goes past Alpha Centauri it changes its speed to a new constant value of 0.77c in the reference frame of Alpha Centauri. Calculate the relativistic momentum of the spacecraft at this speed.

(3 marks)

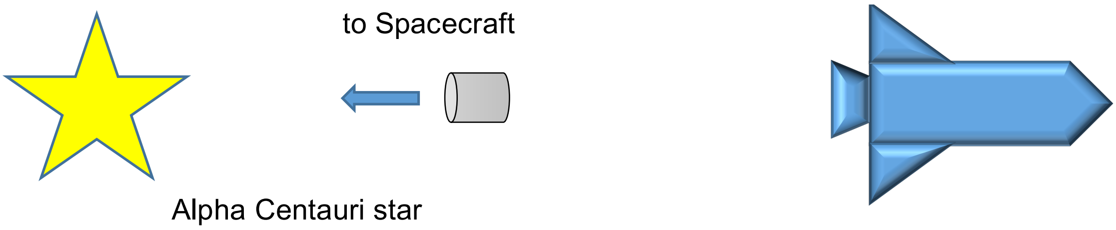
v = 0.77 x 3 x 10^8 m s^{-1} m = 90 000 kg identifies variables correctly ✓

$$p_v = \frac{m.v}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$p_v = \frac{90000 \times 0.77 \times 3 \times 10^8}{\sqrt{1-\frac{(0.77c)^2}{c^2}}} \checkmark$$

$$p_v = 3.26 \times 10^{13}\ kg\ m\ s^{-1} \checkmark$$

As the spacecraft is moving away from Alpha Centauri at a speed of 0.77c it fires a mail canister back towards Alpha Centauri. The canister moves at a speed of 0.58c relative to the spacecraft.



d) Determine the speed and direction of the canister in the frame of reference of Alpha Centauri. (3 marks)

v = +0.77c u' = -0.58c u = ? positive = away from Alpha Centauri

$$u = \frac{v + u'}{1 + \frac{vu}{c^2}}$$

$$u = \frac{0.77c - 0.58c}{1 + \frac{0.77c \times -.58c}{c^2}} \checkmark$$

$u = \frac{0.19c}{0.5534} = 0.343c$ ✓ *away from Alpha Centauri* ✓ (1.03×10^8 ms^{-1})

e) As the mail canister moves back towards Alpha Centauri it directs a laser beam towards the star. What is the speed of the laser beam in the reference frame of Alpha Centauri? Explain briefly

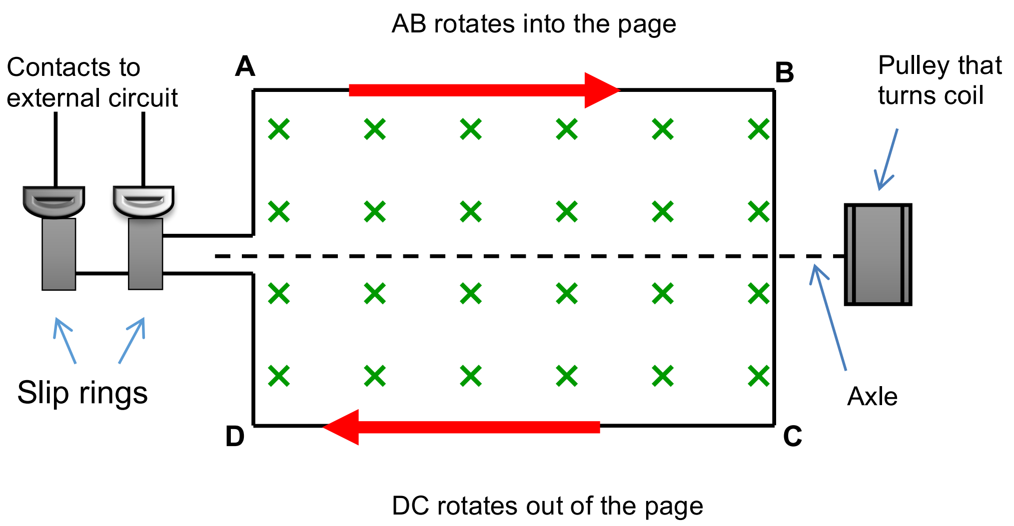
(2 marks)

3×10^8 m/s. ✓
According to Einstein's Special Relativity the speed of all emr in a vacuum is fixed.✓

Question 17 **(14 marks)**

The diagram shows the coil ABCD of an AC generator placed between magnetic poles.

