ST ANDREW'S CATHEDRAL SCHOOL
FOUNDED 1885

Candidate Session Number

S	O	L	U	T	I	O	N	S	

Year 12 IB Physics
Standard Level

Paper 2

2020 Semester 2 Examination

Wednesday 26 August 2020

1 hour 15 minutes

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. A pyramid has a square base of side x and height h. The volume V of a square pyramid is given by the expression:

$$V = \frac{x^2 h}{3}$$

(a) h is measured with an uncertainty of 2% and x is measured to 4%. What is the percentage uncertainty in V? [2]

$\frac{\Delta V}{V} = 2\frac{\Delta x}{x} + \frac{\Delta h}{h}$ $\therefore \left(\frac{\Delta V}{V} \times 100\right)\% = 2\left(\frac{\Delta x}{x} \times 100\%\right) + \left(\frac{\Delta h}{h} \times 100\%\right)$ (1)

$\therefore$ % uncertainty in V = 2 × % uncertainty in x + % uncertainty in h

= 2 × 4% + 2%

$\boxed{= 10\%}$ (1)

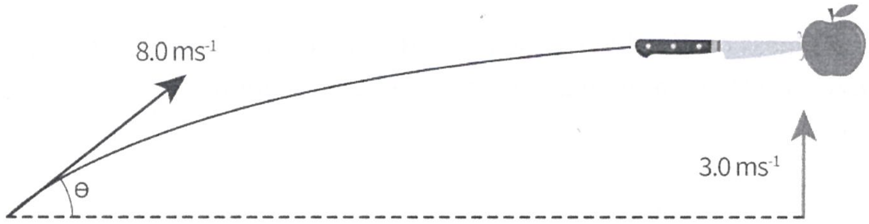
(b) The volume of a square pyramid was calculated from measurements of x and h to be 8.275 m^3. Give the value of V including an uncertainty estimate. [1]

10% of 8.275 m^3 = 0.8275 m^3 = 0.8 m^3 (1 sig. fig)

$\therefore$ $\boxed{V = 8.3 \pm 0.8 \text{ m}^3}$

Value of V given to same accuracy as uncertainty estimate i.e. 1 decimal place

2. In a circus trick, a knife-thrower throws a knife to hit an apple in mid-air.



The thrower releases the knife at the same time that the apple is thrown, and at the same height above the ground.

The apple is thrown vertically at 3.0 m s^{-1}. The knife is thrown at 8.0 m s^{-1}.

When the knife and apple collide, they are both at the highest points of their trajectories.

(a) How long after being thrown did the knife collide with the apple? [2]

DATA

At maximum height, vertical velocity = 0 ms^{-1}.

For apple vertically $v = u + at$ DATA BOOKLET

$\therefore t = \frac{v-u}{a} = \frac{0-(3.0)}{(-9.8)}$ ①

$= 0.31$ s ①

Apple vertical

$u = +3.0$ ms^{-1}

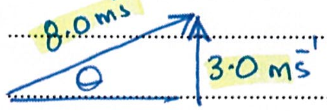
$a = -9.8$ ms^{-2}

$v = 0$ ms^{-1}

$t = ?$

(b) At what angle from the horizontal, θ, was the knife thrown? [2]

Knife and apple must have same initial vertical velocity to be at the same height at the same time.

