AS CHALLENGE PAPER 2019

Name	
School	

Total Mark / 50

Friday 8th March

*Time allowed: **One hour***

Attempt as many questions as you can. If you are stuck, move on to the next question.

*Write your answers on this question paper. **Draw diagrams**.*

Marks allocated for each question are shown in brackets on the right.

You may use any calculator.

You may use any public examination formula booklet.

*Allow no more than **5 or 6 minutes** for **section A**.*

Scribbled or unclear working will not gain marks.

This paper is about problem solving. It is designed to be a challenge for the top AS physicists in the country. If you find the questions hard, they are. Do not be put off. The only way to overcome them is to struggle through and learn from them.

Good Luck.

Useful constants and equations

$$c = 3.00 \times 10^{8}\ \mathrm{m}\ s^{-1}$$
$$h = 6.63 \times 10^{-34}\ \mathrm{J\ s}$$
$$e = 1.60 \times 10^{-19}\ \mathrm{C}$$
$$g = 9.81\ \mathrm{m\ s^{-2}}$$
Avogadro constant $N_{\mathrm{A}} = 6.0 \times 10^{23}$

surface area of a sphere $= 4\pi r^2$

volume of a sphere $= \frac{4}{3}\pi r^3$

$$\boldsymbol{v^2 = u^2 + 2as}$$

$$\boldsymbol{v = u + at}$$

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

$$\boldsymbol{s = \frac{1}{2}(u + v)t}$$

power $=$ force $\times$ velocity

$$P = E/t$$

$$v = f\lambda$$

$$V = IR$$

$$R = R_1 + R_2$$

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

<u>Answers</u>

Qu 1	Qu 2	Qu 3	Qu 4	Qu 5

Section A: Multiple Choice

Circle the correct answer to each question and write your answers in the table on page 2.

Each question is worth 1 mark. There is only one correct answer to each question.

1. The mass of a car is approximately

A. 10^2 kg B. 10^3 kg C. 10^4 kg D. 10^5 kg

2. The Planck constant, h, is measured in units of joule.second in the SI system. If it was to be measured in units of (centimeters, grams, second) instead of (metres, kilograms, seconds) by how much would its numerical value increase?

A. 10^7 B. 10^5 C. 10^{-2} D. 10^{-5}

3. A large boulder of mass m lies in a riverbed. It can be rolled over by the water in the river flowing over it at speed v. Which of the following equations could relate the mass of the boulder to the speed of the river, v, its density ρ and the gravitational field strength, g? k is a constant with no units.

A. $m = \frac{k\rho v}{g}$ B. $m = \frac{k\rho v^2}{g^3}$ C. $m = \frac{k\rho v^6}{g^3}$ D. $m = \frac{k\rho g}{v^3}$

4. The number of molecules in a teaspoonful of sugar is approximately

A. 10^{13} B. 10^{18} C. 10^{23} D. 10^{28}

5. You knock a plate of food off the table and observe that it lands upside down. This might be due to:

A. The weight of the food on top of the plate makes it turn over.

B. The air drag on the plate makes it turn over.

C. When you push the plate, you provide a spinning motion to it.

D. As it slides off the edge of the table, there is a turning force applied by gravity.

/5

Section B: Written Answers

Question 6.

a) A cyclist wants to carry a heavy bag of books on her bicycle, using a shopping bag hanging from the handlebars. When she attaches the bag, it swings from side to side with a period of 1.2 s. When she rides the bicycle, her body swings from side to side each time she turns the pedals. If the bag swings with the same period, it makes the bike wobble dangerously from side to side.
The diameter of the back wheel is 650 mm. There are 15 teeth on the rear cog and 48 teeth on the chain ring. What speed on the road should the cyclist try to avoid?