- The uniform magnetic field of flux density 0.204 T is indicated.
- The dimensions of the coil are: AB = DC = 16.0 cm and AD = BC = 10.0 cm
- The coil rotates about the axle as indicated as a torque is applied to the pulley.
- The coil has 350 turns of wire and is rotated at 750 rpm.



a) Calculate the flux contained within the coil ABCD at the instant shown.

(2 marks)

$\phi = B.A = 0.204 \times 0.16 \times 0.10$ ✓
$\phi = 3.26 \times 10^{-3}\ Wb$ ✓

b) Draw on the diagram the direction of induced current along AB and DC as the coil rotates from the position shown and explain briefly how you arrived at your answer.

(2 marks)

As above (A to B, C to D) ✓
Charge in wire AB, moving down through field into page, by RH palm rule force on charge is right✓
OR By Lenz's Law a current moves right in AB to produce its own field to replace the loss. By RH grip rule.

c) To get the coil to turn a torque is applied on the pulley. Explain why a counter-torque is also applied to the pulley as this happens.

(2 marks)

The induced current is moving through the magnetic field and it experiences a force given by F = IlB (up on AB, down on DC) ✓
By RH Palm rule this acts to produce a torque on the coil that opposes the torque required for generation.✓
Or - The induced current produces a magnetic field that opposes the original change in flux (Lenz's law). The two fields interact to produce a force that resists the coil's motion.

d) Calculate the magnitude of the maximum emf from the AC generator.

(3 marks)

N = 350 f = 750/60 = 12.5 Hz

B = 0.204 T A = 0.16 x 0.10 = 0.0160 m² ✓

$V_{max} = NAB2\pi f$

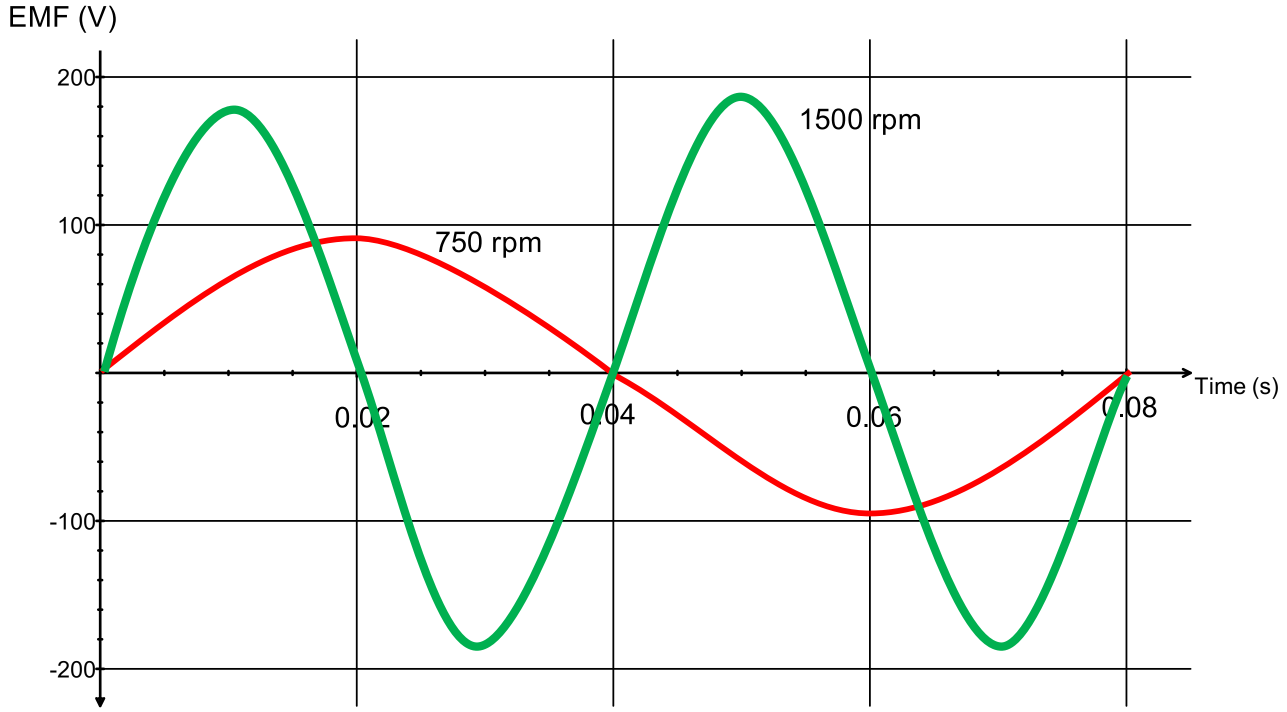
$V_{max} = 350 \times 0.0160 \times 0.204 \times 2\pi \times 12.5$ ✓

$V_{max} = 89.7$ V ✓

e) On the axes shown below, sketch the shape of the emf output for this generator as it rotates one full turn from the initial position shown. Add a suitable numerical time scale on the time axis and label your curve '750 rpm'.

