AUDENDO ATQUE AGENDO

Wesley College

PHYSICS
YEAR 12
Trial WACE
STAGE 3
2011

Name: Solution

Teacher: Perlmutter, Riess and Schmidt.

TIME ALLOWED FOR THIS PAPER

Reading time before commencing work: Ten minutes
Working time for the paper: Three hours

MATERIALS REQUIRED/RECOMMENDED FOR THIS PAPER

To be provided by the supervisor:

- This Question/Answer Booklet; Formula and Constants sheet

To be provided by the candidate:

- Standard items: pens, pencils, eraser or correction fluid, ruler, highlighter.
- Special items: Calculators satisfying the conditions set by the Curriculum Council for this subject.

IMPORTANT NOTE TO CANDIDATES

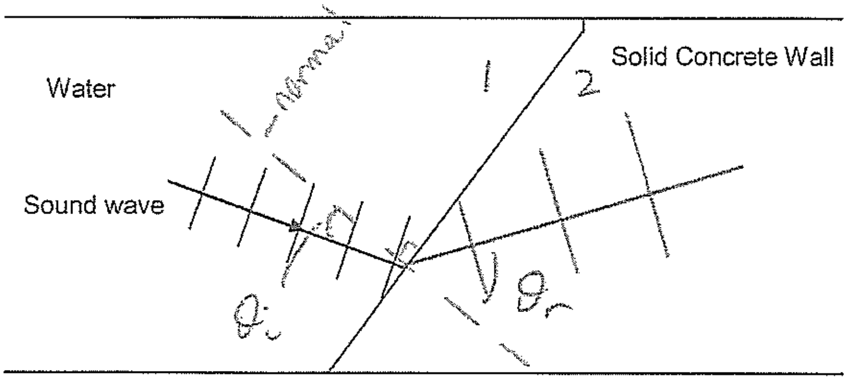
No other items may be taken into the examination room. It is **your** responsibility to ensure that you do not have any unauthorised notes or other items of a non-personal nature in the examination room. If you have any unauthorised material with you, hand it to the supervisor **before** reading any further.

Section One: Short response 30% (54 Marks)

This section has **13** questions. Answer **all** questions. Write your answers in the space provided. Suggested working time for this section is 50 minutes.

Question 1

A sound wave travels through water to meet a boundary with a solid concrete wall of a dam.



a) Draw a possible path of the sound wave as it refracts into the concrete. Indicate appropriate angles.

Shows refraction away from normal $\theta_r > \theta_i$ (1)

b) The wave fronts in the water are shown on the diagram. Indicate the general pattern of wave fronts when the sound wave travels in the solid concrete wall.

Larger spacing in concrete (1)

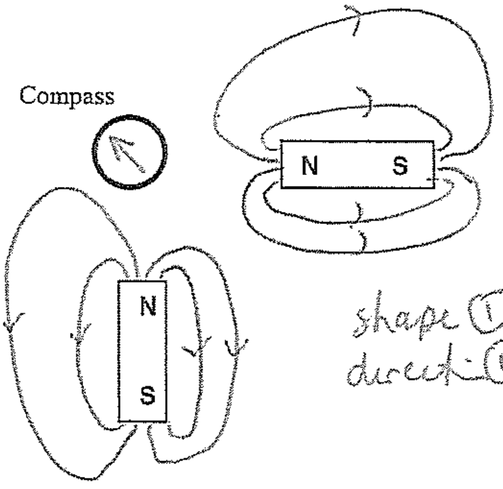
c) Is it possible for total internal reflection to occur at this boundary? Explain briefly. (1)

YES. TIR can occur when $V_2 > V_1$

Question 2

Two identical magnets are fixed in position on a flat bench. A compass is placed near the magnets.

a) Sketch the magnetic field in the region around the magnets. Draw at least 4 field lines for each magnet.



shape ① direct ① (2)

(−1) if field lines crossed over each other

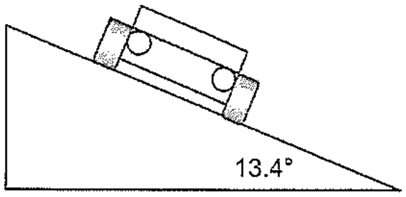
b) Indicate the direction that the compass needle will point by placing an arrow in the circle.

Vector addition of two fields at that point. (1)

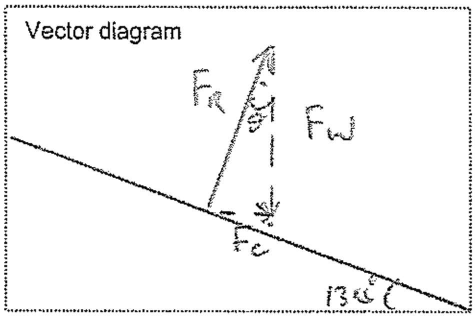
⑥

Question 3

By banking the curves of racetracks it is possible for vehicles to turn in a horizontal circle without relying on friction. For a car of mass 1 700 kg the angle of banking is set at 13.4° above the horizontal. The curve has a radius of 171 m and the car drives at a speed to maintain its height.



Vector diagram



a) Draw a vector diagram showing the forces acting on the car and the sum of those forces in the space indicated above.

(1)

b) Calculate the centripetal force acting on the car.

(3)

$F_w = 1.7 \times 10^3 \times 9.8$

$= 1.46 \times 10^4 N$ · ①

$\tan \theta = \frac{F_c}{F_w}$

$F_c = F_w \tan \theta$ ①

$= 1.67 \times 10^4 \times \tan 13.4°$

$= 3.97 \times 10^3 N$ towards centre ①

Question 4

a) What is a neutrino and explain why it has proven to be so elusive to find.

① Neutrino is a subatomic particle with no charge & tiny (if not zero) rest mass. (still being debated). ①

(2)

b) In recent weeks, at CERN, it has been confirmed that neutrinos have travelled faster than the speed of light. What impact will this discovery have on Physics?

Impact on relativity, disproving fundamental principle. that nothing can travel > c.

(2)

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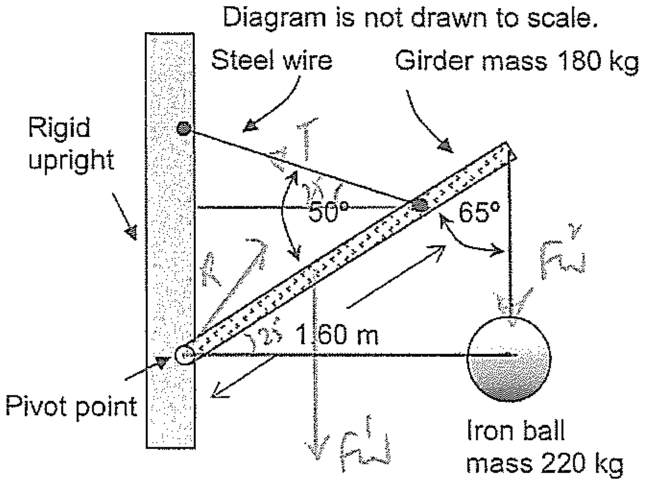
Question 5



An iron ball of mass 220 kg is suspended from the end of a rigid steel girder.

The girder has a mass of 180 kg and a length of 2.40 m.

The girder is pivoted to a rigid upright.

A steel wire is attached 1.60 m along the girder. It holds it in equilibrium with angles between components as shown in the diagram.

a. Identify all the forces acting on the girder by drawing them on the diagram. (1)

b. Demonstrate by calculation that the tension in the steel wire is 5.39 × 10^3 N. (3)

T.M at Pivot: ①
$\Sigma CM = \Sigma ACM$

$1.2 \times 180 \times 9.8 \times \sin 65 + 2.4 \times 220 \times 9.8 \times \sin 65 = 1.6 \times T \sin 50°$ ①

$T = 5.39 \times 10^3 N$ ①

Question 6

Refer to the diagram and description in **Question 5**. If the tension in the steel wire is 5.39 × 10^3 N calculate the magnitude and direction of the reaction force from the pivot acting on the steel girder. (4)

$\Sigma F_{up} = \Sigma F_{DN}$

$T_V + R_y = (180 + 220) \times 9.8$

$R_y = 400 \times 9.8 - T \sin 25$

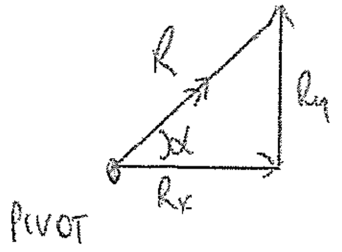
$= 1.64 \times 10^3 N$ ①

$\Sigma F_L = \Sigma F_R$

$T_H = R_x = T \cos \theta$

$= 5.39 \times 10^3 \times \cos 25°$

① $R_x = 4.89 \times 10^3 N$.



