Name:	
School:	

Total Mark	

BPhO British Physics Olympiad

2022 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

$c = f \times \lambda$ wave speed = frequency x wavelength

$n = {}^{c}/_{v}$ refractive index = speed of light in vacuum / speed of light in medium

The following constants should be used:

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

$c = 3.0 \times 10^{8}\,\mathrm{m/s}$ speed of light in a vacuum

Photo Credits

Page 12, Question 14: NASA Photo, Public Domain

Section A: Multiple Choice Answers

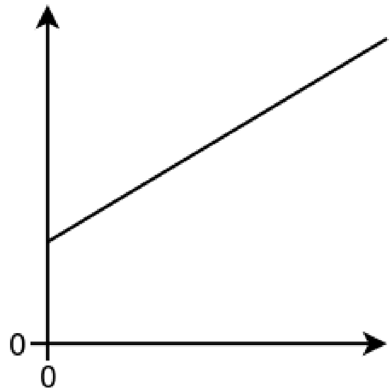
Write the letter corresponding to your chosen answer in the grid below.

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 graph shows

A. Current vs Potential difference for a fixed resistor

B. Kinetic energy vs velocity for a fixed mass

C. Pressure vs Volume at a constant temperature for a fixed mass of gas

D. Mass of a beaker containing water vs volume of water in the beaker at a fixed temperature

Question 2

The energy transferred by electromagnetic radiation in a vacuum (such as microwaves, radiowaves, X-rays etc) **increases** as:

A. Wavelength increases

B. Frequency increases

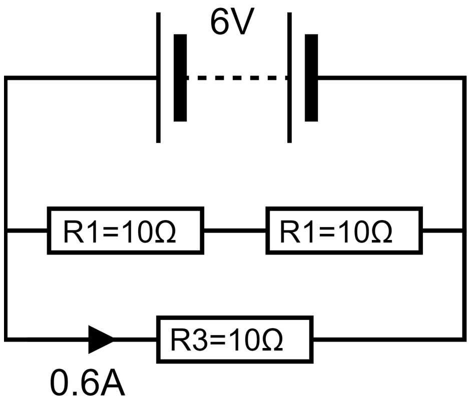
C. Speed increases

D. Volume increases

Question 3

Consider the circuit shown. Each of the fixed resistors has a value of 10 Ω.

A current of 0.6 A flows through resistor R3.



The total current flowing through the battery is:

A. 0.6 A

B. 0.9 A

C. 1.2 A

D. 1.8 A

Question 4

For the circuit in question 3, the power dissipated by **resistor R3** is:

A. The same power as dissipated by resistor R1

B. 2 x the power dissipated by resistor R1

C. 3 x the power dissipated by resistor R1

D. 4 x the power dissipated by resistor R1

Question 5

An out of control model rocket accelerates vertically downwards at 12 m/s^2. The mass of the rocket is 8 kg. Ignoring air resistance, the thrust from the rocket engine is:

A. 16 N

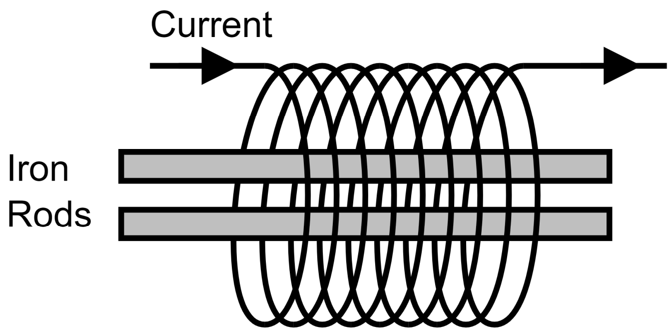
B. 80 N

C. 96 N

D. 176 N

Question 6

The diagram shows a coil of wire containing two unmagnetized soft iron rods. The iron rods are parallel to each other and free to move.



When a current is passed through the coil the rods will:

A. Remain stationary

B. Both move in the same direction along the axis

C. Move away from each other

D. Move towards each other

Question 7

The speed of sound in air depends on the temperature of the air. Sound travels faster in warmer air and slower in cooler air. During the day the ground is warmed by the sun and the air just above the ground is warmer than the air higher up. In this situation sound waves can curve upwards creating “sound shadows” where sounds are not heard by listeners on the ground.

This phenomenon is an example of:

A. Dispersion

B. Diffraction

C. Refraction

D. Reflection

Question 8

Stopping distance is the sum of thinking distance and braking distance.

