Name:	
School:	

Total Mark	

BPhO British Physics Olympiad

2023 Intermediate Physics Challenge

Friday 3rd March

Time allowed: 1 hour

Attempt all questions

Write your answers on this question paper

You may use a calculator

You may use any standard exam board formula and data booklet

Others sit this paper at different times. You should not make any comments about this paper on the internet until Monday 13th March

Section A: Ten multiple choice questions worth 1 mark each (worth 10 marks in total).

Allow about 15 minutes for this section.

Section B: Two short written questions (worth 10 marks in total).

Questions require a clear explanation of the underlying physics principles.

Allow about 10 minutes for this section.

Section C: Two extended numerical questions requiring calculations (worth 30 marks in total).

Questions may be set on unfamiliar topics. Additional information necessary to answer the question will be given in each question.

Allow about 35 minutes for this section.

Useful Constants and Equations

The following useful equation may be unfamiliar to some students:

$\rho = {}^{m}/_{V}$	density = mass ÷ volume
$c = f \times \lambda$	wave speed = frequency x wavelength
$p \times V = constant$	pressure x Volume = constant for an ideal gas at a constant temperature
$\frac{1}{2}mv^2$	kinetic energy
mgh	gravitational potential energy
$P = V \times I$	

The following constants should be used

$\mathrm{g} = 9.8\,\mathrm{N/kg}$	gravitational field strength on Earth

Section A: Multiple Choice Answers

Write the letter corresponding to your chosen answer in the grid below.

The first column has been done as an example if the answer to question zero were C.

Question	0	1	2	3	4	5	6	7	8	9	10
Answer	C										

Multiple Choice Questions

Question 1

The total mass of a cyclist and their bike is 95 kg.

Ignoring the effects of air resistance and friction with the road, how much work is done by the rider to increase their speed from 2.0 m/s to 6.0 m/s?

A. 190 J

B. 760 J

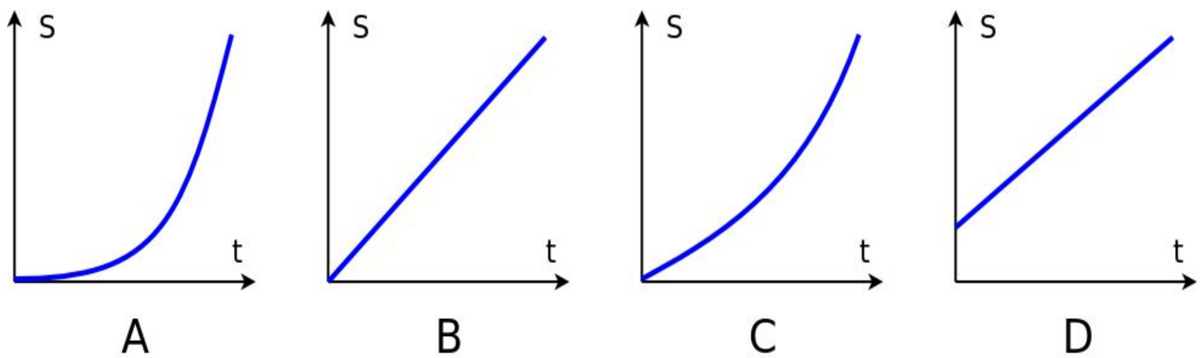
C. 1500 J

D. 1700 J

Question 2

A marathon runner crosses the start line of a race at a speed of 1 m/s and accelerates at a constant rate of 2 m/s^2 for 2 seconds.

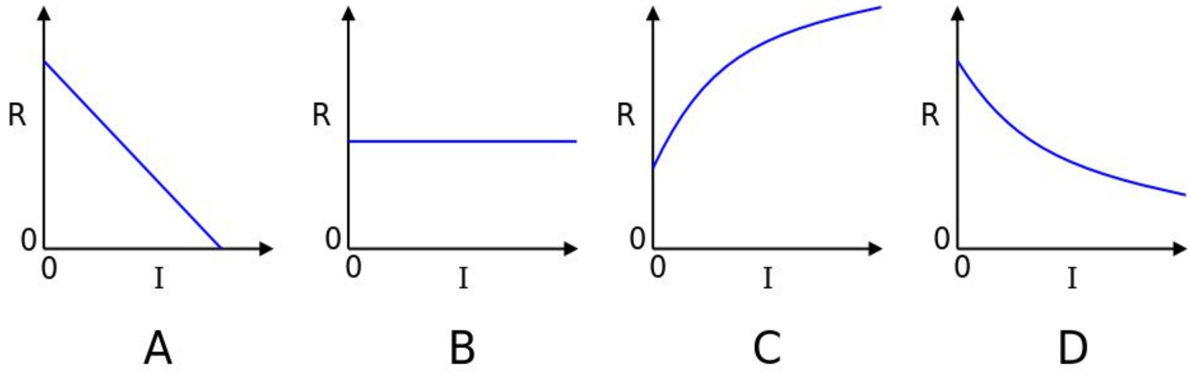
Which graph shows the relationship between displacement from the start line and time after crossing the start line?