(3)

Sine wave peak 90 V ✓ *starts as zero at zero time* ✓ T = 0.08 s ✓



f) Sketch a second shape of the emf output for a rate of rotation of 1500 rpm and label this curve '1500 rpm'.

(2)

Sine wave peak 180 V ✓ T = 0.04 s ✓

Question 18 **(16 marks)**

A photoelectric effect experiment was performed in which a monochromatic light beam was shone onto a clean metal surface. The wavelength of the incident beam was varied and the maximum kinetic energy of the emitted photoelectrons was recorded in the table below.

Wavelength (nm)	Light Frequency (Hz)	KE (max) photoelectrons (eV)	KE (max) (J)
750	4.00×10^{14}	0.22	3.52×10^{-20}
587	**5.11×10^{14}**	0.67	**1.07×10^{-19}**
506	**5.93×10^{14}**	0.98	**1.57×10^{-19}**
444	**6.76×10^{14}**	1.35	**2.16×10^{-19}**
400	7.50×10^{14}	1.63	2.61×10^{-19}

The equation that governs this relationship is:

$$E = hf + W$$

E = maximum kinetic energy of photoelectrons (J)
W = the work function of the metal (J)
f = the frequency of the incident light beam (Hz)
h = Planck's constant

a) Complete the second column in the table for light frequency (Hz). Two values have been done for you.

(1 mark)

b) Complete the fourth column for the maximum kinetic energy of photoelectrons (joules). Two values have been done for you.

(1 mark)

c) Plot the data from the table onto the graph paper. Photon frequency (Hz) should be plotted on the x-axis. Maximum kinetic energy of photoelectrons should be plotted on the y-axis. You must allow a range of -3.0×10^{-19} J to $+3.0 \times 10^{-19}$ J on the y-axis so that you can determine the y-intercept value. Draw the line of best fit.

(4 marks)

Axes labels ✓	Axes units ✓	Axes Scaling ✓	Accurate plotting ✓

d) Use the gradient of the graph to determine an experimental value of Planck's constant.

