Name:	
School:	

Total Mark	

British Physics Olympiad

2018 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: Three longer answer questions requiring calculations (worth 30 marks in total). Questions may be set on unfamiliar topics. Additional information necessary to answer each question will be given in the question.
Allow about 35 minutes for this section.

Useful Constants and Equations

The following useful equations may be unfamiliar to some students:

$v^2 = u^2 + 2as$ (final velocity)^2 = (initial velocity)^2 + 2 x acceleration x distance

$\rho = {}^{m}/_{V}$ density = mass ÷ Volume

$\Delta p = \rho g \Delta h$ pressure due to a column of liquid

= density of liquid x acceleration due to gravity x height of column

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

Section A: Multiple Choice Answers

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

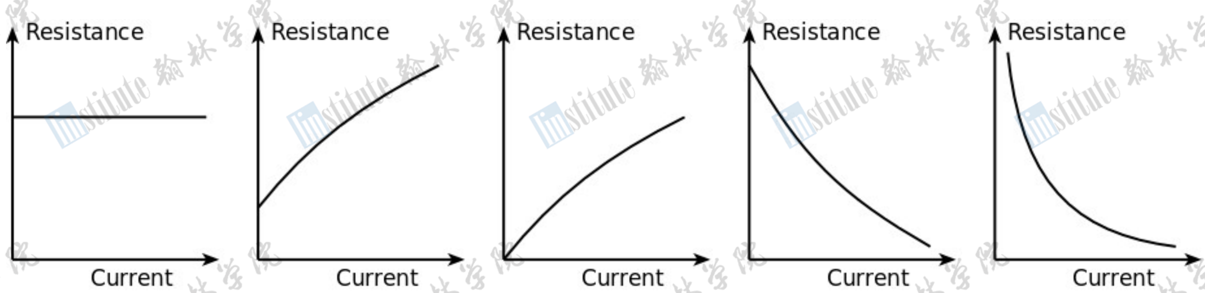
The first column has been done as an example if the answer to question zero were C.

Question	0	1	2	3	4	5	6	7	8	9	10
Answer	C										

Section A: Multiple Choice Questions

1. Graphs of the resistance of an electrical component against current through the component are shown below.

   Which is the correct graph for a filament lamp?

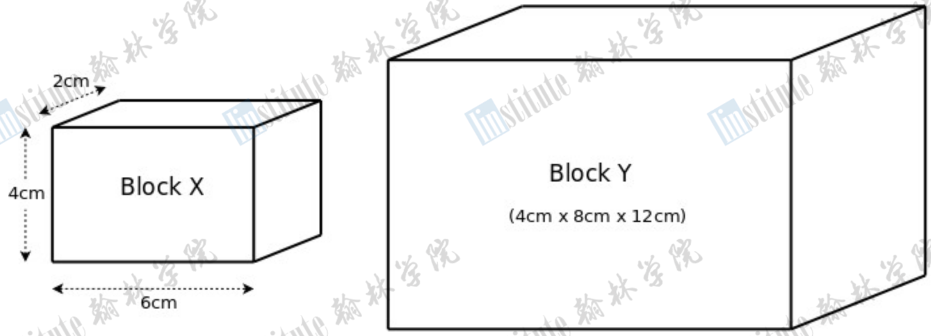


A B C D E

2. Block X has a mass m_X and a density ρ_X.
   Block Y has a mass m_Y and a density ρ_Y.

   Block X, is made from the **same material** as block Y.

   Block Y is **twice as big** in each dimension as block X.



   Which line in the table is correct?

	Mass	Density
A	$m_Y = m_X$	$\rho_Y = \rho_X$
B	$m_Y = 2 \times m_X$	$\rho_Y = \rho_X$
C	$m_Y = 8 \times m_X$	$\rho_Y = \rho_X$
D	$m_Y = 2 \times m_X$	$\rho_Y = 2 \times \rho_X$
E	$m_Y = 8 \times m_X$	$\rho_Y = 2 \times \rho_X$

3. Consider the smaller block, labelled X, from question 2:
   Standing on its smallest face it exerts a pressure p_1 on the ground.
   Standing on its largest face it exerts a pressure p_2 on the ground.

