Candidate Session Number

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SUGGESTED SOLUTIONS

**ST ANDREW'S CATHEDRAL SCHOOL**
**FOUNDED 1885**

# Year 12 IB Physics
# Standard Level

## Paper 2

## 2021 Semester 2 Examination

Wednesday 18 August 2021

1 hour 15 minutes

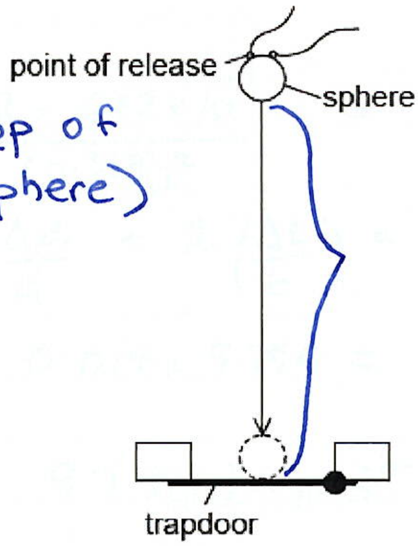
$\frac{75 \text{ minutes}}{50 \text{ marks}} = 1.5$ minutes per mark

**Instructions to candidates**

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all questions.
- Give any equations used.
- Show ALL working including the substitution of values into equations.
- Answers must be written in the answer boxes provided.
- A calculator is required for this paper.
- A clean copy of the **physics data booklet** is required for this paper.
- The maximum mark for this examination paper is **[50 marks]**

**Answer all questions. Answers must be written in the answer boxes provided.**

**1.** To determine the acceleration due to gravity, a small metal sphere is dropped from rest and the time it takes to fall through a known distance and open a trapdoor is measured.




(top of sphere)

Distance fallen
= (distance from point of release)
− (diameter of sphere)

The following data are available.

Diameter of metal sphere = 12.0 ± 0.1 mm
Distance between point of release and trapdoor = 654 ± 2 mm
Measured time for fall = 0.363 ± 0.002 s

(a) Determine the distance fallen by the sphere, in m, including an estimate of the absolute uncertainty in your answer. [1]

Distance fallen = (654 ± 2 mm) − (12.0 ± 0.1 mm)
= 642 ± 2.1 mm (1)
= $(642 \pm 2) \times 10^{-3}$ m

correct - but 1 mark awarded if absolute uncertainties are added.

(This question continues on the following page)

642 ± 2 mm

same accuracy as uncertainty

1 sig. fig



1

**(Question 1 continued)**

(b) Using the following equation [3]

$$acceleration\ due\ to\ gravity = \frac{2 \times distance\ fallen\ by\ sphere}{(measured\ time\ to\ fall)^2}$$

calculate the acceleration due to gravity including an estimate of the absolute uncertainty in your answer.

$g = \frac{2 \times 642 \times 10^{-3}}{(0.363)^2} = 9.744\ m\,s^{-2}$ (1)

Must have unit

$\frac{\Delta g}{g} = \frac{\Delta d}{d} + 2\left(\frac{\Delta t}{t}\right) = \frac{2}{642} + 2\left(\frac{0.002}{0.363}\right) = 0.014$

$\therefore \Delta g = 0.014 \times 9.744 = 0.14 = 0.1\ m\,s^{-2}$ (1)

