HOLY CROSS COLLEGE

SEMESTER 2, 2016

Question/Answer Booklet

12 PHYSICS

Please place your student identification label in this box

Student Name SOLUTIONS

Student's Teacher

Time allowed for this paper

Reading time before commencing work: 10 minutes
Working time for paper: 3 hours

Materials required/recommended for this paper

To be provided by the supervisor
This Question/Answer Booklet
Multiple-choice Answer Sheet
Data Sheet

To be provided by the candidate
Standard items: pens, pencils, eraser, correction fluid, ruler, highlighters

Special items: non-programmable calculators satisfying the conditions set by the School Curriculum and Standards Authority for this course

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.

Structure of this paper

Section	Number of questions available	Number of questions to be answered	Suggested working time (minutes)	Marks available	Percentage of exam
Section One: Short Answers	14	14	50	54	30
Section Two: Problem-solving	7	7	90	90	50
Section Three: Comprehension	16	16	40	36	20
				180	100

Instructions to candidates

1. The rules for the conduct of examinations at Holy Cross College are detailed in the College Examination Policy. Sitting this examination implies that you agree to abide by these rules.

2. Write your answers in this Question/Answer Booklet.

3. Working or reasoning should be clearly shown when calculating or estimating answers.

4. You must be careful to confine your responses to the specific questions asked and to follow any instructions that are specific to a particular question.

5. Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.
   - Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
   - Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question(s) that you are continuing to answer at the top of the page.

6. Answers to questions involving calculations should be ***evaluated and given in decimal form.*** It is suggested that you quote all answers to ***three significant figures***, with the exception of questions for which estimates are required. Despite an incorrect final result, credit may be obtained for method and working, providing these are ***clearly and legibly set out***.

7. Questions containing the instruction *"**estimate**"* may give insufficient numerical data for their solution. Students should provide appropriate figures to enable an approximate solution to be obtained. Give final answers to a maximum of ***two significant figures*** and include appropriate units where applicable.

8. Note that when an answer is a vector quantity, it must be given with magnitude and direction.

9. In all calculations, units must be consistent throughout your working.

Additional Data

Hubble's Law $v_{galaxy} = H_o d$

Velocity of galaxies $v_{galaxy} = \frac{\Delta\lambda}{\lambda} c$

Parallax distance $d = \frac{1}{p}$ where p = angle in arcsecs

d = distance in parsecs

1.00 parsec = 3.26 light years

PARTICLE PHYSICS

Rest energy values

class	*name*	*symbol*	*rest energy /MeV*
photon	photon	γ	0
lepton	neutrino	ν_e	0
		ν_μ	0
	electron	$e^{\pm}$	0.510999
	muon	$\mu^{\pm}$	105.659
mesons	π meson	$\pi^{\pm}$	139.576
		π^0	134.972
	K meson	$K^{\pm}$	493.821
		K^0	497.762
baryons	proton	p	938.257
	neutron	n	939.551

Properties of quarks
antiquarks have opposite signs

type	*charge*	*baryon number*	*strangeness*
u	$+\frac{2}{3}e$	$+\frac{1}{3}$	0
d	$-\frac{1}{3}e$	$+\frac{1}{3}$	0
s	$-\frac{1}{3}e$	$+\frac{1}{3}$	-1

Properties of leptons

	lepton number
particles: e^-, ν_e ; μ^-, ν_μ	+1
antiparticles: e^+, $\overline{\nu_e}$; μ^+, $\overline{\nu_\mu}$	−1

SECTION ONE: Short Answers

Marks Allotted: 54 marks out of 180 total.

Attempt **ALL 14** questions in this section. Answers are to be written in the space below or next to each question.

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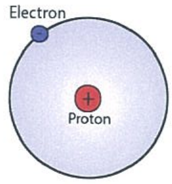
1. The distance between the proton and the electron in the ground state of the hydrogen atom is defined as the Bohr radius. Given that the Bohr radius can be measured as r = 5.29×10^{-11} metres, what is the force experienced by the electron as it orbits in the atom?



[4 marks]

$$F = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{r^2}$$

$$= \frac{1}{4\pi(8.85\times10^{-12})} \cdot \frac{(1.60\times10^{-19})^2}{(5.29\times10^{-11})^2} \quad (2)$$

$$= \underbrace{8.23\times10^{-8}\ \text{N}}_{(1)}\ \underbrace{\text{towards the proton}}_{(1)}$$

2. Consider the decay equation shown here showing hadron interactions. Show that charge, baryon number and lepton number are all conserved. **[3 marks]**

$$K^0 + p \rightarrow K^+ + n$$

$$(d\bar{s}) + (uud) \rightarrow (u\bar{s}) + (udd)$$

Charge $\left(-\frac{1}{3}+\frac{1}{3}\right)+\left(+\frac{2}{3}+\frac{2}{3}-\frac{1}{3}\right) \rightarrow \left(+\frac{2}{3}+\frac{1}{3}\right)+\left(+\frac{2}{3}-\frac{1}{3}-\frac{1}{3}\right) = +1$ both sides

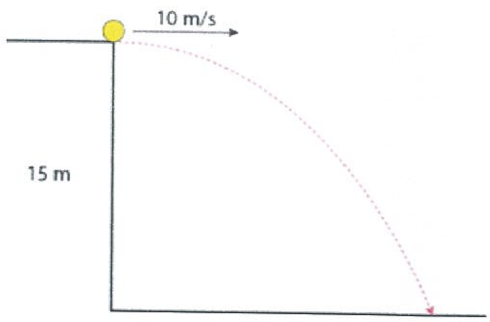
Baryon number $\left(+\frac{1}{3}-\frac{1}{3}\right)+\left(+\frac{1}{3}+\frac{1}{3}+\frac{1}{3}\right) \rightarrow \left(+\frac{1}{3}-\frac{1}{3}\right)+\left(+\frac{1}{3}+\frac{1}{3}+\frac{1}{3}\right) = +1$ both sides

Lepton number $0 + 0 \rightarrow 0 + 0 = 0$ both sides

[1 mark each]

3. A football is kicked horizontally from the edge of a cliff into a river below with a speed of 10.0 ms^{-1}, as shown here. Calculate the ***velocity*** with which the ball enters the water.

[5 marks]



$\downarrow$ +ve

<u>VERTICALLY</u>

$v = ?$

$u = 0 \text{ ms}^{-1}$

$a = 9.80 \text{ ms}^{-2}$

$t =$

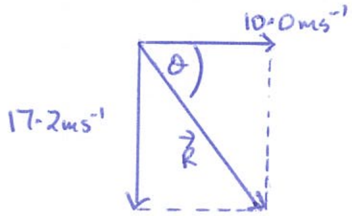
$s = 15.0 \text{ m}$

$$v^2 = u^2 + 2as$$

$$= 0 + 2(9.80)(15.0) \quad (1)$$

$$\Rightarrow V_v = 17.2 \text{ ms}^{-1}. \quad (1)$$

<u>AT IMPACT</u>



$$\vec{R} = \sqrt{(10.0)^2 + (17.2)^2}$$

$$= 19.9 \text{ ms}^{-1} \quad (1)$$

$$\tan\theta = \frac{17.2}{10.0}$$

$$\Rightarrow \theta = 59.8^\circ \quad (1)$$

$\therefore$ <u>velocity</u> = <u>19.9 ms^{-1} at 59.8° to the horizontal</u> (1)

4. Find the De Broglie wavelength of an electron of rest mass 0.511 MeV travelling at a velocity of 3.00 x 10^5 ms^{-1}.

[2 marks]

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

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

$$= \frac{6.63\times10^{-34}}{(9.11\times10^{-31})(3.00\times10^{5})} \quad (1)$$

$$= \underline{2.43\times10^{-9} \text{ m}} \quad (1)$$

5. A light source of wavelength 45.0 nm strikes a metal whose work function is 4.00 eV.

(a) What is the maximum kinetic energy of the emitted photoelectrons? **[3 marks]**

$$E_k = \frac{hc}{\lambda} - W$$

(1) (1)

$$= \frac{(6.63\times10^{-34})(3.00\times10^{8})}{(45.0\times10^{-9})} - (4.00)(1.60\times10^{-19})$$

$$= \underline{3.78\times10^{-18}\ \text{J}}$$ (1)

(b) The intensity of the light being used is doubled. How will this affect the numbers of photoelectrons emitted, the photocurrent produced and the energy of the kinetic energy photoelectrons emitted? **[3 marks]**

Number of photoelectrons increases (1)

Photocurrent increases (1)

Kinetic energy no change (1)

6. In 2012, the Hot-Wheels toy company executed a car stunt where a typical family car successfully performed an inverted loop on a specially designed, 6-storey loop.