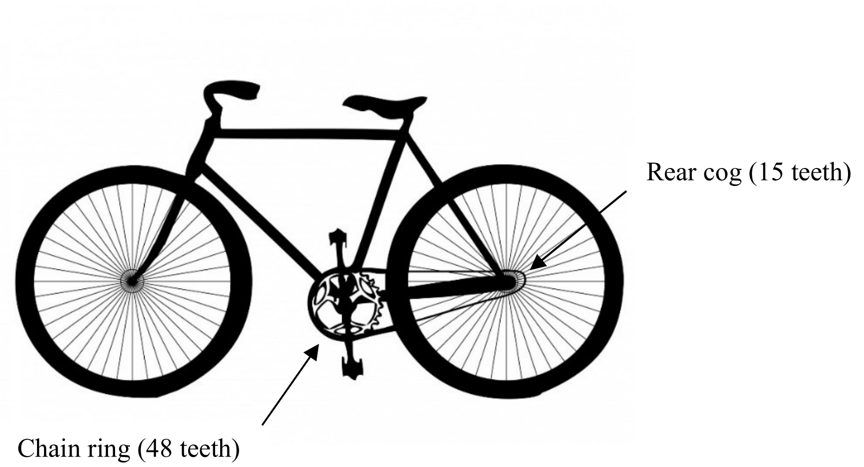

Figure 1

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Question 7.

A light, rigid rod with two equal masses, m, at the ends, is held with one end on a horizontal surface. The other end rests on a circular curve of radius 3.4 m, at a distance from the horizontal corresponding to $\frac{1}{8}$ of the circumference of a circle, as shown in Fig 2.

If the surface is frictionless, what is the speed of the rod and masses when released and both masses slide on the flat surface? The masses remain in the same vertical plane.

Figure 2

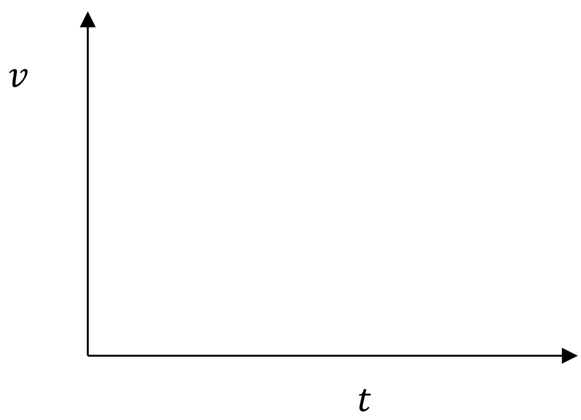
____ [4]

/4

Question 8.

A ball is dropped from rest at height h, and accelerates towards the ground, reaching it with final speed v_f after time t. Ignore air resistance.

a) Sketch a $v - t$ graph and on the graph mark on the average speed, $v_{av}(t)$. State its value in terms of v_f.



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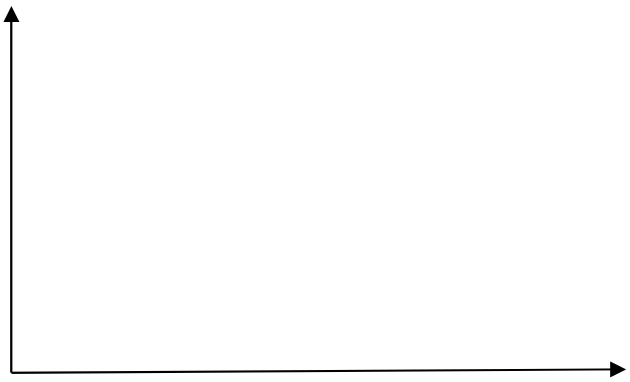
b) Describe, **referring to the area under the curve** in your graph, what is meant by this *time averaged speed*, $v_{av}(t)$.

[1]

c) It can be of interest to determine the average speed over a distance instead. Sketch a suitable graph to help explain the idea of *distance averaged speed*, $v_{av}(s)$.



[3]

d) (i) Referring to your graph, use it to explain what is meant by *distance averaged speed*, $v_{av}(s)$.

[1]

(ii) Calculate the distance averaged speed, $v_{av}(s)$ in terms of v_f.

[1]

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Question 9.

A circuit with two resistors, R_1 and R_2 connected in parallel, is shown in Fig 3 below. Current I_1 flows through R_1.

a) Obtain an expression for the total power, P_t, dissipated in R_1 and R_2, in terms of R_1, R_2 and I_1.