1 sig fig

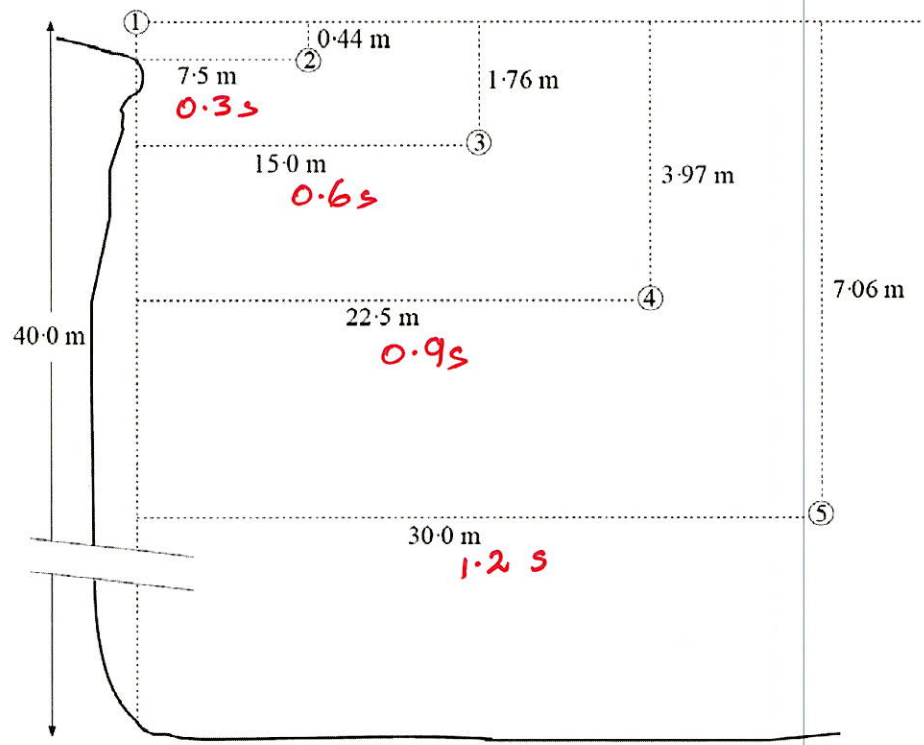
$\therefore g = \underbrace{9.7 \pm 0.1}\ m\,s^{-2}$ (1)

to same accuracy



3

**2.** A ball is thrown horizontally from the top of a cliff 40·0 m high. The position of the ball is shown at five points on its path. Position 1 is the point where it leaves the thrower's hand. The time interval in moving from any position to the next is 0·3 s. The diagram is not to scale. Air resistance is negligible.




(a) How far from the bottom of the cliff does the ball land? [2]

Horizontal distance

$S_H = u_H \times t$

$u_H = \frac{30}{4\times0.3} = 25\ ms^{-1}$ (1)

Find time to fall 40.0 m vertically

$S_v = \cancel{u_v t} + \frac{1}{2} a_v t^2$

$t^2 = \frac{2 S_v}{a_v} = \frac{2\times(-40)}{-9.81} = 8.15$

$t = 2.86\ s$

Data (vertical)

$a = -9.81\ ms^{-2}$

$s = -40.0m$

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

$t = ?$

$S_H = 25 \times 2.86 = 71.4\ m$ (1)

(b) At what speed does the ball hit the ground? [2]

use vertical data

from (a)

$V_v = u_v + a_v t$

$= 0 + (-9.81)\times 2.86$

$= 28\ ms^{-1}$

Using given data

$V_v^2 = u_v^2 + 2 a_v s_v$

$= 0 + 2(-9.81)(-40m)$

$= 784.8\ m^2s^{-2}$

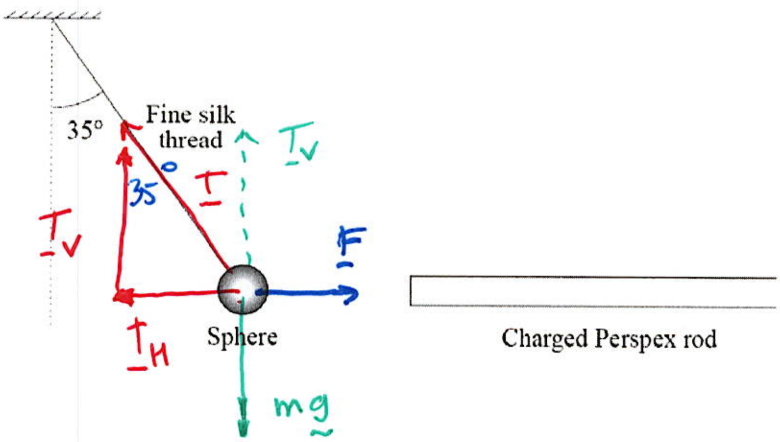
$V_v = 28\ ms^{-1}$ (1)

$\therefore V = \sqrt{V_H^2 + V_v^2} = \sqrt{25^2 + 28^2} = 37.5\ ms^{-1}$ (1)



4

3. A small sphere of mass $2{\cdot}00 \times 10^{-3}$ kg is held in a fixed position by a fine silk thread and the force $F$ due to a charged perspex rod, as shown in the diagram.