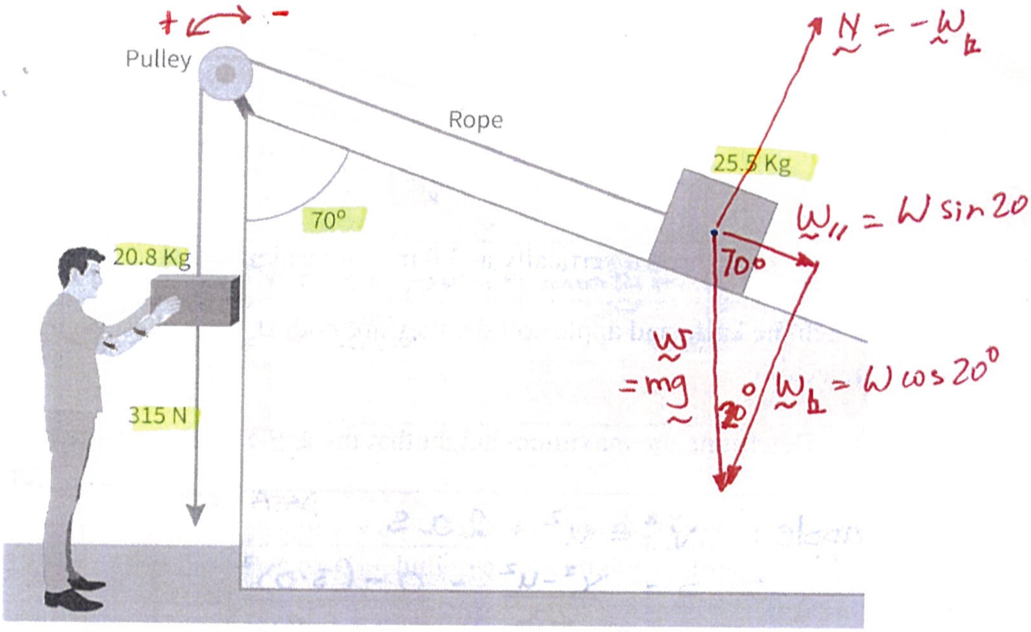


$\therefore \sin\theta = \frac{3}{8}$ $\therefore \theta = \sin^{-1}(3/8)$

$= 22°$

3. A smooth pulley is used to drag a 25.5 kg mass up a slope as shown in the diagram below. The coefficient of dynamic friction between the mass and the slope is 0.410.

A second mass of 20.8 kg is attached to the end of the rope. A person pulls downwards with a force 315 N on the mass as shown in the diagram.



(a) Calculate the component of the weight force of the 25.5 kg mass acting down the slope. [1]

$\sin 20° = \frac{W_{\parallel}}{mg}$ $\therefore W_{\parallel} = mg \sin 20° = 25.5 \times 9.81 \times \sin 20°$

$= 85.6 \text{ N}$ (1)

(b) Determine the friction force acting on the 25.5 kg mass as it slides up the ramp. [2]

$F_f = \mu_d R$ $R = W_\perp = mg \cos 20°$

DATA BOOKLET

$= 25.5 \times 9.81 \times \cos 20°$

$= 235 \text{ N}$ (1)

$F_f = 0.410 \times 235 \text{ N} = 96.4 \text{ N}$ (1)

DATA

$\mu_d = 0.410$

$F = ?$

$R = mg \cos 20°$

(This question continues on the following page)

(Question 3 continued)

(c) Determine the acceleration of the masses. [2]

$a = \frac{F_{net}}{m_{total}} = \frac{\text{Weight of 20.8 kg mass} \downarrow + 315\,N \downarrow + \text{weight of 25.5 kg down ramp} + \text{friction on 25.5 kg mass}}{(20.8 + 25.5)}$ from (a)

DATA BOOKLET

$= \frac{(20.8 \times 9.81) + (315) + (-85.6) + (-96.4)}{46.3}$ from (b)

$= +7.28\ m s^{-2}$

4. A space probe of mass 1312 kg far from the Earth is travelling at 14.8 km s⁻¹. The probe fires its rockets to give a constant force of 156 kN for 220 seconds. During this time it burns 150 kg of fuel and accelerates in the same direction as its initial velocity.

Calculate final speed of the space probe. $F\Delta t = \Delta p$ DATA BOOKLET [2]

$F\Delta t = \Delta p = m_f v - m_i u \quad (P_f - P_i)$ NOTE that mass changes

$\therefore v = \frac{F\Delta t + m_i u}{m_f} = \frac{(156 \times 10^3 \times 220) + (1312 \times 14.8 \times 10^3)}{1162}$

$= 46246\ m s^{-1}$

OR $46.2\ km\ s^{-1}$

DATA:
$m_i = 1312\ kg$
$u = 14.8 \times 10^3\ m s^{-1}$
$F = 156 \times 10^3\ N$
$\Delta t = 220\ s$
$m_f = 1312 - 150 = 1162\ kg$
$v = ?$

5. A bicycle tyre of volume 3.1×10^{-3} m³ contains air at a temperature of 18 °C.

A bicycle pump is used to put air into the tyre. The temperature of the air in the tyre increases to 26 °C and the pressure in the tyre increases to 360 kPa. The volume of the tyre does not change.

Assume that air behaves as an ideal gas.