$R^2 = R_y^2 + R_x^2$

$= (1.64 \times 10^3)^2 + (4.89 \times 10^3)^2$

$R = 5.15 \times 10^3 N$ ①

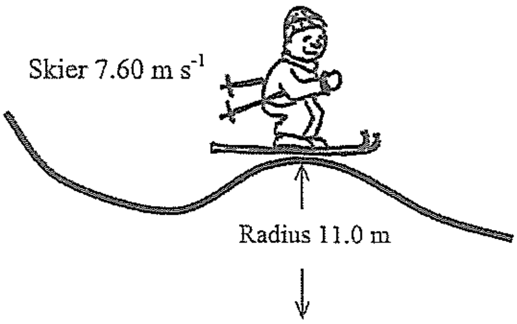
$\tan \alpha = \frac{1.64}{4.89}$

$\alpha = 18.5°$ ①

$\therefore R = 5.15 \times 10^3 N$ @ 18.5° above horizontal
@ 71.5° from vertical.

Question 7

A 70 kg skier is on a frictionless slope. He follows a circular path of radius 11.0 m as he goes over a mound and has a speed of 7.60 m s^{-1} at the top of the circle.



Calculate the normal reaction force he experiences from the mound at the top of the circle.

(4)

At top

$$T = \frac{mv^2}{r} - mg \quad ①$$

$$= \frac{70 \times 7.6^2}{11} - 70 \times 9.8$$

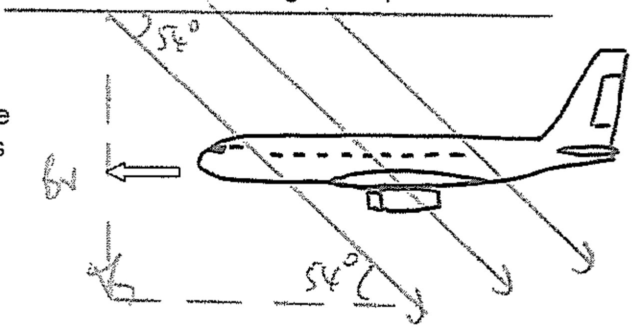
$$= -3.18 \times 10^2 N \quad ②$$

$$\therefore F_R = 318 N \text{ (up)} \quad ①$$

Question 8

A jet airliner is flying due South in the Northern geographical hemisphere where the Earth's magnetic field has a flux density of 5.20 × 10^{-5} T at an angle of dip of 54°

a) Sketch the alignment of the Earth's magnetic field lines relative to the jet airliner on the diagram, indicating any angles and direction.



angle ①
direct ①

(2)

b) Calculate the emf induced across the 60.0 metre wingspan if the jet has a speed of 140 m s^{-1}.

(3)

$$\mathcal{E} = BVl \quad ①$$

$$= 5.2 \times 10^{-5} \times \sin 54^\circ \times 140 \times 60 \quad ①$$

$$= 3.54 \times 10^{-1} V \quad ①$$

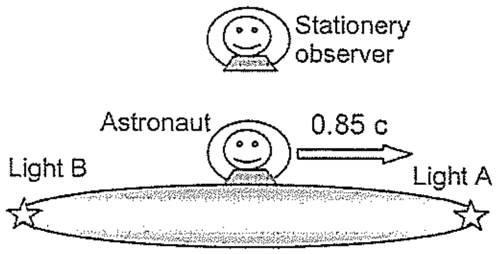
c) Circle the best response. There would be a build-up of electrons at the:

[✓ A. West wing tip] B. East wing tip C. Middle of the wings

(1)

Question 9

An astronaut flies past a stationary observer at a constant 85% of the speed of light. His spacecraft has light A at the front and light B at the rear.



a) Comment on the distance between Light A and Light B as perceived by the stationary observer.

(2)

Apponent distance $\overline{AB}$ would have decreased ① due to length contraction ①.

b) What effect has this had on the other dimensions of the spacecraft? Explain.

NONE ① L.C only occurs in the direction of motion ①

(2)

c) The astronaut and the observer have synchronised watches prior to the astronaut travelling at close to the speed of light past the observer. If the observer's watch reads 33.0 seconds, then compare;

(i). The astronaut's watch as seen by the observer.

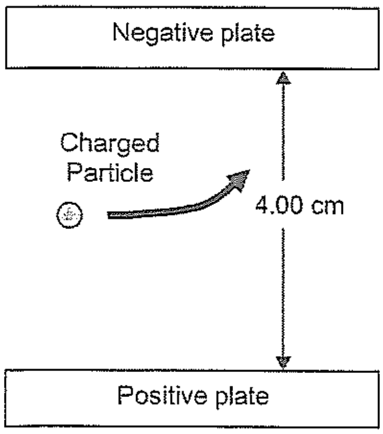
less than 33 seconds ①

(ii). The astronaut's watch as seen by the astronaut.

= 33 seconds. ①

(2)

Question 10



A charged particle enters a region between 2 parallel charged plates. The plates are separated by 4.00 cm. The electric field strength in the region between the charged plates is 8.75 × 10^4 V m^{-1}.

a. Calculate the potential difference between the plates. (2)

$d = 4 \times 10^{-2}$ m

~~V~~ $E = 8.75 \times 10^4$ Vm^{-1}

$E = \frac{V}{d}$ } ①

$V = Ed$

$= 8.75 \times 10^4 \times 4 \times 10^{-2}$

$V = 3.5 \times 10^3$ V. ①

b. The charged particle experiences a force of magnitude 2.80 ×10^{-14} N that causes it to deflect towards the negative plate. Determine the magnitude and nature of the charge of the particle. (3)

$F = 2.8 \times 10^{-14}$ N

$E = \frac{F}{q}$ } ①

$q = F/E$

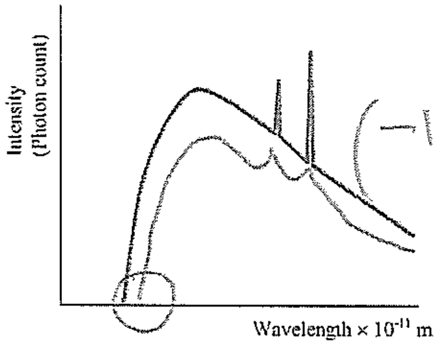
$= 2.8 \times 10^{-14} / 8.75 \times 10^4$

$= +3.2 \times 10^{-19}$ C (positive) ①

①

Question 11

The graph shows the X-ray spectrum from a target metal bombarded by electrons with a supply voltage of 33.0 kV



(−1 any error)

a) Explain why the spectrum has two distinct spikes? (3)

① They represent photon emission from inner shells due to ① electrons being removed. Hence electrons drop from higher shells to ① fill the holes.

b) Sketch on the graph, the general shape of the X-ray spectrum if the supply voltage is decreased to 31.0 kV. (2)

1. longer min λ
2. whole curve lower intensity
3. same spikes.

Question 12

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

Hadron	Quarks
Kaon-minus	$s\bar{u}$
Pi-plus (π^+)	$u\bar{d}$
Sigma-plus	uus
Lambda-zero	uds
Charmed Omega	ssc

(RIGHT/ WRONG)

a) Determine the charge (coulombs) of the Lambda-zero: $\left(+\frac{2}{3}\right)+\left(-\frac{1}{3}\right)+\left(-\frac{1}{3}\right) = 0\,C$ (1)

b) Determine the charge (coulombs) of the Kaon-minus: $\left(-\frac{1}{3}\right)+\left(-\frac{2}{3}\right) = -1 = -1.6\times10^{-19}\,C$ (1)

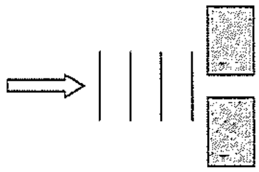
c) State the quark makeup for the proton. uuD (1)

d) State the quark makeup for the neutron. UDD. (1)

Question 13

A source of sound waves can be directed through air at 25°C towards an 8.65 cm gap between two wooden blocks. The wave source can emit either

A. Sound waves at a frequency of 5.0 kHz, or
B. Sound waves at a frequency of 500 Hz



Explain briefly which wave will diffract more and why. (2)

$\lambda_A = \frac{346}{5000} = 6.92\,cm$

$\lambda_B = \frac{346}{500} = 69.2\,cm$

Diffraction more pronounced when $\lambda > d$ ①

Hence B. ①

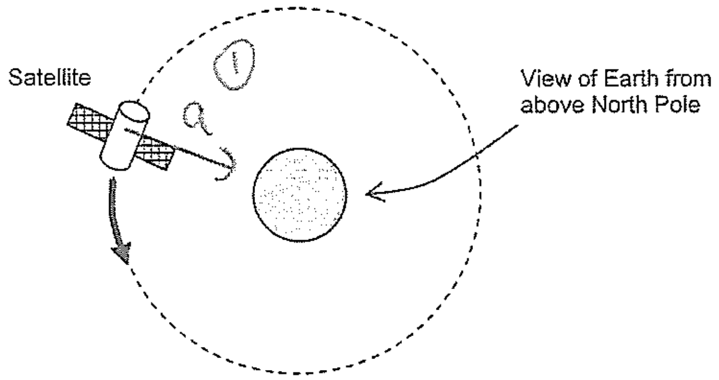
End of Section One

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

This section has **eight (8)** questions. You must answer **all** questions. Write your answers in the space provided. Suggested working time for this section is 90 minutes.