Question 3

A thermistor is an electrical component. The resistance of a thermistor decreases as the temperature of the thermistor increases.

Which graph shows the resistance of a thermistor against current through the thermistor?



Question 4

Water waves on the surface of water (ripples) travel more slowly in shallow water than they do in deeper water.

Water waves in a ripple tank travel from deeper water to shallower water.

What are the corresponding changes in the wavelength and frequency of the water waves?

A	Wavelength decreases	Frequency decreases
B	Wavelength decreases	Frequency remains the same
C	Wavelength stays the same	Frequency decreases
D	Wavelength stays the same	Frequency remains the same

Question 5

An electric kettle rated at 2.5 kW and designed for use in the UK at a mains voltage of 230 V takes just under 3 minutes to bring 1.25 L of cold water to the boil when used in the UK.

Assume the resistance of the heating element remains constant.

Approximately how long would the same kettle take to boil the same quantity of cold water when used in America where the domestic mains voltage is only 110 V?

A. 1 ½ minutes

B. 3 minutes

C. 6 ½ minutes

D. 13 minutes

Question 6

In practical work, repeat readings are taken to:

A. Reduce the effect of random errors

B. Reduce the likelihood of a mistake being made

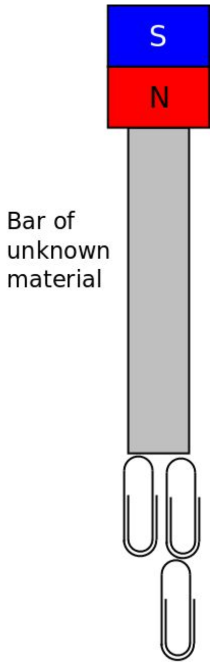
C. Reduce any systematic errors

D. Ensure a fair test

Question 7

A physics teacher demonstrates a magnetic phenomenon.

The north pole of a permanent magnet is placed on top of a bar of an unknown material. With the magnet in place the bar attracts small steel paper clips. When the magnet is removed and the paper clips fall off.



For this demonstration to work as described the bar must be:

A. Soft iron

B. Copper or Aluminium

C. A magnet with the North pole at the top

D. A magnet with the South pole at the top

Question 8

A physics experiment a golf ball and a squash ball are both launched horizontally in such a way that they both have the **same momentum**.

The mass of the golf ball is 46 g and the mass of the squash ball is 23 g.

The ratio $\frac{\text{kinetic energy golf ball}}{\text{kinetic energy squash ball}}$ is:

A. 1:4

B. 1:2

C. 2:1

D. 4:1

Question 9

A radioisotope power source of the type used to provide electrical energy for space missions uses the radioactive isotope Plutonium-238 (Pu^{238}). Plutonium-238 decays by alpha decay.

The activity of 1 gram of Plutonium-238 is 6.3×10^{11} Bq.
The energy released by each alpha decay is 9.0×10^{-13} J.

The mass of Plutonium-238 needed to provide a power of 100 W is approximately:

A. 100 g

B. 140 g

C. 180 g

D. 238 g

Question 10

A bicycle tyre has a volume of 1800 cm and contains compressed air at pressure of 36 psi. The air in the tyre behaves as an ideal gas.

The air in the tyre is released slowly so that it is at a pressure of 1 atmosphere with no change in temperature.

- 1 psi = 6900 Pa
- 1 atmosphere = 100 000 Pa

What volume does the air from the tyre occupy after it is released?

A. 0.0045 m^3

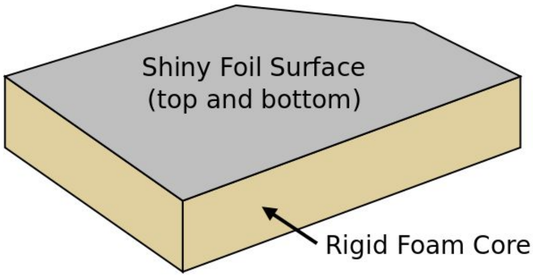
B. 0.45 m^3

C. 45 m^3

D. 4500 m^3

Short Written Questions

Question 11



It is very important to insulate buildings to make them as energy efficient as possible.

One particular type of insulation comprises a thick solid foam core with shiny foil bonded to each side.

Explain how using this form of insulation reduces heat loss from buildings.