(a) Calculate the tension in the thread. [2]

Vertical component of tension = weight of shpere

$T \cos 35° = mg$

$T = \frac{mg}{\cos 35} = \frac{2 \times 10^{-3} \times 9{\cdot}81}{\cos 35} = 0{\cdot}024$ N

$= 2{\cdot}4 \times 10^{-2}$ N

(b) Calculate the magnitude of the electrostatic force $F$. [1]

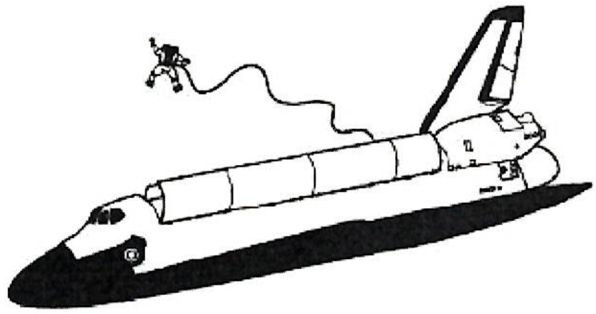
$F = T_H = T \sin 35° = 2{\cdot}4 \times 10^{-2} \times \sin 35°$

$= 1{\cdot}4 \times 10^{-2}$ N



3

**4.** The diagram below shows an astronaut undertaking a spacewalk. The astronaut is tethered by a rope to a spacecraft of mass $4.0 \times 10^4$ kg. The spacecraft is moving at constant velocity before the astronaut pushes away from it.



Total momentum is constant.

The astronaut and spacesuit have a total mass of 130 kg. The change in velocity of the astronaut after pushing off is $1.80\ \text{m s}^{-1}$.

(a) Determine the change in velocity of the spacecraft. [2]

$\Delta p$ of astronaut $= m\Delta v = 130\ \text{kg} \times 1.80\ \text{m s}^{-1} = 234\ \text{kg m s}^{-1}$

Conservation of momentum: $\Delta \underset{\sim}{p}_{spacecraft} = -\Delta \underset{\sim}{p}_{astronaut}$

$\therefore m_s \Delta \underset{\sim}{v}_s = -234\ \text{kg m s}^{-1}$

$\therefore \Delta \underset{\sim}{v}_s = \dfrac{-234\ \text{kg m s}^{-1}}{4 \times 10^4\ \text{kg}} = -5.85 \times 10^{-3}\ \text{m s}^{-1}$ (opposite to direction of astronaut's $\Delta \underset{\sim}{v}$)

(b) The astronaut pushes on the side of the spacecraft for 0.60 s. Calculate the average power developed by the astronaut. [2]

$\bar{P} = \dfrac{\Delta E_K}{t} \left(\dfrac{\text{work}}{\text{time}}\right) = \dfrac{\frac{1}{2} m \Delta v^2}{0.6\ \text{s}} \Rightarrow \underbrace{\dfrac{0.5 \times 130 \times (1.80)^2}{0.6}}_{\Delta E_k\ \text{astronaut}} + \underbrace{\dfrac{0.5 \times 4 \times 10^4 \times (5.85 \times 10^{-3})^2}{0.6}}_{\Delta E_k\ \text{spacecraft}}$

$= 351\ \text{W} + 1\ \text{W}$

$= 352\ \text{W}$

Alternatively: Use $E_K = p^2/2m$

$\Delta E_K = \Delta E_{astronaut} + \Delta E_{spaceship} = \dfrac{p^2}{2m_{astronaut}} + \dfrac{p^2}{2M_{spacecraft}}$

