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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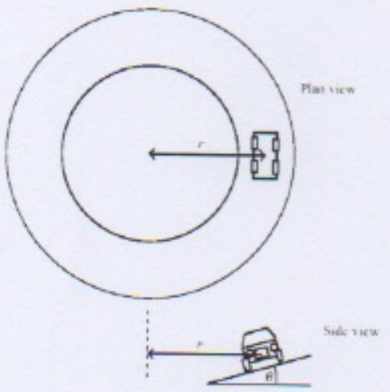
15. **[14 marks]**

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)

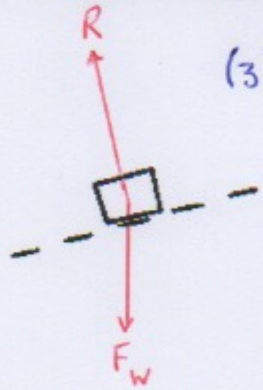


Does Tom's car have an acceleration? Explain your answer.

[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]

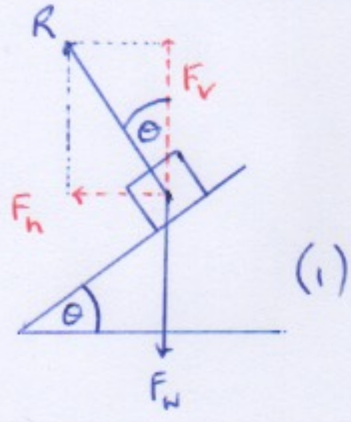
(c) Is there a resultant force acing on the car? Explain

[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]**

$$F = \frac{G m_1 m_2}{r^2}$$

$$= \frac{(6.67\times10^{-11})(1.99\times10^{30})(4.31\times10^{9})(1.99\times10^{30})}{[(26500)(365.25)(24.0)(3.60\times10^{3})(3.00\times10^{8})]^2} \quad (2)$$

$$= 1.81\times10^{19}\ \text{N} \quad (1)$$

[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]**

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

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

$$= \sqrt{\frac{(1.81\times10^{19})(26500)(365.25)(24.0)(3.60\times10^{3})(3.00\times10^{8})}{(1.99\times10^{30})}} \quad (1)$$

$$= \underline{4.78\times10^{4}\ \text{ms}^{-1}} \quad (1)$$

(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]**

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

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

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

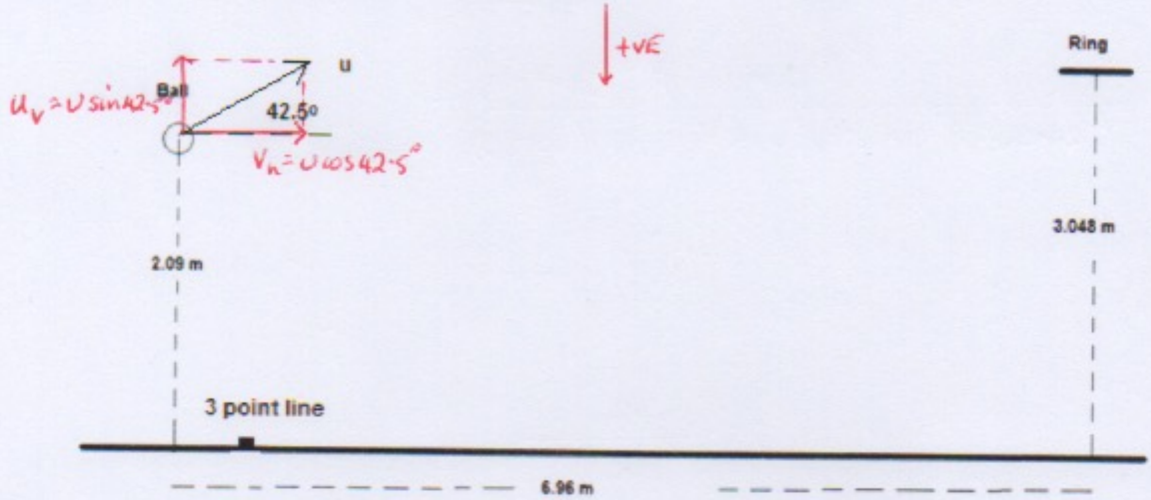
(d) Compare the values of part (b) and (c). Explain why they are different. **[3 marks]**

- Second force is approximately 20 × 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.]