Question 14 (13 marks)

A satellite is in orbit around the equator of the Earth. It has a mass of 1495 kg and is at an altitude of 1.91 × 10^4 km above the Earth's surface.



a) Calculate the **period** of this satellite and state your answer in hours. (4)

$M_s = 1.495 \times 10^3$ kg.

$h = 1.91 \times 10^7$ m

$\therefore r_0 = 1.91 \times 10^7 + 6.37 \times 10^6$

$= 2.55 \times 10^7$ m. ①

$$F_c = F_g$$

$$\frac{\cancel{m_s} v^2}{\cancel{r_0}} = \frac{G \cancel{m_s} M_E}{r_0^{\cancel{2}}} \qquad \left(v = \frac{2\pi r}{T}\right)$$

$$\frac{4\pi^2 r_0^2}{T^2} = \frac{G M_E}{r_0}$$

$$T^2 = \frac{4\pi^2 r_0^3}{G M_E} \quad ①$$

$$T = 4.05 \times 10^4 \text{ s} \quad ①$$

$$= 675 \text{ mins}$$

$$= 11.2 \text{ hrs}. \quad ①$$

b) Explain whether or not a satellite can be geostationary at this altitude. (2)

No ① For a specific altitude there is only one possible Period. ①

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c) Place **labelled** arrow(s) on the diagram to show the direction of the **net acceleration** of the satellite.

(1)

d) Give two examples of the uses of artificial satellites in everyday life.

(2)

communicatn Any thig sensible .

GPS . etc .

The Earth is a natural satellite that orbits the Sun. (Assume a circular orbit for this question)

e) Calculate the orbital speed of the Earth as it goes around the Sun.

(3)

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

$r = 1.50 \times 10^{11}$ m

$$\left.\begin{aligned} F_c &= F_g \\ \frac{\cancel{m_E} v^2}{\cancel{r_o}} &= \frac{G M_S \cancel{M_E}}{r_o^{\cancel{2}}} \end{aligned}\right\} ①$$

$$V = \sqrt{\frac{G M_S}{r_o}}$$

$$\underline{V = 2.97 \times 10^4 \text{ ms}^{-1}} \ ②$$

Alternatively

$$V = \frac{2\pi r}{T}.$$

f) If the Sun was 90% of its current mass, describe how the orbital speed of the Earth would be affected if it remained at the same distance from Sun. *(A calculation is not required)*

(1)

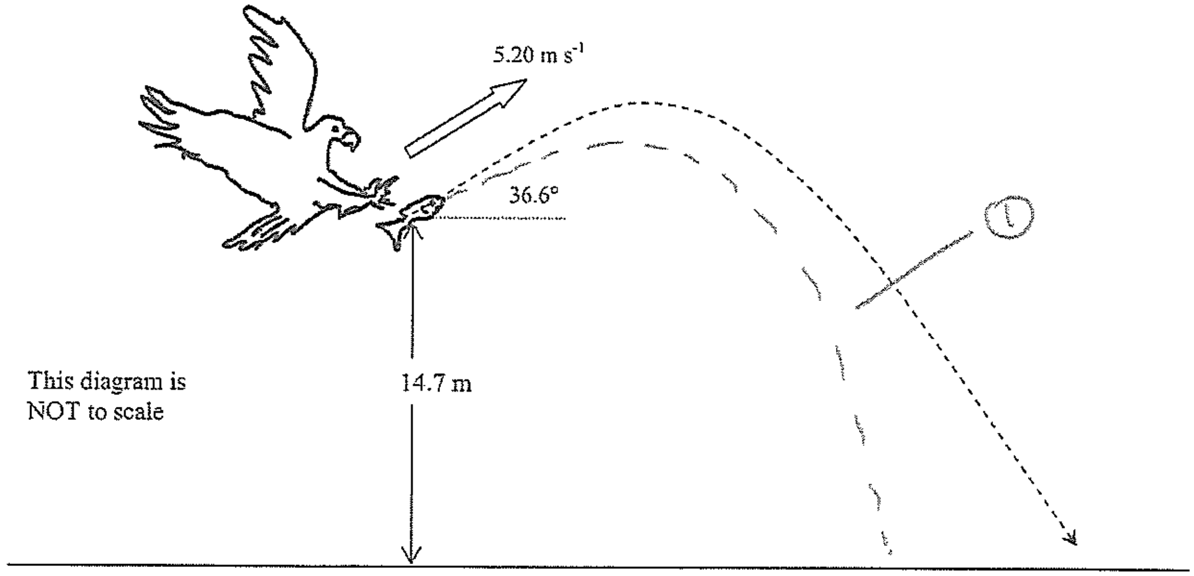
Given $V^2 \propto M_S$

then if M_S decreases ①

then so will $\underline{\underline{V}}$

Question 15 (13 marks)

An eagle has captured a fish and is 14.7 m directly above the water when it releases the fish. The eagle is moving with a velocity of 5.20 m s^{-1} at an angle of 36.6° above the horizontal when the fish is released. Ignore air resistance for calculations.

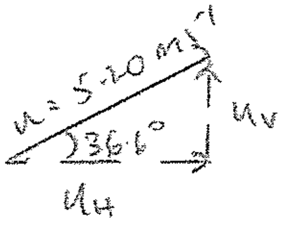


a) Calculate the time taken for the fish to reach the water. (4)

↓ +VE.

$s = +14.7 m$

$g = +9.8 ms^{-2}$



$u_V = u \sin 36.6$

$= 3.10 ms^{-1}$ (up) ①

$u_H = u \cos 36.6$

$= 4.17 ms^{-1}$

mark in part b

$v^2 = u^2 + 2gs$

$v^2 = (-3.1)^2 + 2 \times 9.8 \times 14.7$

$v = 17.3 ms^{-1}$ (down) ①

$\therefore \quad v = u + gt$

$t = \frac{v - u}{g}$

$t = 2.08 s$ ②

Alternatively

$s = ut + \frac{1}{2}gt^2$

b) Calculate the horizontal distance that the fish travels during its flight back to the water. (3)

$u_H = 4.17 ms^{-1}$ ①

$t = 2.08s$

$s = ?$

$u_H = \frac{s}{t}$

$s = u_H \times t$

$= 4.17 \times 2.08$

$\approx \underline{8.67 m}$ horizontally. ②

c) Calculate the maximum height above the water that the fish reaches during its flight. (3)

$u_V = -3.1 ms^{-1}$

$v = 0$

$g = +9.8 ms^{-2}$

$s = ?$

$$\left.\begin{aligned} v^2 &= u^2 + 2gs \\ s &= \frac{v^2 - u^2}{2g} \end{aligned}\right\} ①$$

$= \frac{0^2 - (-3.1)^2}{2 \times 9.8}$

$= \underline{0.49 m}$ from release ①

$\therefore H_{MAX} = 14.7 + 0.49$

$= \underline{15.2 m}$ above water ①

If air resistance is taken into account then the flight path is altered.

d) Sketch the altered flight path onto the diagram. (1)

e) Will the time of flight be longer or shorter when air resistance is taken into account? Discuss the factors that affect this. (2)

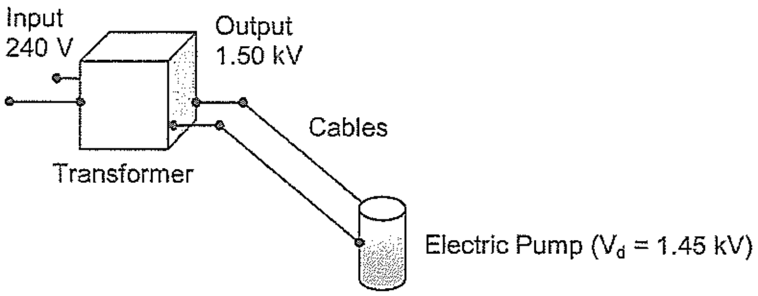
AR will act against fish on BOTH ascent & descent. MAX height will decrease, as will range.