Which of the following changes gives the longest stopping distance of a vehicle being driven fast along a straight road and coming to a stop with a constant deceleration using just the vehicle brakes?

A. Doubling the initial speed of the vehicle

B. Doubling the mass of the vehicle

C. Doubling the reaction time of the driver

D. Halving the braking force of the vehicle (for example due to road conditions)

Question 9

In a science experiment an insulated block of metal is heated using an electric heater for 10 minutes. The mass of the block is 900 g. The initial temperature of the block is measured to be 17 °C and the final temperature is measured as 43 °C.

The experiment is repeated using the same metal block and electric heater. This time the starting temperature is 19 °C and the block is heated for 15 minutes.

The final temperature of the metal block in the second experiment will be approximately:

A. 39 °C

B. 45 °C

C. 58 °C

D. 65 °C

Question 10

In an experiment to investigate Boyle's law a fixed mass of gas is trapped in a syringe at a constant temperature. The gas is **slowly** compressed decreasing the volume of the trapped gas. After waiting for a short time, the pressure of the gas is measured.

The experiment is undertaken slowly and there is a pause between compressing the gas and measuring the pressure because:

A. Compressing the gas decreases the temperature and it needs time to warm up again

B. Compressing the gas increases the temperature and it needs time to cool down

C. The pressure takes time to equalise throughout the volume of the syringe

D. Smaller forces are required which makes the experiment safer

Short Answer Questions

Question 11

In 2022 there will be two solar eclipses and two lunar eclipses.

The partial solar eclipse on 30th April will only be visible in the south of South America and Antarctica. The total lunar eclipse on 15th May will be visible across most of North America, all of South America, much of southern Europe, south west Asia, all of Africa and Antarctica.

Explain why a solar eclipse can be observed directly from only a relatively small area of Earth whereas a lunar eclipse can be observed directly from many different places on Earth covering a much larger area.

You should draw a diagram.

[5 marks]

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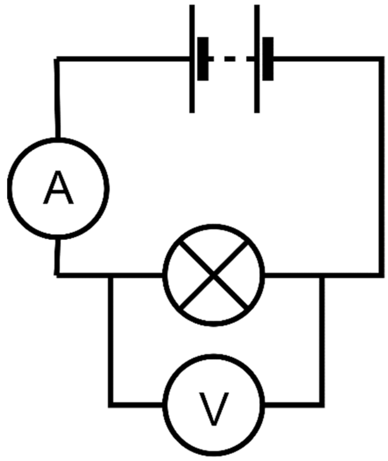
Question 12

An ideal voltmeter has an "infinite" resistance.

In reality, voltmeters do not have an infinite resistance but they do have a very high resistance, often significantly greater than 1 MΩ.

The circuit shows a bulb in series with a power supply and an ammeter, both of which have negligible resistance.



Explain why an ideal voltmeter should have an infinite resistance.

[2 marks]

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For the circuit shown, **state** and **explain** how using a voltmeter with a resistance of 1 MΩ instead of an ideal voltmeter would affect the:

[3 marks]

a) Current measured in the circuit by the ammeter

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b) Potential difference measured across the bulb by the voltmeter

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c) Resistance of the bulb calculated using the relationship $R = {}^{V}/_{I}$

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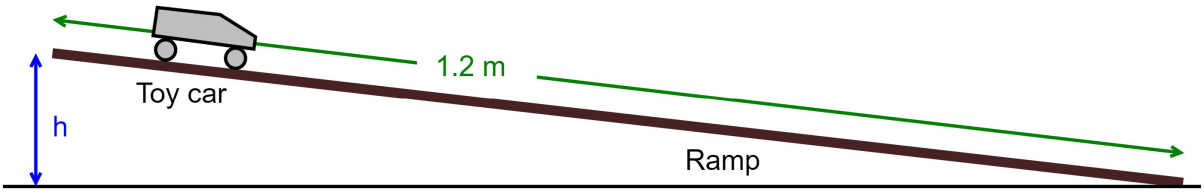
Extended Written Questions

Question 13

This question is about a familiar school practical to measure acceleration where a student investigates the acceleration of a toy car on a ramp.

The height of the ramp is changed and the resulting acceleration obtained from the measurements given below.

The experimental setup is shown in the diagram.