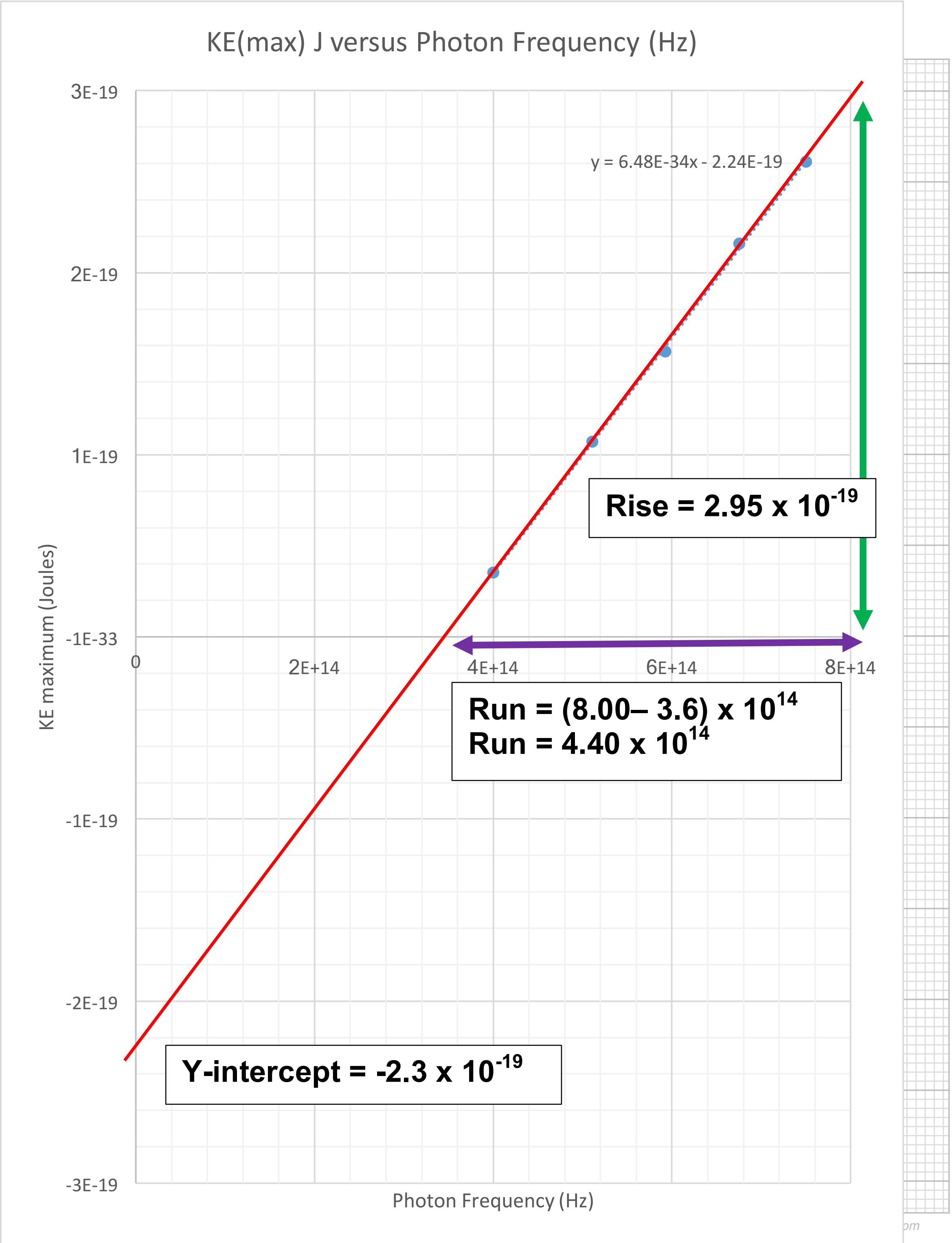
(3 marks)

Clearly show rise and run construction lines on the graph✓

Example: gradient = $2.95 \times 10^{-19} / 4.40 \times 10^{14}$ ✓

Gradient = 6.7×10^{-34} ✓ (Planck's constant by experiment)

Questions continued after the graph paper.



Spare graph paper is included at the end of this question. If you want to use it, cross out this attempt.

e) Determine the value of the work function of this metal from the graph and express you answer in electron volts.

(2 marks)

Clearly shows intercept on the graph = -2.3×10^{-19} J ✓

Work function (eV) = $2.3 \times 10^{-19} / 1.60 \times 10^{-19} = 1.4$ eV ✓

f) Explain why light of wavelength 900 nm would not cause photoelectrons to be emitted from the surface of the metal.

(3 marks)

The photon energy must equal or exceed the work function ✓

$E = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3\times10^{8}}{900\times10^{-9}}$ ✓ (can allow calculated value of h)

E = 2.21×10^{-19} J which is less than the work function ✓

OR

$f = \frac{c}{\lambda} = \frac{3.00\times10^{8}}{900\times10^{-9}} = 3.33\times10^{14}\ Hz$

Threshold freq, from the graph x intercept is $3.5\times10^{14}\ Hz$

As the photon frequency is below the threshold frequency of this metal, the photon will not have enough energy to overcome the work function

g) Does this experiment indicate that light is behaving as a particle or a wave? Explain your response with reference to physics principles.

(2 marks)

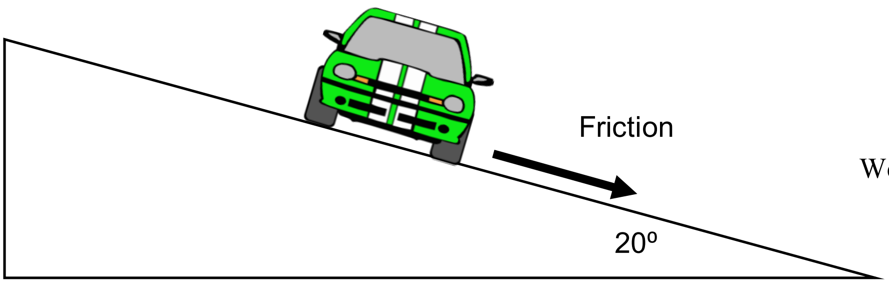
Light behaving as a particle – photon quanta of energy ✓

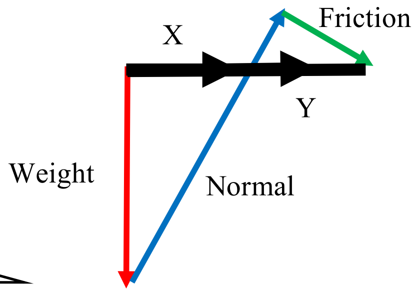
Only photons above a certain threshold energy can ionise photoelectrons regardless of intensity ✓ Or similar.