No certain answer.

Logical discussion required. } ②

Question 16 (12 marks)

A mining company use an electric pump with an operating voltage in the range 1.25 kV-1.50 kV. There is only a 240 V supply available. A transformer is used to step up the output voltage to 1.50 kV. The secondary winding of the transformer has 2000 turns of wire.



a) Calculate the number of turns required on the primary winding of the transformer. (2)

$V_p = 240V$

$V_s = 1500V$

$N_s = 2000$

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

$$N_p = \frac{N_s V_p}{V_s} = \frac{20\cancel{00} \times 240}{15\cancel{00}} \quad ①$$

$$\underline{N_p = 320 \text{ turns}.} \quad ①$$

The transformer has an electrical power output of 6.45 kW. The underground pump is connected by 1.10 km of cables to the surface. The potential difference across the pump is 1.45 kV.

b) Calculate the total resistance of the cables. (4)

$P_{out} = 6.45 \times 10^3 W$

$V_{out} = 1.5 \times 10^3 V$

$$P = VI$$

$$I = \frac{P}{V} = \frac{6.45 \times 10^3}{1.5 \times 10^3} = \underline{4.30A}. \quad ①$$

$$V_{DROP}(CABLE) = 1500 - 1450 = \underline{50V} \quad ①$$

$$\therefore R = \frac{V}{I} = \frac{50}{4.3} = 11.6\Omega$$

$$\therefore \underline{Resistance = 11.6\Omega} \quad ②$$

c) Calculate how much electrical energy per second is transformed to heat in the cables. (2)

$P_{loss} = I^2 R$ ①

$= 4.3^2 \times 11.6$

$P = 2.14 \times 10^2$ W ①

$\therefore \underline{P_{loss} = 2.14 \times 10^2 \text{ W}}$

d) Describe two design features of a commercial transformer that increase its efficiency. (2)

x Laminated soft iron core - reduce Eddy Currents

x Large diameter wire on windings to reduce heat

x Oil cooling

x Cooling fins

} not both of these only.

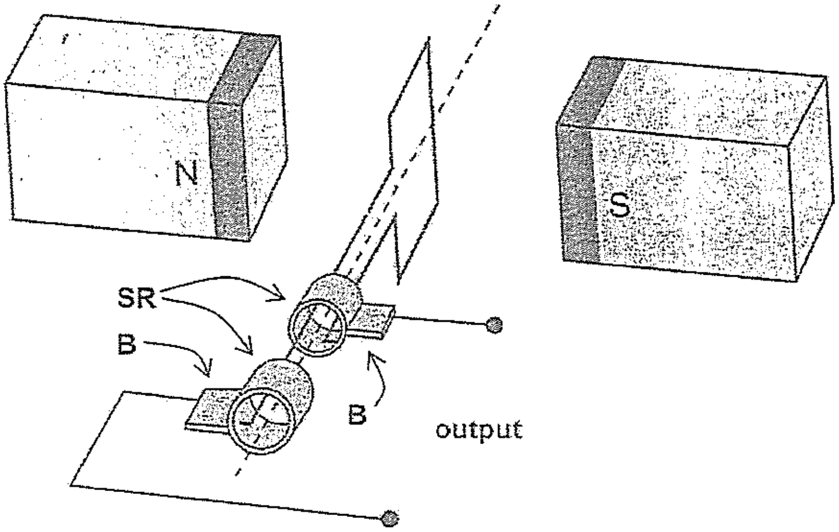
Any two

e) Explain why it is more efficient to transfer electricity to the pump at a high voltage of 1.50 kV rather than 240 V. (2)

Same power can be delivered ($P = VI$) at ① either voltage but at 1500V the current will be much less & hence given $P_{loss} \propto I^2$ ① will result in more power delivered to pump.

Question 17 (13 marks)

The diagram below shows an AC generator consisting of a rectangular coil with dimensions of 14.0 cm × 21.0 cm, and 800 turns of copper wire. The magnetic flux density between the poles is 9.40 mT. The coil is turned at a uniform rate.



a) Explain the function of the components labelled SR and B. (2)

SR = slip rings are rotating contacts connected to the armature. ①

B = brushes which connect to the power source. ①

b) Referring to Lenz's law, explain how induced emf is achieved from such a generator and why the output is a sine or cosine shape rather than being constant. (3)

Coil rotates

Amount of flux in coil changes (-1 any omission)

Charge carriers exp a force

move in a direction that opposes the Δ that caused it

As rate of ϕ cut changes in a cycle, a sin $\mathcal{E}$ output results and $\mathcal{E} \propto \Delta\phi$

c) The coil is rotated at 1500 rpm. Calculate the magnitude of the average induced emf in the coil as it rotates through 90° from the position shown.

(3)

Rate = 1500 rpm

= 25 rps

$\therefore T = \frac{1}{25}$

$= 4 \times 10^{-2}$ s

$\therefore \Delta t = \frac{T}{4} = 1 \times 10^{-2}$ s ①

$\Phi_{MAX} = BA$

$= 9.4 \times 10^{-3} \times 0.14 \times 0.21$

$= 2.76 \times 10^{-4}$ Wb. ①

$\Phi_{MIN} = 0$

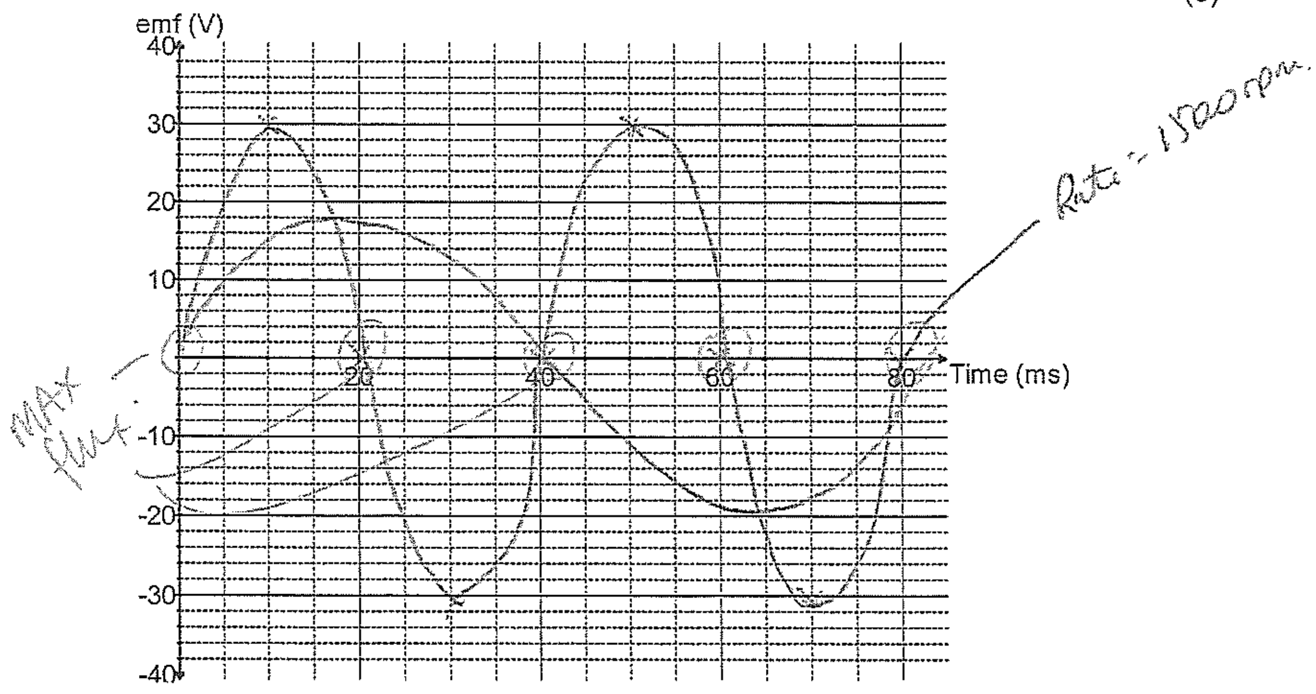
$\therefore \quad \mathcal{E} = -\frac{N \Delta \Phi}{\Delta t} = -\frac{800 \times 2.76 \times 10^{-4}}{1 \times 10^{-2}}$

$= 22.1$ V

$\therefore \quad \mathcal{E} = 22.1$ V. ①

d) Sketch the emf output curve for this AC generator on the graph below. You must start from the position shown on the diagram and continue up to 80 ms. No EMF values are required to be calculated.

