Question 14 **(8 marks)**

An experimental technique in the field of radiography in treating aggressive brain tumours is that of Boron Neutron Capture Therapy. This technique uses the fact that when Boron-10 is injected into the body of a patient, the Boron-10 collects in the brain tumours.

The patient is then bombarded with neutrons which are strongly absorbed by the Boron-10, becoming fissile (radioactive) Boron-11 which produces Lithium-7 and high-energy alpha particles which then kill the cancer cells. On average, each neutron has an energy of 0.650 eV.

(a) Write two nuclear equations describing the above two processes. (2 marks)

$^{1}_{0}n + ^{10}_{5}B \rightarrow ^{11}_{5}B$ (1)

$^{11}_{5}B \rightarrow ^{7}_{3}Li + ^{4}_{2}He$ (1)

(1) $^{10}_{5}B + ^{1}_{0}n \rightarrow ^{7}_{3}Li + ^{4}_{2}He$

missing.

(b) Given that the amount of Boron-10 (10.013 u) required to treat a 2.20 g brain tumour is 25.0 μg per gram of tumour, determine the absorbed dose administered to a 45.0 kg patient. (5 marks)

errors

FOR MASS OF B-10 REQ.

Bee Nice $25 \times 10^{-6} \times 2.2 = 5.5 \times 10^{-5}$ g $= 5.50 \times 10^{-8}$ kg (1)

FOR NO: B-10 ATOMS AND HENCE, NO: $^{1}_{0}n$ REQ.

$No: = \dfrac{5.50 \times 10^{-8}}{10.013u \times 1.66 \times 10^{-27}} = 3.30895 \times 10^{18}$, $^{1}_{0}n$ (1)

FOR TOTAL ENERGY ADMINISTERED

$E = 3.30895 \times 10^{18} \times 0.65 \times 1.60 \times 10^{-19}$

$= 0.34413$ J (1)

NOW, FOR A.D $A.D = \dfrac{E}{m}$ (1) $\dfrac{0.34413}{45} = 7.647 \times 10^{-3}$ (1) $= 7.65$ mGy

(c) Suggest a possible reason why an alpha source (the fission of Boron-11) is used in this context rather than a beta source. (1 mark)

NOT - "not a beta source"

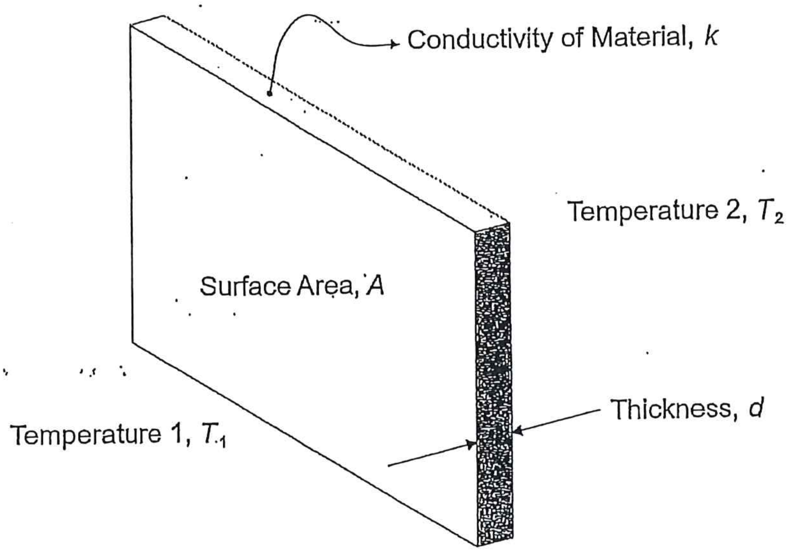
AN ALPHA SOURCE WILL ONLY PENETRATE A SHORT DISTANCE (½) THROUGH BODY TISSUE AND HENCE, THE ALPHA PARTICLES WILL ONLY KILL THE TARGET (½) TISSUE AND NOT THE SURROUNDING TISSUE (½). Ignore: More Ionising.

8

Question 15 **(21 marks)**

The following question involves heat transfer through materials and heating an office space.

The rate at which heat is conducted through a material depends on several quantities relating to the physical environment and the shape and size of the material, as shown in the diagram below.