At the top of the loop, the car is just in contact with the road. ***Estimate*** the minimum velocity (v) required to keep the car in contact with the road at this point. **[4 marks]**

Estimated height: 20m

$$\Sigma F = F_c = F_W + R \quad (1)$$

If $R = 0$, $F_c = F_W$

$$\Rightarrow \frac{mv^2}{r} = mg$$

$$\Rightarrow v = \sqrt{gr} \quad (1)$$

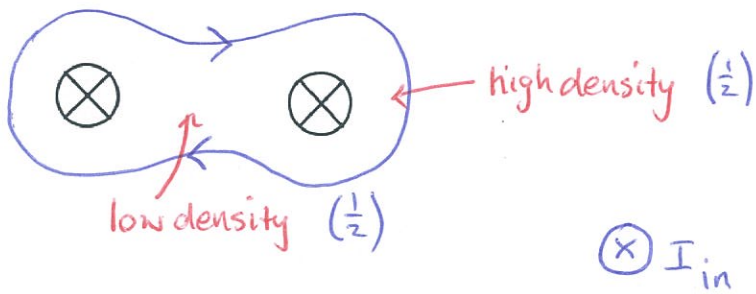
$$= \sqrt{(9.80)(10)} \quad (1)$$

$$= \underline{9.9 ms^{-1}} \quad (1)$$

7. Two current carrying conductors are shown in the diagram below.

(a) Sketch the resultant magnetic field and clearly label any areas of high or low flux density. **[2 marks]**

Direction - 1 mark



(b) Is there any force between the two conductors? Circle the correct answer below. **[1 mark]**

There is a force of repulsion.	***There is no force.***	***There is a force of attraction.*** (1)

8. The large hadron collider (LHC) is a particle collider located on the Swiss/French border. A large magnetic field, created using superconducting solenoids, keeps hadrons circling around a 27.0 km circumference at speeds approaching the speed of light. Calculate the magnetic field strength required to keep a proton circulating inside the solenoids, travelling at 5.00×10^5 ms^{-1}.

[4 marks]

$$C = 2\pi r$$

$$\Rightarrow r = \frac{C}{2\pi} = \frac{27.0\times10^{3}}{2\pi} = 4.297\times10^{3}\ m. \quad (1)$$

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

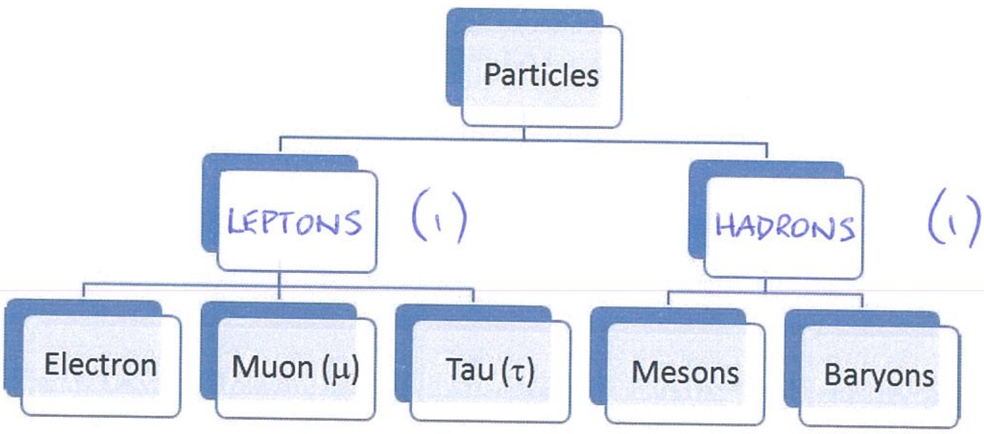
$$\Rightarrow B = \frac{mv}{qr} \quad (1)$$

$$= \frac{(1.67\times10^{-27})(5.00\times10^{5})}{(1.60\times10^{-19})(4.297\times10^{3})} \quad (1)$$

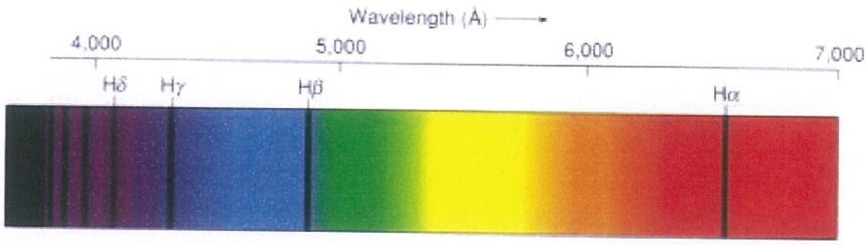
$$= \underline{1.22\times10^{-6}\ T} \quad (1)$$

9. Consider the classification table (below) for elementary particles. Write the missing headings in the spaces provided.

[2 marks]



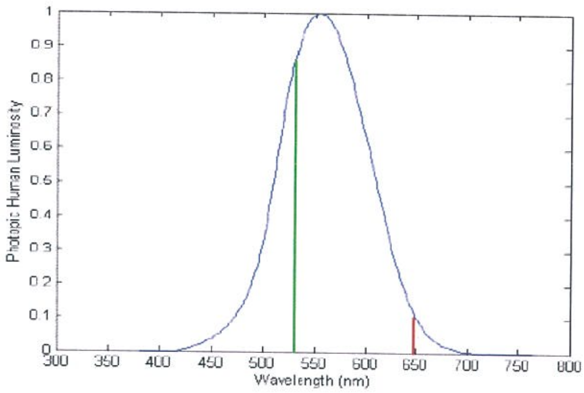
10. The visible part of the solar spectrum shows numerous thin dark lines appearing on the continuous spectrum as shown here:



Explain what these lines are and how they are produced. **[3 marks]**

- light from the interior of the Sun passes through the cooler gases of its "atmosphere" (corona). (1)
- Frequencies corresponding to energy levels above ground state are absorbed. (1)
- These are re-emitted in all directions, creating dark lines. (1)

11. The diagram shows the typical human visual response for a green laser pointer (GLP). The wavelength of the GLP line is at 532 nm and the 650 nm wavelength of a typical red laser pointer is shown. Given that the GLP operates with a power of 110 W, calculate the number of photons emitted in 10.0 seconds. **[4 marks]**



$$E_{photon} = \frac{hc}{\lambda}$$

$$= \frac{(6.63\times10^{-34})(3.00\times10^{8})}{(532\times10^{-9})} \quad (1)$$

$$= 3.74\times10^{-19}\ J \quad (1)$$

$$E_{laser} = P.t$$

$$= (110)(10.0)$$

$$= 1.10\times10^{3}\ J \quad (1)$$

$$\#\ photons = \frac{1.10\times10^{3}}{3.74\times10^{-19}}$$

$$= \underline{2.94\times10^{21}} \quad (1)$$

12. A pion is a subatomic particle consisting of a quark and an antiquark. What is the speed of a pion if its average lifetime is measured to be 4.10 x 10^{-8} seconds? At rest, its average lifetime is 2.60 x 10^{-8} seconds.