(3)



e) Identify three times on the graph when the flux enclosed by the coil is a maximum value at 1500 rpm. Circle these times.

R/W

(1)

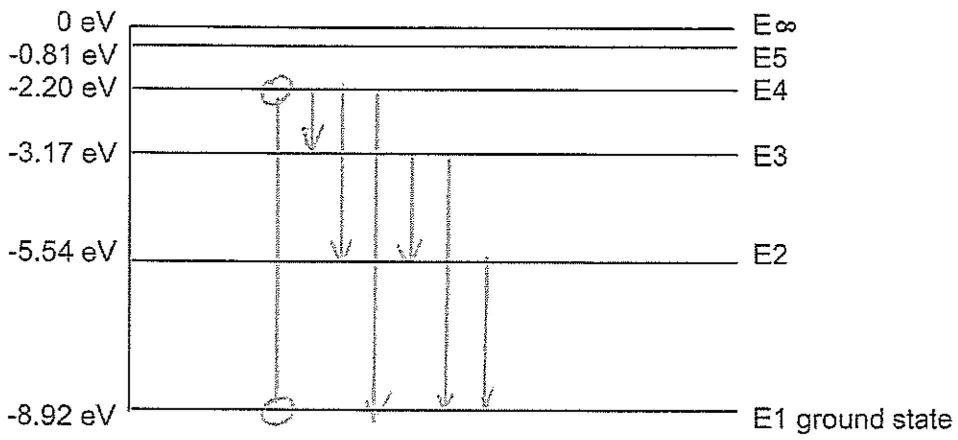
f) When the coil is rotated at 750 rpm the emf output changes. Sketch the voltage curve for 750 rpm onto the graph and clearly label it '750 rpm'.

(1)

PERIOD = 80ms $\quad \mathcal{E}_{750} = \frac{1}{2} \mathcal{E}_{1500}$ ($\frac{1}{2}$ each)

Question 18 (13 marks)

The diagram below details some of the energy levels for a metallic vapour that surrounds a star



a) Is it possible for this atom to absorb a 6.50 eV photon whilst in the ground state? Explain briefly. (1)

NO. There is no energy level difference equal to 6.50 eV!

R/W

b) Whilst in the ground state the atom absorbs a 6.72 eV photon. How many lines in the emission spectrum would be possible as the atom de-excites? Indicate them on the diagram. (1)

Number of lines = 6.

c) Calculate the longest wavelength possible in the emission spectrum when an atomic electron at E4 can de-excite by one or more steps to ground level. (3)

Longest λ = lowest energy = smallest $E\Delta$ ①

$\therefore E_{\text{lowest } E} = E_4 \rightarrow E_3$

$= 0.97\text{ eV} = 0.97 \times 1.6\times10^{-19} = 1.55\times10^{-19}\text{ J}$. ①

$\therefore E = hf = h\frac{c}{\lambda}$

$\lambda = \frac{hc}{E} = \frac{6.63\times10^{-34} \times 3\times10^{8}}{1.55\times10^{-19}} = 1.28\times10^{-6}\text{ m}$. ①

d) For the wavelength you calculated in part c) state which area of the electromagnetic spectrum this belongs to. (1)

INFRARED

particle can donate part energy.

A **single** atom in the ground state is bombarded by **one** electron with a kinetic energy of 6.10 eV.

e) Detail in the table below the possible photon energies observable on de-excitation and the possible bombarding electron energies after its interactions with the atom.

(3)

∴ TRANSITION TO E_2 & E_3 possible.

Possible photon energies on de-excitation (eV)	Possible bombarding electron energy after interaction with the atom (eV)
$E_3 \to E_1 = 5.75$ eV	$6.1 - 5.75 = 0.35$ eV
$E_2 \to E_1 = 3.38$ eV	$6.1 - 3.38 = 2.72$ eV
$E_3 \to E_2 = 2.37$ eV	$6.1 - 2.37 = 3.73$ eV

not essential → OR 6.1 eV (passes through without interact).

(−1 any error or omiss)

f) Explain briefly how analysis of a line absorption spectrum of light from distant galaxies can be used to determine the composition of stars and gas clouds.

(2)

Line absorption spectrum for each atom is a unique set of frequencies (fingerprint) corresponding to atomic energy level differences. ①

① This finger print allows the element to be identified.

g) The line absorption spectrum is also useful to determine the speed of a galaxy. Explain the fundamental principles of this technique.

(2)

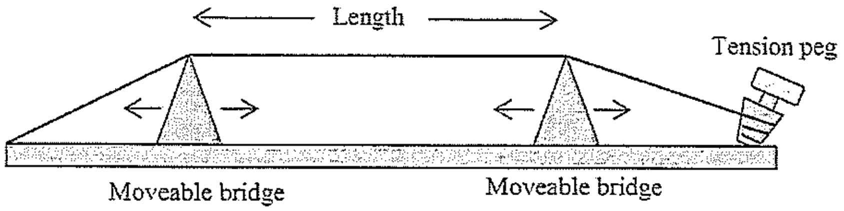
When a light source (stars) are moving away from an observer the wavelengths ① in the absorpt spectrum get longer & is called RED SHIFT.

R.S. can be used to ① determine recessional velocity.

SEE NEXT PAGE

Question 19 (13 marks)

A simple musical instrument consists of one steel string held in tension between two moveable bridges. The string is plucked between the bridges so that a musical note is heard. When the sound wave is analysed it can be seen that several frequencies are present at the same time.



a) Explain why several frequencies of sound are present when the single string is plucked. (2)

Single note on instrument comprises the fundamental frequency ① and other harmonics ① (overtones)

b) Explain how standing waves can form along the string. (2)

(−1 any omissn)

When plucked, transverse waves move along & are reflected back out of phase. As the reflected wave interacts in same medium as primary wave the principle of superposit results in fixed points of constructive (antinodes) & destructive (nodes) interference

c) The length of the string is set to 30.0 cm and the speed of the transverse waves along the string is 535 m s^{-1}. Calculate the fundamental frequency of the string. (3)

$L = \frac{\lambda}{2}$

$\lambda = 2 \times 0.3$

$= 0.6 m.$ ①

$\therefore \quad V = \lambda f$

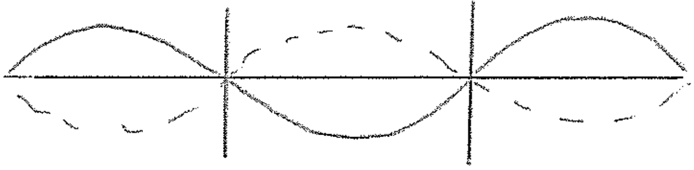
$f = \frac{V}{\lambda}$

$= \frac{535}{0.6}$ ①

$f_f = 892 Hz$ ①

For a given note played on a musical instrument, the dominant frequency heard is called the fundamental frequency or the first harmonic. The sequence of harmonic frequencies above the fundamental frequency, that are actually present, are known as overtones. So those harmonics above the fundamental are known as the first overtone, the second overtone etc.

d) The bridges can be moved and the tension set so that the wave speed along the string stays the same. What length of string is required so that its fundamental frequency is the same as the second overtone of the 30.0 cm string?



2ND OVERTONE = 3RD HARMONIC (1)

∴ Equal λ for new fundamental

$= \frac{30}{3} = \underline{10\ cm.}$ ①

Another simple musical instrument is a pipe, which is an air column closed at one end.

e) Sketch the particle displacement wave envelope for the second overtone in the closed pipe. ✓ (2)

SECOND OT = 3RD HARMONIC

f) Calculate the frequency of the second overtone in a closed pipe of length 15.0 cm when the air temperature is 25°C. (3)

$L = \frac{5\lambda}{4}$

$\lambda = \frac{4}{5}L$

$= \frac{4}{5} \times 0.15$

$= \underline{0.12m}$ ①

$f = \frac{v}{\lambda}$

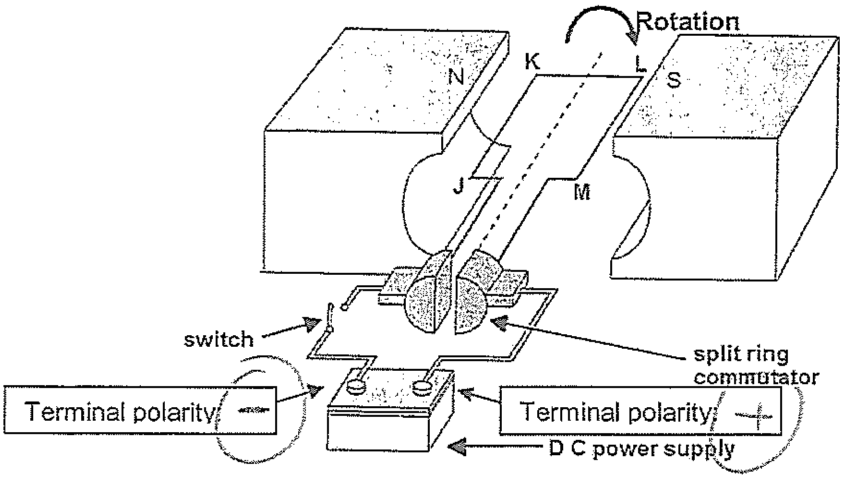
$= \frac{346}{0.12}$ ①

$= \underline{2.88 \times 10^3 Hz}$ ①

Question 20 (7 marks)

The figure below represents a DC motor whose coil is initially stationary.