The rate at which heat is conducted through a material depends on temperature (K) on both sides of the material (T_1 and T_2), the surface area A (m^2) exposed, the thickness of the material d (m) and the property of the material known as conductivity k.

The rate of heat transfer through the material is power P (units of J s^{-1}) and is given by:

$$P = \frac{Q}{t} = \frac{kA(T_2 - T_1)}{d}$$

(a) Correctly determine the units of conductivity k. Very poorly done! Very basic. (1 mark)

$$\frac{J}{s} = \frac{k.m.m.K}{m}$$

$$\therefore k = \frac{J}{s.m.K} \Rightarrow k = J s^{-1} m^{-1} K^{-1}$$

WATCH C.O.

(b) A single 1.20 m high by 2.30 m wide by 6.00 mm thick glass window separates a 28.0 °C exterior from the 18.0 °C interior office space. The window is letting heat in at a rate of 3.59 kW.

i) Determine the conductivity k of the glass window. (3 marks)

$$\frac{3.59\times10^3}{1} = \frac{k\,(1.2\times2.3)\,10}{6\times10^{-3}} \quad ①$$

error

$$k = \frac{3.59\times10^3 \times 6\times10^{-3}}{27.6} \; ① = 0.7804 \checkmark$$

$$= 0.780\ J s^{-1} m^{-1} K^{-1} \quad ①$$

error: add K to 10°C

4

Question 15 (b) continued $Q = Pt = mc\Delta T$

ii) Calculate the **theoretical** rise in temperature of 215 kg of air within the office over a period of 15 minutes (the specific heat capacity of air is 1.10×10^3 J kg^{-1} K^{-1}). (3 marks)

FIRSTLY, FIND HEATING ENERGY (Q).

$E = Pt = 3.59 \times 10^3 \times 15 \times 60 = 3.231 \times 10^6$ J (1)

error

NOW, FOR (Δt)

$Q = mc\Delta t$ (½)

$\therefore t = \frac{Q}{mc} = \frac{3.231 \times 10^6}{215 \times 1.10 \times 10^3}$ (½) $= 13.661$

$= 13.7\ °C$ (1)

- To internal surrounding; objects, material (1) (explain well)

Value → discussion #Realistic#

iii) Explain why the answer to part b) ii) is impossible. Use relevant physics concept to justify your response. (2 marks)

- FOR HEAT ENERGY TO FLOW (TRANSFER) INTO THE ROOM $T_{OUTSIDE} > T_{INSIDE}$. (1)
- THE ABOVE CASE IS NOT POSSIBLE AS $T_{INSIDE} = 18.0 + 13.7 = 31.7\ °C > T_{OUTSIDE}$ (28.0 °C) (1)

(c) The owner of the office decides to replace the window mentioned in part b with a double-glazed window in order to reduce heat transfer. The double-glazed window has identical dimensions to the single pane window (1.20 m by 2.30 m) but is 30.00 mm thick and consists of two panes of glass separated by a sealed section containing air.

In order to test this double-glazed window, the amount of energy conducted per second through the window and the difference in temperature across the window is recorded for eight trials in the table below.

Trial	1	2	3	4	5	6	7	8
Temp Difference ΔT (K)	2	3	6	9	12	14	17	19
Energy Rate Q/t (J s^{-1})	24	30	72	100	125	155	192	212

i) State why the sealed section containing air reduces heat transfer. (1 mark)

- AIR IS A POOR CONDUCTOR OF HEAT (1)

AND/OR

- THE TRAPPED AIR REDUCES HEAT TRANSFER VIA CONVECTION.

