Name:	
School:	

Total Mark	

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2024 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 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 Equations

The following useful equation may be unfamiliar to some students:

$\rho = {}^{m}/_{V}$	density = mass ÷ volume
$\Delta E = m \times L$	energy transferred = mass x specific latent heat
$p = m \times v$	momentum = mass x velocity
$P = I^2 \times R$	Power dissipated in a resistor = current ^{2} x resistance

Work = force × distance

Circumference of a circle $= 2\pi r$

The following constants should be used

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

Unfamiliar units

1 metric tonne = 1000 kg

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

Early in February 2024, the record for the longest cumulative time spent in orbit around the Earth of approximately 878.5 days, was set by Russian cosmonaut Oleg Kononenko.

Assume that each orbit was at an average height of 400 km above the Earth's surface and at an average velocity of 8000 m/s.

Approximately how many complete orbits of Earth has Oleg Kononenko completed?

Radius of Earth = 6370 km

A. 165

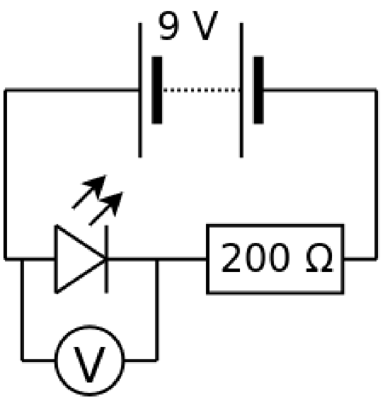
B. 14 300

C. 15 200

D. 242 000

Question 2

A very simple circuit is made from a 9 V battery, a 200 Ω resistor and an LED all in series. The circuit is shown in the diagram.



The potential difference across the LED is measured, using a voltmeter, to be 0.7 volts.

The current flowing through the battery is:

A. zero

B. 3.5 mA

C. 42 mA

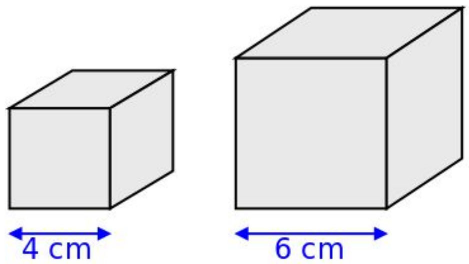
D. 45 mA

Question 3

A cube of metal has sides of length 4 cm.

A second cube, made of a different metal, has sides of length 6 cm.

Both cubes exert the **same pressure** on the ground.



The ratio $\frac{density\ of\ the\ smaller\ cube}{density\ of\ the\ larger\ cube}$ is:

A. 4 : 9

B. 2 : 3

C. 3 : 2

D. 9 : 4

Question 4

A current carrying conductor in the Earth's magnetic field can experience a force.

The **magnitude** of the force does **not** depend on:

A. the magnetic flux density (B) (the "strength") of the magnetic field

B. the angle between the conductor and the magnetic field lines

C. the material of the current carrying conductor

D. the direction of the current

Question 5

A prototype demonstration rocket has a mass of 800 kg and is designed to lift a payload (the cargo) of an additional 20 kg to a height of several kilometres.

The rocket engines are controlled so that the rocket and payload experience a constant acceleration of 12 m/s^2 for the duration of the 20 second long flight.

The initial thrust from the rocket engines is approximately:

A. 1800 N

B. 8000 N

C. 9800 N

D. 18 000 N

Question 6

Consider the rocket and payload in question 5.

During the 20 second flight, the work done by the rocket on the payload is approximately:

A. 470 kJ

B. 580 kJ

C. 1.0 MJ

D. 43 MJ

Question 7

Carbon-14 is a radioactive isotope with a half-life of approximately 5700 years.

The amount of Carbon-14 in a sample of organic material reduces over time as the Carbon-14 decays. In this way, measuring the amount of Carbon-14 in a sample of material can give an estimate of the age of the sample. This is known as carbon dating.

Carbon dating can be usefully used to date samples that are roughly:

A. 1 000 000 years old

B. 10 000 years old

C. 100 years old

D. 1 year old

Question 8

Liquid nitrogen is stored, at its boiling point, at a temperature of –196 °C in a special container called a dewar.

A particular dewar contains 20 litres of liquid nitrogen. The insulation used is such that the rate of change of internal energy of the liquid nitrogen in the dewar is 1.2 W.

Over time the liquid nitrogen boils away to become nitrogen gas.