$= \dfrac{(234)^2}{(2 \times 130)} + \dfrac{(234)^2}{2 \times 4 \times 10^4} = \boxed{211.28\ \text{J}}$

$\therefore \boxed{P = \dfrac{\Delta E_K}{t} = \dfrac{211.28\ \text{J}}{0.6\ \text{s}} = 352\ \text{W}}$

4

**5.** In an experiment to determine the efficiency of a 240 V, 2000 W electric kettle, a student boiled water and recorded the following results.

| | |
|---|---|
| Mass of water | 1.2 kg |
| Initial temperature of water | 25 °C |
| Time taken to reach 100 °C | 3 minutes 30 seconds |

= 210 s

The following data are available.

Specific heat capacity of water = 4.186 kJ $kg^{-1}$ $K^{-1}$ $4.186 \times 10^3$ J $kg^{-1}$ $K^{-1}$

Specific latent heat of vaporisation of water = 2.257 MJ $kg^{-1}$ $2.257 \times 10^6$ J $kg^{-1}$

(a) Determine the amount of energy absorbed by the water. [1]

$\Delta E_w = m_w c_w \Delta T_w = 1.2 \times 4.186 \times 10^3 \times 75$ $\Delta T = 75$ K $= 75$ °C

$= 3.767 \times 10^5$ J

(b) Determine the amount of electrical energy supplied ~~by~~ to the kettle. [1]

$E = P \times t = \underset{W}{2000} \times \underset{s}{210} = 4.20 \times 10^5$ J

(c) Calculate the efficiency of the kettle. [1]

$$\text{Efficience} = \frac{\text{useful energy output}}{\text{energy input}} = \frac{3.767 \times 10^5 \text{ J}}{4.20 \times 10^5 \text{ J}}$$

$= 0.9$ OR 90%

**(This question continues on the following page)**

Note: Q numbering omitted Q6.

3

5

(Question ~~1~~ continued)

after it is switched on

(d) Determine the time required for the kettle to boil dry if it operates at the efficiency calculated in (c).

[3]

Energy required to vaporise water $= mL = 1.2 \times 2.257 \times 10^6$ J $= 2.7 \times 10^6$ J

* Total $Q = 3.0851\ 10^6$ J (1)

2000 W kettle at 90% efficiency = (1) 1800 W $= \frac{Q}{t} \Rightarrow t = \frac{Q}{1800}$

$\therefore$ time to vaporise water $= \frac{3.0851 \times 10^6}{1800} = 1714$ s (1)

(No need to add 210 s for full marks)

$$\text{* Total } Q = Q_{\text{raise temp}} + Q_{\text{vaporise}}$$
$$= (3.767 \times 10^5) + (2.708 \times 10^6)$$
$$= 3.0851 \times 10^6 \text{ J}$$

- If students only calculate the time taken to completely vaporise the water:

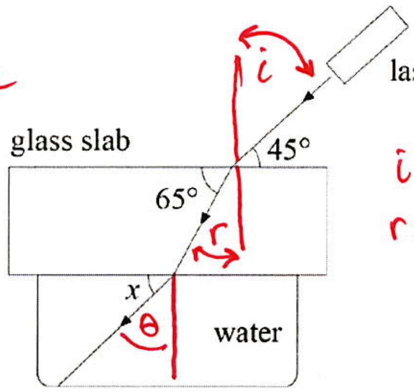
$$t = \frac{Q_{vap}\,(J)}{1800\,(W)} = \frac{2.708 \times 10^6}{1800} = \boxed{1504\ s.}$$



/3

**7.** A student passed a beam of laser light of wavelength 633 nm through a glass slab into some water. She recorded the information shown in the diagram below.

For equations given, Angles are measured to the NORMAL.




