BPhO
British Physics Olympiad

AS CHALLENGE PAPER 2018

Name	
School	

Friday 2nd March

Total Mark/50

Time Allowed: ***One hour***

Attempt as many questions as you can.

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.

Students*: Again, this year, this paper is being used to select students to invite to the BAAO Astronomy & Astrophysics Training Camp at Oxford from Monday 9th to Thursday 12th April 2018. Previous experience in these subjects is not required.*

Useful constants and equations

$c = 3.00 \times 10^{8}$ m s^{-1}

$h = 6.63 \times 10^{-34}$ J s

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

$g = 9.81$ m s^{-2}

Avogadro constant $N_A = 6.0 \times 10^{23}$

surface area of a sphere $= 4\pi r^2$ volume of a sphere $= \frac{4}{3}\pi r^3$

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

$s = ut + \frac{1}{2}at^2$ $s = \frac{1}{2}(u + v)t$

power = force × velocity $P = E/t$ $v = f\lambda$

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

Answers

Qu 1	Qu 2	Qu 3	Qu 4	Qu 5

Section A: Multiple Choice

Circle the correct answer to each question. 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 thickness of a page of this exam paper is approximately

A. 0.01 mm B. 0.1 mm C. 1 mm D. 10 mm

2. A volt is a joule per coulomb. The unit of electrical resistance, R, in terms of base units (m, kg, s, A) is

A. $\frac{\text{kg m}^2}{\text{s}^3\ \text{A}^2}$ B. $\frac{\text{kg m}}{\text{s}^2\ \text{A}^2}$ C. $\frac{\text{kg}^2\ \text{m}^2}{\text{s}^2\ \text{A}^2}$ D. $\frac{\text{kg m}^2}{\text{s}^2}$

3. A student has to solve a difficult problem on calculating a speed of an astronomical object v, which involves masses m_1 and m_2, an acceleration a, the age of the object t, and the speed of light c. He tries several times, each time getting a different answer. Finally, he runs out of time and has to pick one of his answers. Which one is the best option?

A. $v = \frac{(m_1+m_2)}{c}at$ B. $v = m_1 t + \frac{m_2 c}{a}$ C. $v = m_1.\frac{m_2 c}{at}$ D. $v = \frac{m_1}{m_2}.\frac{c^2}{at}$

4. The number of atoms in a typical course grain of sand found on a beach is approximately

A. 10^4 B. 10^8 C. 10^{20} D. 10^{46}

5. A beaker of water sits on a top pan balance. When a student sticks his finger in the water, the reading on the balance

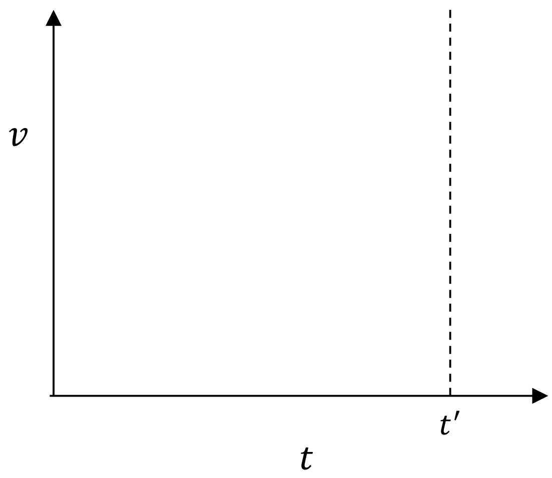
A. Decreases B. Increases C. Remains the same D. Increases or decreases depending on the relative depth of the finger and the water

Section B: Written Answers

Question 6.

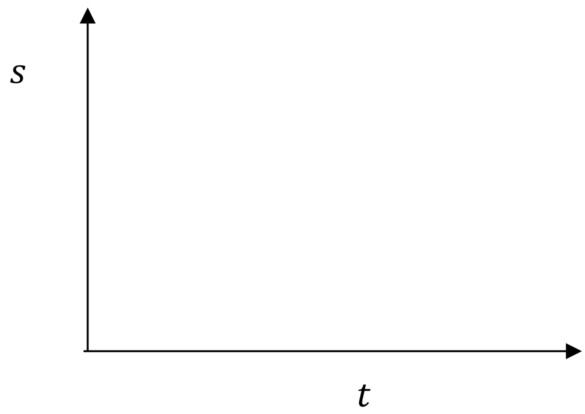
A car travels along a straight road at constant speed u. It passes a stationary motorbike, which immediately begins to accelerate from rest with a constant acceleration, f. Thus they move off from the same starting point at the same time.

a) Sketch two **speed-time** graphs on the same axes below, of the speeds of the car and motorbike before the time t', when the motorbike overtakes the car.