Additional graph paper if required.

Question 19 **(7 marks)**

A car of mass 2200 kg is in horizontal circular motion on a banked track. The car has a speed of 14.0 m s^{-1} and is relying on friction to stay at a fixed height on the banked track. The radius of the circle is 32.0 m. The track is banked at an angle of 20.0^0 to the horizontal. Friction acts from the track onto the car parallel to the track as shown.





a) Construct a vector diagram to the right of the diagram above. Show the forces acting on the car and the net force.

(2)

Head to tail to show sum of forces acting to centre. ✓
Friction parallel to slope ✓

b) Calculate the magnitude of friction acting on the car from the banked track.

(5)

r = 32 m   W = mg = 2200 × 9.8 = 21560 N

v = 14 m s^{-1} $\frac{mv^2}{r} = X + Y$ ✓

$$\Sigma F = \frac{mv^2}{r} = \frac{2200 \times 14^2}{32} = 13475\ N$$ ✓

$$X = mg \times \tan 20 = 2200 \times 9.8 \times \tan 20$$
$$X = 7847.198$$ ✓

$$Y = \frac{mv^2}{r} - X = 13475 - 7847.198$$
$$Y = 5627.8$$ ✓

$$\text{Friction} = Y \times \cos 20 = 5627.8 \times \cos 20$$
Friction = 5288.4 = 5.29×10^3 N ✓

End of Section 2

Section Three: Comprehension 20% (36 Marks)

This section contains **two (2)** questions. You must answer both questions. Write your answers in the space provided. Suggested working time for this section is 40 minutes.

Question 20 Hadrons and conservation laws of particle physics (18 marks)

You have probably heard of the particle accelerator operated by CERN in Switzerland, the Large Hadron Collider or LHC**.** The LHC is the largest and most powerful particle collider in the world, the most complex experimental facility ever built, and the largest single machine in the world. It consists of a 27-kilometre ring of superconducting magnets with several accelerating structures to boost the energy of the particles along the way. It has been built to study the interactions of sub-atomic particles.

Inside the LHC, two high-energy particle beams travel at close to light speed before they are made to collide. The beams travel in opposite directions in separate beam pipes – two tubes kept at ultrahigh vacuum. They are guided around the accelerator ring by a strong magnetic field maintained by superconducting electromagnets. The electromagnets are built from coils of special electric cable that operate in a superconducting state, they conduct electricity efficiently with no resistance or energy loss. This requires the magnets to be cooled to a temperature close to absolute zero. Much of the accelerator is connected to a distribution system of liquid helium, which cools the magnets.

Hadrons are subatomic particles that are made from quarks. There are two types of hadrons.

Baryons – are made from 3 quarks. The only stable baryon is the proton. All other baryons in isolation decay into protons. Even the neutron is unstable outside the nucleus and decays with a half-life of 11 minutes.

$$^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e + \bar{v}_e$$

Mesons - are made from 2 quarks – a quark and an anti-quark. There are no stable mesons, they rapidly decay into leptons or photons. Pions and kaons are mesons that last just long enough to leave tracks in a bubble chamber.

Quark properties of charge and baryon number are detailed in the tables at the end of this article. In any particle interaction, total charge is always conserved.

Baryon number must also be conserved in particle interactions. All anti-quarks have the opposite charge and baryon number of their standard matter counterparts.

Lepton number must also be conserved in particle interactions. Anti-leptons have a lepton number of -1. There are 3 ‘generations’ of lepton – electron, muon and tau. When leptons are formed from non-leptons they always appear in pairs – a lepton and an anti-lepton of the same generation. E.g.

$$\pi^+ \rightarrow \mu^+ + v_\mu$$

Strangeness – hadrons that contain strange quarks are called ‘strange’ particles. They can exist for an unusually long time, which to early particle physicists was very ‘strange’. Strangeness number can vary from +3 to -3 according to the number of strange or anti-strange quarks it contains. If an interaction involves the strong nuclear force, then strangeness is conserved but in weak interactions strangeness can be changed by ±1 or conserved.