$n_{air} = 1$

$i = 45° \ (= \theta_1)$

$r = 25° \ (= \theta_2)$

DATA BOOKLET

$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1} \Rightarrow \frac{n_2}{n_1} = \frac{\sin\theta_1}{\sin\theta_2}$

(a) Show that the refractive index of glass for the laser light is 1.67. [2]

$\frac{n_2}{n_1} = \frac{\sin\theta_1}{\sin\theta_2} = \frac{\sin 45}{\sin 25} = 1.67$ (1)

$n_2 = n_{glass}$

$n_1 = n_{air} = 1$

DATA
$\theta_1 = 45°$
(1) $\theta_2 = 25°$
$n_2 = ?$

(b) Determine the wavelength of the laser light in the glass slab. [1]

$\lambda_{glass} = \frac{633 \times 10^{-9}\,m}{n_{glass}} = \frac{633 \times 10^{-9}}{1.67} = 379 \times 10^{-9}\,m$

379 nm

OR $\frac{\sin\theta_2}{\sin\theta_1} = \frac{V_2}{V_1} = \frac{f\lambda_2}{f\lambda_1} := \frac{n_1}{n_2} \Rightarrow \lambda_2 = \frac{n_1}{n_2} \times \lambda_1$

(c) The water has a refractive index of 1·33. Calculate the angle *x*. [2] $\theta_1 = 25°$

$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1} \Rightarrow \sin\theta_2 = \frac{n_1}{n_2}\sin\theta_1 = \frac{1.67 . \sin 25}{1.33}$

$= 0.538$

$\therefore \theta_2 = \sin^{-1}(0.538) = 32.5°$

$\therefore x = 90 - 32.5 = 57.5°$



5

**8.** Light, with intensity $I_0$, passes through a sheet of Polaroid material that reduces the light intensity to $0\cdot5\ I_0$. The optical axis of the Polaroid material is vertical. The light then passes through a second sheet of Polaroid material with its face parallel to that of the first.

(a) At what angle should the optical axis of the second sheet (relative to the optical axis of the first sheet) be placed to reduce the intensity of the light to 30% of $I_0$? [2]

(transmitted) = (incident) $\cos^2\theta$ For polarised incident light.

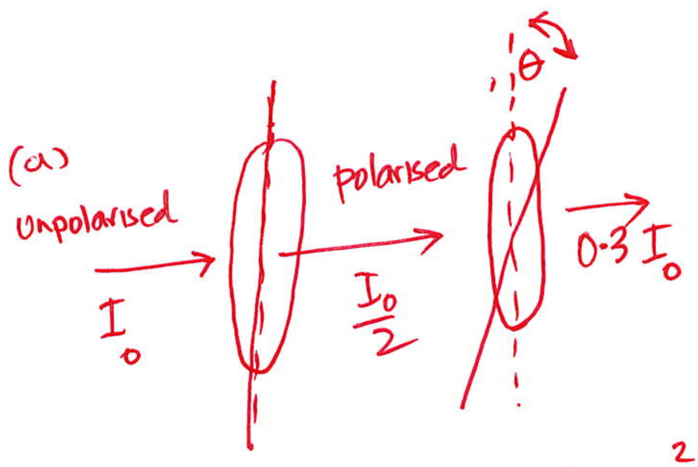
$0\cdot3\ I_0 = 0\cdot5\ I_0 \cos^2\theta$ (1)

$\therefore \cos^2\theta = \frac{0\cdot3}{0\cdot5} = 0\cdot6 \Rightarrow \cos\theta = \sqrt{0\cdot6} = 0\cdot775$

$\theta = \cos^{-1}(\sqrt{0\cdot6}) = 39°$ (1)

(b) People who go fishing prefer to wear polarising sunglasses because they say it helps them to see the fish below the surface of the water more clearly. Outline the physical principle that could be used to support this belief. [1]

When unpolarised light reflects off a non-metallic surface the reflected light is partially polarised.




