BPhO British Physics Olympiad

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SENIOR PHYSICS CHALLENGE

(Year 12)

Friday 7th MARCH 2025

This question paper must not be taken out of the exam room

Name: ______________________________

School: ______________________________

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.
- **Calculators**: Any standard calculator may be used, but calculators must not have symbolic algebra capability. If they are programmable, then they must be cleared or used in “exam mode”.
- You may use any public examination formula booklet.
- Scribbled or unclear working will not gain marks.

This paper is about problem solving and the skills needed. It is designed to be a challenge even for the top Y12 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.

Important Constants

Constant	**Symbol**	**Value**
Speed of light in free space	c	$3.00 \times 10^{8}\,\mathrm{m\,s^{-1}}$
Elementary charge	e	$1.60 \times 10^{-19}\,\mathrm{C}$
Planck constant	h	$6.63 \times 10^{-34}\,\mathrm{J\,s}$
Mass of electron	m_{e}	$9.11 \times 10^{-31}\,\mathrm{kg}$
Mass of proton	m_{p}	$1.67 \times 10^{-27}\,\mathrm{kg}$
Acceleration of free fall at Earth's surface	g	$9.81\,\mathrm{m\,s^{-2}}$
Avogadro constant	N_{A}	$6.02 \times 10^{23}\,\mathrm{mol^{-1}}$
Radius of Earth	R_{E}	$6.37 \times 10^{6}\,\mathrm{m}$
Radius of Earth's orbit	R_0	$1.496 \times 10^{11}\,\mathrm{m}$

$$T_{(\mathrm{K})} = T_{(^\circ\mathrm{C})} + 273$$

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

$$\text{Surface area of a sphere} = 4\pi r^2$$

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

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

$$E = hf \qquad R = \frac{\rho\ell}{A}$$

$$P = Fv \qquad P = E/t$$

$$P = VI \qquad V = IR$$

$$v = f\lambda \qquad P = \rho g h$$

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

$$PV = \textit{const.} \qquad \frac{PV}{T} = \textit{const.}$$

Section A - Multiple Choice Questions 1-6   Circle the best answer.

1. **Sliding Block**
   The period (time) of oscillation, T, of a mass attached to two springs, moving to and fro horizontally on a frictionless surface, depends on the mass of the spring, m, and the spring constant k.

   Dimensions (units) suggest that the equation must have the form: $T = C \times m^a \times k^b$, where C, a and b are dimensionless constants.

   By considering the units of T, m and k, which of the following could be a correct equation for T?

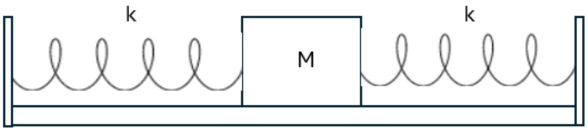

Figure 1

A. $C\sqrt{\frac{m}{k}}$ B. $C\sqrt{\frac{k}{m}}$ C. $Ck^2\sqrt{m}$ D. $C^{-1}km$

[2]

2. **Water World**
   The average thickness of the ice covering Antarctica is about $2\,\mathrm{km}$ and has an area of approximately 10 million square kilometres. If all this ice melted, which of the following is a good estimate of the rise in sea level?
   (Radius of Earth $\approx 6400\,\mathrm{km}$)

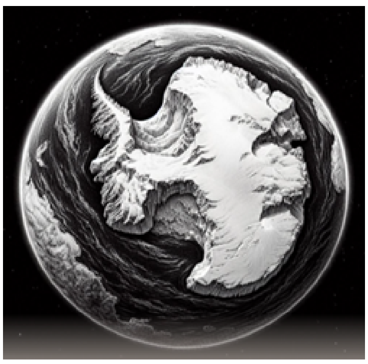

Figure 2

A. $2\,\mathrm{m}$ B. $10\,\mathrm{m}$ C. $50\,\mathrm{m}$ D. $200\,\mathrm{m}$

[2]