Quarks and Leptons are collectively known as Fermions and are the building blocks of all matter in the universe. These particles interact with each other by exchanging force particles known as **gauge bosons**. The exchange of gauge bosons governs attraction, repulsion, decay and the conversion between mass and energy. These processes are studied in machines such as the LHC.

Tables of some particles are shown below

Lepton	Charge (q_e)	Lepton number	Baryon Number
Electron (e^-)	-1	1	0
Electron-neutrino	0	1	0
Muon (μ^-)	-1	1	0
Muon-neutrino	0	1	0
Tau (τ^-)	-1	1	0
Tau-neutrino	0	1	0

Quark	Charge (q_e)	Baryon number
Up (u)	$+\frac{2}{3}$	$\frac{1}{3}$
Down (d)	$-\frac{1}{3}$	$\frac{1}{3}$
Top (t)	$+\frac{2}{3}$	$\frac{1}{3}$
Bottom (b)	$-\frac{1}{3}$	$\frac{1}{3}$
Charm (c)	$+\frac{2}{3}$	$\frac{1}{3}$
Strange (s)	$-\frac{1}{3}$	$\frac{1}{3}$

Hadron	Quarks	Mass (MeV/c^2)	Baryon Number	Lepton number
Proton	uud	938.3	+1	0
Neutron	udd	939.6	+1	0
Pion-plus (π^+)	$u\bar{d}$	139.6	0	0
Sigma-plus	uus	1189.4	+1	0
Charmed Omega	ssc	1672.0	+1	0

Questions

a) How are the magnets in the LHC able to operate at high electrical efficiency? Describe the method used and the effect this has on electrical properties.

(2)

Kept at temperatures close to absolute zero (by cooling with liquid helium). ✓
Resistance (and energy transformed out as heat) is zero. ✓

b) Explain whether neutrons could be accelerated by the LHC. You must refer to the accelerating principles of the LHC.

(2)

No as the neutrons have zero electrical charge they are not affected by magnetic fields ✓
Acceleration is achieved by applying a magnetic force from a magnetic field to accelerate the particles in circular motion ✓

c) Identify a meson from the tables of particles.

(1)

Pion-plus. ✓

d) Is it possible for an electron and a tau-neutrino to be produced from the decay of a pion-plus particle? Explain briefly.

(2)

No, the lepton pairs must be from the same generation ✓
Electron and Tau are different generations. ✓

e) In beta-positive decay a proton decays to a neutron, a positron and a third particle X.

$${}^{1}_{1}p \rightarrow {}^{1}_{0}n + {}^{0}_{+1}e + X$$

i. State the properties required of this third particle in terms of charge, baryon number and lepton number.

(3)

Charge = 0✓ Baryon number = 0 ✓ Lepton number = 1 (of same generation) ✓

ii. State what this third particle is.

(1)

Electron neutrino ✓

f) Determine the mass of the Sigma-plus hadron in kilograms using scientific notation to 3 significant figures.

(2)

m (kg) = $1189.4 \times 10^{6} \times 1.60 \times 10^{-19} / (3 \times 10^{8})^{2}$ ✓
m (kg) = 2.11×10^{-27} kg ✓

g) Determine the "strangeness" of the charmed-omega particle.

(1)

+2 ✓

h) Is 'strangeness' always conserved in particle interactions? Explain briefly.

(2)

No✓ in weak interactions strangeness can be changed by ±1 or conserved ✓

i) Identify one type of gauge boson and describe its role in particle interactions.

(2)

Photon✓ Mediates electrostatic repulsion/attraction ✓
Or any other acceptable response.

Question 21 Gravitational Waves Detected 100 Years After Einstein's Prediction (18 marks)

Excerpt from: News Release • February 11, 2016
https://www.ligo.caltech.edu/news/ligo20160211

For the first time, scientists have observed ripples in the fabric of spacetime called gravitational waves, arriving at the earth from a cataclysmic event in the distant universe. This confirms a major prediction of Albert Einstein's 1915 general theory of relativity and opens an unprecedented new window onto the cosmos.

Gravitational waves carry information about their dramatic origins and about the nature of gravity that cannot otherwise be obtained. Physicists have concluded that the detected gravitational waves were produced during the final fraction of a second of the merger of two black holes to produce a single, more massive spinning black hole. This collision of two black holes had been predicted but never observed.