- Specific heat capacity of liquid nitrogen ≈ 2 kJ / kg °C
- Specific latent heat of liquid nitrogen ≈ 200 kJ / kg
- Density liquid nitrogen ≈ 0.8 g / ml (grams per millilitre)

The 20 litres of liquid nitrogen will have completely boiled away after about:

A. 39 days

B. 31 days

C. 9 hours

D. 7 hours

Question 9

An ultrasonic transmitter with a frequency of 40 kHz is used to create a sound wave in a body of water.

The body of water is unusual because it comprises a layer of fresh water on top of a layer of more dense saltwater.

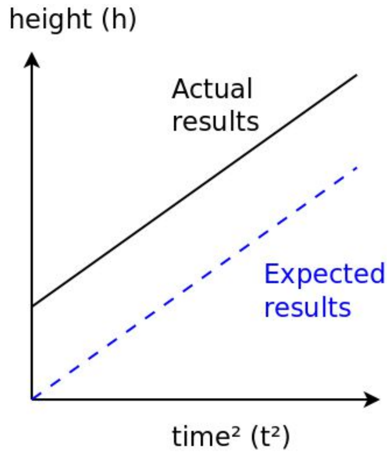
- Speed of sound in fresh water = 1480 m/s
- Speed of sound in saltwater = 1500 m/s

When the sound waves cross from the fresh water into the saltwater, which of the following occurs?

	Frequency	**Wavelength**
A.	Stays the same	Increases by 0.5 mm
B.	Stays the same	Decreases by 0.5 mm
C.	Increases by 500 Hz	Stays the same
D.	Decreases by 500 Hz	Stays the same

Question 10

A student carried out an experiment to measure the acceleration due to gravity by dropping a steel ball through a height (h) and recording the time taken (t).



The student plotted a graph of the results.

They expected to obtain a graph showing a straight line passing through the origin.

However, they actually obtained a graph showing a straight line that did not pass through the origin, as shown.

The difference between the actual and expected results can be explained by:

A. the measured height being greater than the true height

B. the measured height being less than the true height

C. the recorded time being less than the true time taken

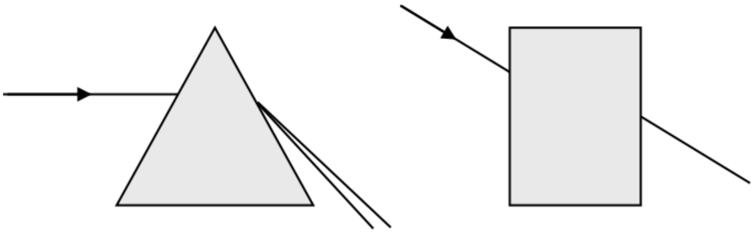
D. the value for the acceleration due to gravity being less than expected

Short Written Questions

Question 11

A raybox can be used to demonstrate refraction in a rectangular glass block and dispersion in a triangular glass prism.

In both cases the incident ray is a narrow light ray of white light which is incident on the glass air boundary at an angle of 30° to the normal line.



Explain why:

[5 marks]

- In the prism, the light emerging is diverging and forms a spectrum of different colours
- Whereas in the rectangular glass block the light emerges as a narrow light ray of white light which does not form a spectrum of different colours

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Question 12

A student carries out an experiment to investigate the motion of falling masses. The student drops three balls **simultaneously** from a fixed height of 2 m. Each ball is released from rest.

The balls used (from left to right in the picture) are a ping-pong ball, a golf ball and a squash ball. The three balls are approximately the **same size**. Each ball has a **different mass**.

3 grams	46 grams	24 grams

The student makes the following observations:

"Despite their different masses, the golf ball and squash ball hit the ground at almost exactly the same time"

"The ping-pong ball hit the ground slightly after the other two balls"

Explain **each** of the student's observations

[5 marks]

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Extended Numerical Questions

Question 13: Asteroid Impact

This question is about the possibility of preventing an asteroid collision with Earth by intercepting any asteroids on a collision course with a satellite to cause a change in direction.

In the following questions, ignore the motion of the Earth around the Sun. All velocities and distances are relative to the Earth.

Consider an asteroid that is heading directly towards Earth, on a collision course.

- Mass of asteroid = 100×10^6 kg
- Velocity of asteroid = 15 km/s

a) Show that the kinetic energy of the asteroid is equivalent to the energy released by approximately 200 atomic bombs.