3. **Puppy and Toilet Roll**

Figure 3

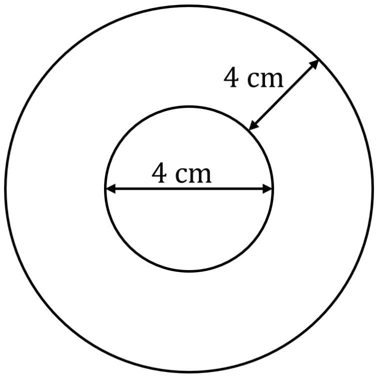

Figure 4

A playful puppy grabs the end of an unused roll of lavatory paper and runs off with it at $1\,\mathrm{m\,s^{-1}}$. The thickness of the paper is $0.2\,\mathrm{mm}$, the thickness of paper on the roll is $4\,\mathrm{cm}$ and the diameter of the inner cardboard tube is $4\,\mathrm{cm}$. Approximately, how long does it take for all the paper to unwind?

A. $5\,\mathrm{s}$ B. $20\,\mathrm{s}$ C. $40\,\mathrm{s}$ D. $1\,\mathrm{minute}$

[2]

4. **Golfing Distance**

Figure 5

A boy playing golf hits his ball and it lands a certain distance away. His friend is much stronger and hits her ball so that it leaves the ground at the same angle to the horizontal as the boy's but moving twice as fast.

How much further will the second ball travel before hitting the ground?

A. Twice as far B. Same distance C. $\sqrt{2}$ as far D. Four times as far

[2]

5. **Distance Between Stars**
Our Milky Way galaxy has an estimated 100 billion stars, is about 100 thousand light years (ly) in diameter and a thousand light years thick. Assuming the stars are spread evenly throughout the disc of the galaxy (which they most definitely are not), what is a reasonable estimate of the average distance between them?

Figure 6

A. $100\,\text{ly}$ B. $20\,\text{ly}$ C. $5\,\text{ly}$ D. $0.5\,\text{ly}$

[2]

6. **Container on a spring**
A light cylindrical container of cross-sectional area A, open at the top, is filled with water of density ρ. The cylinder sits on top of a spring, compressing it as shown in **Fig. 7**. As the water evaporates, the load on the spring is reduced and it extends, raising the container. Which is a correct expression for the spring constant, k, that keeps the water level at a constant height H above the floor.

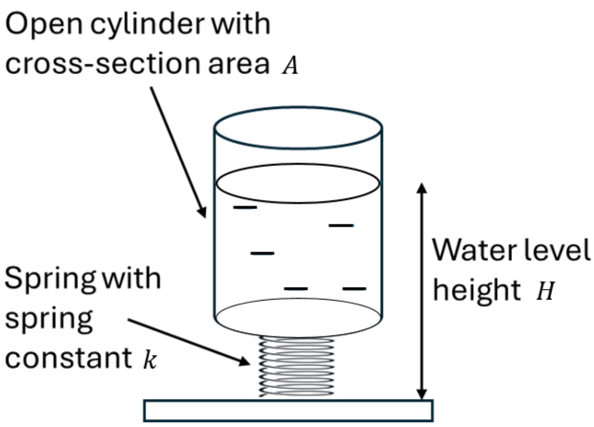

Figure 7

A. $\rho g A$ B. $\dfrac{\rho g}{A}$ C. $\dfrac{H\rho A}{g}$ D. $\dfrac{Ag}{\rho H}$

[2]

[12 marks]

Section B - Longer Answer Questions

7. **Bored physicist on a train**
You are on a train, travelling between two local train stations you know to be about $4\,\mathrm{km}$ apart.
You decide to try determining the average speed of the train by throwing a book up until it almost touches the ceiling of the train ($2\,\mathrm{m}$ up), then falls back to your hand. You do this repeatedly, from the beginning of the journey, counting that you catch it 100 times before you reach the next station. People give you funny looks.

Figure 8

What was the average speed of the train? Explain the steps in your thinking.

[3]

8. **Stationary Sun**

Oxford is at an angle of 52° north of the equator. At what minimum speed, and in which direction, should a low flying plane fly in order to keep the Sun in the same position in the sky?