Determine the number of moles of air in the tyre after it has been inflated with the pump. [2]

$pV = nRT \quad \therefore n = \frac{pV}{RT}$

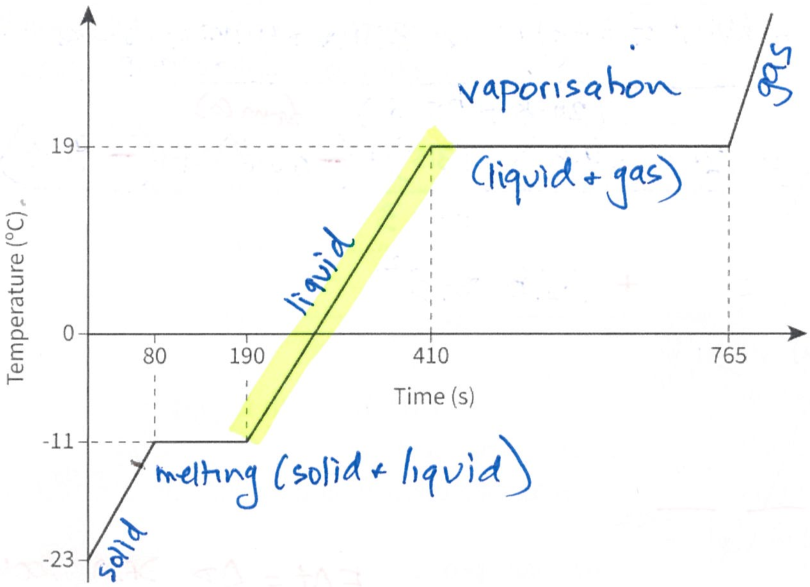
DATA BOOKLET

$= \frac{(360 \times 10^3) \times (3.1 \times 10^{-3})}{(8.31) \times (299)}$

$= 0.499\ mol$

DATA:
$p = 360 \times 10^3\ Pa$
$V = 3.1 \times 10^{-3}\ m^3$
$T = (273 + 26)\ K = 299\ K$
$n = ?$

6. Heat energy is added to a substance of mass 0.24 kg at a rate of 0.82 kW. The following graph shows how the temperature of the substance changes.



DATA
$m = 0.24 kg$
$P = 0.82 \times 10^3 W$

(a) Determine the increase in internal energy of the substance while it is purely in the liquid phase. [2]

Q = heat energy added = increase in internal energy
= power × time
$= (0.82 \times 10^3) \times (410 - 190)$ (1)
= 180 400 J
$= 1.804 \times 10^5$ kJ (1)

(b) Determine the specific heat capacity of the liquid phase of this substance. [2]

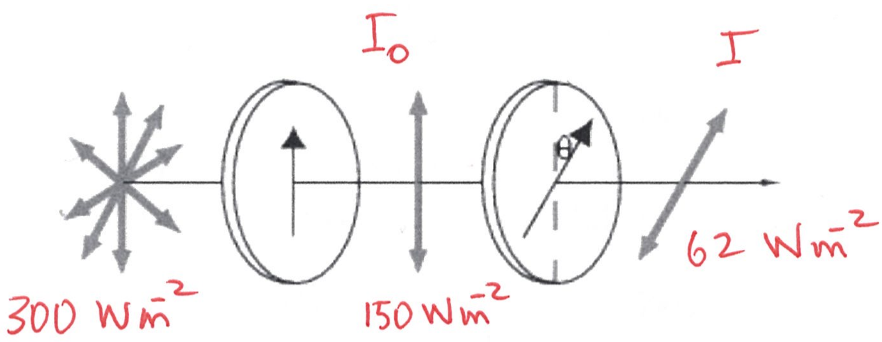
$Q = mc\Delta T \Rightarrow c = \frac{Q}{m\Delta T} = \frac{1.804 \times 10^5}{(0.24 \times 30)}$ from (a) (1)

DATA BOOKLET

$\Delta T = 19 - (-11)$ °C
= 30 °C or K

$= 25\,056$ J kg^{-1} K^{-1}
$= 25.056$ kJ kg^{-1} K^{-1}

7. A narrow beam of unpolarised light of intensity 300 W m^{-2} is incident upon two polarisers which have an angle of θ between their planes (axes) of polarisation.