[5 marks]

$$t = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$\Rightarrow 4.10 \times 10^{-8} = \frac{2.60 \times 10^{-8}}{\sqrt{1 - \frac{v^2}{(3.00 \times 10^8)^2}}} \quad (1)$$

$$\Rightarrow (4.10 \times 10^{-8})^2 \left(1 - \frac{v^2}{(3.00 \times 10^8)^2}\right) = (2.60 \times 10^{-8})^2 \quad (1)$$

$$\Rightarrow 1.681 \times 10^{-15} - 1.868 \times 10^{-32} v^2 = 6.76 \times 10^{-16} \quad (1)$$

$$\Rightarrow v^2 = 5.38 \times 10^{16} \quad (1)$$

$$\Rightarrow \underline{v = 2.32 \times 10^8 \text{ ms}^{-1}} \quad (1)$$

13. The 355 nm spectral line of an element is found to be 366 nm in the light coming from the galaxy shown here.

(a) Is this a red shift or a blue shift? **[1 mark]**

red shift (1)

(b) Is the galaxy receding or moving towards us? **[1 mark]**

receding (1)

(c) Calculate the velocity of the galaxy. **[2 marks]**

$$V_{galaxy} = \frac{\Delta\lambda}{\lambda} c$$

$$= \frac{[(366-355)\times10^{-9}](3.00\times10^{8})}{(355\times10^{-9})} \quad (1)$$

$$= \underline{9.30\times10^{6}\ ms^{-1}} \quad (1)$$

(d) Use a Hubble constant of H_0 = 71.0 $kms^{-1}Mpc^{-1}$ to determine the distance to the galaxy in light years. **[2 marks]**

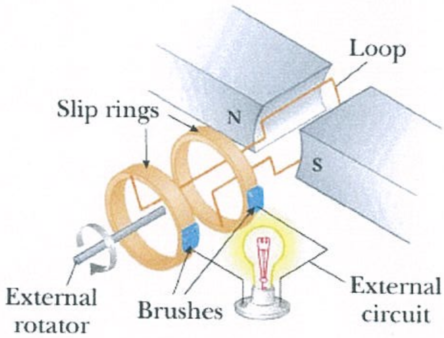
$$V_{galaxy} = H_o d$$

$$\Rightarrow d = \frac{9.30\times10^{3}}{71.0} \quad (1)$$

$$= 1.31\times10^{2}\ Mpc$$

$$= \underline{4.27\times10^{8}\ ly.} \quad (1)$$

14. An armature of an AC generator rotates in a field of strength 0.200 T. The area of the armature is 5.00 x 10^{-2} m^2. As the coil rotates from the vertical to the horizontal in 20.0 ms, the maximum voltage required is 150 volts. How many loops should the coil contain to achieve this? **[3 marks]**



$$EMF_{max} = -2\pi NBAf$$

$$\Rightarrow N = \frac{EMF_{max}}{-2\pi BAf} \quad (1)$$

$$= \frac{150}{-2\pi(0.200)(0.5.00\times10^{-2})(12.5)} \quad (1)$$

$$= \underline{191 \text{ loops}} \quad (1)$$

$$f = \frac{1}{T} = \frac{1}{80.0\times10^{-3}} = 12.5 \text{ Hz}.$$

[Best answer].

$$EMF_{average} = \frac{-N\Delta\phi}{\Delta t} = \frac{-NB\Delta A}{\Delta t}$$

$$\Rightarrow N = \frac{EMF_{ave}\Delta t}{-B\Delta A} \quad (1)$$

$$= \frac{(150)(20.0\times10^{-3})}{-(0.200)(0-5.00\times10^{-2})} \quad (1)$$

$$= \underline{3.00\times10^{2} \text{ loops}} \quad (1)$$

SECTION TWO: Problem Solving

Marks allotted: 90 marks out of 180 marks total.

Attempt **ALL 7** questions in this section. The marks allocated to each question are given and the answers should be written in the spaces provided.

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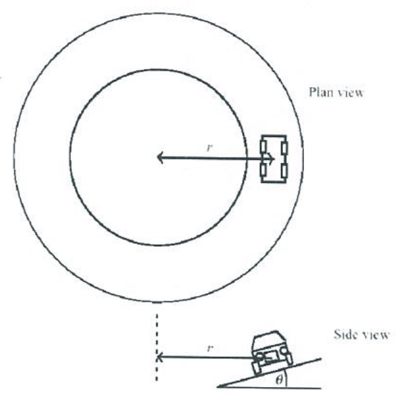
15. **[14 marks]**

Tom is caught on a banked roundabout in East Perth. He is travelling at a steady speed and his situation is shown in the plan and side views below. The car's speed is such that there is no sideways frictional force between the tyres and the road.

(a)

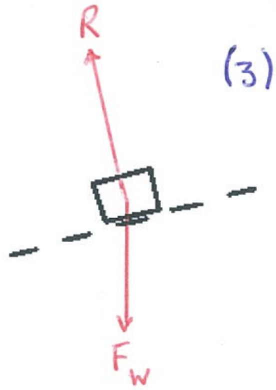


Does Tom's car have an acceleration? Explain your answer.

[2 marks]

- yes (1)
- Δv is towards the centre of the roundabout. (1)

(b) We could represent Tom's car on the roundabout by a block in the diagram below.



(3) [subtract 1 mark for non-existent or wrong forces.]

On the diagram above, draw and label all the forces acting on the moving car?

[3 marks]

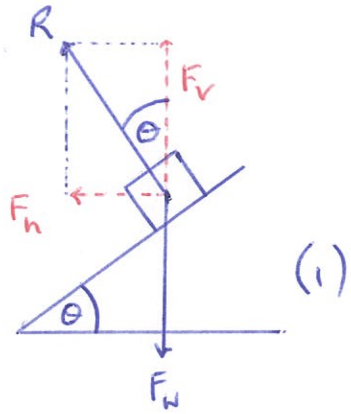
(c) Is there a resultant force acing on the car? Explain

[2 marks]

- yes (1)
- $\Sigma F = F_c$, which is acting towards the centre of the roundabout. (1)

(d) Why is it that engineers, when designing roundabouts and freeway off ramps, often bank them? Use a diagram to assist your answer.

[2 marks]



• Reaction force (R) has a horizontal component that supplies F_c required to keep the car on the curve. (1)

(e) Using any necessary assumptions, calculate the speed that the car must travel at in order for there to be no sideways frictional force between the tyres and the road?

[3 marks]

ASSUMPTIONS: $\theta = 15^\circ$, $r = 30\text{ m}$

VERTICALLY: $R\cos\theta = F_W = mg$ — ① (1)

HORIZONTALLY: $R\sin\theta = F_h = F_c = \frac{mv^2}{r}$ — ②

$$\frac{②}{①} \Rightarrow \frac{R\sin\theta}{R\cos\theta} = \frac{mv^2}{r} \times \frac{1}{mg}$$

$$\Rightarrow \tan\theta = \frac{v^2}{rg} \quad (1)$$

$$\Rightarrow v = \sqrt{\tan\theta\, rg}$$

$$= \sqrt{(\tan 15^\circ)(30)(9.80)}$$

$$= \underline{8.9\text{ ms}^{-1}} \quad (1)$$

(f) Suppose now that some oil had been spilled on the roundabout. What effect would this have on Tom's car if he maintained the speed you calculated in part (e)? Explain.

[2 marks]

• No effect. (1)

• F_c is supplied by the horizontal component of R - friction is not involved. (1)

16. **(15 marks)**

At the centre of the Milky Way is a black hole known as Sagittarius A. It has a mass equivalent to 4.31 billion Suns. It is 26 500 light years from the Sun. A light year is the distance light would travel in one year.

(a) Calculate the gravitational force between the black hole and the Sun. **[3 marks]**

$$F = \frac{G M_1 M_2}{r^2}$$

$$= \frac{(6.67 \times 10^{-11})(1.99 \times 10^{30})(4.31 \times 10^{9})(1.99 \times 10^{30})}{[(26500)(365.25)(24.0)(3.60 \times 10^{3})(3.00 \times 10^{8})]^2} \quad (2)$$

$$= 1.81 \times 10^{19} \text{ N} \quad (1)$$

[Allow for 1 year = 365 days.]