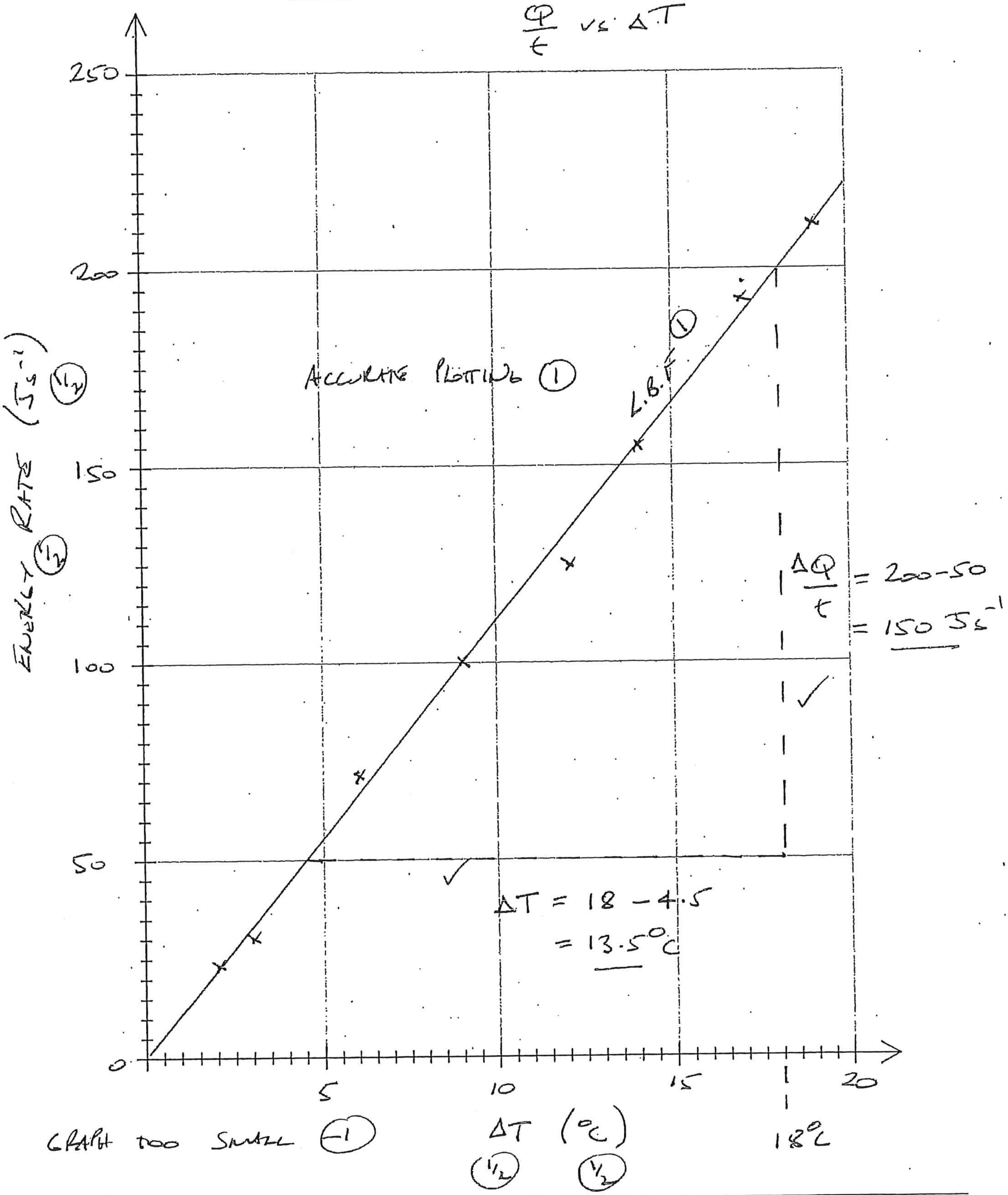
ii) Use the data in the table above to construct a graph by plotting Energy Rate Q/t on the vertical axis and Temp Difference ΔT on the horizontal axis. Include title, axes labels, units and a line of best fit. (5 marks)

(Question 15 continued)

(1)

RATE OF HEAT FLOW VS TEMP. DIFFERENCE

$\frac{Q}{t}$ vs ΔT



/5

IF (triangle) TOO SMALL −½ ONLY. /18

(Question 15 continued)

iii) Calculate the gradient of the line of best fit. **Show construction lines** on the graph. (3 marks)

① (for construction lines)

$$\text{GRADIENT} = \frac{Q/t}{\Delta T} = \frac{200-50}{18-4.5} = 11.11$$ ①

$= 11.1\dot{1}\ J\,s^{-1}\,K^{-1}$ ①

$P\,K^{-1}$ O.K.

(−½) IF INC. UNITS. !!!

iv) Use the value of the gradient of the line of best fit, and information given in the question, to determine a value for the conductivity *k* of the double-glazed window. **Note**: if you didn't determine a value for the gradient, you may use a gradient of 11.0 J s^{-1} K^{-1}. (3 marks)

NOTE: A LOT OF STUDENTS WROTE: $11 = \frac{kA\Delta T}{d}$ ← THIS IS NOT POWER!

