BPhO British Physics Olympiad

AS CHALLENGE PAPER 2016

Name	
School	

Friday 11th March

Total Mark/50

Time Allowed: ***One hour***

Attempt as many questions as you can.

Write your answers on this question paper.

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 ***6 or 7 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.

BPhO sponsors

Cambridge University

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Useful constants and equations

$$c = 3.00 \times 10^8 \text{ m s}^{-1}$$
$$h = 6.63 \times 10^{-34} \text{ J s}$$
$$e = 1.60 \times 10^{-19} \text{ C}$$
$$g = 9.81 \text{ m s}^{-2}$$

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

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

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	Qu 6

Section A: Multiple Choice

Circle the correct answer to each question. Write your answers in the table on page 3.

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

1. Which are the correct dimensions of energy in terms of mass [M], length [L] and time [T]?

A. $\frac{MT^2}{L^2}$ B. $\frac{ML}{T^2}$ C. $\frac{ML^2}{T^2}$ D. $\frac{ML^2}{T}$

Questions 2 and 3 refer to Figure 1.

An incompressible liquid flows through a pipe of circular cross section which narrows at some point on its length. The diameter reduces to $\frac{1}{3}$ of its original diameter.

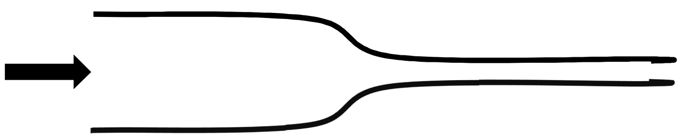

Figure 1. Incompressible liquid flowing through a tube which narrows.

The rate of flow of liquid on the left is $6\ \mathrm{m^3 s^{-1}}$ and the speed is $2\ \mathrm{m\ s^{-1}}$.

2. What is the rate of flow of the liquid in the narrow section of tube?

A. $\frac{2}{3}\ \mathrm{m^3 s^{-1}}$ B. $\frac{3}{4}\ \mathrm{m^3 s^{-1}}$ C. $2\ \mathrm{m^3 s^{-1}}$ D. $6\ \mathrm{m^3 s^{-1}}$

3. In Fig 1, the speed of the liquid flow through the narrow tube is

A. $\frac{2}{3}\ \mathrm{m\ s^{-1}}$ B. $2\ \mathrm{m\ s^{-1}}$ C. $6\ \mathrm{m\ s^{-1}}$ D. $18\ \mathrm{m\ s^{-1}}$

Questions 4, 5 and 6 refer to Figure 2.

4. An object of mass m is suspended from a light string attached to a wall, as shown in Fig 2. The force F is horizontal. If the mass is doubled so that mg is replaced by $2mg$, how do forces F and T change? The angle between the string and the wall is kept at 45^{o}.

A. F and T remain the same B. T halves C. F doubles D. F halves

5. In Fig 2, which is the relationship between F, T and mg?

A. $T\tan 45° = F$ B. $F\sin 45° = T$ C. $T\sin 45° = F$ D. $mg\sin 45° = T$

6. How are the magnitudes of F, T and mg related?

A. $F = mg$ B. $F < mg$ C. $F > mg$ D. $F + mg = T$

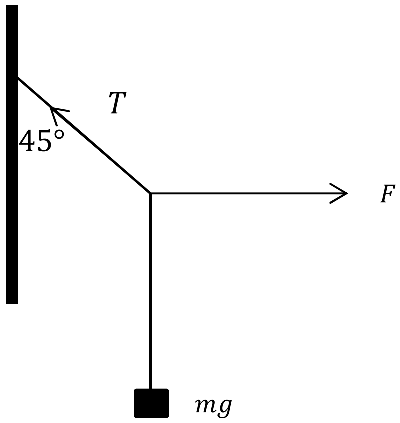

Figure 2. A weight hanging from a string attached to a wall.

Section B: Written Answers

Question 7.

a) When a particle falls under gravity it falls with a constant acceleration. When the particle has an initial speed u, the speed time graph is shown below. Using this graph, show how the equation of motion

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

is obtained, where the symbols have their usual meaning.

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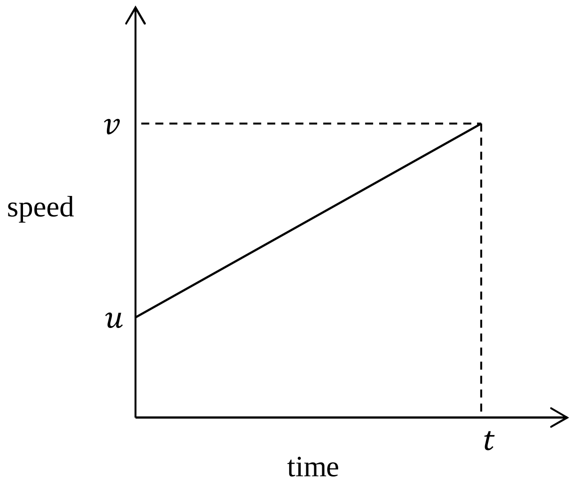

Figure 3. Speed time graph with constant acceleration.