The gravitational waves were detected on September 14, 2015 at 5:51 a.m. Eastern Daylight Time (09:51 UTC) by both of the twin Laser Interferometer Gravitational-wave Observatory (LIGO) detectors, located in Livingston, Louisiana, and Hanford, Washington, USA. The discovery, accepted for publication in the journal Physical Review Letters, was made by the LIGO Scientific Collaboration using data from the two LIGO detectors.

Based on the observed signals, LIGO scientists estimate that the black holes for this event were about 29 and 36 times the mass of the sun, and the event took place 1.3 billion years ago. About 3 times the mass of the sun was converted into gravitational waves in a fraction of a second—with a peak power output about 50 times that of the whole visible universe. By looking at the time of arrival of the signals—the detector in Livingston recorded the event 7 milliseconds before the detector in Hanford—scientists can say that the source was located in the Southern Hemisphere.

According to general relativity, a pair of black holes orbiting around each other lose energy through the emission of gravitational waves, causing them to gradually approach each other over billions of years, and then much more quickly in the final minutes. During the final fraction of a second, the two black holes collide into each other at nearly one-half the speed of light and form a single more massive black hole, converting a portion of the combined black holes' mass to energy, according to Einstein's formula $E=mc^2$. This energy is emitted as a final strong burst of gravitational waves. It is these gravitational waves that LIGO has observed.

At each observatory, the two-and-a-half-mile (4-km) long L-shaped LIGO interferometer uses laser light split into two beams that travel back and forth down the arms (four-foot diameter tubes kept under a near-perfect vacuum). The beams are used to monitor the distance between mirrors precisely positioned at the ends of the arms. According to Einstein's theory, the distance between the mirrors will change by an infinitesimal amount when a gravitational wave passes by the detector. A change in the lengths of the arms smaller than one-ten-thousandth the diameter of a proton (10^{-19} meter) can be detected.

Independent and widely separated observatories are necessary to determine the direction of the event causing the gravitational waves, and also to verify that the signals come from space and are not from some other local phenomenon.

Multiple interferometers are needed to confidently detect and locate the sources of gravitational waves (except continuous signals), since directional observations cannot be made with a single detector like LIGO, which is sensitive to large portions of the sky at once. Gravitational waves have a finite speed and are expected to travel at the speed of light. This will induce a detection delay (in this case 7 milliseconds) between the two LIGO detectors. Using this delay and the delay between LIGO and its international partners will help pinpoint the sky location of the gravitational wave source. Multiple detectors also help sort out candidate gravitational wave events that are caused by local sources, like trees falling in the woods or even a technician dropping a hammer on site. These events are clearly not gravitational waves but they might look like a gravitational wave in the collected data. If a candidate gravitational wave is observed at one detector but not the other within the light travel time between detectors, the candidate event is discarded.

Toward this end, the LIGO Laboratory is working to establish a third Advanced LIGO detector on the Indian subcontinent. Awaiting approval by the government of India, it could be operational early in the next decade. The additional detector will greatly improve the ability of the global detector network to localize gravitational-wave sources.

Questions

a) Calculate the approximate energy converted into gravitational waves.

(2 marks)

$m_S = 1.99 \times 10^{30}$ kg

$E = mc^2$

$E = 1.99 \times 10^{30} \times 3 \times (3 \times 10^8)^2$

$= 5.37 \times 10^{47}$ J

b) Explain why the black holes increased their approach speed as they came closer together.