FROM $\frac{Q}{t} = \frac{kA\Delta T}{d}$

$\frac{d}{kA} \times \frac{Q/t}{\Delta T}$ ... $\frac{kA}{d} = \frac{Q/t}{\Delta T}$] GRADIENT

IF THE STUDENTS DIDN'T USE THE GRADIENT AS INSTRUCTED. (−1) i.e. $k = \frac{Pd}{A\Delta T}$ ← POINT READINGS FROM TABLE ⇒ ② MARKS ONLY IF 'k' IS CORRECT

$$\therefore k = \frac{\text{GRADIENT}}{1} \times \frac{d}{A}$$

WATCH ROUNDING ERRORS

$$= \frac{11.1\dot{1}}{1} \times \frac{30\times10^{-3}}{1.2\times2.3}$$

$= 0.12077$

$= 0.121$ OR $1.21\times10^{-1}\ J\,s^{-1}\,K^{-1}$ OR $P\,K^{-1}$ O.K.

① CLOSE TO.

/6.

Question 16 **(13 marks)**

An electric kettle contains 450 mL of water at an initial temperature of 18.0 °C. The kettle operates on mains voltage (240.0 V) and draws a current of 6.25 A when switched on. The kettle is 90.0 % efficient at converting electrical energy into thermal energy in the water only.

(a) Calculate the amount of heat that the kettle supplies to the water every second after it is switched on. (2 marks)

$Q = E = Pt = VIt$ (½)

$= 240 \times 6.25 \times 1 \times \frac{90}{100}$ (½)

$= \frac{135000}{100}$

$= 1350$

$= 1.35$ kJ (1)

(-1) IF EFF. NOT TAKEN INTO ACCOUNT [1500 J ×]

(b) How much heat is supplied by the kettle to heat the water to reach boiling point (100°C)? (3 marks)

$Q = mc\Delta t$ (½)

$= 0.45 \times 4180 \times 82$ (½)

$= 1.54242 \times 10^5$

$= 1.54 \times 10^5$ J

or 154 kJ (1)

100 °C – 18 °C: $\Delta t = 82$ °C (1)

WATCH C.O

(c) How long will it take for the water to reach boiling point? (3 marks)

$P = \frac{E}{t} = \frac{Q}{t}$

$t = \frac{Q}{P}$ (1) $= \frac{1.54242 \times 10^5}{240 \times 6.25 \times 1 \times \frac{90}{100}}$ (1)

$= \frac{1.54242 \times 10^5}{1350}$

$= 114.25 = 114$ s (1)

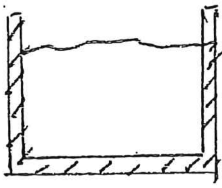
[1 MIN : 54 s]

NOTE TO TEACHERS – REMIND STUD TO LEAVE ANS. IN SECONDS UNLESS OTHERWISE INSTRUCTED

8

THERMAL OR ELECTRICAL — NOT STATED.

(d) How much more energy is required if the 1.20kg stainless steel kettle was included in the heat calculation? Note: The specific heat capacity for stainless steel is 468 J kg^{-1}K^{-1} (3 marks)



$m_{ss} = 1.20kg$

RECALL

$Q_{TOT} = Q_w + Q_{s.st}$

$= (m_w c_w \Delta t_w) + (m_{ss} c_{ss} \Delta t_{ss})$

FOR (Q_{ss})

$Q = m_{ss} c_{ss} \Delta t$ (1)

$= 1.2 \times 468 \times 82$ (1)

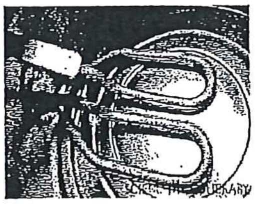
$= 4.61 \times 10^4$ J (1)