(b) Use the force (from part a) to calculate the orbital speed of the Sun around the black hole. **[3 marks]**

$$F = \frac{mv^2}{r}$$

$$\Rightarrow \quad v = \sqrt{\frac{Fr}{m}} \quad (1)$$

$$= \sqrt{\frac{(1.81 \times 10^{19})(26500)(365.25)(24.0)(3.60 \times 10^{3})(3.00 \times 10^{8})}{(1.99 \times 10^{30})}} \quad (1)$$

$$= \underline{4.78 \times 10^{4} \text{ ms}^{-1}} \quad (1)$$

(c) The Sun moves around the black hole (assume circular orbit) with a speed of 2.20×10^2 kms^{-1}. Calculate the centripetal force involved in creating this orbit. **[2 marks]**

$$F = \frac{mv^2}{r}$$

$$= \frac{(1.99\times10^{30})(2.20\times10^5)^2}{(26500)(365.25)(24.0)(3.60\times10^3)(3.00\times10^8)} \quad (1)$$

$$= \underline{3.84\times10^{20}\ \text{N}} \quad (1)$$

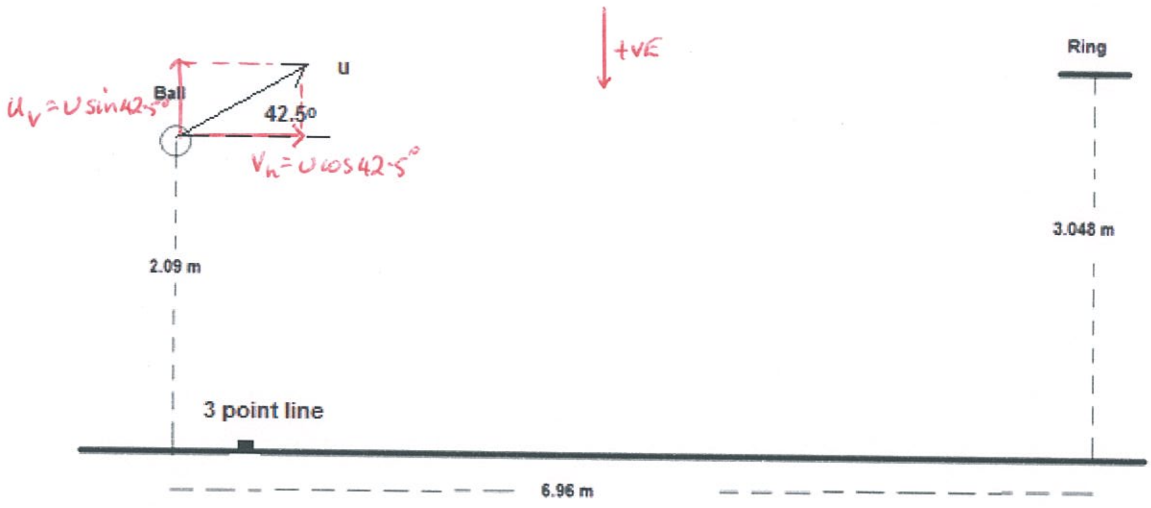
(d) Compare the values of part (b) and (c). Explain why they are different. **[3 marks]**

- Second force is approximately 20 x greater. (1)
- Possible reasons:
  - Mass from the rest of the Milky Way contributes to the force.
  - Dark matter has an effect.
  - Error in estimating the mass of Sagittarius A.
  - Error in estimating distance between objects.

[2 marks for any two or other reasonable possibilities.]

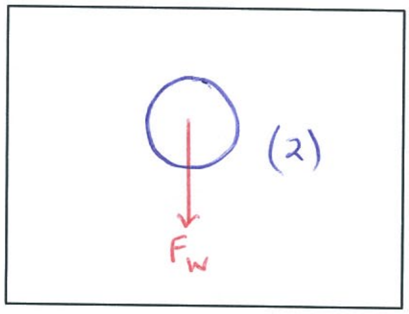
17. **[17 marks]**

The Perth Wildcats basketball team is two points down and Damien Martin has the ball in centre court. He puts up the shot and scores three points.



(a) In the space at right, draw a diagram of the ball showing the force/s acting on it whilst in flight. Assume no air resistance. **[2 marks]**

[1 mark off for each additional force.]



(b) Martin propels the ball at an angle to the horizontal of 42.5°. What is the initial speed of the ball as shown in the diagram? **[6 marks]**

HORIZONTALLY: $v_h = \frac{s_h}{t}$

$\Rightarrow t = \frac{s_h}{v_h} = \frac{6.96}{u \cos 42.5°}$ – ① (1)

VERTICALLY: (1)

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

$v = ?$

$u = -(u \sin 42.5°)\ ms^{-1}$ (1)

$a = 9.80\ ms^{-2}$

$t = ?$

$s = -0.958\ m$ (1)

$\Rightarrow -0.958 = (-u \sin 42.5°)\left(\frac{6.96}{u \cos 42.5°}\right) + \frac{1}{2}\frac{(9.80)(6.96)^2}{u^2(\cos 42.5°)^2}$ (1)

$\Rightarrow -0.958 = -6.378 + \frac{443.5}{u^2}$

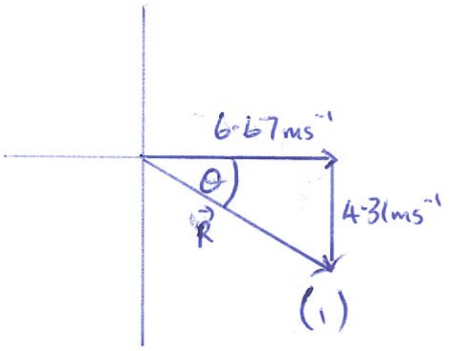
$\Rightarrow \underline{u = 9.05\ ms^{-1}}$. (1)

(c) Calculate the velocity as it passes through the ring in order to score the three points to win the game. **[7 marks]**

HORIZONTALLY: $V_h = 9.05 \cos 42.5^\circ$
$= 6.67 \text{ ms}^{-1}$ (1)

VERTICALLY:
$v = ?$
$u = -(9.05 \sin 42.5^\circ) \text{ ms}^{-1}$ (1)
$a = 9.80 \text{ ms}^{-2}$
$t = ?$
$s = -0.958 \text{ m}$

$v^2 = u^2 + 2as$
$= (-9.05 \sin 42.5^\circ)^2 + 2(9.80)(-0.958)$ (1)
$\Rightarrow v = 4.31 \text{ ms}^{-1}$ down. (1)



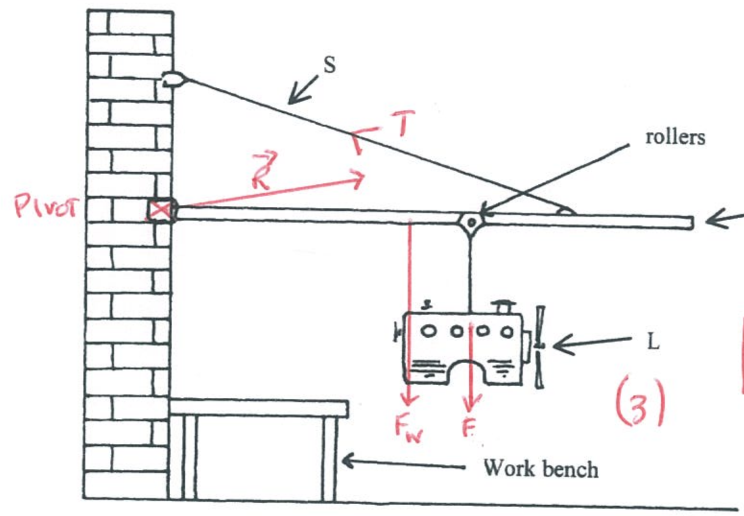
$\vec{R} = \sqrt{(6.67)^2 + (4.31)^2}$
$= 7.94 \text{ ms}^{-1}$ (1)

$\tan\theta = \frac{4.31}{6.67}$
$\Rightarrow \theta = 32.9^\circ$ (1)

$\therefore$ $V = 7.94 \text{ ms}^{-1}$ at 32.9° to the horizontal

18. **[11 marks]**

A simple crane is used in a service station to lift engines (represented as load L) from cars and transfer them to a workbench. Rollers are used so that the mechanic can move the engine from one end of the beam to the other as shown in the diagram. The beam (B) is 2.50 m long, the support wire (S) is attached 0.50 m from the outer end at an angle of 35.0° to the beam.