Assume that this is an equinox so that the Sun is directly over the equator.
Earth radius $\approx 6400\,\mathrm{km}$

Figure 9

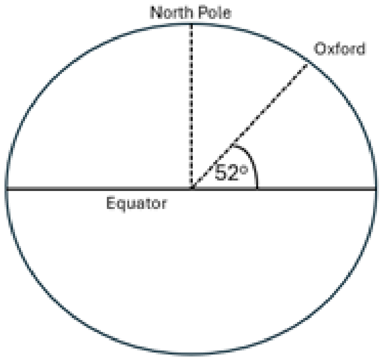

Figure 10

[4]

9. **A Raft**

You've just learned that the buoyancy force ('upthrust') on a submerged body is equal to the weight of the water displaced by that body, and want to have some fun with it.

You decide to make a square floating raft out of $500\,\mathrm{ml}$ water bottles, attached together in a single layer, as shown in **Fig. 11**.
Your raft should be able to keep a $100\,\mathrm{kg}$ person completely out of the water.

Figure 11

By modelling each bottle as a cuboid with equal side dimensions, estimate the length of each side of such a raft. Explain your method. Including a simple diagram might help.

[5]

10. **A false economy**

"It's always cheaper to buy in bulk". An engineer takes this rather too literally, and insists on buying a large number of $4\,\Omega$ resistors to use for all their circuits, instead of getting many different values.

(a) The engineer needs a $7\,\Omega$ resistor for a circuit. Draw a circuit diagram showing how they could make this resistance out of their $4\,\Omega$ resistors. (You're not allowed to 'cut up' any resistors!)

(b) It's good to be efficient. Most answers to (a) involve the use of more than 6 of the $4\,\Omega$ resistors. If that applies to your solution, it's possible to do it with fewer. Try again, to design your $7\,\Omega$ resistor using the **fewest possible** number of $4\,\Omega$ resistors.

[4]

11. **Motorbike flipping**

A motorcyclist is starting from rest on flat ground. If the bike is powerful enough it is possible to 'wheelie', as in **Fig. 12**, rotating around the centre of the rear wheel, and then flip the bike over if the throttle is pulled too harshly.

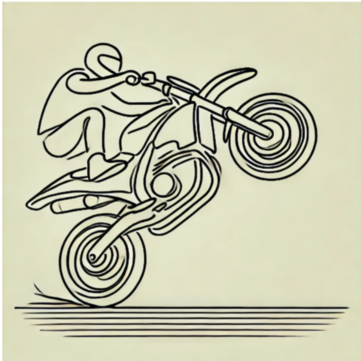

Figure 12

A simplified diagram representing this situation is shown below.

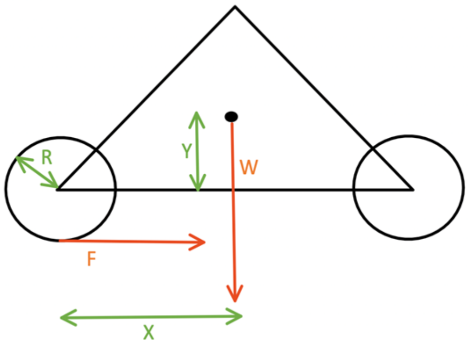

Figure 13

The mass of the motorbike and rider is $250\,\mathrm{kg}$, and produces a weight W. The bike is rear-wheel-drive, so the force accelerating the bike, F, acts where this wheel meets the ground, as shown.

The radius R of the wheels is $0.35\,\mathrm{m}$. The length X is $1.10\,\mathrm{m}$, and Y is $0.60\,\mathrm{m}$.

(a) In words, in terms of physics, describe why the bike might wheelie when the throttle is pulled. Write a relevant word equation if you can.

(b) Calculate the maximum initial acceleration of the bike, if it is to avoid a wheelie.

(c) Therefore calculate a minimum possible time for the bike to accelerate from 0 - 60 mph without pulling a wheelie. (1 mile = 1610 metres)

[6]

12. **It‘s Hardly Rocket Science**

In recent years there has been a rapid development in space launch vehicles. Livestreams of launches are often available online; many sitting this paper will have seen them. In these videos, telemetry from the spacecraft is usually shown on screen alongside the video. An example (courtesy of YouTube) is shown below in **Fig. 14**.

