Name:	
School:	

Total Mark	

BPhO British Physics Olympiad

2020 Intermediate Physics Challenge

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

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 answer 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 longer answer 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

The following constants should be used:

$\mathrm{g} = 10\ \mathrm{N/kg}$ gravitational field strength on Earth

Photo Credits

Page 10: Scooter: https://commons.wikimedia.org/wiki/File:Egret_One.jpg

Page 12: Scooters: https://www.pexels.com/photo/electric-scooter-copenhagen-scooters-2993551/

Page 14: M87* from EHT collaboration: https://www.eso.org/public/images/eso1907a/

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										

Section A: Multiple choice

Question 1

A student measures the density of water by determining the mass and volume of several different quantities of water.

The student plots the measured values of mass and volume on a graph.

How should the student determine the density of water from the graph?

	Quantity on the **y-axis**	Quantity on the **x-axis**	Determine the **density** from the:
A.	volume	mass	gradient
B.	volume	mass	area
C.	mass	volume	gradient
D.	mass	volume	area

Question 2

A light ray from a ray box can be used to demonstrate refraction.

When the light ray passes from the air into the glass the light ray is refracted towards the normal.

Which of the statements is **not** a valid explanation for refraction:

A. The frequency of the light changes as it enters the glass

B. The speed of the light changes as it enters the glass

C. The wavelength of the light changes as it enters the glass

D. The direction of the light changes as it enters the glass

Question 3

A car starts from rest and accelerates down a slope. The acceleration remains constant as the car travels from the top to the bottom of the slope.

The average speed of the car is 2 m/s.

The speed of the car as it reaches the bottom of the slope is:

A. 0 m/s

B. Between 0 m/s and 2 m/s

C. 2 m/s

D. Between 2 m/s and 4 m/s

E. 4 m/s

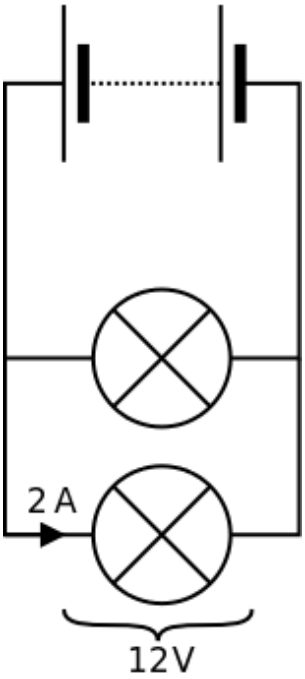
F. Greater than 4 m/s

Question 4

A battery and **two identical bulbs** are connected in parallel.

The current through each bulb is 2 A and the potential difference across each bulb is 12 V.

The battery voltage and current through the battery are:



	Battery voltage / V	Current through battery / A
A.	6	2
B.	6	4
C.	12	2
D.	12	4
E.	24	2
F.	24	4

Question 5

The specific heat capacity of copper is 385 J/(kg °C) which means that 385 Joules of thermal energy are needed to raise the temperature of 1 kg of copper by 1 °C. The melting point of copper is 1085 °C.

How much thermal energy is needed to raise 50.0 grams of copper wire to its melting point when it is initially at room temperature of 20.0 °C?

A. 20.9 MJ

B. 20.5 MJ

C. 20.9 kJ

D. 20.5 kJ

E. 385 J

Question 6

An electromagnet is formed when a current flows through a coil of wire.

Which of the following changes on its own does **not** necessarily increase the strength of an electromagnet?

A. Using thicker wire

B. Using a higher current

C. Adding an iron core

D. Using more turns of wire

E. Making the turns more tightly packed

Question 7

A student measures the mass and acceleration of a trolley and calculates the resultant force. The mass of the trolley was measured to be 0.984 kg and the acceleration was determined to be 1.2 m/s^2.

The student correctly calculates the resultant force to be F = 1.1808 N.

The force should be recorded as:

A. 1 N

B. 1.2 N

C. 1.18 N

D. 1.181 N

E. 1.1808 N

Question 8

A student predicts that a steel ball dropped from rest from a height of 2 m will hit the floor after 0.63 seconds. In their calculation they used an approximate value for the acceleration due to gravity of g = 10 m/s^2.

The accepted value for the acceleration due to gravity is g = 9.8 m/s^2.

This means their calculated time will be:

A. unaffected

B. too long by about 1%

C. too short by about 1%

D. too long by about 0.2 seconds

E. too short by about 0.2 seconds

Question 9

A firework uses a chemical reaction to create a thrust force. This thrust force does work on the rocket to change the velocity and height above the ground.