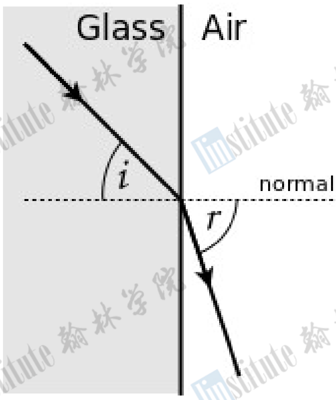
   The ratio $p_1 : p_2$ is:

   A. 3 : 1
   B. 2 : 1
   C. 1 : 1
   D. 1 : 2
   E. 1 : 3

4. A light ray passes from within a glass block out in to the air. The critical angle for the glass – air boundary is 48°.

   When the angle of incidence in the glass block is 40° the angle of refraction in the air will be:

   A. 29°
   B. 48°
   C. 50°
   D. 60°
   E. 90°



5. In 1971, during the Apollo 15 mission to the moon, a hammer and a feather were dropped simultaneously from a height of 1.7 m. The hammer and feather both landed on the lunar surface at the same time.

   On Earth, a hammer dropped from a height of 1.7 m takes approximately 0.6 s to hit the ground. Given that the acceleration due to gravity on the moon is approximately 1.6 m/s^2, the time taken for the hammer and feather to fall to the lunar surface was about:

   A. 0.1 s
   B. 0.6 s
   C. 1.5 s
   D. 3.8 s
   E. 10 s

6. Whilst performing the experiment in question 5, the astronauts on the Apollo 15 mission credited the work of Galileo Galilei and his investigations into the motion of objects.

   Galileo showed that all:

   A. Objects in the same gravity field all experience the same force
   B. Objects in the same gravity field all fall at the same speed
   C. Objects in the same gravity field all fall in the same time
   D. Objects in the same gravity field all fall with the same momentum
   E. Objects in the same gravity field all fall with the same acceleration

7. When measuring (and paying for) domestic electricity in the home, the amount used is usually measured in kilowatt-hours (kWh). The kWh is a unit of:

   A. Charge
   B. Current
   C. Energy
   D. Power
   E. Time

8. A crude method to measure the speed of sound involves banging two wooden blocks together to produce a sharp sound. One person bangs the blocks together. A second person uses a trundle wheel or tape measure to stand 100 m away. When the second person **sees** the blocks hit, they start a stopwatch. When they **hear** the bang, they stop the stopwatch.

   Using this method a value of 420 m/s was measured for the speed of sound. The accepted value is 340 m/s.

   The most likely reason for the difference between the measured and accepted value is:

   A. The time measurement is too short
   B. The time measurement is too long
   C. The distance measurement is too small
   D. The distance measurement is too big
   E. The speed of light was not taken in to account

9. In 2014 the highest freefall jump was made from a height of just over 41 km. As the jumper travelled back towards earth he quickly reached a terminal velocity of over 1300 km/h.

   As he continued to fall towards the ground the atmosphere (which was initially very thin at a height of 41 km) became gradually thicker.

   On his descent and before he released his parachute, his terminal velocity:

   A. Increased
   B. Stayed the same
   C. Reduced
   D. Eventually became zero
   E. Could not be determined

10. As he ascended to the jump height in his balloon, the freefall jumper in question 9 needed to use compressed air from gas cylinders to be able to breathe. The pressure in these gas cylinders changed during the flight as:

    (i) The freefall jumper used the air
    (ii) The gas in the cylinders became cold due to the height
    (iii) The cylinders got slightly smaller as they contracted due to the cold

    The pressure in the cylinder **reduced** due to:

    A. (ii) and (iii) only
    B. (i) and (ii) only
    C. (iii) only
    D. (ii) only
    E. (i), (ii) and (iii)

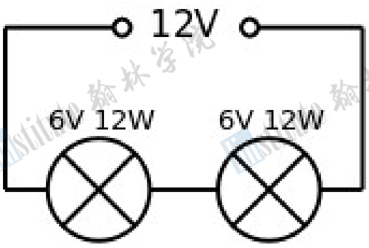
Section B: Short answer questions

11. On a cold winter's day a piece of wood and a piece of metal are left outside for a long time. When the wood and then the metal are each handled in turn the metal feels much colder that the wood.

    Explain why the metal feels much colder than the wood even though they have both been outside and are therefore at the same temperature.

[5 marks]

12. Two identical bulbs are rated at 6 V and 12 W.



They are connected in series to a 12 V power supply and are each lit to their normal brightness.