[1 mark off for each error]

The beam is uniform and has a mass of 38.5 kg. The combined mass of the engine and the rollers is 165 kg. In the current position, the load is 1.50 m from the wall.

(a) On the diagram above, draw all of the forces acting with the load in the position shown. **[3 marks]**

(b) Find the tension in the support cable "S", when the engine is at the position shown. **[3 marks]**

Take moments about the pivot.

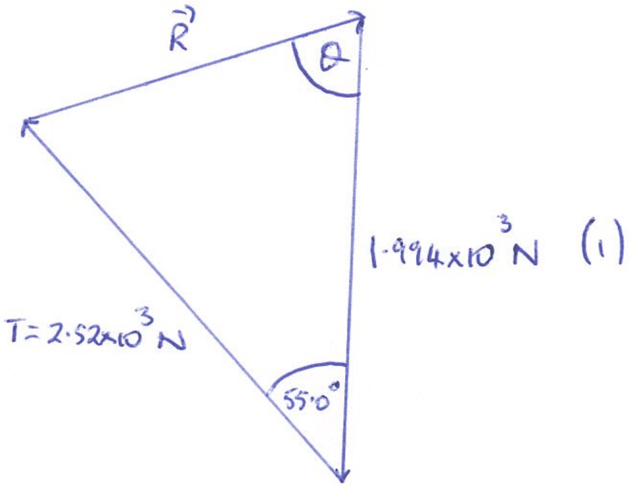
$$\Sigma CM = \Sigma ACM$$

$$\Rightarrow (38.5)(9.80)(1.25) + (165)(9.80)(1.50) = (T\cos 55.0^\circ)(2.00) \quad (2)$$

$$\Rightarrow \underline{T = 2.52 \times 10^3\ N} \quad (1)$$

(c) Find the magnitude and direction of the reaction force that the wall exerts on the beam.

[5 marks]



$$\vec{R} = \sqrt{(2.52\times10^3)^2 + (1.994\times10^3)^2 - 2(2.52\times10^3)(1.994\times10^3)\cos 55.0°} \quad (1)$$

$$= 2.136 \times 10^3 \text{ N} \quad (1)$$

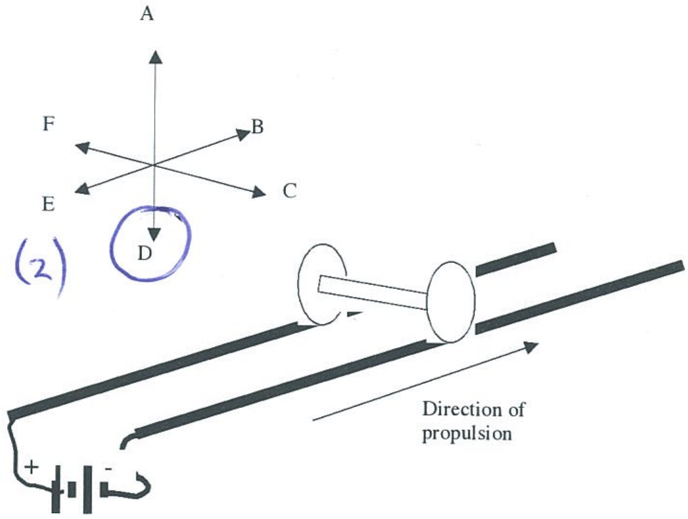
$$\frac{2.136\times10^3}{\sin 55.0°} = \frac{2.52\times10^3}{\sin\theta} \quad (1)$$

$$\Rightarrow \theta = 75.11° \quad (1)$$

$\therefore$ $\vec{R} = 2.14\times10^3$ N at $75.1°$ to the vertical

19. **[14 marks]**

(a) A metal axle from a model railway train is propelled along two live rails as shown in the diagram below.



(i) For the axle to move in the direction shown, a magnetic field of intensity of 4.00×10^{-2} T is applied. ***Circle the direction/letter*** next to the arrow that indicates the direction of the magnetic field.

[2 marks]

(ii) The axle has a mass of 55.0 g and has a length of 4.00 cm. Find its acceleration if the current through the axle is 16.0 A.

[3 marks]

$$F = Il B = ma \quad (1)$$

$$\Rightarrow (16.0)(4.00 \times 10^{-2})(4.00 \times 10^{-2}) = (55.0 \times 10^{-3})a \quad (1)$$

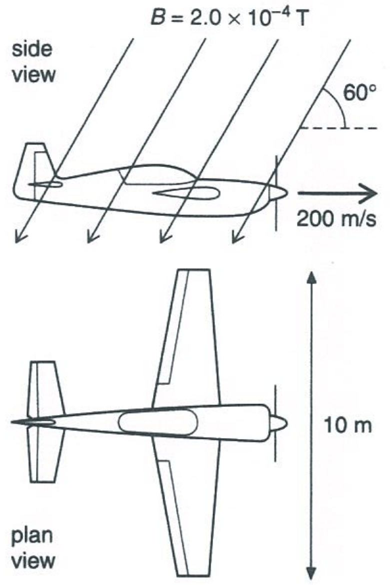
$$\Rightarrow \underline{a = 0.466 \text{ ms}^{-2} \text{ towards B}}. \quad (1)$$

(iii) In fact, the acceleration is somewhat less than that calculated in part (iii). Suggest ***two*** reasons for this.

[2 marks]

- Friction – between the wheels and the rails, and with the air. (1)
- Axle induces a current as it moves, providing an opposing force (application of Lenz's law). (1)

(b) An aeroplane with a wingspan of 10.0 m is flying horizontally at a velocity of 2.00×10^2 ms^{-1} due north in the southern hemisphere. In the region the plane is flying, the Earth's magnetic field is 2.00×10^{-4} T at an angle of 60.0° to the horizontal.



(i) Which component (horizontal or vertical) of the Earth's magnetic field is used to calculate EMF across the wings?

[1 mark]

• vertical (1)

(ii) Find the size of this component of the field.

[2 marks]

$B_v = 2.00 \times 10^{-4} \cos 30.0°$ (1)

$= \underline{1.73 \times 10^{-4} \text{ T}}$ (1)

(iii) Calculate the EMF is induced across the wingtips of the plane.

[2 marks]

$EMF = B l v$

$= (1.73 \times 10^{-4})(10.0)(2.00 \times 10^{2})$ (1)

$= \underline{0.346 \text{ V}}$ (1)

(iv) Could this EMF be used to power the cabin lights? Explain your answer.

[2 marks]

• No (1)

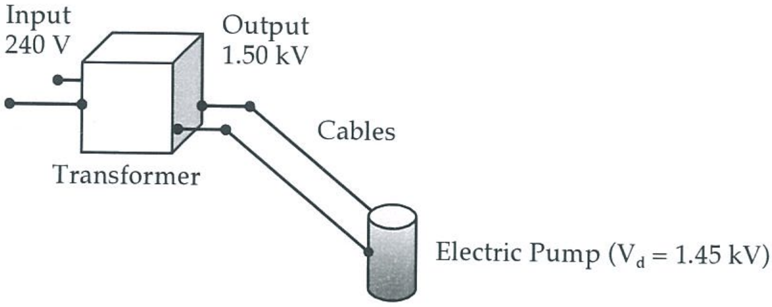
• Choose from:

1 mark for any of these.

- The EMF would vary as the wings move through changing values for B_{EARTH}.
- The EMF is too small to run the lights.
- Any wiring used to complete a circuit would generate an opposing EMF.