If the intensity of light emerging from the second polariser is 62 W m^{-2}, what is the value of θ, to the nearest degree? [2]

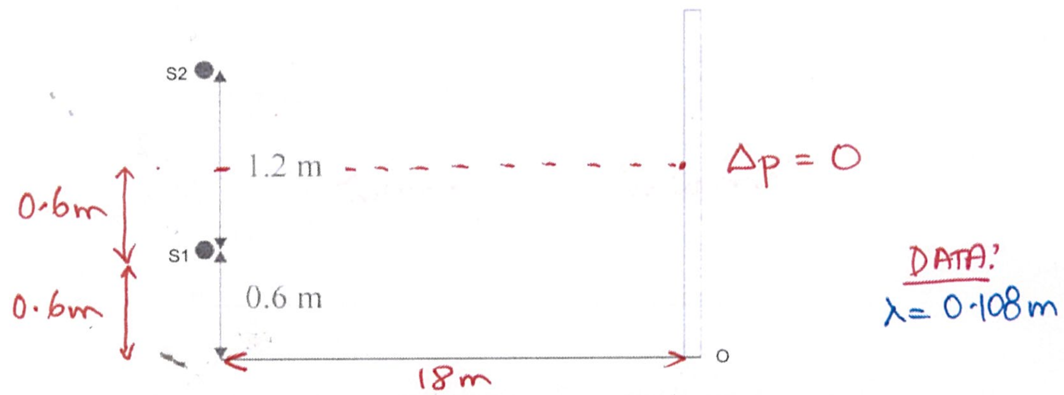
- The first polariser reduces the intensity by half. Hence the intensity is 150 W m^{-2} before the second polariser.
- Intensity transmitted by 2nd polariser – use Malus's Law

$I = I_o \cos^2\theta$ $\quad 62 = 150\cos^2\theta \Rightarrow \cos^2\theta = 62/150$ (1)

DATA BOOKLET $\quad \therefore \cos\theta = \sqrt{62/150} = 0.643$

$\theta = \cos^{-1}(0.643) = 50°$ (1)

8. Below are two identical sources of sound of wavelength 0.108 m, placed a horizontal distance of 18 m from a wall. Source S1 is 0.6 m above the floor and source S2 is at a height of 1.2 m vertically above S1. (The diagram is not drawn to scale.)



(a) A microphone is moved up the wall starting from the floor. At what height will the volume of the sound be a maximum? Give a reason for your answer. [1]

At a point halfway between the sources where path length difference = 0 i.e. 1·2 m

(b) At what height will the volume of the sound be a minimum? [2]

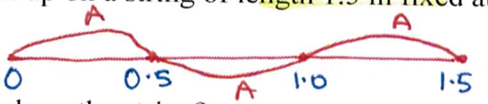
Separation between 2 points of constructive interference

$s = \frac{\lambda D}{d} = \frac{0{\cdot}108 \times 18}{1{\cdot}2} = 1{\cdot}62$ m (1)

DATA BOOKLET ∴ Distance between constructive + destructive point of interference $= \frac{1{\cdot}62}{2} = 0{\cdot}81$. (1)

∴ Height $= 1{\cdot}2 - 0{\cdot}81 = 0{\cdot}39$ m

9. A standing wave of frequency 120 Hz is set up on a string of length 1.5 m fixed at both ends. It vibrates with 3 antinodes.



(a) What is the speed of waves travelling along the string? [2]

$V = f\lambda$ $\lambda = \frac{2}{3} \times 1.5\,m = 1.0\,m$ (1)

DATA BOOKLET

$c = f\lambda$ $V = f\lambda = 120 \times 1 = 120\ ms^{-1}$ (1)

(b) What is the lowest frequency at which a standing wave can be formed on the string? [1]

f_1 = Lowest frequency $f = 3f_1$

$\therefore f_1 = \frac{f}{3} = \frac{120}{3} = 40\ s^{-1}$ (1)

Frequencies $f_1, 2f_1, 3f_1 \ldots nf_1$ where $n = 1, 2, 3, \ldots$ for a string fixed at both ends

10. An electron orbits a proton at a distance of 10^{-15} m.

(a) What is the magnitude of the electrostatic force between the proton and the electron? [2]

$F = \frac{kq_1q_2}{r^2} = \frac{8.99 \times 10^9 \times 1.6 \times 10^{-19} \times 1.6 \times 10^{-19}}{(10^{-15})^2}$ (1)

DATA BOOKLET

$= 230\ N$ (1)