[3]

b) Sketch, on the same axes below, **distance-time** graphs of the distances travelled by the car and motorbike, from the start until they pass each other.



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c) On your graph in (b), mark with a dotted line the time t'' when the vehicles have the greatest separation. State in words how you have chosen this time.

[2]

d) Without using calculus, show that the vehicles have maximum separation (Δs_{max}) at time $t'' = \frac{u}{f}$.

[2]

e) Without using calculus, obtain an expression for the maximum separation of the vehicles, Δs_{max}, in terms of u and f.

[2]

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Question 7.

A glass prism has a cross section that is an isosceles triangle. One of the equal faces is silver coated to reflect a ray internally. A ray of light is incident on the prism, normal to the unsilvered face, with the incident ray being reflected twice within the prism, and emerging from the base of the prism at normal incidence.

a) Sketch a large (realistic) diagram of the path of the light ray, marking on angles α and β for the apex and base angle of the prism respectively.
   Hint: the angle α is less than $60°$.
   (You may wish to practise your diagram on the back page of the exam paper)

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b) Calculate the value of angle α, the apex of the prism.

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Question 8.

The European Space Agency runs experiments on Earth which require a weightless environment (freefall) for a few seconds. It uses compressed air to fire a container with the apparatus inside, upwards from a long, vertical tube. The lower end of the tube rests on the ground, as shown in Fig. 1. The container falls back onto thin cushions on the ground. The tube is 8.0 m long and the container is fired upwards with a vertical acceleration of $25g$. You should ignore air resistance in this question.

$g = 9.81 \text{ m s}^{-2}$

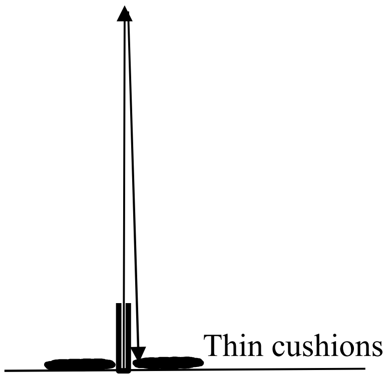

Figure 1. Sketch of the up and down trajectory.

a) Calculate the exit velocity of the container from the tube.

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b) Calculate the maximum height reached above the ground.

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c) Calculate the time for which the apparatus experiences the effect of weightlessness; that is, the time for which it is in free fall.

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Question 9.

A circuit consists of a battery of emf $\varepsilon = 4.5$ V and negligible internal resistance, connected in series with three resistors, R_1, R_2, R_3 of values $200\ \Omega, 300\ \Omega$ and $400\ \Omega$ respectively. A digital voltmeter is connected between points A and B, shown in Fig. 2.

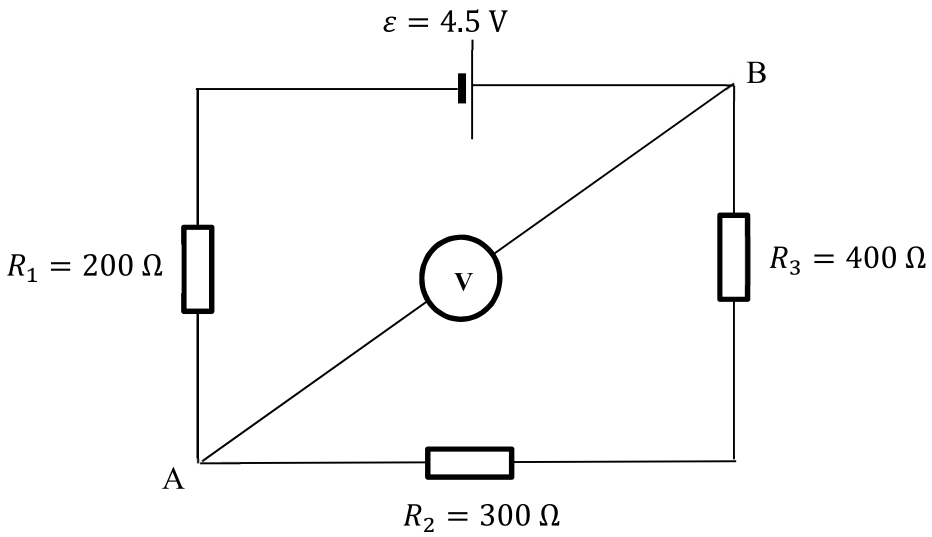

Figure 2.

a) What is the potential difference between A and B measured by the voltmeter in Fig. 2?