20. **[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_{RMS} supply available. A transformer is used to step up the output voltage to 1.50 kV_{RMS}. 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 marks]**

$$\frac{V_P}{V_S} = \frac{N_P}{N_S}$$

$$\Rightarrow N_P = \frac{(2000)(240)}{(1500)} \quad (1)$$

$$= \underline{320 \text{ turns}} \quad (1)$$

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 marks]**

$$P_S = V_S I_S$$

$$\Rightarrow I_S = \frac{6450}{1500}$$

$$= 4.30 \text{ A} \quad (1)$$

$$V_{cables} = V_S - V_{pump}$$

$$= 1500 - 1450$$

$$= \underline{50.0 \text{ V}} \quad (1)$$

$$V_{cables} = I_S R_{cables}$$

$$\Rightarrow R_{cables} = \frac{50.0}{4.30} \quad (1)$$

$$= \underline{11.6\ \Omega} \quad (1)$$

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

[2 marks]

$$P_{cables} = P_{loss} = I_s^2 R_{cable}$$
$$= (4.30)^2(11.6) \quad (1)$$
$$= 214 \text{ W} \quad (1)$$

[Note: Can also use $P_{cables} = V_{cable} I_{cable}$ or $P_{cable} = \frac{V_{cable}^2}{R_{cable}}$]

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

[2 marks]

- Laminated soft iron core - reduces the formation of eddy currents that transform electrical energy into heat.
- Use large diameter wire on the winding carrying the larger current to reduce heat loss.
- Oil cooling or cooling fins to minimise heat build up that could increase the resistance of the windings.

[Any 2 reasonable answers - 1 mark each]

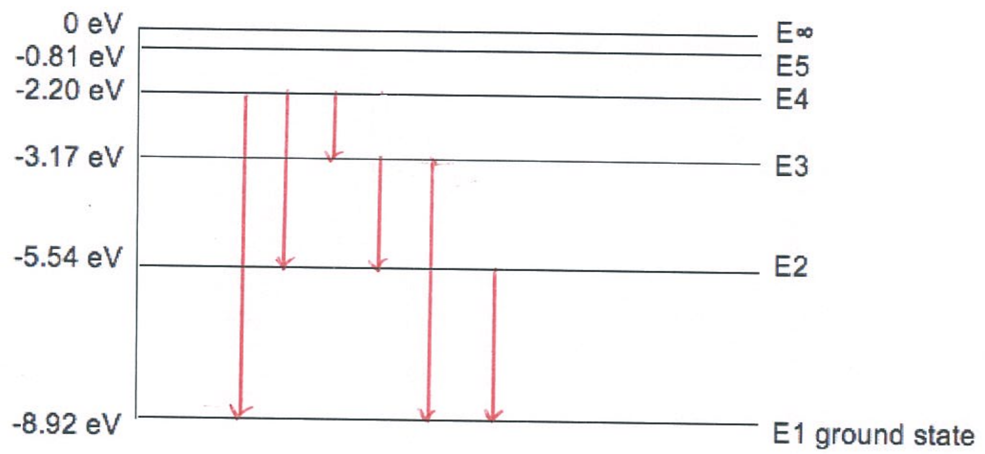
(e) Explain why it is more efficient to transfer electricity to the pump at a high voltage of 1.50 kV rather than 240 V.

[2 marks]

- Power output from the transformer is $P_s = V_s I_s$
  $\Rightarrow$ increasing V_s decreases I_s (1)
- Power loss is given by $P_{loss} = I_s^2 R_{cable}$
  $\Rightarrow$ smaller I_s gives smaller P_{loss}. (1)

21. **[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 mark]**

- No - there is no energy level difference above ground state that exactly matches 6.50eV. (1)

(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 mark]**

Number of lines = 6

(1)

(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 marks]**

Longest $\lambda \Rightarrow$ lowest f, hence lowest energy change.

ie. $E_4 \rightarrow E_3$ (1)

$$E_4 - E_3 = hf = \frac{hc}{\lambda}$$

$$\Rightarrow (-2.20 - (-3.17))(1.60 \times 10^{-19}) = \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{\lambda} \quad (1)$$

$$\Rightarrow \underline{\lambda = 1.28 \times 10^{-6} \text{ m}} \quad (1)$$

(d) For the wavelength you calculated in part (c), state which area of the electromagnetic spectrum this belongs. **[1 mark]**

infra-red. (1)

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 marks]**

[6.10 eV electron can only reach the E_3 level for excitation]

Possible photon energies on de-excitation (eV)	Possible bombarding electron energy after interaction with the atom (eV)
$E_3 - E_1 = -3.17 - (-8.92) = 5.75$ eV	$6.10 - 5.75 = 0.35$ eV
$E_2 - E_1 = -5.54 - (-8.92) = 3.38$ eV	$6.10 - 3.38 = 2.72$ eV
$E_3 - E_2 = -3.17 - (-5.54) = 2.37$ eV	6.10 eV – passes through with no collision.
[1 mark off for each error]	(3)

(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 marks]**

- Each element has a unique set of absorption line frequencies that can be identified in the laboratory. (1)
- The absorption spectra from the stars is compared to these laboratory absorption spectra, identifying the elements in stars. (1)

(g) The line absorption spectrum is also useful to determine the speed of a galaxy. Explain the fundamental principles of this technique. **[2 marks]**

- Light from galaxies moving away from Earth, causing light to have longer wavelengths. The absorption lines appear to move towards the red end of the spectrum (called red-shift). (1)
- The amount of red shift can be used to determine the recessional speed (using $v_{recessional} = \frac{\Delta\lambda}{\lambda} c$). (1)

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SECTION C: Comprehension and Interpretation

Marks Allotted: 36 marks out of 180 marks total.

Read the passage carefully and answer all of the questions at the end. Candidates are reminded of the need for correct English and clear and concise presentation of answers. Diagrams (sketches), equations and/or numerical results should be included where appropriate.

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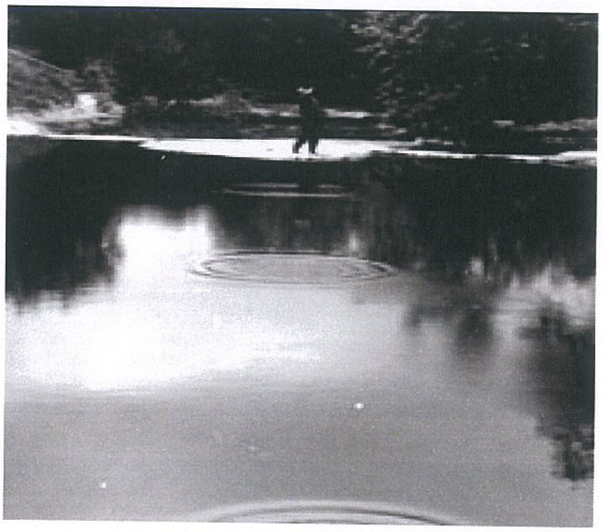
22. **[18 marks]**

The Physics of Skipping Stones

(Adapted from: The Mystery of the Skipping Stone, Physics World Vol 19 No 2 February 2006 Bocquet L and Clanet C)



Champion stone skipper Kurt Steiner has been stopped going through customs with bags full of rocks and always carries a five-sided stone in his pocket.

In 2002, an American named Kurt Steiner set a new world record when he threw a stone across a river in Pennsylvania and made it bounce 40 times. Most people will not have been quite as successful as Steiner, but many will be familiar with the principle of stone skipping: to throw a flattish stone across the surface of a body of water so that it bounces as many times as possible.