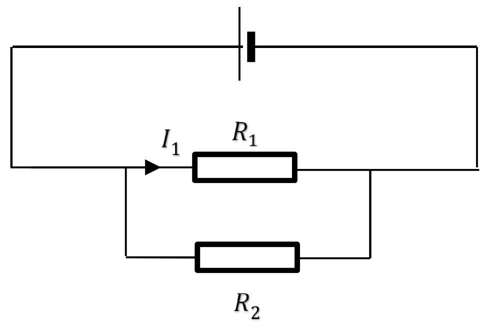
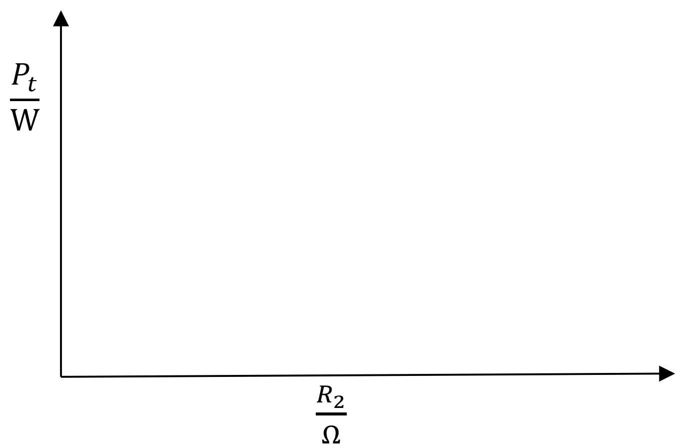


Figure 3

____ [3]

b) Sketch a graph of P_t against R_2, as R_2 is varied from 0 to ∞. Mark on any values.



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Question 10.

The Sun can be treated as a large ball of gas, in which 99.9% of the nuclear energy generation is within the core. The process is well understood, but experiments to confirm the theory are important. Photons from the core are absorbed by atoms and then reradiated at lower energy, reaching the surface after about 100 000 years of travelling through the Sun's layers.
The (simplified) structure of the Sun is shown in Fig 4. Densities, ρ, are all in kg m^{-3}.

To obtain the wavelength of a photon radiated, we can use the equation for thermal radiation,

$$\lambda T = 2.9 \times 10^{-3} \text{ m K}$$

in which T is the temperature measured in kelvin, and λ is the wavelength of the radiation.