- JK = LM = 16.0 cm KL = JM = 12.0 cm
- The coil has 120 turns of wire
- The uniform magnetic flux density between the poles = 95.0 mT
- The current in the coil is 6.30 A when the motor is switched on and it turns clockwise.



a) Indicate the positive and negative terminals on the DC power supply for this direction of rotation. (1)

b) Calculate the force acting on side LM of the coil when the switch is closed. (2)

$F = NIBL$

$= 120 \times 6.3 \times 95 \times 10^{-3} \times 16 \times 10^{-2}$ ①

$= 11.5\ N$ (down) ①

c) Calculate the maximum torque that this motor can produce. (2)

$\tau = 2rF$

$\tau_{MAX} = 2 \times \left(\frac{12 \times 10^{-2}}{2}\right) \times 11.5$ ①

$= 1.38\ Nm$ clockwise ①

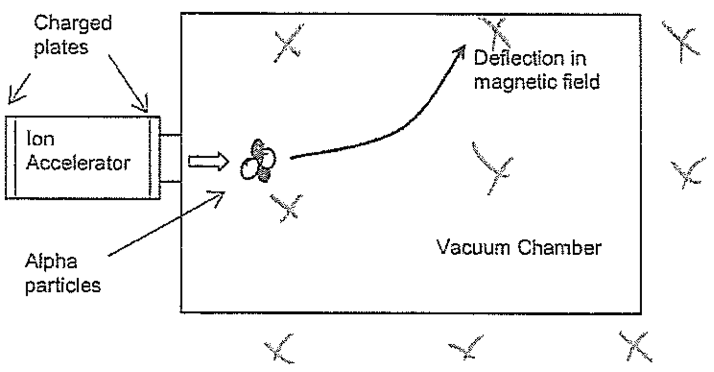
d) How much torque will the motor produce when it has rotated 90° from the position shown. Explain. (2)

$\tau = 0$ ①

Given $\tau = rF$, in the vertical position, $r = 0$ hence $\tau = 0$. ①

Question 21 (6 marks)

Alpha particles (He^{2+}) are doubly charged positive ions. They are accelerated through an electric field between charged parallel plates before entering a vacuum chamber where they are deflected by a magnetic field.



X (B INTO PAGE)

① R/W.

a. Calculate the potential difference between the charged plates in the Ion Accelerator that will give the alpha particles a maximum velocity of 3.40 × 10^5 m s^{-1} (3)

$q = 2 \times 1.6 \times 10^{-19} C$

$= \underline{3.2 \times 10^{-19} C}$ ①

$m = 6.65 \times 10^{-27} kg$

$v = 3.4 \times 10^5 ms^{-1}$

$W = qV = \Delta E_k = \frac{1}{2}mv^2$ ①

$\therefore V = \frac{\frac{1}{2}mv^2}{q} = \frac{\frac{1}{2} \times 6.65 \times 10^{-27} \times (3.4 \times 10^5)^2}{3.2 \times 10^{-19}}$

$V = 1.20 \times 10^3 V$

$\therefore \underline{V = 1.20 \times 10^3 V.}$ ①

b. Indicate on the diagram, the direction of the magnetic field within the vacuum chamber that will cause the deflection shown. (1)

c. The magnetic flux density within the chamber is set to 72.5 mT. Calculate the magnitude of force experienced by an alpha particle travelling at 3.40 × 10^5 m s^{-1}. (2)

$B = 72.5 \times 10^{-3} T$

$F = ?$

$v = 3.4 \times 10^5 ms^{-1}$

$F = qBv$

$= 3.2 \times 10^{-19} \times 72.5 \times 10^{-3} \times 3.4 \times 10^5$ ①

$\underline{= 7.89 \times 10^{-15} N}$ ①.

End of Section 2

SEE NEXT PAGE

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 22 Hubble's Law (18 marks)

When a source of waves is moving, a stationary observer notices a change in frequency of the waves. This effect is observed for both longitudinal and transverse waves. For example, if an ambulance moves towards you the sound frequency you hear is higher than the frequency its siren is emitting. This is known as the Doppler Effect.

If a source of electromagnetic waves, such as a star, is travelling away from an observer then the wavelengths of the lines in its electromagnetic spectrum are shifted to higher values. This is called red shift. An equation for the relationship is as follows:

$z = \frac{\Delta\lambda}{\lambda}$ It can also be shown that: $z = \frac{v}{c_0}$

z = red shift
$\Delta\lambda$ = change in wavelength (moving source) (nm)
λ = wavelength of stationary source (nm)
v = recessional speed of galaxy (m s^{-1})
c_0 = speed of light in a vacuum (m s^{-1})

Edwin Hubble analysed the red shifts of various galaxies in 1920 and deduced that most galaxies are moving away from the Earth, this suggests that the Universe is expanding. Hubble also discovered that the further away a galaxy is, the bigger its red shift and the faster it is moving away. This relationship is known as Hubble's Law and can be stated algebraically as follows:

$v_{galaxy} = H_0.d$

v_{galaxy} = recessional speed of galaxy (km s^{-1})
d = distance to galaxy (Mpc)
H_0 = Hubble's constant (km s^{-1} Mpc^{-1})

The distances to galaxies can be estimated by observing Cepheid Variables within a galaxy. A Cepheid Variable is a class of star that pulsates. The relationship between the period of pulsation and the size of the star is very precise. An understanding of how brightness diminishes with distance allows astronomers to estimate distances to galaxies with a high degree of confidence.

The following data was recorded by the Hubble Space Telescope for five galaxies.

$v = zC_0$

$ms^{-1} \rightarrow kms^{-1}$

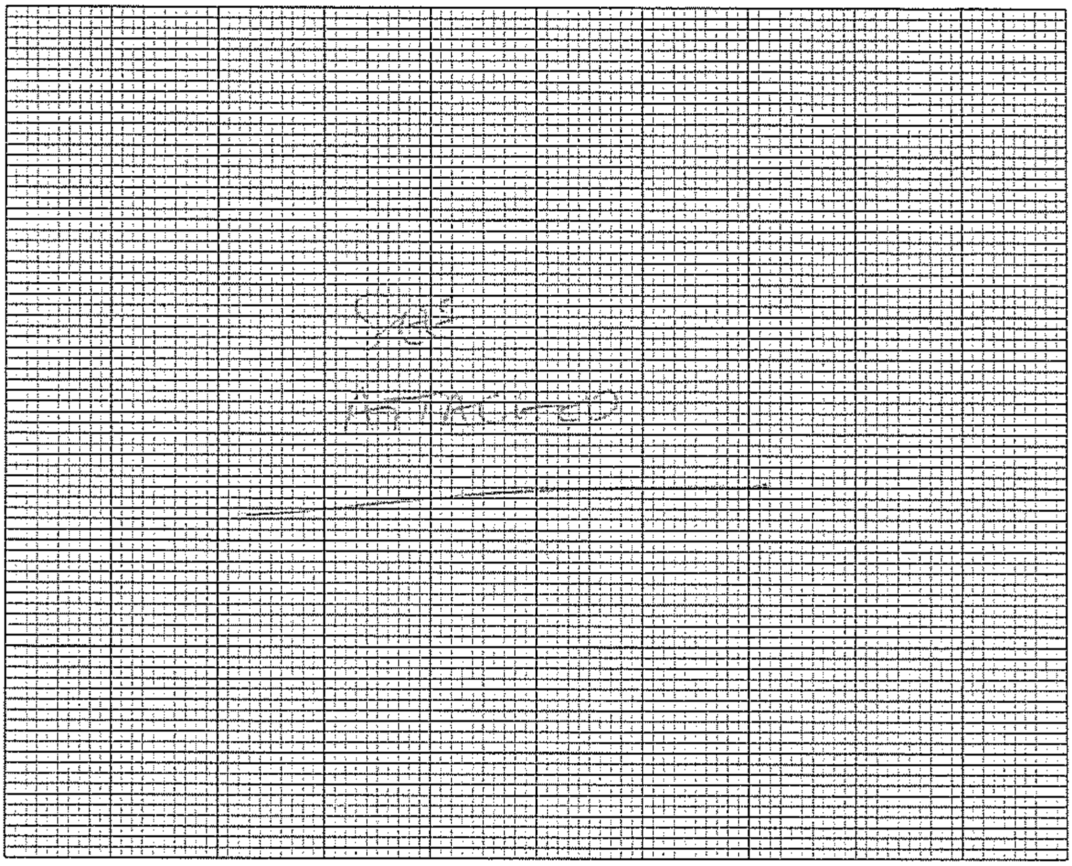
Distance (Mpc)	**Red shift - z**	**Recessional speed of galaxy** v_{galaxy} (km s^{-1})
3.1	0.00095	285
8.6	0.00212	636
12.2	0.00273	819
16.1	0.00402	1206
19.4	0.00473	1419

a) Calculate the appropriate values in the final column of the table (the first value has been done for you)

(2)

b) Plot a correctly labelled graph of **recessional speed** versus **distance to galaxy** on the graph paper and draw a line of best fit.