$I = I_0 \cos^2\theta$ DATA BOOKLET

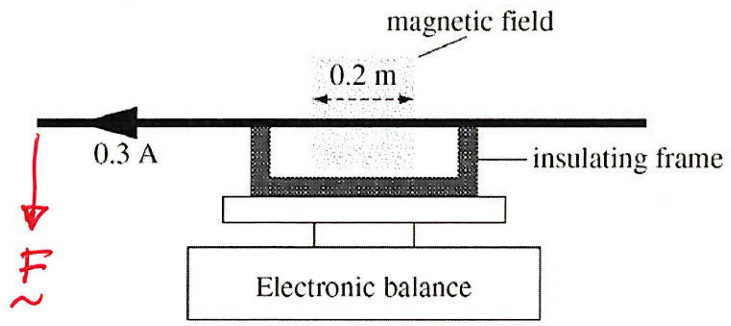
$I$: transmitted intensity

$I_0$: intensity of polarised light incident on polariser



/3

**9.** A copper rod is placed on a wooden frame, which is placed on an electronic balance. A length of 0.2 m of the rod passes at right angles to a horizontal magnetic field.




When a current of 0.3 A is passed through the rod the reading on the balance increases by $7.5 \times 10^{-4}$ kg. What is the strength and direction of the magnetic field? [3]

$F = mg = (7.5\times10^{-4}) \times 9.81 = 7.36\times10^{-3}$ N (1)

DATA

$F = BIL\sin\theta \Rightarrow B = \dfrac{F}{IL\sin\theta} = \dfrac{7.36\times10^{-3}}{0.3\times0.2\times1}$

$\theta = 90°$

$L = 0.2$ m

$= 0.12$ T (1)

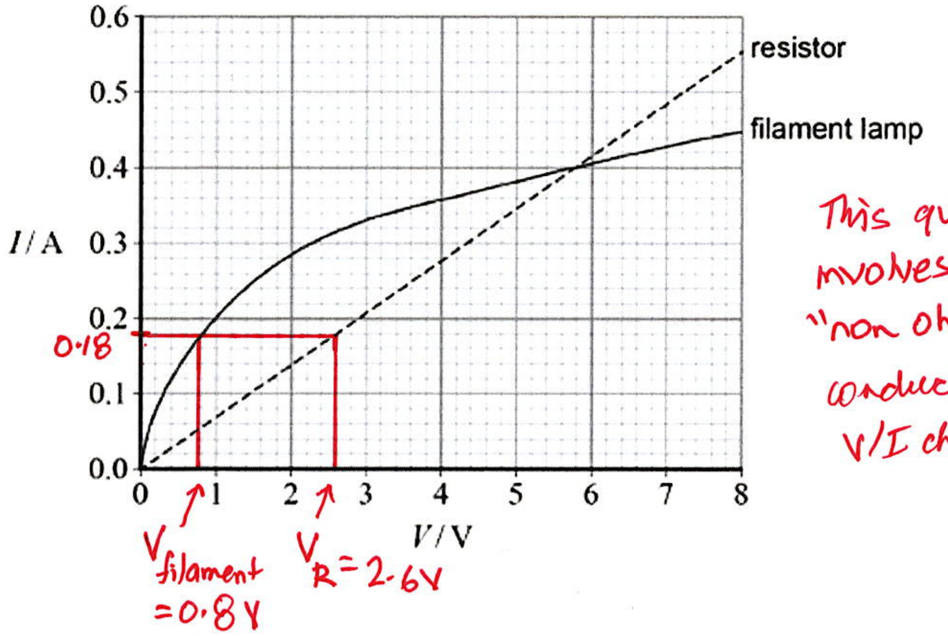
$I = 0.3$ A

horizontal Into the page (1)



/3

**10.** The graph below shows the current–potential difference (I–V) characteristics for a resistor and a filament lamp.




This question involves a "non ohmic" conductor + V/I characteristics.

(a) Determine the resistance of the resistor. [1]

$R = \frac{V}{I} = \frac{8.0}{0.55} = 14.55\ \Omega$

OR for an Ohmic conductor, $R = \frac{\Delta V}{\Delta I}$ OR $\frac{\Delta I}{\Delta V} = \frac{1}{R}$ etc.