To measure the acceleration, the student releases the car from **rest** at the **top** of the ramp and uses a stopwatch to time how long it takes for the car to reach the bottom of the ramp.

The student records the following results:

Ramp height / cm	time (1st attempt) / s	time (2nd attempt) / s	time (3rd attempt) / s
5	2.45	2.48	2.41

a) Calculate the average speed of the toy car.

[1 mark]

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The student's teacher states "the final speed of the car is twice the average speed"

b) Explain why the teacher's statement is reasonable, stating any assumptions that are necessary.

[2 marks]

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c) Calculate the acceleration of the toy car.

[1 mark]

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The teacher states "theory suggests that the acceleration of the car is directly proportional to the height of the ramp"

The student takes further readings of time for different heights of the ramp

Ramp height / cm	time (1st attempt) / s	time (2nd attempt) / s	time (3rd attempt) / s
9	1.84	1.82	1.82
13	1.50	1.52	1.56

d) Use the student's data to show that acceleration of the car is proportional to the height of the ramp.

[3 marks]

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Theory shows that the relationship between ramp height (h) and acceleration (a) is given by the equation $a = \frac{g \times h}{L}$ where g is the acceleration due to gravity and L is the length of the ramp.

e) Use the student's data to calculate a value for the acceleration due to gravity.

[2 marks]

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The student comments that “the value of g is not very accurate because we only measured the ramp height **to the nearest 0.5 cm**”, but the student’s teacher disagrees and replies, “the lack of accuracy is due to the random errors in the timing”

f) By considering the range of values of the timing and the uncertainty in the measurement of the height of the ramp, determine whether the conclusions stated by the student and by the teacher are justified.

Hint: Calculating the uncertainty in a measurement as a **percentage** of the average value makes it easier to appreciate the significance of the uncertainty.

[4 marks]

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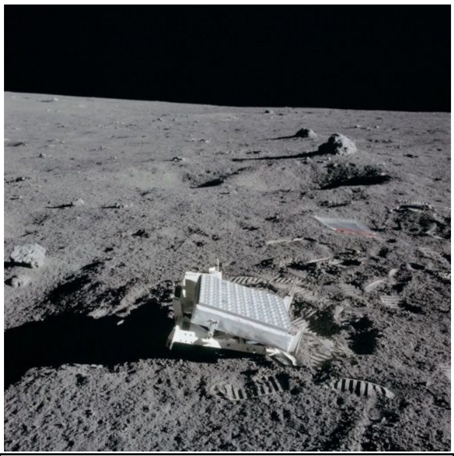
Question 14

This question is about some of the challenges that need to be overcome when determining the distance to the Moon by measuring the round-trip-time of a laser beam reflected from the surface (Lunar Laser Ranging).

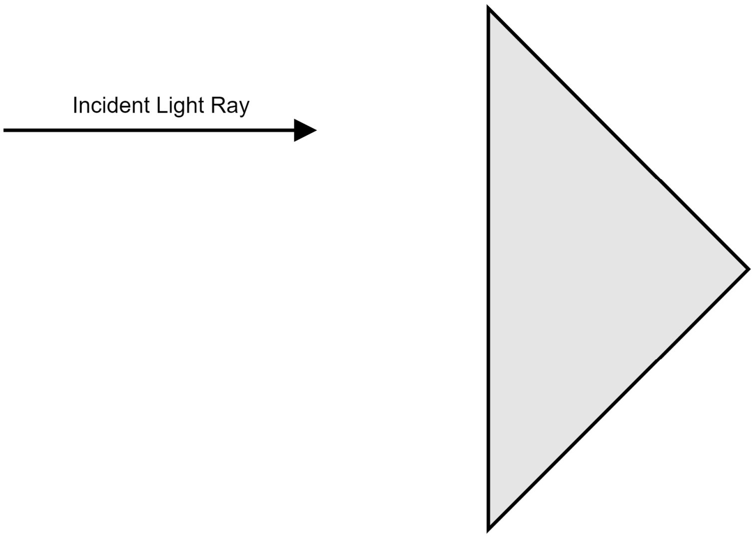
In 1969, Apollo 11 astronauts placed a mirror on the Moon. The mirror, called a retroreflector, is made from a number of “corner cubes” which act like prisms to reflect light due to **total internal reflection**.



Retroreflector placed by the Apollo 14 mission

a) Complete the path of the incident light ray on the diagram to show the reflected light ray emerging from the prism.