(4)



c) Calculate a value for Hubble's constant, in the correct units, showing how you obtained this value from your graph. (3)

H_0 = gradient = $\frac{\text{RISE}}{\text{RUN}}$.

XL − 70.4 } kms⁻¹ Mpc⁻¹

SOLUTION − 72 }

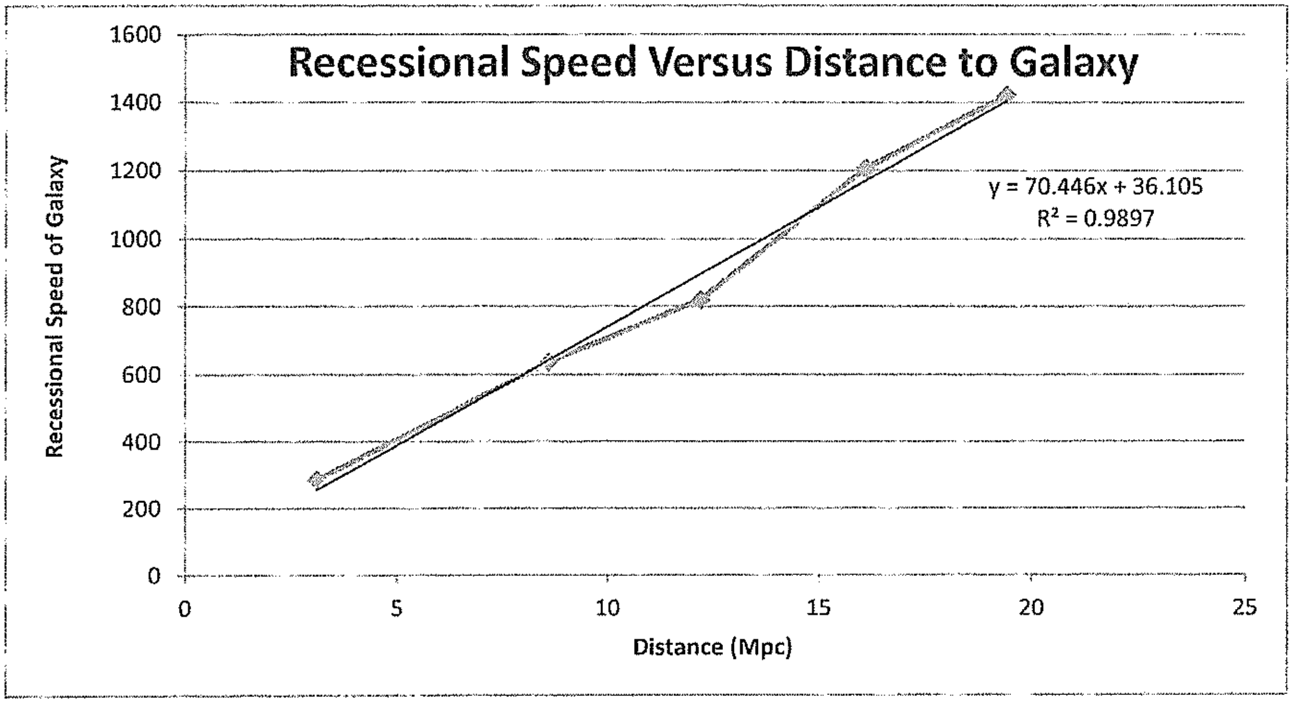
MUST USE LINE OF BEST FIT
NOT JUST POINTT.

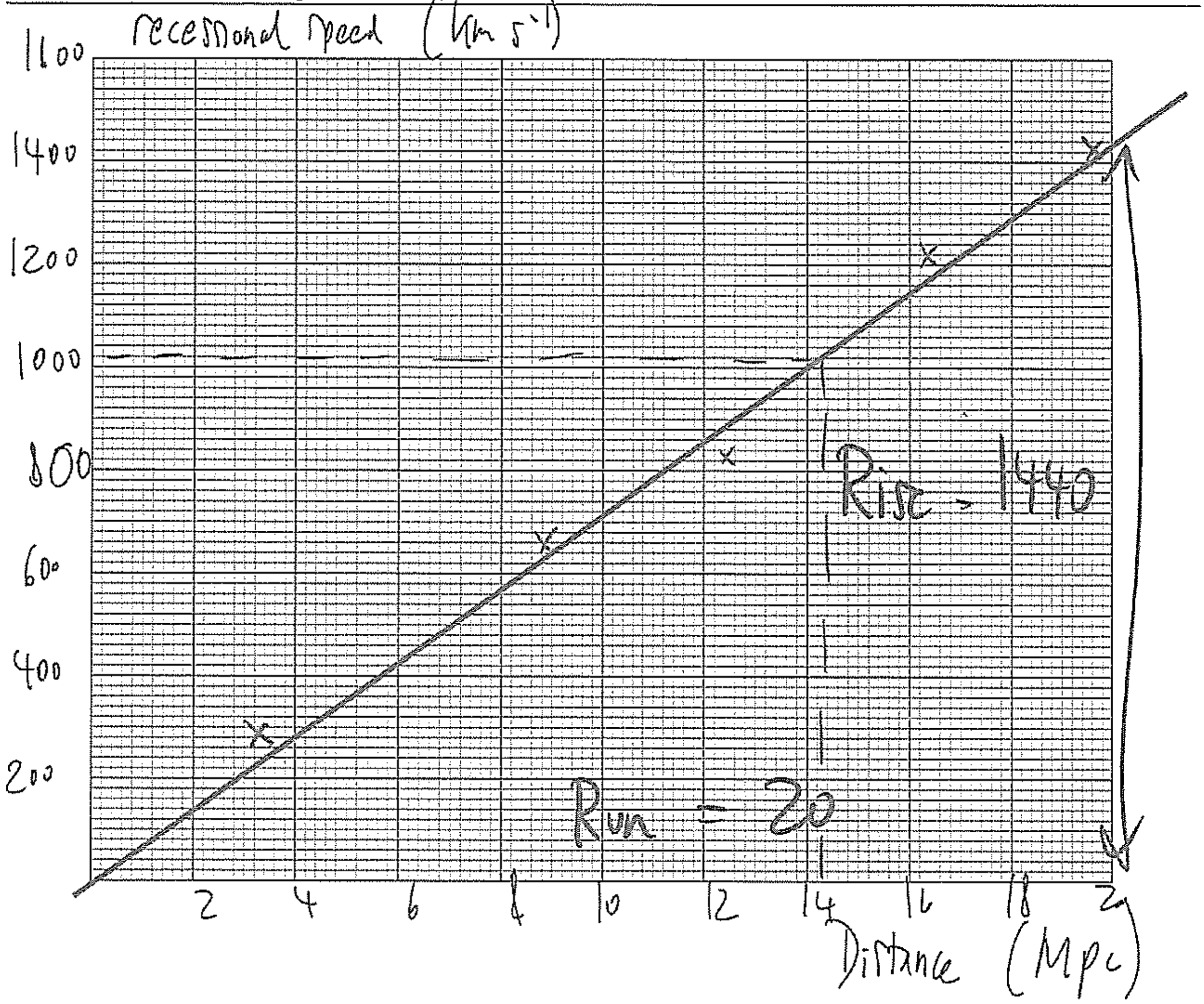
d) State three reasons why you think that measurements of Hubble's constant have varied widely since Hubble's first determination in 1920. (3)

- × Improved technology to measure RED SHIFT.
- × BETTER TELESCOPES. eg Hubble above atmosphere.
- × More Cepheid variables discovered

Any 3 credible reasons.