Figure 14: Image credit: taken from Starship Flight Test 6 livestream, November 2024

By watching the telemetry from such a flight, a speed vs altitude graph can be plotted for the spacecraft, as in **Fig. 15**:

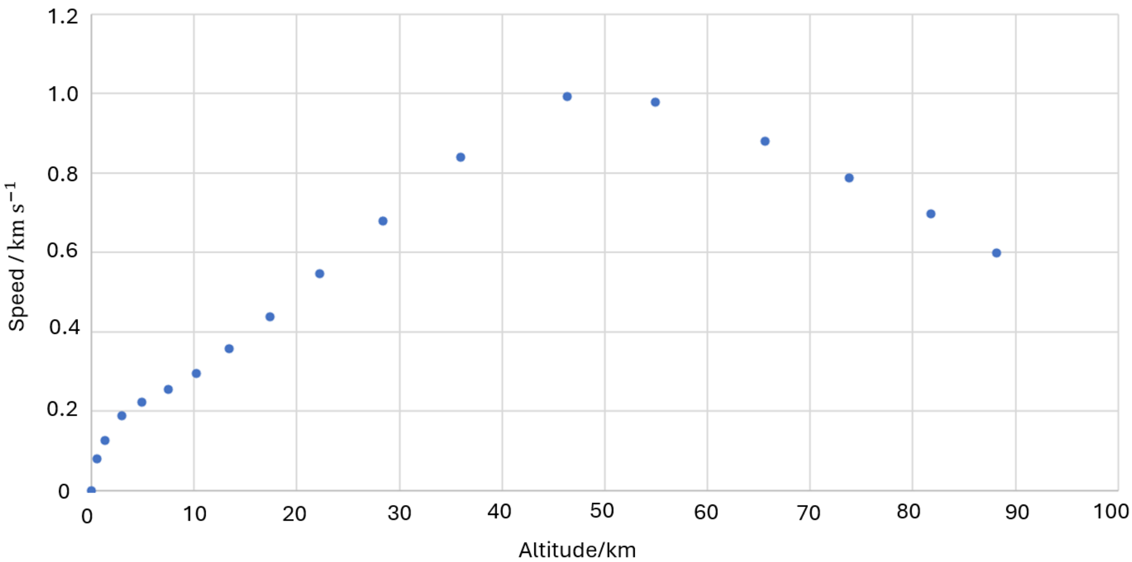

Figure 15

(a) What happened when the craft reached around $50\,\mathrm{km}$ altitude? Describe what it is doing.

(b) Using data from the graph from $55\,\mathrm{km}$ onwards, calculate the acceleration. Comment on your answer.

(c) An important concept in launching a rocket out of the atmosphere is the 'Max Q'. This is essentially the moment when the craft experiences maximum stress from friction with the atmosphere. Explain the factors affecting the position of Max Q, and therefore suggest a coordinate on the graph where Max Q might occur.

[8]

13. **Water from a tap**

A constant stream of water flows vertically downwards from a running tap, as shown in **Fig. 16**. A little way down the flow, there is a $3\,\mathrm{cm}$ long segment of flowing water where the diameter of the circular stream reduces from $d_1 = 5\,\mathrm{mm}$ to a diameter $d_2 = 4\,\mathrm{mm}$. From this we can determine the flow rate and how long it will take to fill a beaker of volume $200\,\mathrm{cm}^3$. We shall assume that water is incompressible.

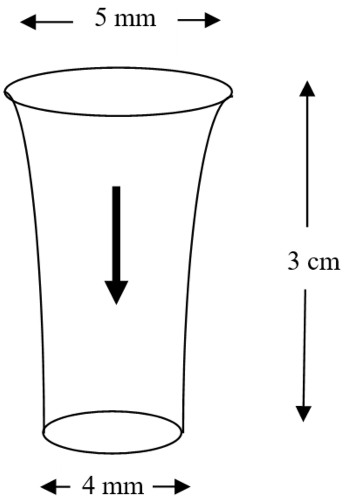

Figure 16

(a) Explain why the segment of water becomes narrower.

(b) If the speed of the water at the top of the segment is v_1 then what is the speed v_2 of the water at the bottom of the segment expressed in terms of v_1, d_1 and d_2 ?

(c) Calculate the speed of the water flow at the top of the segment. You may want to use the equation of motion $v^2 - u^2 = 2as$

(d) From your answer to part (c), calculate the volume flow of water per second.

(e) Calculate the time taken to fill a $200\,\mathrm{cm}$ beaker.

[8]

END OF PAPER

Questions proposed by
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