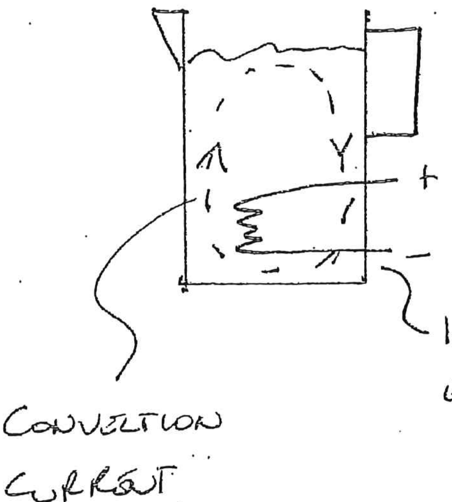
$E_{ELEC} = 4.61 \times 10^4 \times \frac{100}{90} = 5.12 \times 10^4$ J

OR $\frac{4.6051 \times 10^4}{1.542 \times 10^5} \times \frac{100}{1}$

= AN EXTRA 29.9%

(e) The manufacturer of the electric kettle placed the heating element very close to the bottom of the kettle in order to maximise its efficiency. Briefly explain the benefit of this design. Include a well labelled sketch to aid your explanation. (2 marks)



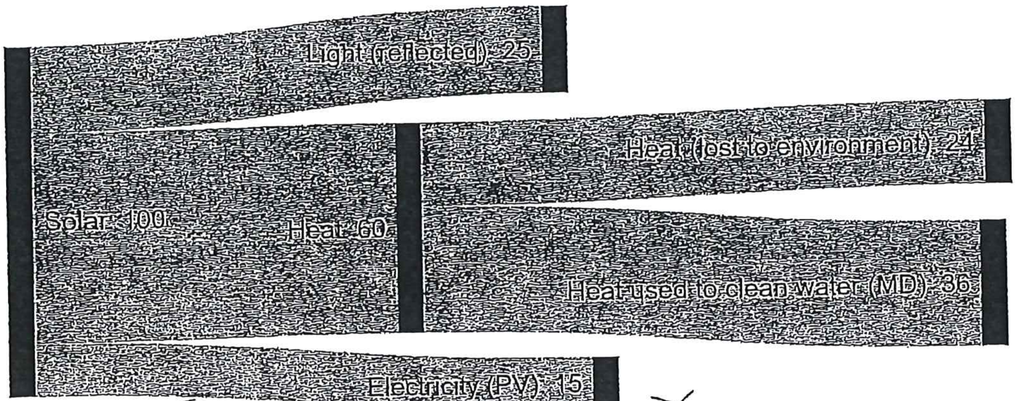


• NEATLY LABELLED SKETCH (1)

EXPL. • THE ELEMENT AT THE BOTTOM ENABLES THE WATER TO CONVECT (1) AND TRANSFER HEAT THROUGHOUT THE JUG WATER.

END OF SECTION TWO

Figure 2 below shows the energy flow of 100 J of solar energy incident on the PV-MD device. The solar panel is 15% efficient (converting 15 J out of every 100 J into electrical energy), 25 J is reflected as light, and of the remaining 60 J absorbed as heat, 36 J of heat is used to create clean drinking water with 24 J of heat lost to the surrounding environment.



• ELEC → THERMAL ✗

Figure 2 Energy flow diagram for 100 J of incoming solar energy

• HEAT → ELECTRICAL ✗

(a) State one energy transformation taking place in a typical PV–MD device. (1 mark)

• LIGHT → ELECTRICITY ✓ (1)

OR • LIGHT → HEAT ✓ (WATER CONVERT.

• ~~LIGHT → KINETIC / MECHANICAL~~

(b) With reference to the design of a typical PV-MD device and the kinetic particle model, explain why the hot vapour condenses as it nears the clean water outlet. (3 marks)

• THE INLET WATER IS AT A LOWER TEMPERATURE (1) THAN THE HOT VAPOUR.

• THERMAL ENERGY WILL BE TRANSFERED FROM THE VAPOUR TOWARDS THE WATER INLET. (1)

• SOME OF THE KINETIC AND POTENTIAL (1) ENERGY OF THE VAPOUR PARTICLES IS TRANSFERED TO COOLER PARTICLES IN THE MEMBRANE.