It has been shown that the formula that relates collision time (of a stone with the water surface) and velocity for a stone is given by:

$$T = \left(\frac{MR}{\rho S}\right)\left(\frac{1}{v}\right)$$

where:
- T is the collision time (s)
- M is the mass of the stone (kg)
- R is the radius of the stone (m)
- ρ is the density of water (kgm^{-3})
- S is the cross-sectional area of the stone (m^2)
- v is the velocity of the stone (ms^{-1})

The data below pertains to a stone of dimensions:

M = 15 g; R = 3.0 cm; S = 3.6 x 10^{-6} m^2 [SIG. FIG - 1 mark]

Collision Time (ms)	Velocity (ms^{-1})	$(\text{VELOCITY})^{-1}$ $(m^{-1}s)$ (1)
56	2	0.50
37	3	0.33
22	5	0.20
16	7	0.14
12	9	0.11
10	11	0.091
7.5	15	0.067

(1)

(a) Given the formula on the previous page, what should you plot to obtain a linear graph? **[2 marks]**

Plot T versus v^{-1} (2)

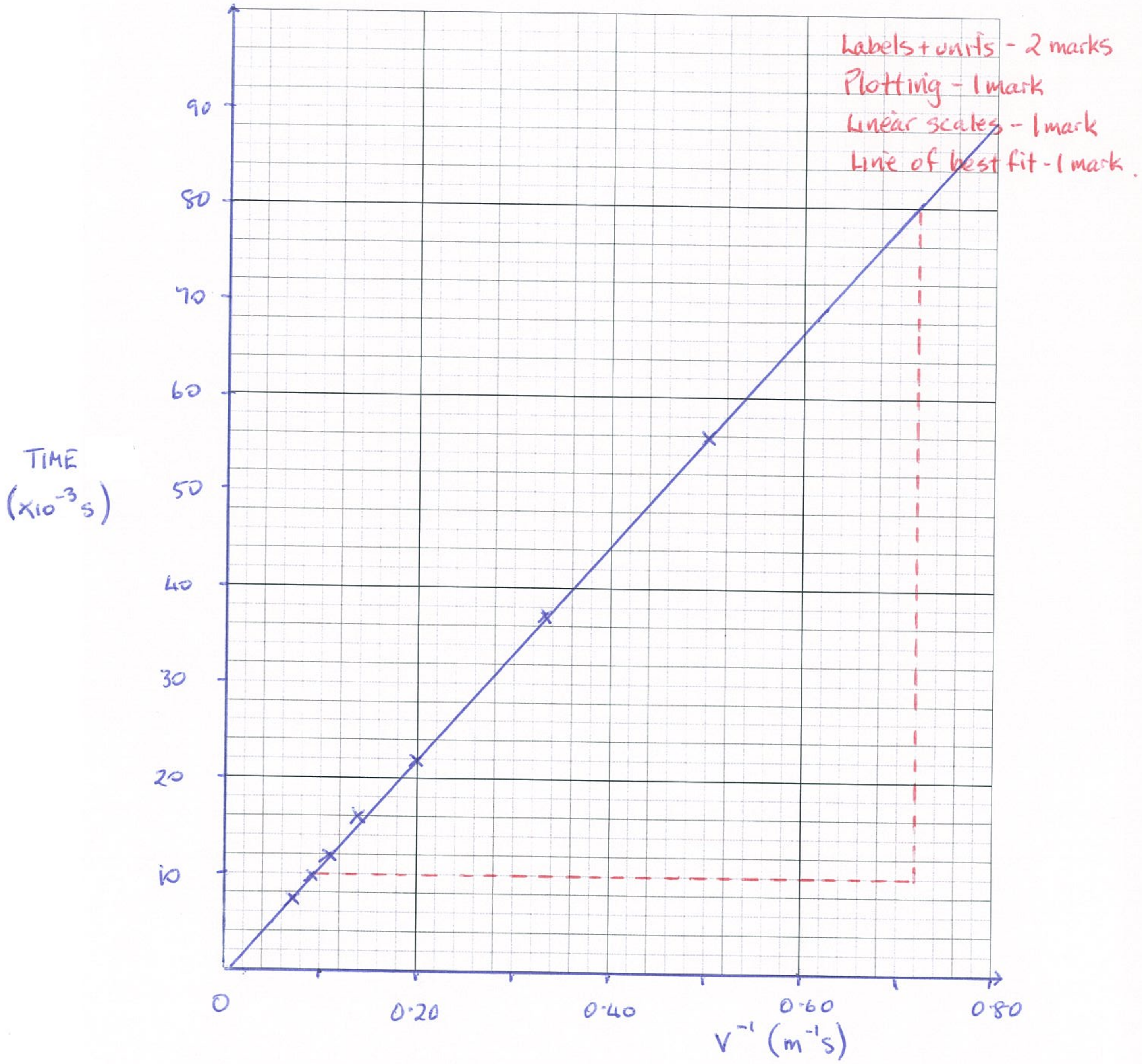
(b) Use the third column in the table to process the given data to allow you to plot a linear graph. Label the column with appropriate units. **[3 marks]**

(c) Plot the graph on the graph paper provided on the next page. **[5 marks]**

(d) Determine the gradient of your line. **[2 marks]**

$$\text{gradient} = \frac{(80-10)\times 10^{-3}}{(0.72-0.09)} \quad (1)$$

$$= \underline{0.11\ m} \quad (1)$$



(e) Use the gradient of your curve to determine the density of water. **[2 marks]**

$$\text{gradient} = \frac{(80-10)\times10^{-3}}{(0.72-0.09)}$$

$$= 0.11 \text{ m}$$

$$T = \frac{MR}{\rho S}\cdot\frac{1}{v}$$

$$\Rightarrow \text{gradient} = \frac{T}{1/v} = \frac{MR}{\rho S}$$

$$\Rightarrow \rho = \frac{MR}{(\text{gradient})S} \quad (1)$$

$$= \frac{(15\times10^{-3})(3.0\times10^{-2})}{(0.11)(3.6\times10^{-6})}$$

$$= \underline{1.1\times10^{3}\ \text{kgm}^{-3}} \quad (1)$$

Experiments have also shown that a bouncing stone must spin with a certain minimum rotational velocity if it is to be stable i.e. if the angle between the plane of the stone and the water surface is to remain constant. To remain stable, a stone typically needs to rotate at least once during its collision time. If this rotation does not take place, the stone's collision becomes quite complex and a second bounce becomes much less likely.

(f) If a stone is to rotate at least once during its collision time, what is the minimum spin velocity required? (***Hint – this does not require a numerical answer.***) **[1 mark]**

- $V = \frac{1}{T}$, where T = collision time. (1)

(g) People, who are good at stone skipping, intuitively rotate stones with a flick from the finger. Why do they do this? **[1 mark]**

- Gives the stone increased spin (or rotational velocity)
- Increase the likelihood that the stone rotates once during the collision.

[Either - 1 mark]

Researchers found that, surprisingly, the stone does not slow down during the skipping process, but rather the stone's trajectory 'flattens' with time. This is because the angle with which the stone moves relative to the water dictates that the stone displaces more water when it moves down than rises. This results in a smaller transfer of momentum in the latter stage of each skip and therefore in reduced lift. When the stone no longer has enough energy to jump, it simply surfs over the water before finally sinking.

The number of skips is also determined by the type of stone used and the angle at which it is thrown. And as all stone skippers know, the flatter the stone, the better!

(h) The passage describes the stone's trajectory as 'flattening'. Explain what this means with regards to changes in the horizontal and vertical components of the velocity. **[1 mark]**

- Horizontal velocity stays the same.
- Vertical velocity decreases.

(1)

(i) Why would there be reduced lift in the latter stages of the motion? **[1 mark]**

- Stone displaces more water on the way down than as it rises.
- The greater the displacement of water, the greater the force on the stone and the greater the change in momentum.
- Vertical component of the velocity decreases with each skip.

[Any of these - 1 mark]

23. **[18 marks]**

Gravitational Red Shift

Red shift is often explained as being similar to the Doppler Effect. An example of the Doppler Effect is the alteration in sound that occurs when a car passes. As the car approaches the observer the sound of the engine is higher than after the car has passed.

Cosmological Red shift and Blue shift occurs in a similar way. Instead of sound being emitted by a car moving towards or away from you however, it is light being emitted by a star as it moves towards or away from the earth. If the star is moving towards the Earth, all of the frequencies emitted will be slightly increased. This is called Blue shift. Conversely, if the star is moving away from the earth all of the frequencies emitted will be slightly lowered. This is called Red shift.

The formula for cosmological red-shift is:

$$f_L = \left(\sqrt{\frac{c-v}{c+v}}\right) f_S$$

where:

Symbol	Definition	Units
f_L	Frequency observed by the person on earth.	Hz
f_S	Frequency of the source	Hz
c	Speed of light in a vacuum (3×10^8 ms^{-1})	ms^{-1}
v	Speed of the object producing the electromagnetic radiation (light) v = away from earth → v = positive. v = towards the earth → v = negative.	ms^{-1}

Instead of considering blue and red shift purely as a frequency effect, a better understanding can be found by consider the energy of the situation. When photons are blue shifted, they have a higher frequency. This means they have more energy. Red shift reduces the energy that a photon has. This can be considered analogous to kinetic energy.

