Name:	
School:	

Total Mark	

BPhO British Physics Olympiad

2017 Physics Challenge

Time allowed: 1 hour

Attempt all questions

Write your answers on this question paper

You may use a calculator

Use g = 10 N / kg

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 physical principles
Allow about 15 minutes for this section

Section C: Longer answer question(s) 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 the question
Allow 30 minutes for this section

Total 50 marks; mark allocations for each sub-section are shown in brackets

Section A: Multiple Choice Answers

Write the correct letter in the grid. 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										

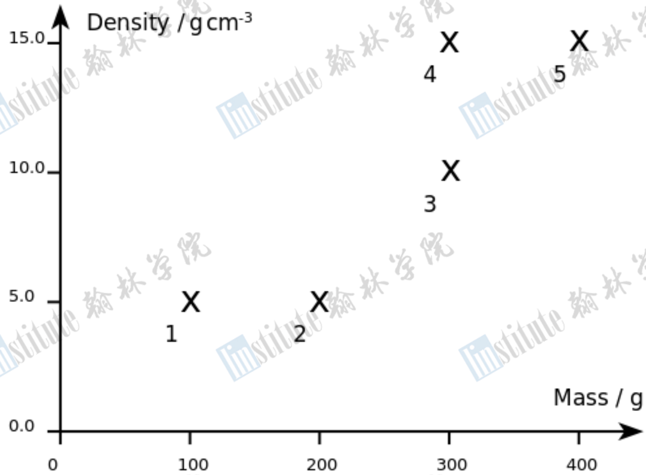
Section A: Multiple Choice Questions

1. The masses of several different material samples are recorded and the mass is plotted against the density of the sample.

The samples are labelled 1 to 5.

Which two samples have the same volume?

A. 1 and 2
B. 4 and 5
C. 3 and 4
D. 1 and 4
E. None of them



2. In particle accelerators such as those at CERN, particle energies are measured in giga electronvolts (GeV) where 1 eV = 1.60×10^{-19} J. Giga is a unit prefix meaning 10^9.

A particle has an energy of 920 GeV. The energy of the particle in joules is

A. 1.74×10^{-22} J
B. 1.47×10^{-16} J
C. 1.47×10^{-7} J
D. 5.72×10^{21} J
E. 5.72×10^{30} J

3. Two gas cylinders have the same volume.

Each cylinder contains 1 mole of gas at 20°C.

One cylinder contains hydrogen gas and the other contains oxygen.

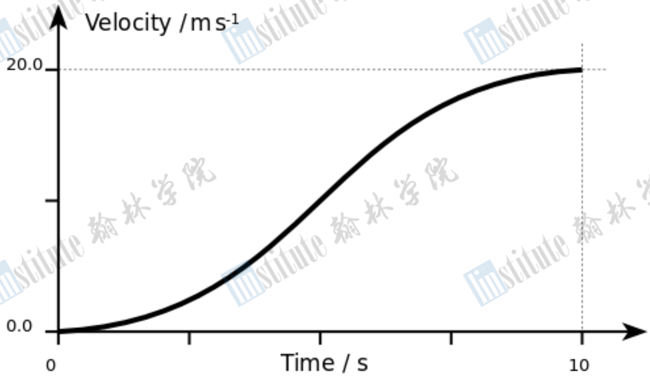
What can be determined about the pressure in each gas cylinder and the speed of the gas molecules in each cylinder?

	Relative pressure	*Speed of gas molecules*
A.	Both have the **same** pressure	Both have the **same** speed
B.	Both have the **same** pressure	Speed of Hydrogen is greater
C.	Both have the **same** pressure	Speed of Oxygen is greater
D.	Pressure of Hydrogen is greater	Both have the **same** speed
E.	Pressure of Oxygen is greater	Both have the **same** speed

Question 4 & 5 refer to the following velocity – time graph.

The graph shows how the velocity of a car changes over a period of 10 seconds.

The car is travelling along a straight road.



4. The maximum acceleration of the car is approximately

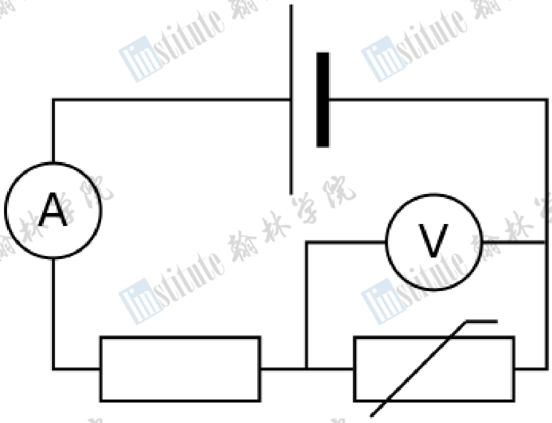
A. 0.5 m s^{-2}
B. 2.0 m s^{-2}
C. 2.5 m s^{-2}
D. 3.6 m s^{-2}
E. 6.0 m s^{-2}