(b) The resistor and the filament lamp are connected in series with a supply of variable emf and negligible internal resistance. Determine the emf that produces a current of 0.18 A in the circuit. [2]

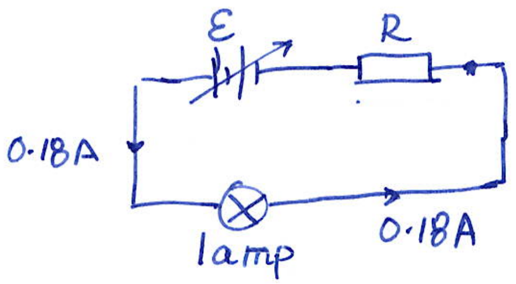
0·18 A flows through both lamp and resistor.

From graph, $V_{filament} = 0.8$ V when $I = 0.18$ A

$V_R = 2.6$ V " " "

$\therefore$ Total voltage drop $= \mathcal{E} = 2.6 + 0.8$ V

$= 3.4$ V




series → same current through lamp & resistor = 0·18A



3

**11.** Data related to the Earth and its orbital motion around the Sun are given below.

Mean orbital radius = 1.5 x $10^{11}$ m
Orbital period = 365.24 days
Mass of the Earth = 5.97 x $10^{24}$ kg

(a) Determine the net force acting on the Earth. [2]

$2.987 \times 10^{4}\ ms^{-1}$

$F_{net} = F_c = \frac{mv^2}{r} = \frac{m \cdot 4\pi^2 r^{\cancel{2}}}{\cancel{r}\, T^2}$ (✓)  $v = \frac{2\pi r}{T}$

$= \frac{5.97 \times 10^{24} \times 4 \times \pi^2 \times 1.5 \times 10^{11}}{(3.1557 \times 10^{7})^2}$  $T = 365.24\,d$

$= 365.24 \times 24 \times 60 \times 60\ s$

$= 3.55 \times 10^{22}\ N$ (1)  $= 3.1557 \times 10^{7}\ s$

(b) Estimate the mass of the Sun. [1] [2]*

$F_{net} = F = \frac{G m_S m_E}{r^2}$ $\therefore$ $m_S = \frac{F_{net} \times r^2}{G M_E}$ (1)

$= \frac{3.55 \times 10^{22} \times (1.5 \times 10^{11})^2}{6.67 \times 10^{-11} \times 5.97 \times 10^{24}}$

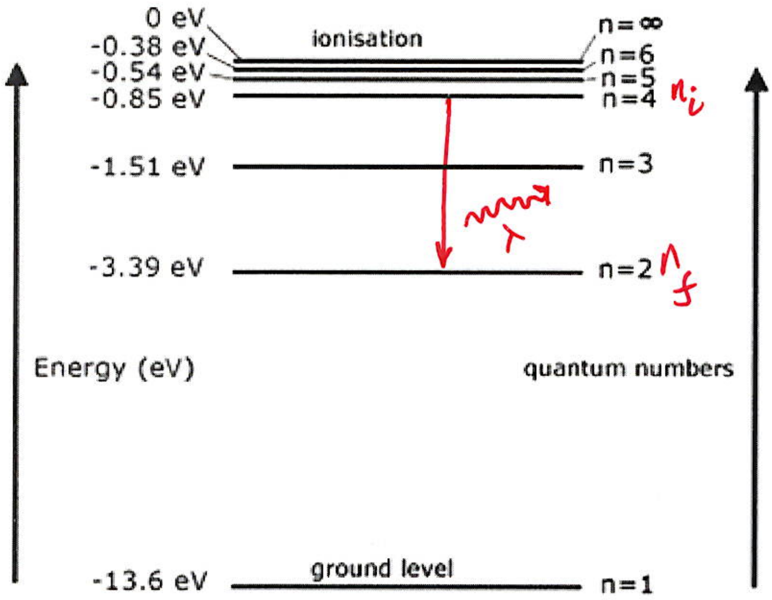
$= 2 \times 10^{30}\ kg.$ (1)