Let's do 3 thought experiments ...

i) A stationary person throws a 100 g ball forwards at 10 ms^{-1}.

ii) A person riding a bike forwards at 5 m s^{-1} throws a 100 g ball forwards at 10 ms^{-1}.

iii) A person riding a bike backwards at 5 m s^{-1} throws a 100 g ball forwards at 10 ms^{-1}.

The velocities of each ball are 10 m s^{-1}, 15 m s^{-1} and 5 m s^{-1} respectively.

The kinetic energies of each ball are 5.0 J, 11.25 J and 1.25 J respectively.

In the above thought experiment, we see that the velocity of the bike affected the kinetic energy of the ball. When the movement of the bike was in the same direction as the ball, the kinetic energy increased and when they were in opposite directions it decreased.

Light from a star is actually a stream of photons being thrown from the star out into space. Photons have different properties to a ball however and so the formula for calculating the energy of a photon will be different from the energy of a ball. Both of these energies (ball or photon) can be regarded as kinetic energies.

So to summarise the story so far we see that the kinetic energies of particles can be modified by

Kinetic energies of objects can also be modified by gravity. When a ball is thrown up into the air, the kinetic energy of the ball drops as its speed decreases. The potential energy of the ball increases as the distance of separation between the centre of the earth and the centre of the ball increases.

It is not surprising to discover therefore that gravity can also alter the energy of a photon. Gravity cannot alter the speed at which light / photons travel. This speed is constant regardless of the situation. If we cannot alter speed, we will have to alter another variable that is related to photon energy. We will alter frequency.

When photons are emitted by stars, they have to escape the gravitational field of the star. This means that as the photon travels outwards it will lose "kinetic" energy and its frequency will be progressively red shifted. The stronger the gravitational field of the star, the more red shifted the photons produced by the star. This is called Gravitational Red Shift.

The formula for gravitational red shift is:

$$f_L = f_S \left(1 - \frac{GM}{Rc^2}\right)$$

where:

Symbol	Definition	Units
f_L	Frequency of the photon observed by the person outside stars gravitational field.	Hz
f_S	Frequency of the photon observed in the stars gravitational field	Hz
c	Speed of light in a vacuum (3×10^8 ms^{-1})	ms^{-1}
G	The gravitational constant (6.67×10^{-11} Nm^2kg^{-2})	Nm^2kg^{-2}
M	Mass of the star.	kg
R	Distance from the centre of the star.	m

Let's suppose the "kinetic" energy required to escape a particular star's gravitational field is larger than the energy of the most energetic photon. Based on this logic, the photon will not escape. In this situation, the star will be called a black hole.

(a) State ***TWO*** similarities and ***TWO*** differences between the gravitational red shift of a photon and the ionisation energy of an electron and atom. **[4 marks]**

	Gravitational Red Shift	Ionisation Energy
Similarities	• Similar fields – gravitational potential and ionisation energy lost. (1) • There is a minimum energy required to escape.	
	• Energy loss due to escape • Work done in escaping the fields.	(1)
Differences	• Loss of kinetic energy.	• Loss of frequency (1)
	• Virtual particle	• Mass particle. (1)

(b) Based on cosmological red shift, what will be the frequency of an originally blue photon of wavelength 500 nm that that has been emitted from an electric torch moving away from an astronaut in empty space at a speed of 20,000 kms^{-1}?

[3 marks]

$$c = f\lambda$$

$$\Rightarrow f = \frac{3 \cdot 00 \times 10^{8}}{2 \cdot 00 \times 10^{7}}$$

$$= 6 \cdot 00 \times 10^{14} \text{ Hz} \quad (1)$$

$$f_L = \left(\sqrt{\frac{c - v}{c + v}}\right) f_s$$

$$= \left(\sqrt{\frac{3 \cdot 00 \times 10^{8} - 2 \cdot 00 \times 10^{7}}{3 \cdot 00 \times 10^{8} + 2 \cdot 00 \times 10^{7}}}\right)(6 \cdot 00 \times 10^{14}) \quad (1)$$

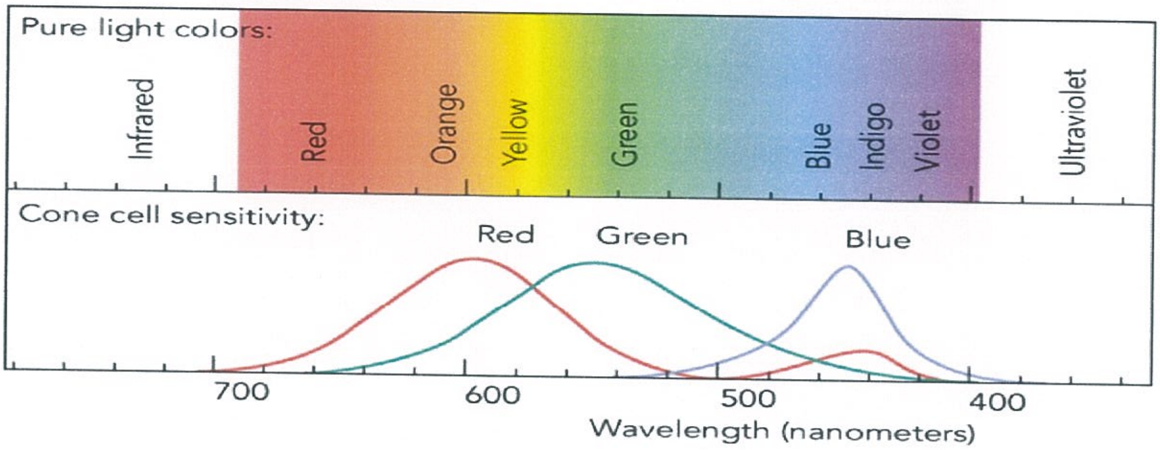
$$= \underline{5 \cdot 61 \times 10^{14} \text{ Hz}} \quad (1)$$

(c) To which part of the electromagnetic spectrum does the photon received by the astronaut belong? State the colour if it is within the visible spectrum using the chart below. 2 [~~1~~ mark]

$$\lambda = \frac{c}{f} = \frac{3.00\times10^{8}}{5.61\times10^{14}} = 5.35\times10^{-7}\text{ m} = 535\text{ nm}. \quad (1)$$

$\therefore$ green (1)

The visible spectrum:



(d) The astronaut returns to Earth and is looking through a telescope at the torch, which is still flying away one hour later. Explain ***two*** ways in which the photons from the torch will now look different from your answer to part (b). **[2 marks]**

- Dimmer – torch is further away.
- Twinkles – light is passing through Earth's atmosphere.
- Frequency increased slightly by Earth's gravitational field.

[Any 2 - 1 mark each]

(e) Using the gravitational red shift formula shown on page 34, calculate the new frequency of a 9.00×10^{15} Hz photon originating at the surface of our Sun. The new frequency is received/measured in empty space outside the Sun's gravitational field. 3 [~~4~~ marks]

$$f_L = f_s\left(1 - \frac{GM}{Rc^2}\right)$$

$$= 9.00\times10^{15}\left(1 - \frac{(6.67\times10^{-11})(1.99\times10^{30})}{(6.96\times10^{8})(3.00\times10^{8})^2}\right) \quad (2)$$

$$= \underline{9.00\times10^{15}\text{ Hz}} \quad (1)$$

(f) Would Edwin Hubble need to take gravitational red shift into account in formulating his theory of an expanding universe? Explain why or why not. **[2 marks]**

- Yes (1)
- light from large-mass stars is increasingly red-shifted and so appears to be receding faster. (1)

(g) A satellite orbiting the earth is set to receive signals at a frequency of 3.00×10^6 Hz. Should the signal be sent from the transmitter at the surface of the Earth at a frequency above, equal to or below 3.00×10^6 Hz, taking into account gravitational red shift? Do not calculate your answer. **[2 marks]**

- Above. (1)
- The photon will lose frequency as it leaves Earth's gravitational field. (1)

END OF EXAMINATION

ADDITIONAL WORKING SPACE

ADDITIONAL WORKING SPACE