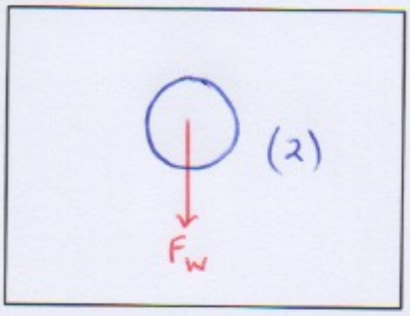
17. **[17 marks]**

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)

(1)

VERTICALLY:

$v = ?$

$u = -(u \sin 42.5°)\ ms^{-1}$ (1)

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

$t = ?$

$s = -0.958\ m$ (1)

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

$\Rightarrow -0.958 = (-\cancel{u}\sin 42.5°)\left(\frac{6.96}{\cancel{u}\cos 42.5°}\right) + \frac{1}{2}(9.80)\frac{(6.96)^2}{u^2(\cos 42.5°)^2}$ (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: $V_h = 9.05 \cos 42.5^\circ$

$= 6.67\ ms^{-1}$ (1)

VERTICALLY:

$V = ?$

$u = -(9.05 \sin 42.5^\circ)\ ms^{-1}$ (1)

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

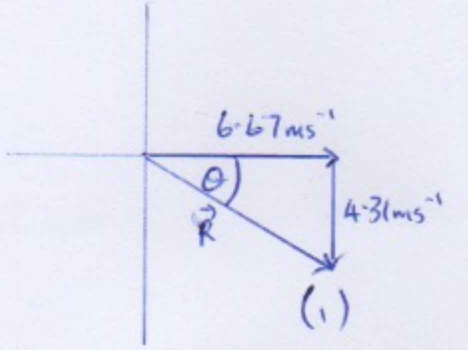
$t = ?$

$s = -0.958\ m$

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

$= (-9.05 \sin 42.5^\circ)^2 + 2(9.80)(-0.958)$ (1)

$\Rightarrow v = 4.31\ ms^{-1}$ down. (1)



$\vec{R} = \sqrt{(6.67)^2 + (4.31)^2}$

$= 7.94\ ms^{-1}$ (1)

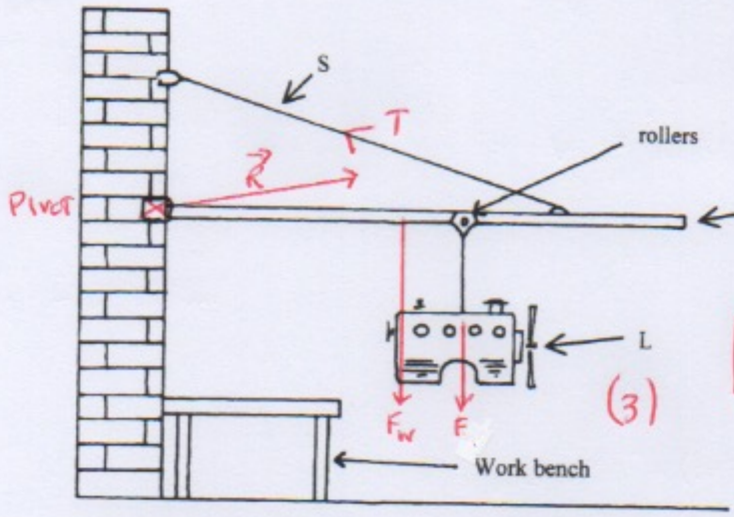
$\tan\theta = \frac{4.31}{6.67}$

$\Rightarrow \theta = 32.9^\circ$ (1)

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

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.

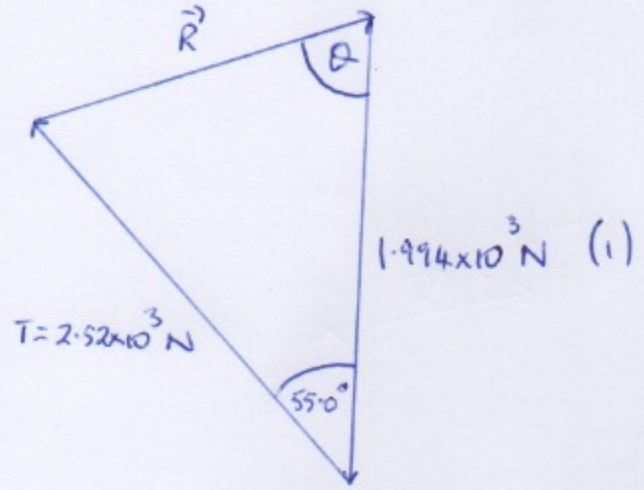
$$\Sigma CM = \Sigma ACM$$

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

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

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

[5 marks]



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

$$= 2.136\times10^{3} \text{ N} \quad (1)$$

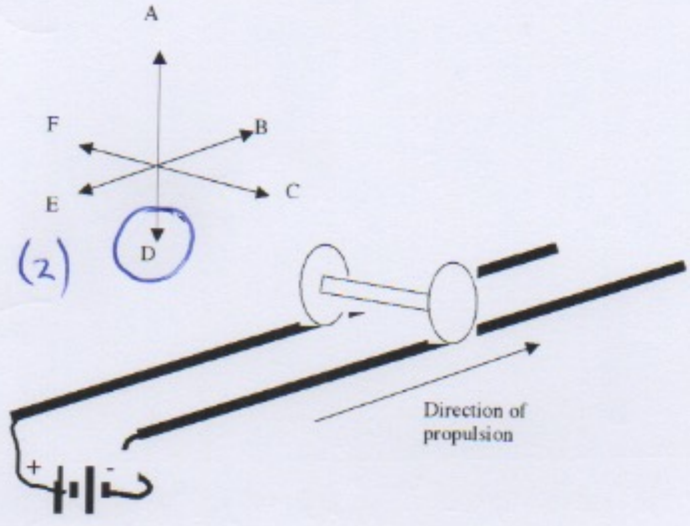
$$\frac{2.136\times10^{3}}{\sin 55.0°} = \frac{2.52\times10^{3}}{\sin\theta} \quad (1)$$