DATA

$q_e = 1.60 \times 10^{-19} C$

$q_p = 1.60 \times 10^{-19} C$

$k = 8.99 \times 10^9$

$r = 10^{-15}\ m$

(b) Estimate the orbital speed of the electron. [2]

$F_c = \frac{mV^2}{r} = F_E$ $\frac{M_e V^2}{r} = 230$ (1) $M_e = 9.11 \times 10^{-31} kg$

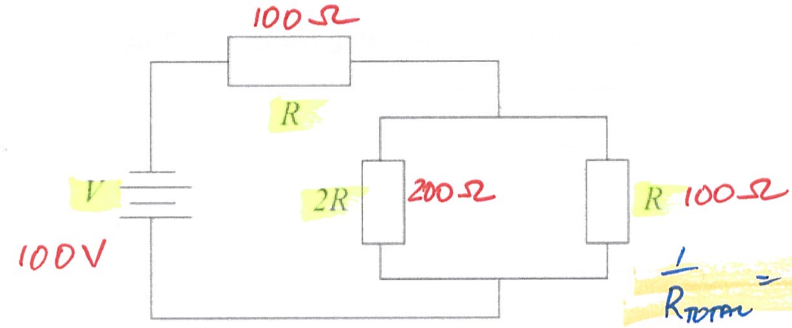
DATA BOOKLET

$\therefore V^2 = \frac{230 \times r}{M_e} = \frac{230 \times 10^{-15}}{9.11 \times 10^{-31}} = 2.52 \times 10^{17}$

$\therefore V = \sqrt{2.52 \times 10^{17}} \approx 5 \times 10^8\ ms^{-1}$ (1)

(NOTE: electron "orbits" H nucleus at $r \approx 5.3 \times 10^{-11} \Rightarrow V = 2.2 \times 10^6\ ms^{-1}$)

11. The circuit below has $V = 100$ V and $R = 100\ \Omega$ and the battery has negligible internal resistance.



$\frac{1}{R_{TOTAL}} = \frac{1}{R_1} + \frac{1}{R_2}$

DATA BOOKLET

(a) Determine the total resistance of the circuit. [2]

$\frac{1}{R_p} = \frac{1}{R} + \frac{1}{2R} = \frac{1}{100} + \frac{1}{200}$ OR $\frac{2+1}{2R} = \frac{3}{2R}$

$\therefore 1/R_p = \frac{3}{200}$ $\therefore R_p = 66.7\ \Omega$ (1)

$\therefore$ Total resistance $= 100 + 66.7\ \Omega = 166.67\ \Omega$ (1)

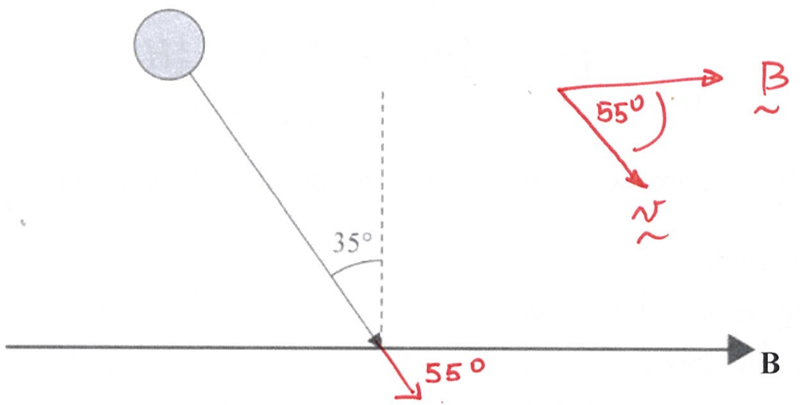
$R_{TOTAL} = R_1 + R_2 \ldots$

(b) What is the power output in the circuit? [2]

$P = \frac{V^2}{R_{total}}$, $= \frac{(100)^2}{166.67}$ (1) $= 60\ \text{W}$ (1)

DATA BOOKLET

12. A helium nucleus ${}^4_2He^{2+}$ of mass 6.696×10^{-27} kg enters a uniform magnetic field B at an angle of 35° as shown below.