* This question awarded (2) marks



3

**12.** An energy level diagram for the hydrogen atom is shown below.




A photon of wavelength 489 nm is emitted from an excited hydrogen atom. The emerging photon is caused by a transition between two energy states. Determine the initial and final energy states $n_i$ and $n_f$ of this transition. [3]

$\Delta E = hf = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{489 \times 10^{-9}} = 4.067 \times 10^{-19}\ J$ (1)

$= \frac{4.067 \times 10^{-19}}{1.60 \times 10^{-19}}\ eV$

$= 2.54\ eV.$ (1)

$\therefore n_i = 4 \rightarrow n_f = 2$ (1)

$\Delta E = (-3.39) - (-0.85) = -2.54\ eV$

$\Delta E = E_f - E_i$

3

**13.** The table below may be useful in answering the questions which follow.

| particle | baryon number | lepton number | strangeness |
|---|---|---|---|
| $\pi^-$ | 0 | 0 | 0 |
| p | 1 | 0 | 0 |
| $\bar{p}$ | −1 | 0 | 0 |
| $e^-$ | 0 | 1 | 0 |
| $e^+$ | 0 | −1 | 0 |
| $\bar{\nu}_e$ | 0 | −1 | 0 |

A particle X, which is a strange particle, decays in the following way:

$$X \rightarrow \pi^- + p$$

(a) Explain whether X is a meson, a baryon or a lepton. [1]

X is a baryon. As baryon number is conserved (1) X must have a baryon number of 1, equal to that of the product particles.

(b) State with justification the kind of interaction involved in this decay. [2]

Strangeness is {not conserved / violated} in this interaction. (1)

Hence the weak (1) interaction must be involved as this is the only interaction where strangeness may be violated / not conserved.

(c) State the approximate time interval for the decay of particle X to occur. [1]

Weak ⇒ long lifetime ≈ $10^{-10}$ s.

(The strong interaction involves much shorter times, ≈ $10^{-25}$ s)



4

**14.** The fusion of two nuclei of deuterium ${}^2_1H$ to give one nucleus of helium ${}^3_2He$ may one day be used in nuclear power generation. The equation for this reaction is

$$ {}^2_1H + {}^2_1H \rightarrow {}^3_2He + {}^1_0n $$

The following data are available.

Mass of deuterium nucleus = 2·01355 u
Mass of helium nucleus = 3·01492 u
Mass of neutron = 1·00867 u

(a) Determine the energy (J) released in each fusion reaction. [2]

Mass defect $= (2\times 2{\cdot}01355) - (3{\cdot}01492 + 1{\cdot}00867)\,u$
$= 3{\cdot}51\times 10^{-3}\,u$ (1)

$mc^2 = \Delta E = (3{\cdot}51\times 10^{-3}\times 1{\cdot}661\times 10^{-27})\times(3{\cdot}00\times 10^{8})^2$

convert u to eV $= 5{\cdot}247\times 10^{-13}\,J$ (1)

40% is useful energy $= 0{\cdot}4\times 1\,GW = 0{\cdot}4\,GW$

(b) Assume that this fusion reaction could be used in a nuclear power station producing 1 GW of electrical power with an overall efficiency of 40%. Determine the mass of deuterium used per year. [3]

Energy produced by fusion per year @ 40% efficiency $= \dfrac{\text{Power}\times\text{time}}{\text{Efficiency}} = \dfrac{10^9\times 365\times 24\times 60\times 60}{0{\cdot}4}$

$= 7{\cdot}884\times 10^{16}\,J.$ (1)

Number of fusion reactions per year $= \dfrac{7{\cdot}884\times 10^{16}}{5{\cdot}247\times 10^{-13}} = 1{\cdot}503\times 10^{29}$ (1)

$\therefore$ Mass of deuterium $= 1{\cdot}503\times 10^{29}\times 2\times 2{\cdot}01355\times 1{\cdot}661\times 10^{-27}\,kg$ (1)
$= 1005\,kg.$

Also accept $6{\cdot}05\times 10^{29}\,u$



/5