[1 mark]



b) Explain why a prism arrangement, relying on total internal reflection, is a better choice of reflector on the Moon’s surface than a simple plane mirror (like you might find in a bathroom).

[2 marks]

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The laser beam can be thought of as a stream of "particles of light" called photons.

Each photon of light has an energy (E) that depends on the frequency (f) of the light and a constant called the Planck constant (h).

The equation for the energy (E) of a single photon is: $E = h \times f$ where h denotes the Planck constant and has a value of $h = 6.63 \times 10^{-34}$ Js

One particular Lunar Laser Ranging experiment uses short pulses of green laser light with a wavelength of 532 nm $(532 \times 10^{-9}\ \mathrm{m})$.

The duration of each pulse is $100\ \mathrm{ps}\ (100 \times 10^{-12}\ \mathrm{s})$. The energy in each pulse is 115 mJ.

c) Show that the power of the laser is approximately 1 GW

[1 mark]

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d) Show that the frequency of the laser light is approximately $5.6 \times 10^{14}\ \mathrm{Hz}$

[1 marks]

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e) Hence calculate the number of photons of light in a single pulse of laser light

[2 marks]

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f) Explain why pulses of laser light are used rather than a continuous beam of laser light

[1 mark]

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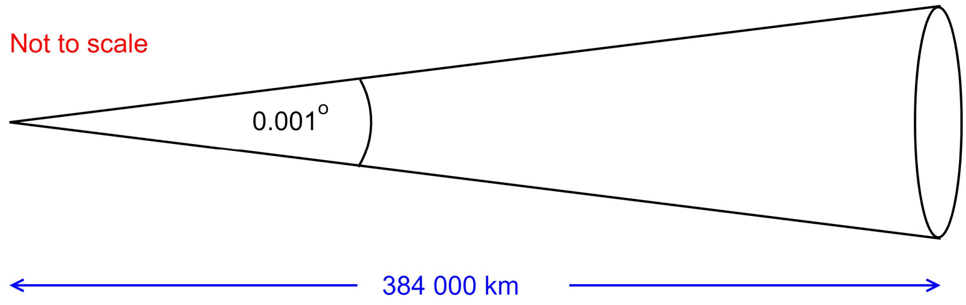
As the pulse of laser light travels towards the Moon, the beam spreads out (or diverges).

The divergence of the laser beam is approximately 1.00×10^{-3} degrees and the distance between the Earth and the Moon is approximately $384\ 000\ \mathrm{km}$. See diagram (not to scale).



g) Show that when the laser beam reaches the Moon, it covers an area approximately $7\ \mathrm{km}$ in diameter. Assume that the laser beam forms a circular pattern.

[1 mark]

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The reflector placed on the Moon is a square with each side measuring $46\ \mathrm{cm}$.

h) Show that the number of photons incident on the reflector from each pulse of laser light is approximately 2×10^{9} photons.

[2 mark]

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Assume that the entire surface reflects incoming photons of light. The telescope used to detect the returning photons has a diameter of $3.50\ \mathrm{m}$

i) Hence show that the (theoretical) number of photons received by the telescope from each pulse of laser light is only about 500.

[1 mark]

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Modern Lunar Laser Ranging experiments use very precise timing to determine the distance to the Moon to within $15\ \mathrm{mm}$ (or better).

The atmosphere can be modelled as a layer of air $12\ \mathrm{km}$ in depth with a constant refractive index of 1.0003.

j) Determine whether or not the effect of the atmosphere on the speed of light needs to be taken into consideration when conducting Lunar Laser Ranging experiments to this level of precision.

[3 marks]

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The results of Lunar Laser Ranging experiments show that the distance between the Earth and the Moon is increasing by about $3.8\ \text{cm}$ per year.

k) What difference, if any, would we have noticed if we looked up at the full Moon in the night sky towards the end of the Stone Age, $10\ 000$ years ago?

[2 marks]

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END OF QUESTIONS

Footnote: The data for the LLR experiment is based on the APOLLO programme run by the Apache Point Observatory in New Mexico. This experiment has been running since 2006. The actual number of photons received by the telescope is only 1 or 2 per laser pulse and there are very many other factors that also need to be considered to achieve the level of precision of the experiment.

There were five retroreflectors placed on the Moon, three by the Apollo programme and two by Russian probes. The photograph is the retroreflector placed by Apollo 14 astronauts although the question is based on data from the Apollo 11 retroreflector.