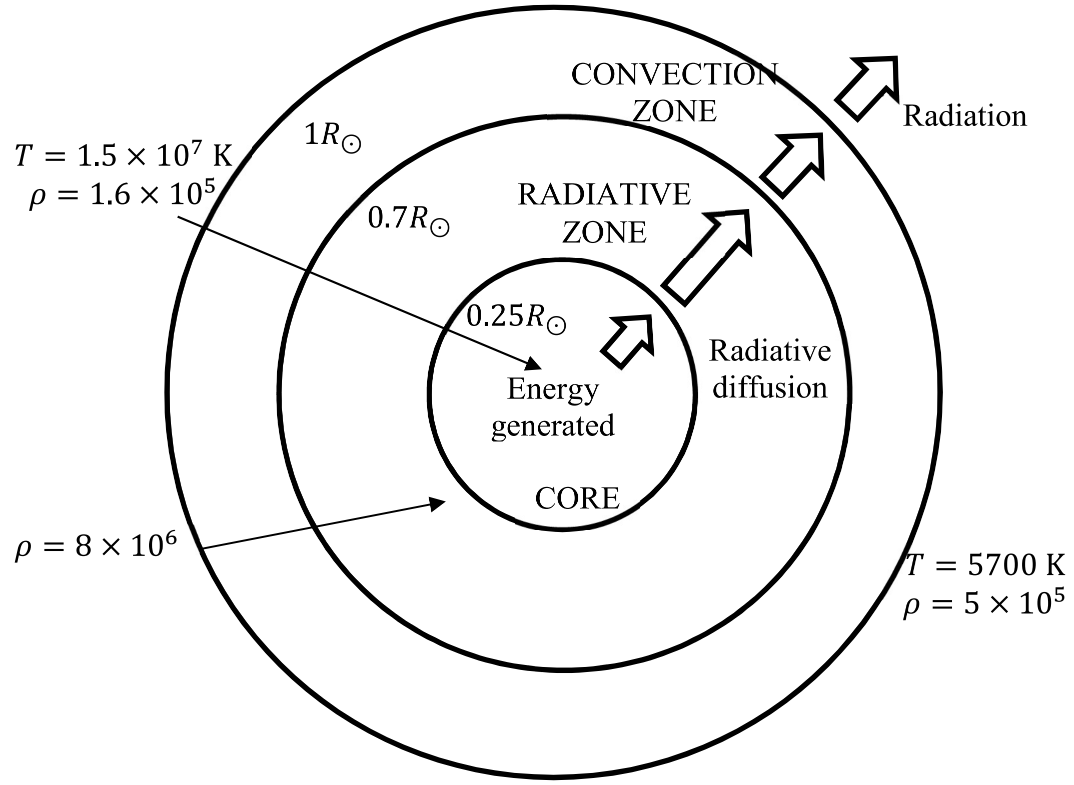

Figure 4. Simplified structure of the Sun. Densities, ρ, are in kg m^{-3}. Temperatures are in kelvin. The solar radius is the symbol $R_\odot$

a) (i) Photons are radiated from the surface of the Sun, at a temperature of 5700 K. Calculate their wavelength, λ, using the formula for thermal radiation, In which region of the electromagnetic spectrum are these photons?

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____ [2]

(ii) What would be the wavelength of a photon radiated in the core of the Sun? In which region of the electromagnetic spectrum is this?

Calculate the energy of this photon (in joules)

____ [3]

b) How is the motion of the gas different in the radiative zone from the convective zone?

____ [1]

c) The density and temperature of the core can be found in the diagram in Fig 4. By what factor is the density of the (hydrogen) gas in the core of the Sun greater than the density of (the metal) lead, ρ_{lead} ?

$$\rho_{\text{lead}} = 11300 \text{ kg m}^{-3}$$

____ [1]

d) Despite the high density of the hydrogen gas in the core, due to the high temperature, we can use the equation for an ideal gas (a combination of Boyle's Law $PV = \text{const.}$ and $\frac{P}{T} = \text{constant}$). This is

$$P = \frac{k}{\mu}\rho T$$

where μ is the mass of a hydrogen atom, and k is a constant.

Calculate a value for the pressure, P, of the gas at the centre of the Sun and compare it with atmospheric pressure on the Earth ($P_{\text{atm}} = 1.01 \times 10^5$ Pa).

$\mu = 1.67 \times 10^{-2}$ kg $\qquad k = 1.38 \times 10^{-23}$ J K^{-1}

____ [1]

e) From the values on the diagram, estimate the percentage of the volume of the Sun that lies within the core

____ [1]

f) Energy is generated in the core by a series of nuclear reactions. We can summarise the beginning and end points by the following nuclear reaction.

$$4\,{}^{1}\mathrm{H} \rightarrow {}^{4}\mathrm{He} + 2e + 2\nu + 4.27 \times 10^{-12} \text{ joules}$$

^{1}H is a hydrogen nucleus
^{4}He is a helium nucleus
e is an electron
ν is a neutrino

i.e. four hydrogen nuclei fuse together to form a helium nucleus and release a pair of electrons, a pair of neutrino particles and some energy.

(i) The Sun radiates in all directions, illuminating an imaginary spherical surface. If the Earth is at a distance of 1.50×10^{11} m from the Sun, and receives about 1.3 kW m^{-2}, show that the Sun generates a power output of about 4×10^{26} W.

____ [2]

(ii) From the energy released in the reaction, calculate how many neutrinos are generated in the core each second.

____ [2]

(iii) If these neutrinos do not interact with anything, they will pass out of the core, straight through the Sun, and reach the Earth (after about 8 minutes of travel time). Calculate how many neutrinos pass through 1 cm^2 each second at the Earth.

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____ [2]

Neutrinos are very difficult to detect. Neutrino physicists construct detectors the size of a small factory and are delighted to detect a few neutrinos each day.

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Question 11.

The Specific Heat Capacity (SHC), c, of a material is defined as the energy needed to raise the temperature of 1 kg of material by 1°C: $\Delta H = mc\Delta T$ where ΔH is the amount of thermal energy supplied to the material, m is its mass, and ΔT is the temperature rise.

An experiment to measure the SHC of a sample of a solid is shown in Fig 5.