Distance (Mpc)	Recessional Speed (kms-1)
3.1	285
8.6	636
12.2	819
16.1	1206
19.4	1419





c) Calculate a value for Hubble's constant, in the correct units, showing how you obtained this value from your graph.

(3)

Identifies rise and run on line of best fit ✓ (not data points)

H_0 = gradient = rise / run
H_0 = 1440 / 20 ✓
H_0 = 72.0 km s^{-1} Mpc^{-1} ✓
Allow small range for "line of best fit" variations.

d) State three reasons why you think that measurements of Hubble's constant have varied widely since Hubble's first determination in 1920.

(3)

- Improved technology to measure red shift (diffraction gratings)
- Better telescopes (e.g. Hubble and others located in space - no atmospheric distortion.)
- More Cepheid Variables discovered - better averages on distance measurements.

Any 3 credible points ✓ ✓ ✓

e) Why does the value of red shift z, have no units? (1)

It is a ratio.

f) A line in the spectrum of ionised calcium has a wavelength of 393.3 nm when measured in the laboratory. When similar light from the galaxy NGC 3350 is measured, its wavelength is 394.64 nm. Use the red shift formulae to determine the recessional speed of this galaxy. (2)

$$\frac{\Delta\lambda}{\lambda} = \frac{V}{C_o}$$

$$V = \frac{\Delta\lambda C_o}{\lambda}$$

$$= \frac{(394.64 - 393.3) \times 3\times10^8}{393.3}$$

$$\underline{V = 1.02\times10^6 \, ms^{-1} \quad (1.02\times10^3 \, kms^{-1})}$$

g) For the recessional speed you calculated in part f), use your graph and the line of best fit to determine the distance to this galaxy in Mpc. (1)

FROM GRAPH.

Approx 14 Mpc

h) Determine how many years it takes for light from galaxy NGC 3350 to reach Earth. (1 parsec = 3.26 ly) (2)

$$14 \text{ Mpc} = 14\times10^6 \times 3.26$$

$$= 45.64 \text{ million light yrs}$$

Accept Range.

Question 23 **(18 marks)**

Particle Physics – basic principles and techniques

Particle physics is the modern version of the age old quest – to find the smallest particles that cannot be broken down. Particle accelerators are the 'laboratory equipment' in this area of study. Charged particles can be accelerated in two senses – by their change of direction in circular paths or by increasing their speed. Studies can be made on the radiation that they emit whilst being accelerated or the after effects of collisions between high speed particles.

The **cyclotron** first came into use in 1928 using a combination of magnetic and electric fields to accelerate particles in a spiral path. Development of this technology led to the **synchrotron** which uses an evacuated circular tube with many magnets placed around its circumference. As particles are accelerated the electric field is adjusted and the strength of the magnets is increased to maintain a constant radius and compensate for relativistic effects that become important at high particle energies.

Any charged particle that accelerates will radiate electromagnetic energy. This is true even at a constant speed in a circular path. So a continual supply of energy is required in synchrotrons to just maintain a constant particle speed let alone increase their speed. The emitted radiation is known as **synchrotron radiation** and can cover the entire electromagnetic spectrum.

Linear accelerators (LINAC) use a straight path and a series of accelerating voltages as the particles move along the line. LINACs are often used to provide the early stages of acceleration before particles are fed into large synchrotrons.

Collider experiments take two beams of particles that have been separately accelerated in opposite directions and smash them into each other. This is difficult to achieve but if successful it is an efficient use of energy.

When two particles with an equal magnitude of momentum collide head on, the total momentum is zero before and after the collision. If particles are stationary after the collision then their kinetic energy is zero. By the conservation of energy and mass principle, the energy before the collision is transformed into the mass of new particles formed in the collision. The particles that are present after a collision reaction can be different to those that went in. This is exactly what particle physicists aim to achieve and the discovery and study of these new particles underpins their work.

Every collision is governed by one of the **fundamental forces** (except the force of gravity which has no significant influence on such tiny particles in this context):

- The **electromagnetic force** leads to simple collisions between charged particles. No new particles are formed when this force is at work. e.g. $p + p \rightarrow p + p$
- The **strong force** dominates reactions between hadrons (which contain quarks). e.g. $p + p \rightarrow p + n + \pi^0$
- The **weak force** is likely to be involved in lepton reactions, especially if one of the leptons is a neutrino. e.g. $\nu_e + \mu^- \rightarrow e^- + \nu_\mu$

Einstein's theory of **special relativity** has led us to the idea that the mass of a moving object is not the same as its rest mass (m_0). The mass of a moving object cannot be measured directly; it must be calculated from a measurement of momentum and velocity. The relativistic equations for momentum ***p*** and total energy ***E*** are as follows:

$$p = \frac{m_0 v}{\sqrt{1 - \frac{v^2}{c^2}}} \qquad E = \frac{m_0 c^2}{\sqrt{1 - \frac{v^2}{c^2}}}$$

(These equations are only applicable for non-zero mass)

Relativity has also given us the idea of mass-energy equivalence. In Newton's version of mechanics a lone particle not influenced by gravity or electromagnetism but moving at a given speed could only have a single form of energy – kinetic. At rest it had no energy at all. This is not the case in relativity. The relationship is described by the equation: $E^2 - p^2c^2 = m_0{}^2c^4$

Photons are packets of energy travelling at the speed of light. Surprisingly it has been proved that although photons have zero mass they do have momentum. It can be shown for a photon that

if: $E^2 - p^2c^2 = m_0{}^2c^4$ then: $p = \frac{E}{c}$ and since $E = hf$ then: $p = \frac{hf}{c} = \frac{h}{\lambda}$

Particle physics has also proven to be vital in understanding the nature of the universe a few fractions of a second after the Big Bang. The conditions created in the mightiest accelerators are very similar to those that existed when the universe was 10^{-12} seconds old.

Questions

a) In what sense can a particle be accelerated if its speed remains constant? Explain. (2)

Velocity has BOTH magnitude & direction ①
Hence, if a particle undergoes circular motion
it will have constant speed but due to Δdirection
will be accelerating. ①

b) Once a charged particle has been accelerated to a given speed in a circular path, is further energy required to maintain a constant speed? Explain. (2)

① YES. It radiates synchrotron radiation so
this energy must be replaced. ①

c) Can electrons and neutrinos be subject to the strong force? Explain (2)

NO. ①
The strong (nuclear) force only acts between
hadrons / nucleons / quarks. ①

d) If neutrinos are involved in a collision reaction why is it unlikely that this was governed by the electromagnetic force?

(1)

Neutrinos have no charge & hence not influenced by the electromagnetic force.

e) If you hit a ping pong ball with a table tennis bat which of the three fundamental forces described governs this collision? Justify your answer.

(2)

① Electromagnetic force, the strong force acts within a nucleus., the weak force is involved with β decay.

Reason ①

* Involves the interact between like charges within the bat & ball.

f) Calculate the momentum of a **proton** travelling at 95% of the speed of light. The rest mass of a proton is given in the formula and constant sheet.

(3)

$$p = \frac{M_o V}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{1.67\times10^{-27}\times0.95\times3\times10^8}{\sqrt{1-\frac{0.95^2}{1^2}}}$$ ①

$$p = 1.52\times10^{-18}\ \text{kgms}^{-1}$$ ②

g) The equation for Einstein's mass-energy equivalence is: $E^2 - p^2c^2 = m_0{}^2c^4$
Show that for a particle at rest this simplifies to $E = m_0c^2$

(2)

If $V = 0$ $\quad p = \dfrac{m_0 V}{\sqrt{1-\frac{v^2}{c^2}}} = 0$ ①

Hence. $\quad E^2 - p^2c^2 = m_0^2 C^4$

$p = 0$ $\quad E^2 = m_0^2 C^4$

$\sqrt{}$ $\quad \underline{E = M_0 C^2}$ ①

h) From the starting point: $E^2 - p^2c^2 = m_0{}^2c^4$ show that the momentum of a **photon** with zero mass can be given by $p = \dfrac{E}{c}$

(2)

If $M_0 = 0$ $\quad E^2 - p^2c^2 = \underline{M_0^2} C^4 = 0$ ①

$\therefore \quad E^2 = p^2 C^2$

$\sqrt{all} \quad E = pC$

$\underline{p = \dfrac{E}{c}}$ ①

i) Calculate the momentum of a photon of 550 nm yellow light.

(2)

$p = \dfrac{h}{\lambda} = \dfrac{6.63 \times 10^{-34}}{550 \times 10^{-9}}$ ①

$= \underline{1.20 \times 10^{-27} \text{ kg ms}^{-1}}$ ①

End of questions