Ignoring air resistance, the relationship between the work done (WD) by the thrust force, the change in kinetic energy (ΔKE) of the rocket and the change in gravitational potential energy (ΔGPE) of the rocket is:

A. ΔGPE = WD + ΔKE

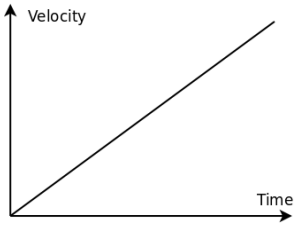
B. ΔKE = WD + ΔGPE

C. WD = ΔGPE + ΔKE

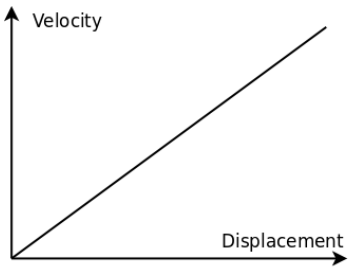
D. WD = ΔGPE - ΔKE

Question 10

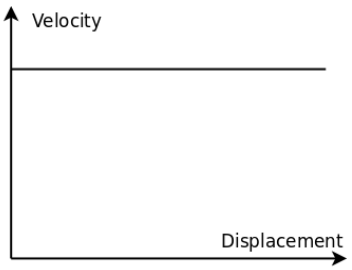
A Physics trolley starts from rest and has a constant acceleration. The velocity – time graph is linear as shown.



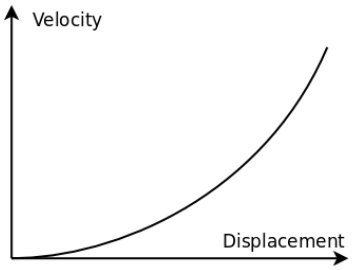
The corresponding graph of velocity against displacement is:



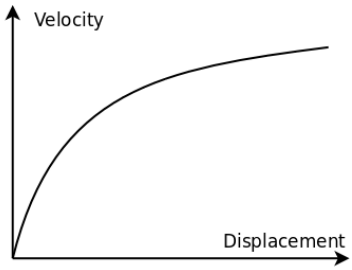
Graph A



Graph B



Graph C



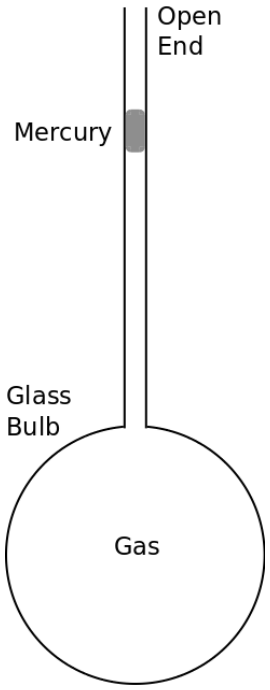
Graph D

Section B: Short Answer Questions

Question 11

When gases are heated they can expand.

This phenomenon is used in a simple thermometer called a gas thermometer. A glass bulb contains gas which is trapped by a small bead of mercury in a capillary tube. When the temperature of the gas increases it expands and the mercury moves up the capillary tube. The top of the capillary tube is open.



Explain why the gas expands when it is heated.

[5 marks]

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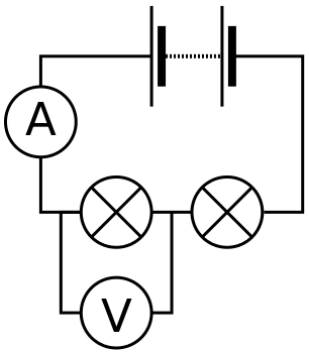
Question 12

In a simple circuit the ammeter is connected in series and the voltmeter is connected in parallel.



Explain why an ammeter should have a (very) low resistance.

[5 marks]

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Section C: Extended Answer Questions

Question 13

Electric scooters are a popular means of urban transport in some cities.

A typical electric scooter has the following specifications:

- Battery capacity = 300 Wh (watt hours)
- Maximum power output = 400 W
- Mass = 12.5 kg
- Maximum range = 30 km

The scooter's electric motor does mechanical work to overcome the drag force (due to rolling friction with the road and air resistance) and to increase the kinetic energy of the scooter and rider.

(a) By considering the equation for Work Done, show that:

$$Power = Resultant\ Force \times velocity$$

[1 mark]

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(b) (i) Using the motor at maximum power, a scooter rider records the maximum possible steady speed as 7 m/s.

Use the data given and the answer to part (a) to show that the drag force acting on the scooter and rider is about 60 N.

[1 mark]

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(b) (ii) The battery capacity is given in units of watt hours (Wh).

1 Wh is a power of 1 watt for 1 hour.

Calculate the energy, in joules, stored in the scooter battery

[2 marks]

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(b) (iii) The manufacturer claims that the maximum range of the scooter (on one full charge of the battery) is 30 km.

Using the values calculated previously and the specifications of the scooter, determine the range of the scooter when travelling at 7 m/s.

[3 marks]

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(b) (iv) The drag force acting on the scooter and rider increases with speed.

Without further calculation, explain whether or not the range of the scooter depends on the speed.

Hence assess the manufacturer's claim that the maximum range is 30 km.

[4 marks]

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Scooters are available to hire in some cities.

To extend the range of the scooter through the day, a hire company plans to add a solar panel to the area of the scooter where the rider stands.