Two points A and B are located on a vertical line with point A vertically above point B. A particle is released from rest at A and at the same time another particle is projected vertically upwards from B at velocity v. The particles collide when the top one has fallen a distance y. The height of point A above point B is h.

b) Show that the time t from the start of the motion to collision is given by $t = \frac{h}{v}$.

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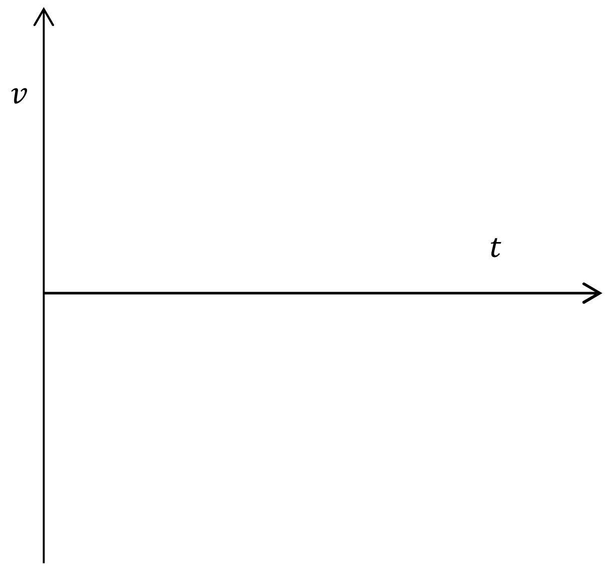
How does the distance the particle falls, y, from point A depend upon v, h and g?

[2]

c) Sketch velocity - time graphs below, on the same set of axes, for the two particles. If $h = 100$ m, $v = 20$ m s^{-1} and $g = 10$ m s^{-2}, mark on the graphs the (t, v) values where the particles collide. Take v to be positive upwards.



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Question 8.

Venus is an inner planet which orbits the Sun in almost the same plane as the Earth. Its average radius of orbit is 0.72 AU. (An AU, or astronomical unit, is the average distance between the Earth and the Sun.) When viewed from the Earth's equator, estimate the maximum number of hours before sunrise for which Venus can be observed in the night sky. You should draw a diagram to explain your working.

Diagram:

[4]

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Question 9.

Here is a question written in the condensed style of old physics papers. The language has been updated a little, but it is not broken down into small steps as is usual nowadays. You are to explain what the question is asking.

> "Two perfectly elastic balls falling from different heights, h, h', in the same vertical line, bounce off a perfectly hard inclined plane to then move along a horizontal plane with the velocities acquired. Find what distance they move along the horizontal plane before collision takes place."

(i) Sketch a diagram

(ii) Explain the physics of this question i.e the motions that take place and why the balls collide.

(iii) Write down the steps you would take to solve the question. **You are not required to write equations or to obtain the solution.**

Diagram

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Question 10.

The resistance of a wire is proportional to its length l, and inversely proportional to its cross sectional area A. The constant of proportionality, ρ is known as the resistivity of the material.

$$R = \frac{\rho l}{A}$$

For copper, the resistivity $\rho_{\text{cu}} = 1.68 \times 10^{-8}\ \Omega\ \text{m}$ and for silicon, a semiconductor, with trace amounts of impurities, $\rho_{\text{si}} = 0.53\ \Omega\ \text{m}$.

a) The resistance between two opposing faces of a copper cube of length $l = 1$ m and cross sectional area $A = 1\ \text{m}^2$ is $1.68 \times 10^{-8}\ \Omega$. What would be the length of the side of a **cube** of silicon with a resistance of $1.68 \times 10^{-8}\ \Omega$ between opposite faces?

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b) Why does silicon have a resistivity 10^8 times greater than copper?

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A long coil, called a solenoid, is formed by winding a long piece of insulated copper wire of circular cross section and resistivity ρ_{cu}, in a single layer, around a tube of length L, which also has a circular cross section. The radius of the wire is r and the radius of the tube is a with $r \ll a$. There are N turns on the coil, which are closely spaced and form a single layer on the tube. Neglect the thickness of the insulation on the wire.

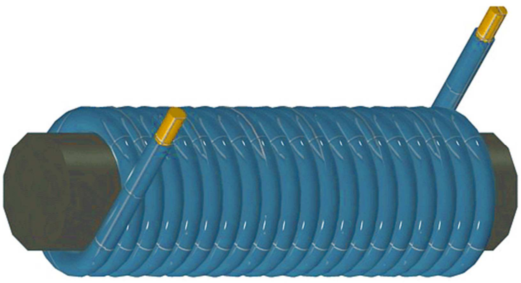

Figure 4. Single layer close-wound solenoid. The turns of wire have no gaps between them.

Source http://study.com/academy/lesson/what-is-solenoid-definition-uses-examples.html

The strength of the magnetic field in the solenoid, B, is proportional to the current I flowing in the coil, and is given by

$$B = \mu_o \frac{N}{L} I$$

with μ_o being a constant of proportionality.