- Energy released by atomic bomb ≈ 15 kilotonnes TNT
- Energy released by 1 kg TNT ≈ 4.2×10^6 J
- 1 tonne = 1000 kg

[2 marks]

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To prevent the asteroid colliding with Earth, it is proposed that a satellite could intercept and collide with the asteroid. The collision would change the momentum and hence direction of the asteroid.

b) Calculate the momentum of the asteroid before the collision

[1 mark]

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The trajectory of the satellite is such that, at the point of impact, the satellite and asteroid are travelling along perpendicular trajectories. See **Diagram 1**.

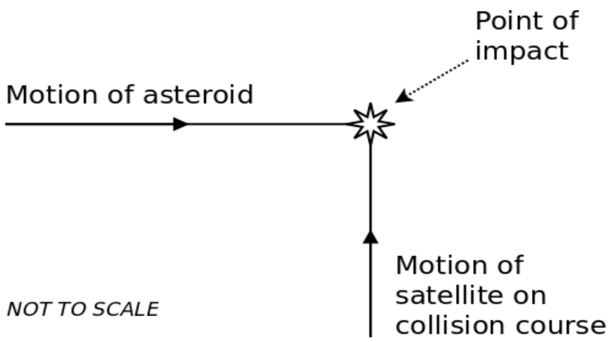

Diagram 1

Assume that, after the collision, the satellite and asteroid combine to form one object. The motion can be analysed by drawing a vector diagram of the momentum vectors. See **Diagram 2**.

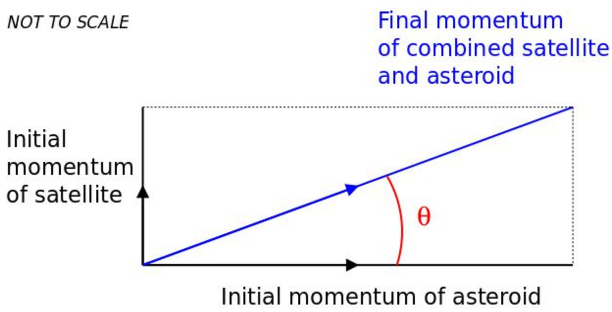

Diagram 2

c) Calculate (i) the momentum of the satellite, and hence (ii) calculate the angle (θ) and (iii) the velocity (v) of the asteroid with the tangled wreckage of the satellite after the collision.

- Mass of satellite = 5000 kg
- Velocity of satellite at impact = 40 km/s

[3 marks]

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θ = ……………………………………

v = ……………………………………

To successfully avoid a collision with Earth, the asteroid needs to be displaced by at least one Earth diameter from its original path.

d) Show that the minimum distance from Earth at which the collision between the asteroid and the satellite must take place is approximately 9.6 x10^7 km

- Radius of Earth = 6370 km

[2 marks]

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The satellite is launched sometime before the impact occurs.

Assume that the satellite travels directly from Earth towards the collision point and that the time to manoeuvre for a perpendicular trajectory as the satellite approaches the asteroid is only a very small part of the journey time. See **Diagram 3**.

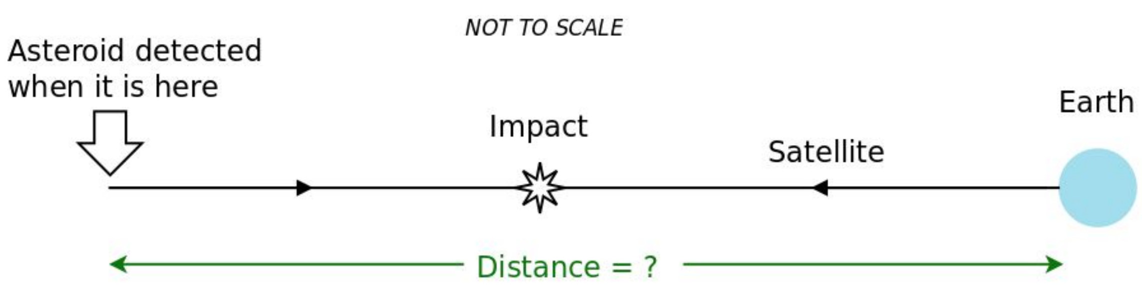

Diagram 3

e) What is the minimum distance from Earth at which the asteroid must be identified as a threat to Earth so as to leave enough time for the satellite to be launched and travel to the collision point?

Assume the velocity of the asteroid (15 km/s) and velocity of the satellite (40 km/s) are constant throughout the satellite's journey.

[2 marks]

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f) A different design of satellite used to intercept asteroids can have either:

- Twice the mass (10 000 kg)

  OR

- Twice the velocity (80 km/s)

State and justify which of these two changes would make the biggest improvement to the effectiveness of the asteroid deflection process?