(c) Using data from Figure 2, explain how a PV-MD device makes better use of solar energy than a conventional solar panel. As part of your explanation determine an overall efficiency of the PV-MD device described in Figure 2. (3 marks)

• A CONVENTIONAL PV PANEL IS ONLY 15% EFF. (1)

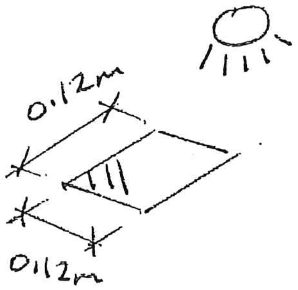
• A PV-MD IS $\frac{15+36}{100}$ = 51% EFF (1)

• THUS, THE PV-MD UNIT IS MORE THAN 3 TIMES MORE EFFICIENT (1) THAN A CONVENTIONAL PV PANEL.

/7

(d) The prototype used in the lab experiments consisted of a solar panel measuring 12.0 cm by 12.0 cm, placed under a lamp of intensity 1.00 kW m^{-2} (like that of the Sun) for one hour, during which time the solar panel produced 1296 C of charge. Given that the efficiency of the solar panel used is 15.0%:

i) determine the radiant energy incident on the solar panel in one hour. (3 marks)



For energy / sec.

$1000\ J/s : 1\ m^2$ (1)

$x : (0.12 \times 0.12)$

$\therefore x = 14.4\ J s^{-1}$

Now $E_{1hr} = 14.4 \times 3600$ (1)

$= 5.184 \times 10^4\ J$

$= 51.8\ kJ$ (1)

ii) determine the electrical energy produced by the panel in one hour. (1 mark)

$E_{Elec} = \frac{5.184 \times 10^4}{1} \times \frac{15}{100}$ (½)

$= 7.776 \times 10^3\ J$

or $= 7.78\ kJ$ (½)

iii) determine the output current and voltage of the panel. (2 marks)

$I = \frac{q}{t}$ (½)

$= \frac{1296}{3600}$

$= 0.360\ A$ or $3.60 \times 10^{-1}\ A$ (½)

$V = \frac{W}{q} = \frac{E}{q}$ (½)

$= \frac{7.776 \times 10^3}{1296}$

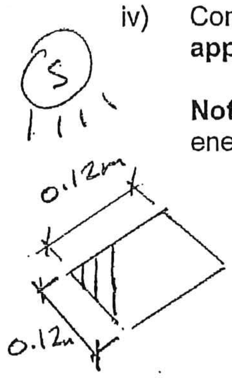
$= 6.00\ V$ (½)

/6

(WATCH C.D)

iv) Confirm by calculations below that the amount of clean water produced by the prototype is **approximately** 0.50 kg per hour per square metre. State your assumptions clearly.

Note: If you could not calculate a value for part (i) you may use a value of 5.0×10^4 J of solar energy incident (falling on) on the solar panel in one hour. (5 marks)



For $E_{HEAT} = 5.184 \times 10^4$ J/HR

$$= \frac{5.184 \times 10^4}{1} \times \frac{36}{100}$$

$$= 1.8662 \times 10^4 \text{ J} \quad (1)$$

Now, $E_{HEAT}/m^2 \Rightarrow 1.8662 \times 10^4 : (0.12 \times 0.12)$

$x : 1m^2$

$$= \frac{1.8662 \times 10^4}{0.0144}$$

$$= 1.2959 \times 10^6 \text{ J hr}^{-1} \text{m}^{-2} \quad (1)$$

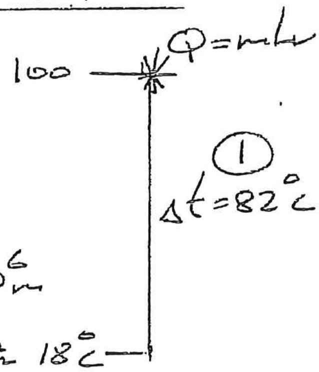
For m_w/hr — METHOD (1)

$$Q = (m c \Delta t) + (m_w L_v)$$

$$= (m \times 4180 \times 82) + (m \times 2.26 \times 10^6)$$

($m \times 4180 \times 82 = 3.4276 \times 10^5$)

ASSUME



Now $1.2959 \times 10^6 = 3.4276 \times 10^5 m + 2.26 \times 10^6 m$

$$\therefore m = \frac{1.2959 \times 10^6}{2.60276 \times 10^6}$$

$$= 0.4978 \quad (1)$$

≈ 0.5 kg of water per hour per m^2

QED

END OF EXAMINATION

5