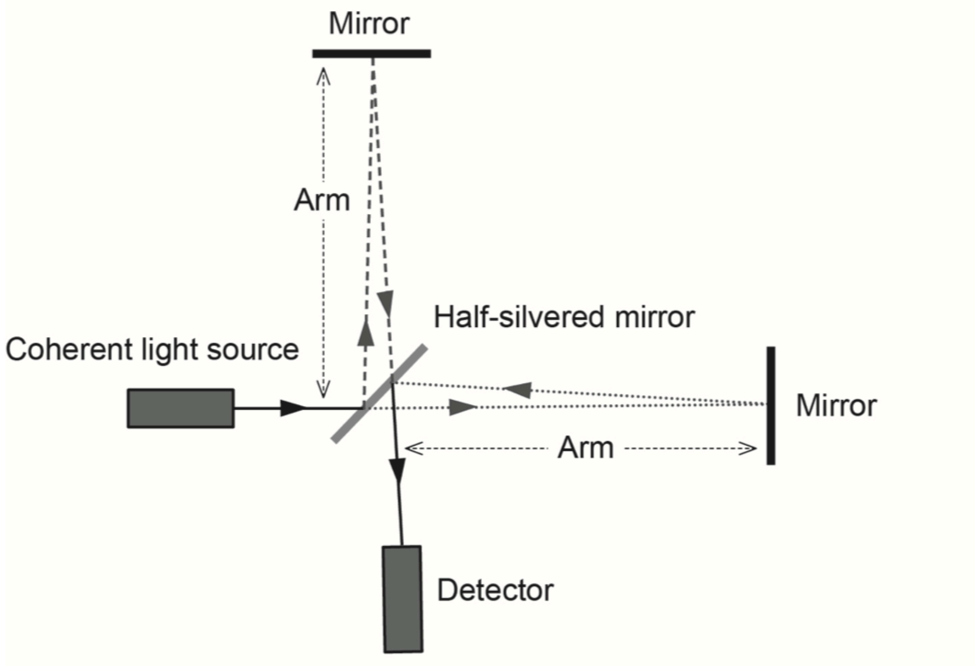
(3 marks)

According to $F = (Gm_1m_2)/r^2$

As radius (distance between objects) is decreased

Force of attraction increases dramatically

c) Below is a diagram of an interferometer. To detect a change in the interference pattern, a path difference (for light travel) between the two arms of the interferometer must occur.



Describe how the direction of the gravitational wave relative to the detector would affect its detection. (2 marks)

Gravitational wave travelling at the same angle to each arm, i.e. 45° between the two would mean no path difference. Whereas parallel to one and perpendicular to the other, results in max length difference.

d) Explain why independent and widely separated observatories are necessary to determine the direction of the event causing the gravitational waves.

(3 marks)

A single interferometer is exposed to large portions of the sky at once

Gravity waves are expected to travel at the speed of light

A detection delay allows scientists to determine direction

e) Using information from the article:

i) Calculate the distance between the two observatories.

(2 marks)

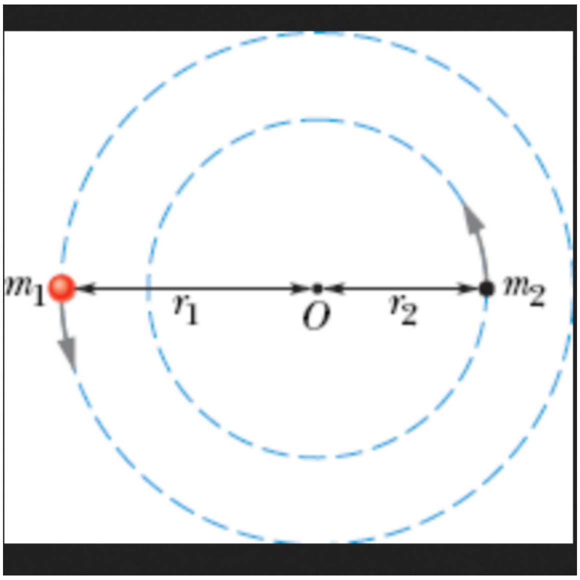
$v = c$
$t = 7 \times 10^{-3}$ s
$s = vt = 7 \times 10^{-3} \times 3 \times 10^{8}$
$= 2.10 \times 10^{6}$ m

ii) Which observatory was further North? How did you decide your answer?

(2 marks)

- Hanford
- Scientists determined the source was located in Southern Hemisphere and Livingston recorded event first.

f) Binary star systems orbit around a combined centre of mass. The diagram below shows the orbital pattern of a binary star system.



Assume, the centre-of-mass O has a mass equivalent 11 times the mass of the Sun. Calculate the orbital radius of m_1 given that its orbital period (T) is 20 minutes.

(4 marks)

T = 20 x 60 = 1200 s

$m = 11 \times 1.99 \times 10^{30}$ kg $= 2.19 \times 10^{31}$ kg 1

$T^2 = (4\pi^2 r^3)/GM$

$\therefore\ r^3 = (GMT^2)/4\pi^2$ 1

$r^3 = (6.67 \times 10^{11} \times 2.19 \times 10^{31} \times 1200^2)/(4\pi^2) = 5.33 \times 10^{25}$ 1

$r = \sqrt[3]{(5.33 \times 10^{25})} = 3.76 \times 10^8$ m 1