[5 marks]

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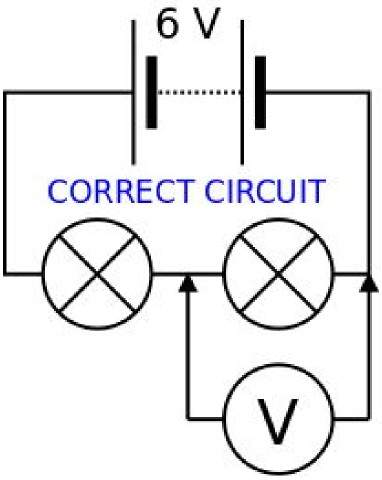
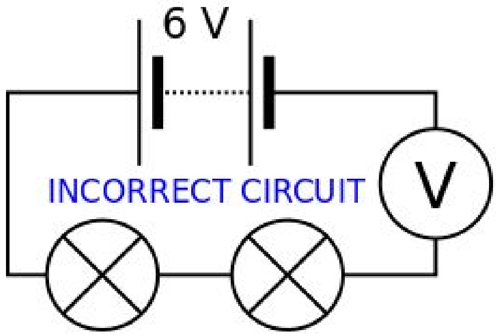
Question 12

A student **correctly** builds the circuit shown with two bulbs, a battery and a voltmeter.

Both bulbs light up and the voltmeter reads 3 V.





A second student uses the same components but rebuilds the circuit **incorrectly** with all three components in series.

For the **incorrect** circuit, **state and explain**:

- Whether or not the bulbs are lit to full brightness
- The approximate reading on the voltmeter

[5 marks]

Extended Numerical Questions

Question 13: Gravity Batteries

This question is about the possibility of large-scale energy storage in the form of gravitational potential energy of large masses. Several such systems are currently being developed and are often referred to as gravity batteries. These energy storage systems are designed to contribute energy to the national grid at short notice when demand is high.

One such system uses large masses lowered down disused mine shafts or purpose built shafts. At times of low demand, when excess electrical energy is available, electric winches raise the masses. At times of high demand, when extra energy is required by the national grid, the masses are allowed to descend with the winch systems acting as electrical generators.

Domestic electrical energy is measured in units of kilowatt-hours (kWh) where 1 kWh is the energy transferred at a rate of 1 kW for 1 hour.

a) Show that 1 kWh is equivalent to 3.6×10^6 J

[1 mark]

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The gravity battery system uses a container of crushed rock as the large mass. The container is cylindrical with a diameter of 5.0 m and a depth of 4.0 m. It is filled with crushed rock with an average density of $5200\ \mathrm{kg/m^3}$.

The mass can be raised or lowered a total distance of 300 m in the shaft.

b) Calculate the maximum energy that can be stored by the gravity battery in units of kWh.

[4 marks]

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At one particular instant, the gravity battery is required to provide energy to the national grid at a rate of 800 kW.

The electrical generators operate with an efficiency of 94%.

c) Calculate the speed at which the mass descends

[2 marks]

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d) Hence, or otherwise, calculate how long the gravity battery can provide energy to the national grid at a rate of 800 kW.

[2 mark]

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Eight cables are used to support the mass. Cables have the following properties:

- Maximum tensile force $2100\ \mathrm{kN}$
- Density $7850\ \mathrm{kg/m^3}$
- Diameter $8.7\ \mathrm{cm}$
- Safe working load $\frac{1}{3} \times$ maximum tensile force
- Number of cables 8

The acceleration of the mass must be carefully controlled to avoid breaking the support cables

e) Ignoring the weight of the cables, show that the maximum acceleration of the mass must be just less than $4\ \mathrm{m/s^2}$.

[3 marks]

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In reality the weight of the cables themselves is significant and cannot be ignored, especially when they are fully extended.

f) Show that, if the maximum acceleration of the mass is assumed to be very small, the cables are suitable for supporting the mass at a depth of 300 m.

[4 marks]

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Question 14: Scale of the Solar System

Note: In this question all of the diagrams are **not** to scale. The planets and the sun are **very** small compared to the distances between them.

In 1619 Johannes Kepler published his 3rd Law of planetary motion. The 3rd Law stated that the square of the orbital period of a planet is proportional to the cube of the mean orbital radius around the Sun. This is written as:

$T^2 \propto R^3$ T = period of orbit R = mean radius of orbit

The mean orbital radius of the Earth is defined as 1 Astronomical Unit (1 AU) i.e. the distance between the Earth and the Sun is 1 AU.

a) The orbital period of Venus is 225 days.

Calculate the mean orbital radius of Venus in astronomical units.