5. The distance travelled by the car in 10 seconds is approximately

A. 20 m
B. 100 m
C. 150 m
D. 200 m
E. 250 m

6. In the circuit shown, the resistance of the thermistor **decreases** as the temperature **increases**.

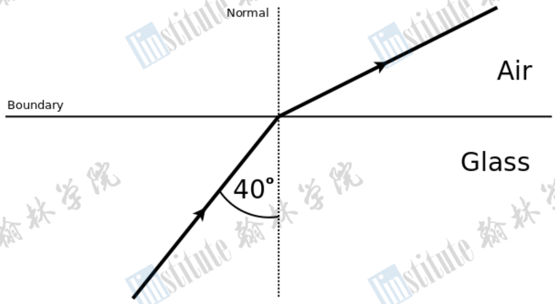
How do the readings on the ammeter and voltmeter change as the temperature of the thermistor **increases**?



	Ammeter Reading	*Voltmeter Reading*
A.	Decreases	Increases
B.	Decreases	Decreases
C.	Increases	Increases
D.	Increases	Decreases
E.	Increases	Stays the same

7. A light ray travels from glass to air as shown.

The refractive index of the air is n =1.0

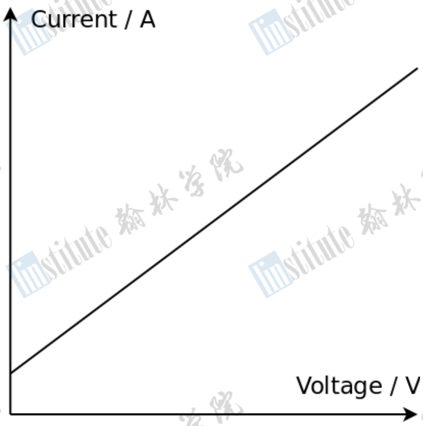


The refractive index of the glass could be

A. 0.6
B. 0.7
C. 1.0
D. 1.4
E. 1.6

8. A student measures the potential difference across a fixed value resistor and also measures the current through the resistor.

A graph of potential difference and current produces a straight line as shown.



The graph shows that

A. Current is directly proportional to potential difference
B. The voltmeter was consistently reading more than it should do
C. The ammeter was consistently reading more than it should do
D. The ammeter and voltmeter were connected incorrectly
E. The resistance of the ammeter affected the measurements

9. Iodine has several radioactive isotopes. A sample of an iodine compound containing a radioactive isotope of iodine can be used as a tracer in medical physics.

The half-life the Iodine isotope is affected by

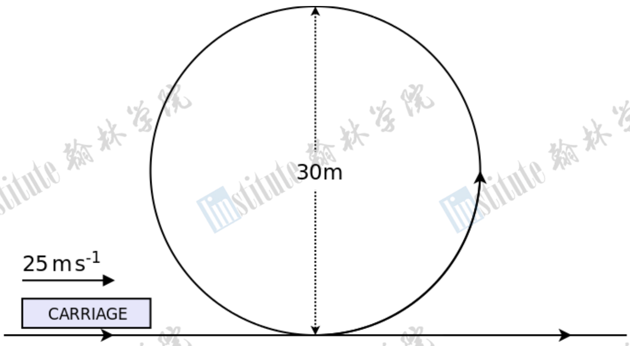
A. The temperature of the sample
B. The chemical composition of the Iodine compound
C. The quantity of isotope present in the sample
D. The time since the sample was prepared
E. None of the above

10. A roller coaster ride includes a circular loop-the-loop.

The roller coaster carriage enters the bottom of the loop at 25 ms^{-1}.

The loop has a diameter of 30 m.

The carriage is free-wheeling along the track meaning that it is not being driven by a motor.



The speed of the carriage at the top of the loop is approximately

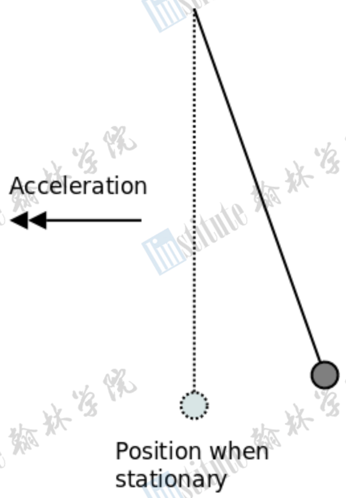
A. 25 ms^{-1}
B. 12 ms^{-1}
C. 5 ms^{-1}
D. 1 ms^{-1}
E. 0 ms^{-1}

Section B: Short Answer Questions

11. The following experiment was conducted to measure the acceleration of an aircraft as it accelerated down the runway:

    - A pendulum was allowed to hang freely inside the aircraft when it was stationary.
    - As the aircraft accelerated down the runway, the pendulum was observed to hang at an angle to the vertical as shown.
    - The angle of the pendulum was measured and used to calculate the acceleration.