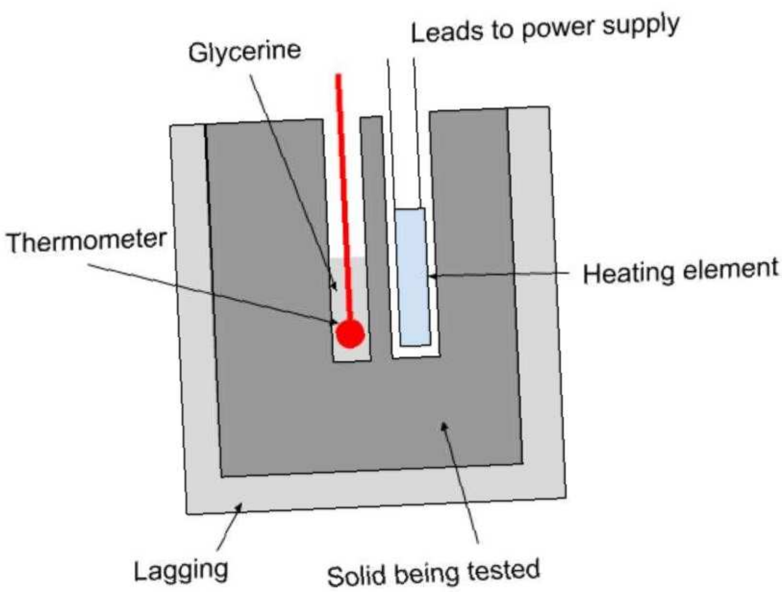

Figure 5. Heating a sample of material surrounded by insulating lagging.

The insulation (lagging) surrounding the sample reduces thermal energy loss. The rate at which thermal energy is lost to the surroundings can be described by Newton's Law of Cooling:

$$\frac{\Delta Q}{\Delta t} = k(T - T_0)$$

where T is the temperature of the material, T_0 is the temperature of the surroundings and $\frac{\Delta Q}{\Delta t}$ is the rate at which thermal energy is lost. k is a constant.

a) What would affect the value of k?

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An accurate method of correction for loss of thermal energy is attributed to the Scottish scientist, Thomas Charles Hope. The material is heated from room temperature, T_{room}, using apparatus as above, and the temperature recorded against time. In Fig 6, the ideal curve shows what would happen in the absence of any thermal energy being lost to the surroundings.

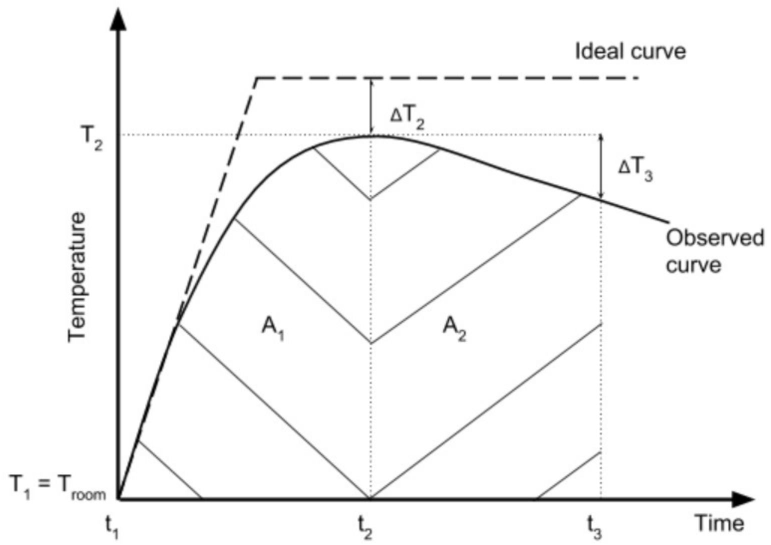

Figure 6

b) The times t_1, t_2 and t_3 are equally spaced, with t_2 being the time at which the temperature reaches its maximum. Explain why t_2 is some time after the change in gradient of the ideal curve.

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c) Use Newton's Law of Cooling to explain why the area A_2 is proportional to the thermal energy lost between times t_2 and t_3.

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d) Hence explain why $\frac{\Delta T_2}{\Delta T_3} = \frac{A_1}{A_2}$

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e) Hence find an expression for c in terms of the quantities you could measure in the experiment and off the graph.

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