[3 marks]

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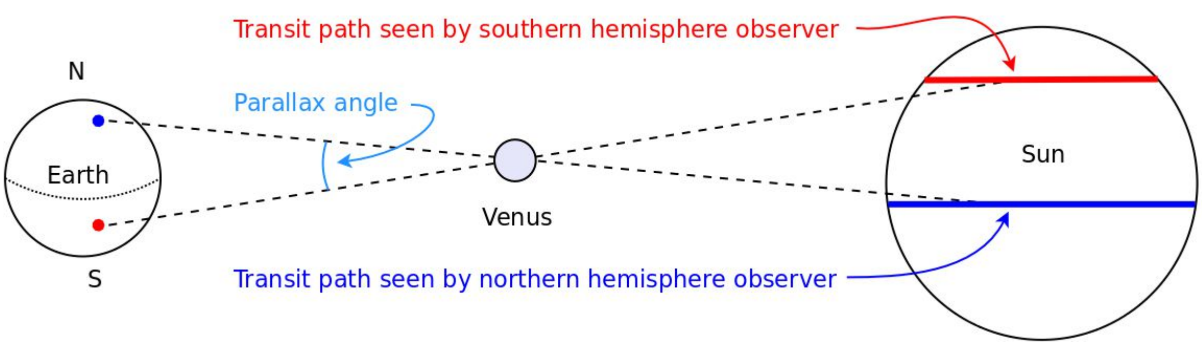
Kepler's Laws allowed early astronomers to find the relative positions of the planets in the solar system but finding the actual (absolute) distances was more challenging.

Edmund Halley (1656-1742) suggested observing the transit of Venus across the Sun from different locations on Earth would allow the absolute scale of the solar system to be determined. Two different observers on opposite sides of the planet would see Venus follow slightly different paths across the face of the sun. The apparent difference in position that comes from viewing an object from two different points is called parallax. Accurately measuring the different transit times would allow the parallax angle to be determined.



NOT to scale

In 1768, Captain James Cook sailed to the island of Tahiti in the southern hemisphere to observe the 1769 transit of Venus.

b) Explain the advantage of making observations simultaneously from the northern and southern hemispheres rather than two different locations in the UK.

[2 marks]

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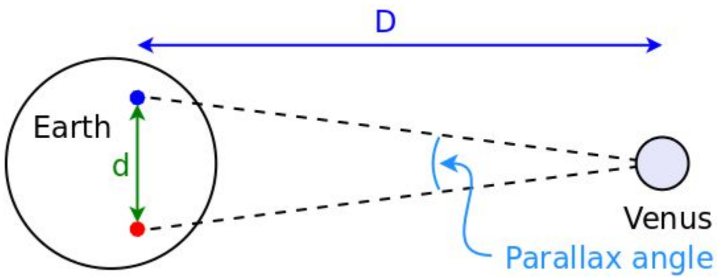
From two different locations separated by a distance of $d = 9560\ \mathrm{km}$, the parallax angle was determined to be 0.0130°.



NOT to scale

Note: $d = 9560\ \mathrm{km}$ is the straight line distance between the two observation locations, not the distance covered by travelling along the curve of the Earth's surface.

c) Use these values to calculate the distance between the Earth and Venus

[3 marks]

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d) Hence show that the corresponding value for 1 AU is approximately 150 million km

[3 mark]

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e) Using the information provided earlier in the question, calculate the orbital speed of Venus

[1 mark]

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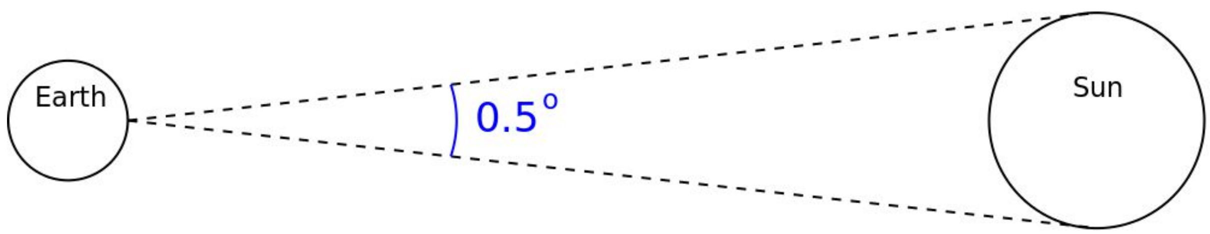
Observed from Earth, the angular size of the sun is approximately 0.5° as shown.



NOT to scale

f) Ignoring the motion of Earth through space, show that the transit of Venus observed by Captain Cook and countless other astronomers last for several hours.

[2 marks]

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END OF QUESTIONS

Footnote: The method used to determine the astronomical unit using the timings of the transit of Venus is far more complex that presented in question 14. In reality astronomers also had to take account of the rotation of the Earth, the Earth's own motion in space, the elliptical orbits of the planets, the effect of parallax on the recorded position of the sun and many other factors. The fact that the value derived for the astronomical unit was within about a 1% of today's accepted value is remarkable given the instruments astronomers had to work with at the time.

Since 2012 the astronomical unit has been defined as exactly 149 597 870 700 m