(c) (i) Estimate the area of a solar panel that could realistically be fitted to the foot plate of a typical scooter.

[1 mark]

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(c) (ii) A typical solar panel is 15% efficient.

On a sunny day, the intensity of sunlight at ground level is about 1.2 kW / m^2.

Estimate the amount of energy supplied to the scooter's battery by the solar panel during a typical day.

State any assumptions necessary and show your working.

Comment on the effectiveness of adding a solar panel to extend the range.

[5 marks]

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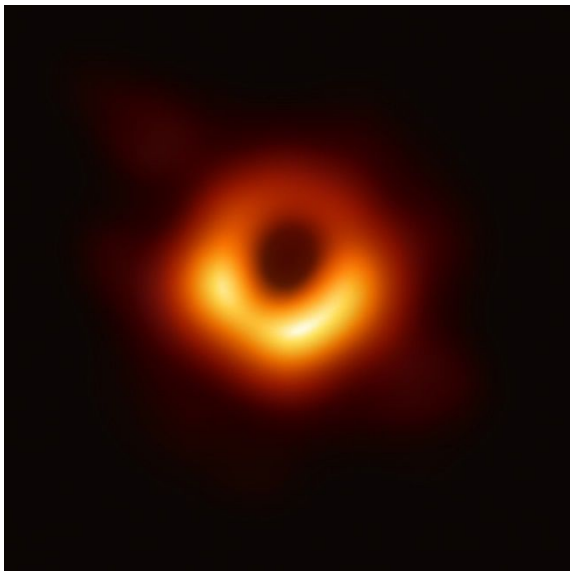
Question 14

In April 2019 The Event Horizon Telescope (EHT) collaboration published the first direct image (shown below) of a supermassive black hole named M87* (read as M87 star) at the centre of a nearby galaxy named M87.

A black hole is a massive astronomical object so dense that even light cannot escape its enormous gravitational field.

The radius of the event horizon of a black hole is the distance from the centre at which light cannot escape and can be thought of as the "size" of the black hole.

The photograph published by the Event Horizon Telescope collaboration shows a dark region of shadow about **2.5 times** the diameter of the event horizon surrounded by clouds of brightly glowing gas.



The following information is required:

- Mass of the Sun = 2×10^{30} kg
- Distance from Sun to Earth = 1 AU
- Distance from Sun to Pluto = 40 AU
- 1 AU = 1.5×10^{11} m
- Radius of Earth = 6400 km
- Mass of M87* = 6.5×10^{9} solar masses
- Distance to M87* = 55 million light years
- Gravitational constant, G = 6.67×10^{-11} N m^2/kg^2
- Speed of light, c = 3×10^{8} m/s

Notes: AU is a measurement of distance called an Astronomical Unit.

A light year is a measurement of distance equal to the distance travelled by light in one (Earth) year.

(a) Before direct imaging was possible, suggest how astronomers could have identified the location of black holes.

[1 mark]

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(b) After the release of the image of M87*, one news article claimed "The black hole M87* is as big as our entire Solar System"

The radius of the event horizon of a black hole is given by the equation for the Schwarzschild radius (r_S)†,

$$r_S = \frac{2GM}{c^2} \qquad \text{where } M \text{ is the mass of the black hole}$$

Use the information given to compare the radius of the event horizon of M87* and the radius of the solar system and hence comment on the validity of the claim.

[4 marks]

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† The Schwarzschild radius only applies to non-rotating uncharged black holes. M87* is rotating and so the equation for the radius of the event horizon is, in reality, more complex. However, the Schwarzschild radius is a good approximation.

(c) (i) Show that the distance to M87* is about 5 x 10^{23} m

[2 marks]

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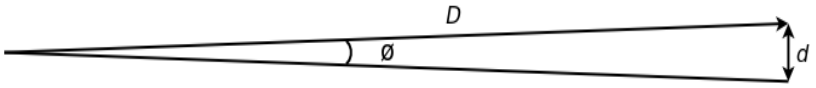
(c) (ii) Astronomers observing a far away object calculate the angular size of an object.

The angular size is the angle (ϕ) from one edge of the object to the other as observed from Earth.



$tan\phi \approx {}^{d}/_{D}$

Using the photograph, show that the angular size of the image of M87* (including the glowing gas clouds) is about 30 x 10^{-9} degrees

[3 marks]

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(c) (iii) The angular resolution of a telescope is the smallest angle (R) between two objects such that they can been seen as separate.

The angular resolution (R) is given by $R \approx 60 \times \lambda / D$ where λ is the wavelength of the radiation being detected, D is the diameter of the telescope aperture and R is measured in degrees. D and λ are in the same units.

The Event Horizon Telescope uses a consortium of smaller telescopes from across the globe all connected together so that the effective diameter of the EHT is approximately the diameter of the earth.

Given that the EHT observes radiation at a frequency of 230 GHz (1 GHz = 1×10^9 Hz), show that the EHT has a good enough resolution to produce the image of M87*.

[3 marks]

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