If the magnetic field strength is 0.36 nT and the nucleus is moving at 2350 m s^{-1}, what is its acceleration? [2]

DATA BOOKLET

$a = \frac{F}{m}$ $\quad F = qvB\sin\theta$ $\quad \theta =$ angle between v and $B = 55^\circ$

$= (2 \times 1.6 \times 10^{-19}) \times 2350 \times 0.36 \times 10^{-9} \times \sin 55^\circ$ (1)

$= 2.218 \times 10^{-25} \times 1$ $\quad q = 2 \times 1.6 \times 10^{-19}$ C

$a = \frac{F}{m} = \frac{2.218 \times 10^{-25}}{6.696 \times 10^{-27}} = 33$ m s^{-2} (1) $\quad B = 0.36$ nT $= 0.36 \times 10^{-9}$ T

13. In a nuclear fusion reaction, a nucleus of deuterium (hydrogen-2) fuses with a nucleus of helium-3 to produce helium-4 and a proton.

$$^{2}_{1}H + ^{3}_{2}He \rightarrow ^{4}_{2}He + ^{1}_{1}H$$

The following are the binding energies per nucleon of the nuclei involved:

Binding energy per nucleon $^{2}_{1}H$ = 1.112287 MeV

Binding energy per nucleon $^{3}_{2}He$ = 2.572681 MeV

Binding energy per nucleon $^{4}_{2}He$ = 7.073915 MeV

(a) How much energy is released per fusion by this reaction? [2]

Energy released = (binding energy of products) − (binding energy of reactants) MeV (1)

$= (4 \times 7.073915) - (2 \times 1.112287 + 3 \times 2.572681)$

$= 18.353043$ MeV (1)

(2)

(b) What is the total mass difference between the nuclei before and after the reaction? [2]

Find mass equivalent of energy released: $1\,eV = 1.6 \times 10^{-19}$ J

18.353043×10^{6} eV $= 1.6 \times 10^{-19} \times 18.353043 \times 10^{6}$ J

$= 2.936 \times 10^{-12}$ J. (1)

$\Delta E = \Delta m c^2$ $\quad \therefore \Delta m = \frac{\Delta E}{c^2} = \frac{2.936 \times 10^{-12}}{(3 \times 10^8)^2} = 3.263 \times 10^{-29}$ kg

DATA BOOKLET (1)

(2)

14. A possible nuclear reaction involving pions is shown below.

$$\pi^+ \rightarrow \pi^0 + \pi^- + 2\pi^+$$

Pions are mesons consisting of two quark flavours, up and down.

(a) What is the quark composition of a π^- pion? [2]

Mesons are quark – anti quark pairs. (1)
For π^- the total charge is $-1e$ — DATA BOOK
If made from $u\left(\frac{2}{3}e\right)$ and $d\left(-\frac{1}{3}e\right)$ the total quark charge must be $-1e$ $\therefore$ $\bar{u}d$ $\left(-\frac{2}{3}e + -\frac{1}{3}e\right)$ (1)

(b) Show, by referring to three conservation laws, that this reaction is theoretically possible. [2]

Conservation of charge: initial $(+1e)$ = final $(+1) = (0 + (-1) + (+2))$
Conservation of lepton no: initial (0) = final (0)
Conservation of baryon no.: each quark has baryon number $+\frac{1}{3}$
each anti-quark " " " $-1/3$
$\therefore$ initial baryon no. $(0) = (0) + (0) + (0) = 0$

(Remember: quarks are NOT baryons – all baryons have 3 quarks)
See p.299 Tsokos

(1) mark for 2 conservation laws

15. The Sun's surface temperature is approximately 5780 K.

(a) Which wavelength is emitted with the highest intensity? [2]

$\lambda_{max} = \frac{2.90 \times 10^{-3}}{T \text{ (kelvin)}} = \frac{2.90 \times 10^{-3}}{5780}$

DATA BOOKLET

$= 5.017 \times 10^{-7}$ m (2)

$= 501.7$ nm

(b) The Sun's power output is 3.9×10^{26} W. What is the intensity of the Sun's radiation at the position of Earth's orbit, a distance of 1.5×10^{11} m from the Sun? [2]

$I = \frac{\text{power}}{A}$ A = surface area of sphere of radius 1.5×10^{11}

DATA BOOKLET

$I = \frac{P}{4\pi r^2} = \frac{3.9\times10^{26} \text{ W}}{4\pi(1.5\times10^{11})^2 \text{ m}^2}$ (1)

$= 1379 \text{ W m}^{-2}$ (1)

Please do not write on this page.

Answers written on this page
will not be marked.