[3 marks]

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g) Actual experiments show that, in actual fact, the material ejected from the surface of the asteroid as the satellite impacts the surface makes a significant contribution to the overall change of direction of the asteroid.

Suggest what the effect of the ejected material would be on the motion of the asteroid.

[2 marks]

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Question 14: Battery Charging

Batteries are an important part of modern day technology. This question is about a very simple (and unrealistic) battery charger.

A simple charging circuit is constructed from a power supply with an EMF of 14 volts and a fixed value resistor, used to limit the current, with a resistance of 0.15 Ω. See **Diagram 4.**

The power supply and resistor are connected in series with the battery to be charged which has an EMF of 12 volts and also has an internal resistance of 0.05 Ω due to the materials that it is made from.

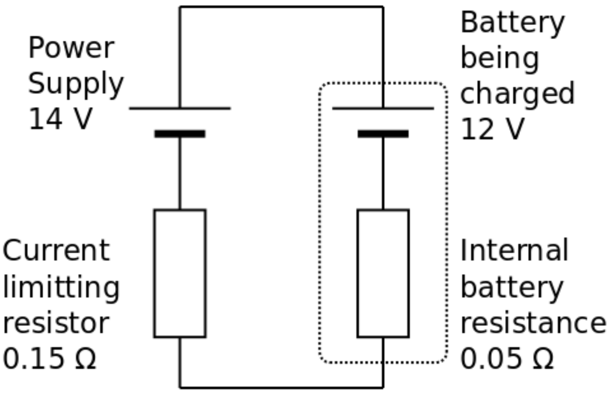

Diagram 4

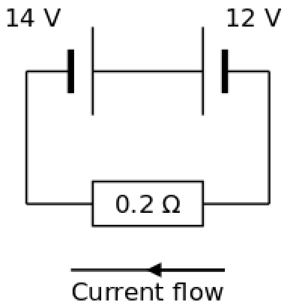

Diagram 5

a) The total resistance of the circuit due to the fixed value resistor and the internal resistance of the battery is 0.2 Ω. The equivalent circuit is shown in **diagram 5**.

State the potential difference across the 0.2 Ω total resistance.

[1 mark]

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b) Calculate the charging current flowing in the circuit.

[1 mark]

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c) By considering the rate of energy transfer in the power supply and the power dissipated in the 0.2 Ω total resistance, show that the efficiency of the charging process is about 85%

[3 marks]

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The current flowing through the 0.05 Ω internal resistance of the battery being charged has a heating effect and therefore the temperature of the battery increases.

d) Calculate the rate of energy transfer to the thermal (internal) energy store of the battery

[1 mark]

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The battery manufacturer states that the temperature should not be allowed to exceed 50 °C when the battery is being charged.

The battery is a lead-acid battery made from lead electrodes immersed in sulphuric acid.

- Mass of lead in the battery = 1.6 kg
- Mass of sulphuric acid in the battery = 1.0 kg
- Specific heat capacity of lead = 130 J / kg°C
- Specific heat capacity of sulphuric acid = 1400 J / kg °C
- Initial temperature of battery = 20 °C

e) Calculate the rate of increase of temperature of the battery when it is being charged.

[3 marks]

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Assume that the battery voltage and charging current remain constant throughout the charging process.

Assume that no energy is transferred to the surroundings during the charging process.

f) Show that the battery can be charged for about 2 ½ hours before it reaches the maximum allowed temperature.

[3 marks]

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g) The battery has a capacity of 50 Ah (Amp-hours).

A battery capacity of 50 Ah means that the battery can supply a continuous current of 50 A for 1 hour or 25 A for 2 hours etc.

As a percentage, what fraction of the battery's capacity is transferred to the battery during the charging process before it reaches the maximum allowed temperature?

[1 mark]

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h) What would be the effect of changing the value of the fixed resistor on the percentage to which the battery is charged before it reaches its maximum allowed temperature?

[2 marks]

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[END OF QUESTIONS]

Notes

Question 13 is inspired by, but not based on, NASA's DART programme whereby a satellite was able to intercept a pair of asteroids and change the motion of one of them.

https://science.nasa.gov/mission/dart/

Question 14: The circuit used is not, and should not, be used to charge batteries. Battery chargers use electronics to carefully monitor the current and state of the battery's charge and adjust the charging rate accordingly. However, the question does illustrate the basic concept and the problem of batteries getting hot when charged.