    The pendulum was made of a pendulum bob hung from a length of string.



Explain why the pendulum hung at an angle as shown while the aircraft was accelerating.

[5 marks]

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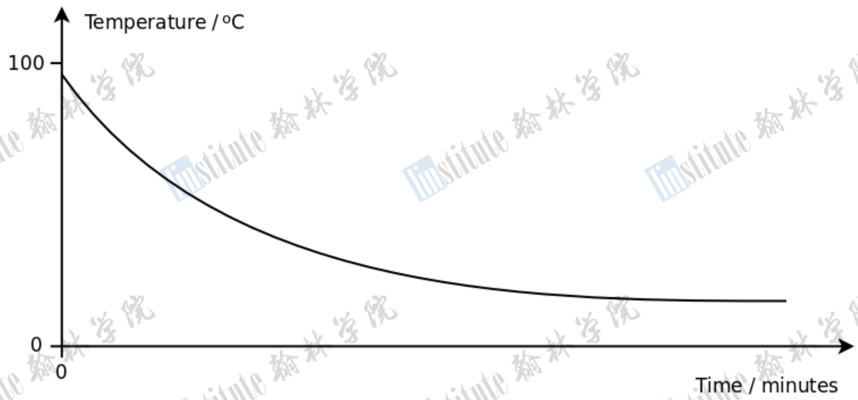
12. A beaker of boiling water was allowed to cool naturally.

Readings of temperature were recorded every minute and the results were plotted on the graph with a line of best fit as shown.



Explain the shape of the graph.

[5 marks]

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Section C: Longer Answer Questions

13. In his 1865 novel "*From the Earth to the Moon*" Jules Verne tells the story of a group of enthusiasts who attempt to build an enormous space gun to launch three people in a capsule with the goal of landing on the moon.

https://en.wikipedia.org/wiki/From_the_Earth_to_the_Moon

This question is about the feasibility of Jules Verne's ideas.

Note: In the following questions ignore all effects due to the rotation of the earth, the position on earth of the cannon and the effect of the atmosphere.

(a) Rather than aiming for the Moon, consider using the cannon to shoot a 1000 kg capsule from the Earth's surface to an orbit equivalent to that of the International Space Station 330 km above the Earth's surface.

Assume that the acceleration due to gravity has a value of $10\,m\,s^{-2}$ and does not change significantly up to a height of 330 km.

Show that the capsule must be shot from the surface of the Earth at a minimum velocity of approximately $2.5\,km\,s^{-1}$

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[3 marks]

(b) The acceleration due to gravity actually reduces with height above the Earth's surface and is less than $10\,m\,s^{-2}$ at a height of 330 km.

Explain what affect this would have on the velocity calculated in (a) above

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[2 marks]

(c) As the capsule is fired along the cannon barrel it accelerates. The capsule can withstand a maximum **constant** acceleration of $a_{max} = 100\,m\,s^{-2}$.

Assume the capsule accelerates uniformly along the length of the barrel and achieves the velocity calculated in part (a) as it leaves the barrel of the cannon.

Sketch a velocity-time graph for the capsule inside the barrel of the cannon as it is accelerated from rest until the moment it leaves the cannon. **Add appropriate values** to each axes.

[4 marks]

(d) Using the graph, or otherwise, **calculate** the minimum length of the cannon

[2 marks]

(e) Comment of the feasibility of shooting a space capsule from the Earth's surface using a large cannon as proposed by Jules Verne.

[1 mark]

The velocity required for an object to *completely* escape from the gravitational field of the Earth, from the surface, is given by the equation

$$v_{escape} = \sqrt{2gR}$$

where R = radius of Earth and g = gravitational field strength at the surface.

(f) Given that the radius of the Earth is 6400 km, **calculate** the escape velocity from the surface of the Earth

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[1 mark]

The same equation for escape velocity can be applied to other similar objects in the solar system.

(g) Use the escape velocity equation to **explain why**

(i) it will be probably be possible to simply shoot minerals mined from the asteroids in the asteroid belt back towards Earth

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[1 mark]

(ii) the Moon, small rocky planets and other moons have very little, if any, atmosphere

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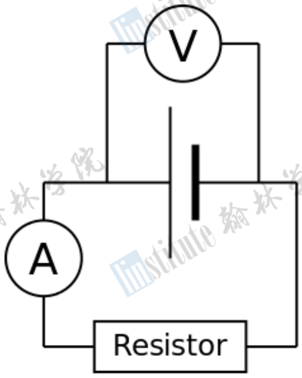
[1 mark]

14. **This question is about energy in a chemical cell and whether or not other technology could easily replace the chemical cell.**

The most common chemical cell is probably the 'AA battery' used in many everyday appliances.