When making a single layer solenoid to produce a large field strength B, we want to know if it is better to use many turns of long, thin wire or fewer turns of shorter, thicker wire. i.e. how does B depend upon the radius of the wire, r.

A circuit is set up with a cell of emf $\mathcal{E}$ and a resistor R in series with the solenoid. The resistance of the coil is R_c.

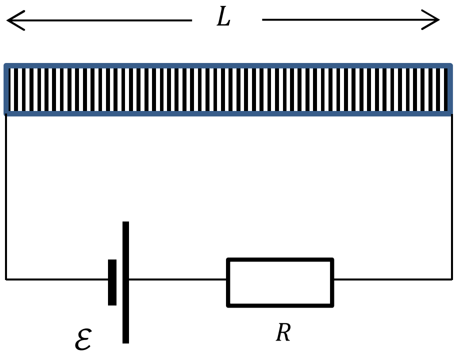

Figure 5. Circuit with solenoid. The solenoid is formed from a single layer of close-wound wire.

c) Write down an expression for the current I in the circuit in terms of R, R_c and $\mathcal{E}$.

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d) Given that the wire is of radius r and the solenoid is of radius a,
   (i) how many turns of wire, N, can be wound on the solenoid of length L, and
   (ii) what is the length l of the wire used? (assume $a \gg r$)

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____ [2]

e) Write down an expression for the resistance of the solenoid wire, R_c.

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f) Now using these terms, write down an expression for the field strength B in terms of $\mu_o, \mathcal{E}, r, R, \rho, L, a$.

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There are two situations to examine; the first is where $R \approx 0$ so that the current is determined by the wire forming the solenoid.

g) If $R \approx 0$ how does B depend upon the radius r of the wire used?

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____ [2]

The second case is where the resistance R dominates and the current in the circuit is determined by this resistance. i.e. $R \gg R_c$

h) Now write down how the field B depends upon r.

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i) Sketch graphs on the same set of axes showing how B depends upon r in these two cases.

[2]

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Question 11.

Interplanetary satellites are very complex platforms with dozens of scientific instruments, mechanical devices and radio transmitters and receivers on board. They require considerable power and operate over many years, and those travelling to the outer planets cannot use solar power. They rely instead on Radioisotope Thermal Generators (RTG), which produces heat by simple radioactive decay, and this heat is converted to electrical energy by heating one side of a semiconductor and cooling the other. There are no moving parts and the efficiency is low at typically 8%, but the reliability is very high.

Rather than have one large mass of the most commonly used radioactive isotope, plutonium-238, many small pellets are used to generate the energy required to run the satellite's systems. One pellet is used to produce 5 W of electrical power.

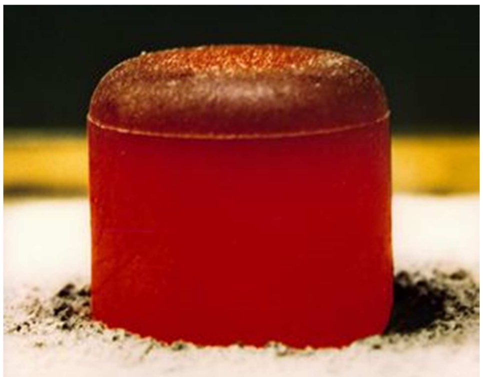

Figure 6. An image of a marshmallow-sized Pu-238 pellet glowing red hot.

(Source: Wikimedia Commons, attributed to Los Alamos National Laboratory)

The following information has been sourced from the internet, and one can find a picture of the pellet, which is described as the size of a marshmallow. Use the following information to calculate the volume of such a pellet.

Use the units as a help in your calculations. State what you intend to calculate even if you do not know how to proceed.

DATA:
Efficiency of conversion of thermal power to electrical 8%
Energy released in a single alpha decay 5.5 MeV
$1\ \text{MeV} = 1.6 \times 10^{-13}\ \text{J}$
Avogadro's number, $N_\text{A} = 6.02 \times 10^{23}\ \text{mol}^{-1}$
Half-life of ^{238}Pu is 87.4 years
When the isotope is new and little of it has decayed, the activity, A_0 (i.e. the number of decays per second) is equal to $0.693 \times$ the number of radiactive atoms present, N_0 $\div$ half life in seconds, t_hl. i.e.

$$A_0 = \frac{0.693 \times N_0}{t_\text{hl}}$$

The plutonium is supplied as a ceramic pellet of PuO_2 which has a density of $10\ \text{g cm}^{-3}$
The mass number of Pu-238 is 238
The mass number of oxygen (O) is 16
Only 80% of the plutonium atoms are actually radioactive Pu-238

Calculate the volume of a pellet of Pu-238 generating 5 W of electrical power.

[Here is a set of quantities that might prove useful in obtaining the result: thermal power, energy of a decay, no. of decays per second needed to generate the thermal power, no. of plutonium atoms needed and no of plutonium oxide molecules needed].

Work out any quantities that you can and make it clear what each result is. There is no particular order.

[10]

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END OF PAPER