One of the bulbs breaks and is replaced by a bulb rated at 6 V and 24 W.

In the new arrangement the bulbs are not the same brightness.

Explain why, in the new arrangement, the bulbs would not be the same brightness

State which bulb would be the brighter.

[5 marks]

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Section C: Long answer questions

13. This question is about maintaining a safe braking distance when driving

Consider a car driving along a straight road at 45 miles per hour (mph). The driver brakes and decelerates at $3\,m/s^2$ until the car comes to rest.

Consider a second car driving behind the first car at the same speed. When the first car brakes the driver of the second car takes 1.2 seconds to react before braking with the same deceleration of $3\,m/s^2$. The second car also comes to rest.

a) 1 mile = 1.6 km. Show that 45 mph = 20 m/s

[1 mark]

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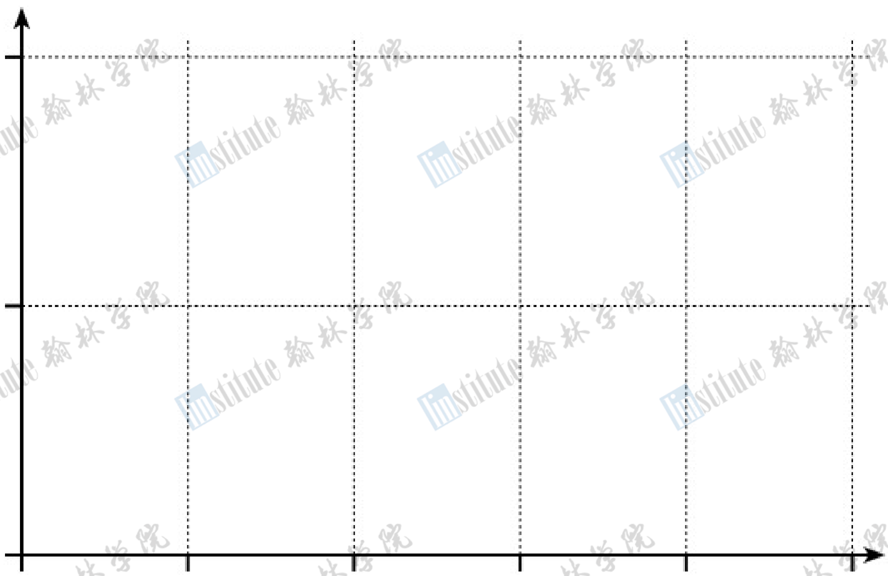
b) Using the axes below, draw a velocity – time graph for each car.

Assume t=0 at the moment when the first car starts to brake. Add an appropriate scale to each axes and label the graphs to show which line corresponds to which car.

[3 marks]



c) State the minimum distance necessary between the two cars, before the first car brakes, to avoid a collision.

[1 mark]

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On some roads chevrons (>) are used to encourage drivers to keep a safe distance. Keeping at least 2 chevrons visible, as shown on the road sign, between your car and the car in front ensures that there is a safe braking distance between the cars.

d) The chevrons in the photograph are 30 m apart. A driver takes 1.2 seconds to react before braking with a deceleration of $3\,m/s^2$. At what speed would using the chevrons no longer provide a safe braking distance?

[1 mark]

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An alternative way to ensure a safe braking distance between two cars is to time 2 seconds between the car in front passing a stationary road side object (such as a tree) and the following car passing the same object. This is easily accomplished by saying the rhyme:

"Only a fool breaks the two second rule" …. which takes about 2 seconds to say.

e) **Explain why** the "only a fool breaks the two second rule" method will maintain a safe braking distance at any speed.

[2 marks]

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14. **This question is about a moving walkway**

Moving walkways are often found in airports and shopping centres. Consider a moving walkway with the following specifications:

- Length = 60 m
- Normal speed = 1.5 m/s
- Idle (energy saving) speed = 0.5 m/s
- Mass of moving section of walkway = 8000 kg
- Friction force experienced by moving walkway = 2000 N

  Note: assume the frictional force is independent of the speed of the walkway, the number of passengers being carried, and remains constant.

a) Assuming that the only energy losses are due to work done against the frictional forces experienced by the moving walkway, **show that** the power required to keep the walkway moving at normal speed, but with no passengers, is 3 kW.

[1 mark]

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b) A group of passengers with a combined mass of 800 kg step on to, and stand still on, the walkway which is moving at normal speed. The passengers can be taken to be initially at rest and are then accelerated from rest by the walkway.