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

$\therefore \vec{R} = 2.14\times10^{3}$ 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]

$$F = I\ell B = ma \quad (1)$$

$$\Rightarrow (16.0)(4.00\times10^{-2})(4.00\times10^{-2}) = (55.0\times10^{-3})a \quad (1)$$

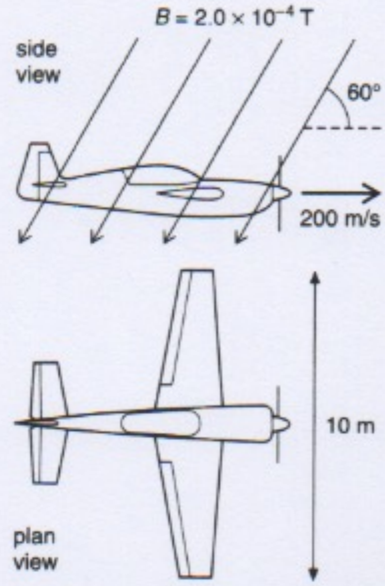
$$\Rightarrow \underline{a = 0.466\ \text{ms}^{-2}\ \text{towards B}} \quad (1)$$

(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]

$$B_v = 2.00 \times 10^{-4} \cos 30.0^\circ \quad (1)$$
$$= \underline{1.73 \times 10^{-4}\ T} \quad (1)$$

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

[2 marks]

$$EMF = B\ell v$$
$$= (1.73 \times 10^{-4})(10.0)(2.00 \times 10^{2}) \quad (1)$$
$$= \underline{0.346\ V} \quad (1)$$

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

[2 marks]

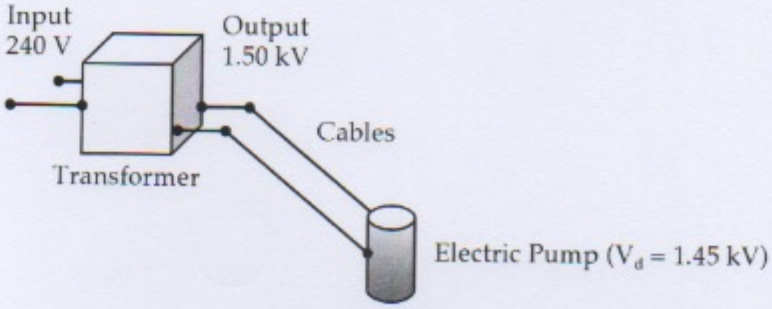
- no (1)
- Choose from:

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]**

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

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

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

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]**

$$P_s = V_s I_s$$

$$\Rightarrow \quad I_s = \frac{6450}{1500}$$

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

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

$$= 1500 - 1450$$

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

$$V_{cables} = I_s R_{cables}$$

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

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

(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]

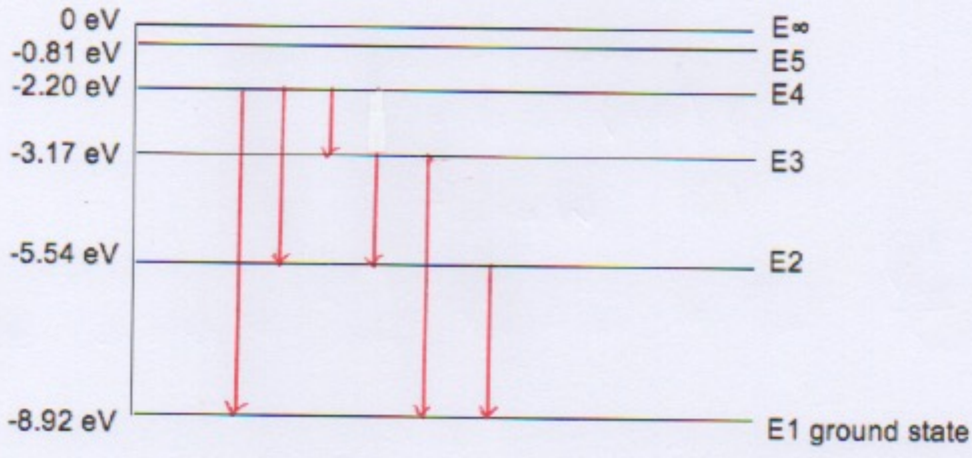
(e) Explain why it is more efficient to transfer electricity to the pump at a high voltage of 1.50 kV rather than 240 V.

[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

i.e. $E_4 \rightarrow E_3$ (1)

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

$$\Rightarrow (-2.20-(-3.17))(1.60\times10^{-19}) = \frac{(6.63\times10^{-34})(3.00\times10^{8})}{\lambda} \quad (1)$$

$$\Rightarrow \underline{\lambda = 1.28\times10^{-6}\ m} \quad (1)$$

(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)