Such an AA chemical cell was connected to a resistor in a circuit as shown.



The voltage across the cell and the current in the circuit were measured at intervals throughout the day until the cell was completely flat.

The results are shown in the table.

Elapsed Time / Hours	Voltage / V	Current / mA
0	1.6	200
1	1.6	200
3	1.4	175
6	1.2	150
7	1.1	140
8	0.2	25

(a) **Show that** the power delivered by the cell when timing started was about 0.3 W

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[1 mark]

(b) **Show that** the energy delivered by the cell in the first hour of the experiment was approximately 1150 J

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[1 marks]

(c) Use the data in the table to estimate the total energy delivered by the cell over the course of the whole experiment

[4 marks]

Rather than giving the actual energy deliverable by a cell in joules, the “energy content” or capacity of the cell is often quoted by the manufacturer in units of milliamp hours (mAh).

For this particular cell, the manufacturer quotes a capacity of 1500 mAh.

This means that, in theory, the cell should deliver 1500 mA for one hour.

(d) **Determine whether or not** the manufacturer’s claims are consistent with the recorded data

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[2 marks]

An alternative technology uses a component called a supercapacitor to store charge.

The capacitance (C) of the supercapacitors is measured in farads (F).

For a supercapacitor, the energy stored is given by $E=\frac{1}{2}CV^2$

where V is the voltage across the capacitor when it is charged.

(e) Consider a supercapacitor with a capacitance of 15 F that is charged so that it has a voltage of 2.8 V across the terminals.

Show that the energy stored in this case is approximately 60 J

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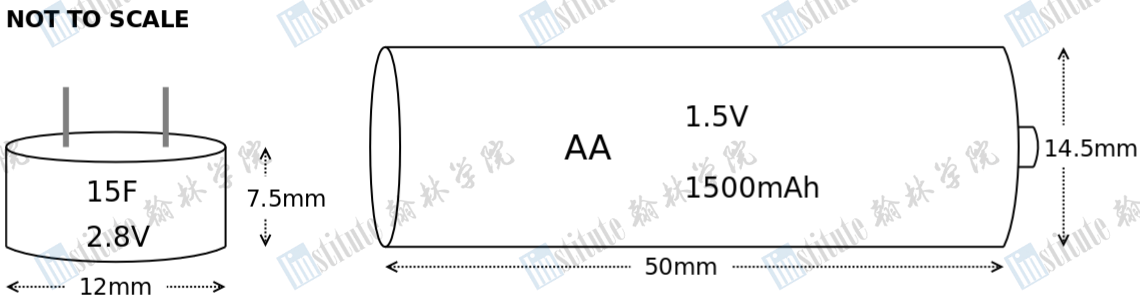
[1 mark]

The dimensions of a AA cell and a supercapacitor are shown in the diagram.



Energy density can be defined as the **energy stored per cm³** for the cell or supercapacitor.

(f) **Calculate** the energy density for the AA chemical cell and for the supercapacitor and **comment on** the feasibility of replacing the traditional AA battery with an equivalent device made from supercapacitors

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Energy density of AA cell = ... Jcm^{-3}

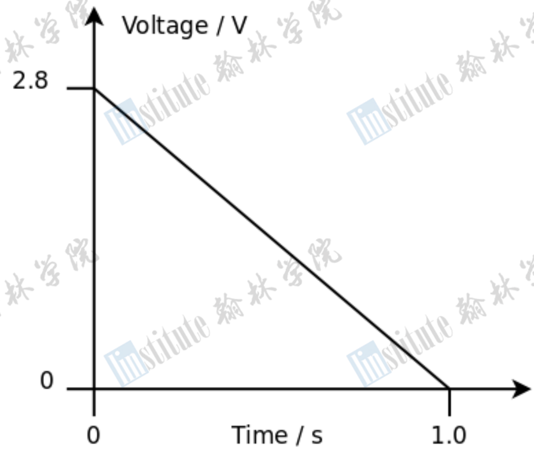
Energy density of supercapacitor = ... Jcm^{-3}

[4 marks]

One of the great advantages of supercapacitors is that they can discharge very quickly and hence deliver very large currents.

A 15 F supercapacitor, initially charged to 2.8 V, is discharged in 1 second.

The discharge circuit is arranged to ensure the **discharge current remains constant** throughout the 1 second period.



As the supercapacitor discharges, the voltage reduces steadily from 2.8 V to 0 V as shown on the voltage – time graph.

(g) **Calculate** the discharge current

[2 marks]

END OF PAPER