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The voltmeter is replaced with an older moving coil meter, which itself has a resistance R_V of only $500\ \Omega$, shown in Fig. 3. This lower resistance affects the circuit, but the voltmeter is calibrated to give the correct reading of the voltage across its terminals, which are connected to A and B.

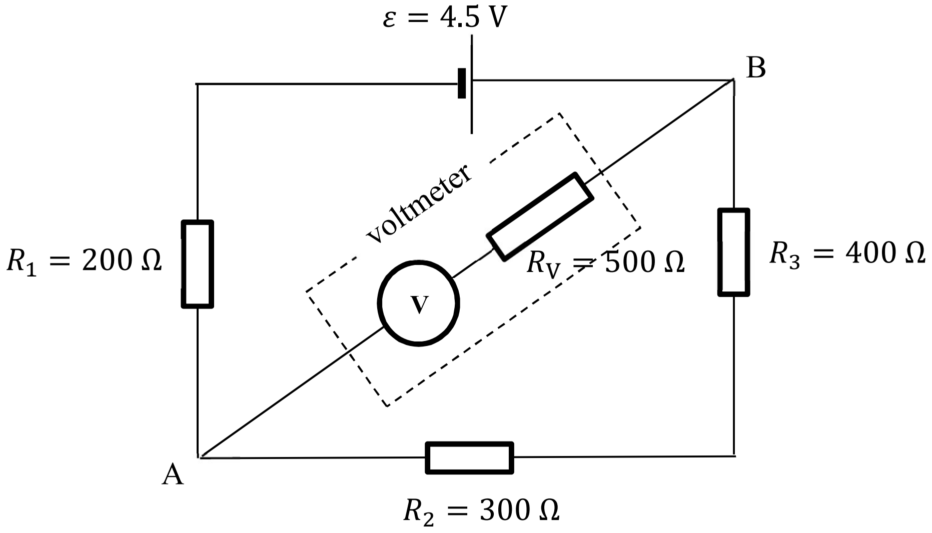

Figure 3.

b) What would be the potential difference between A and B measured by the voltmeter in Fig. 3?

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Question 10.

When viewed from a point above the North Pole of the Earth, all the motions of the Earth and the Moon appear anticlockwise.

a) Sketch a diagram of the Moon and Earth, relative to the Sun's position (not to scale), with arrows to show the directions of the orbital and rotational motions of the Moon and Earth.

[1]

b) As the Moon orbits the Earth, the same face of the Moon always points towards the Earth. Because of this, the Moon is said to be "tidally locked" to the Earth. The far side of the Moon is often called the dark side of the Moon. Explain why the phrase "dark side of the Moon" is misleading. You may use a diagram.

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c) A solar day is 24 hours, from noon when the Sun is overhead in the sky, until the Sun is again overhead at noon the following day. However, if any other star in the sky is used (working from midnight to midnight when the star could be seen overhead), the measured time from the star being overhead from one day to the next day is a few minutes shorter. This is called a sidereal day. Explain why the sidereal day is shorter (you may use a diagram), and calculate by how many minutes the length of a sidereal day is less than 24 hours.

Hint: the Earth takes 365.25 days to orbit the Sun.

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d) The Moon orbits the Earth once every lunar month. A new moon, which cannot be seen, occurs when the Moon lies between the Earth and the Sun. A few days after the new moon, a faint crescent Moon can be seen in the sky in the West. Explain, with the aid of a diagram, why this new crescent moon always appears to the west of an observer on Earth.

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Question 11.

New ultra low power devices (watches and calculators for example) need miniature long-lasting electrical sources. The system described here, uses a thin Pu-238 alpha source, in which the kinetic energy of the alpha particles produces photons of light in the thin layer of phosphor on a glass plate. Then photons emitted from the phosphor then produce a voltage in the photovoltaic layer, illustrated in Fig. 4 below.

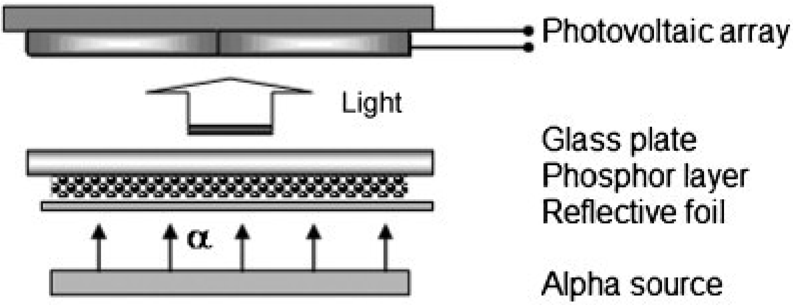

Figure 4. Alpha indirect conversion setup.

Ref. Alpha Indirect Conversion Radioisotope Power Source, *Maxim Sychov et al.*

Applied Radiation and Isotopes Vol 66, Issue 2, February 2008, Pages 173-177

A thin, uniform layer of a zinc sulfide (ZnS) phosphor layer is deposited on the glass slide. A thin layer of an alpha emitting radioactive source placed close to the phosphor layer will cause light to be emitted from the phosphor. The light goes in both directions out of the phosphor layer (up and down in Fig. 4), but a very thin reflecting sheet of aluminium (thin enough to allow most alphas to penetrate) reflects light emitted in the phosphor back towards the photovoltaic array.

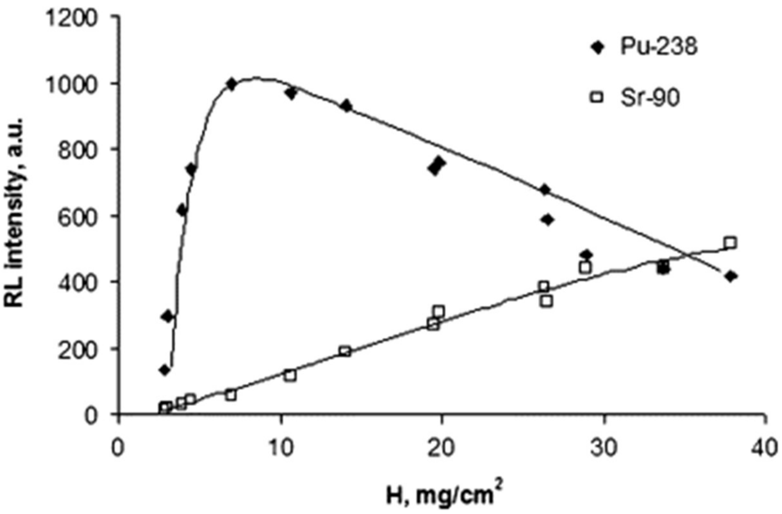

Figure 5. Radioluminescent intensity vs ZnS phosphor layer thickness, H, for an alpha source (Pu-238) and a beta source (Sr-90).

Ref. ibid.

a) From the graph of Fig. 5, read off a value for the optimum thickness to give maximum light intensity from the layer of ZnS phosphor with an alpha source.

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b) The thickness of the layer is given in mg/cm^2 rather than a length measurement. If the density of ZnS is 4.1 g cm^{-3}, calculate the thickness of the ZnS layer in μm (1 μm = 1×10^{-6}m.) You may find a simple diagram of the ZnS layer helpful.

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c) The alpha particle range in a material can be calculated using the formula

$$R_x = \frac{10^{-4}\sqrt{A_x E_0^3}}{\rho_x}$$

in which R_x is the range of the alphas in cm, ρ_x is the density of the material in g cm^{-3}, and E_0 is the initial energy of the alphas in MeV (1 MeV is 1.6×10^{-13} J.)
If $E_0 = 5.5$ MeV, $\rho_x = 4.1$ g cm^{-3} and A_x is 48.7 (the average atomic weight of ZnS), calculate a value of R_x. How does this value compare with the optimal thickness of ZnS from part (b)?

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d) In Fig. 5, the Sr-90 is a source of beta radiation. How does this explain the difference in the shape of the two curves?
Hint: the penetration of beta radiation is different from alpha radiation, with alpha being stopped by a thin sheet of paper.

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e) A 2.15 mW Pu-238 source of power was used in each radioisotope power source (each cell). Five of these cells were connected in series to form a battery with the following three characteristics;

1. The maximum power output of the battery was 21 μW.
2. A short circuit current of 14 μA could be obtained
3. The open circuit voltage was 2.3 V

   i. What would be the efficiency of the power conversion?
   ii. What would be the internal resistance of a single cell?

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END OF PAPER

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