Theory: The energy expended by the walkway, in accelerating the passengers from rest, is **twice** the kinetic energy gained by the passengers.

Calculate the total energy expended transporting the passengers to the end of the walkway.

[3 marks]

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To save energy, the walkway runs at a lower idle speed when there are no passengers on the walkway. When a passenger approaches the walkway, the speed increases to the normal operating speed.

c) The same group of passengers, with a combined mass of 800 kg, approach the walkway when it is running at the lower idle speed, and the walkway responds by increasing to the normal operating speed. They then step on to the walkway in the same manner as in part (b). Assume the time taken to speed up is very small compared to the time taken for the passengers to reach the end of the walkway.

Calculate the total energy expended transporting the passengers to the end of the walkway.

[3 marks]

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d) Once the passengers have reached the end and stepped off the walkway, there is a delay before the runway slows down again.

Suggest and **justify** a suitable time delay, before the walkway slows down again, to make the walkway run as efficiently as possible.

[3 marks]

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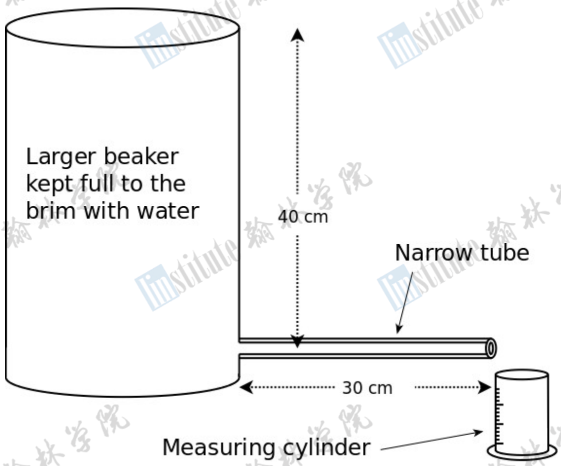
15. Poiseuille was a French physicist and physiologist who was interested in blood flow through narrow tubes such as capillaries and veins. In 1838 he experimentally derived the relationship for the rate of flow of a fluid through a narrow tube. This is known as Poiseuille's Law**.

This question is about experimentally verifying Poiseuille's Law

Poiseuille's Law for water flowing through a tube is: $\frac{\Delta V}{\Delta t} = \frac{\pi r^4 \Delta p}{8 \eta L}$

Where: $\frac{\Delta V}{\Delta t}$ = volume of water flowing through the narrow tube **per second** (flow rate)
r = internal radius of the narrow tube
Δp = pressure difference between the ends of the narrow tube
η = a constant called the viscosity (a measure of the resistance to flow)
L = length of the narrow tube

A student used the apparatus shown to measure the amount of water that flowed through a narrow tube in a minute. The water was collected in a small measuring cylinder. The large beaker of water was kept topped up throughout the experiment by adding more water as necessary.



In the experiment

L = 30 cm (Length of narrow tube)
r = 0.5 mm (Internal diameter of narrow tube)
Density of the water = 1000 kg/m^3

To verify Poiseuille's Law, r was varied and $\frac{\Delta V}{\Delta t}$ was measured.

a) Show that the pressure at a depth of 40cm **due to the water** in the large beaker is 4000 Pa.
[1 mark]

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b) Explain why atmospheric pressure does not affect the flow rate i.e. the amount of water flowing through the tube each second
[1 mark]

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c) Explain why the beaker of water must be constantly topped up to keep it full during the experiment.

[2 mark]

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d) The amount of water collected in 1 minute was 22 cm^3. Calculate the rate of flow of water $\left(\frac{\Delta V}{\Delta t}\right)$ in units of cubic meters per second (m^3/s).

[2 marks]

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e) Use Poiseuille's Law to show that $\eta \approx 9 \times 10^{-4}$ Pa s

[3 marks]

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To verify the equation, the experiment was repeated with different narrow tubes, each 30 cm long but with different radii. The results are shown below:

Internal radius of the narrow tube / mm	Volume of water collected in 1 minute / cm^3
0.3	3
0.5	22
0.7	84
1.0	350

f) Discuss whether or not the results obtained support Poiseuille's Law

[3 marks]

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END OF PAPER

** The same relationship was independently experimentally verified Hagen in 1839, before Poiseuille published his work. The relationship is therefore often referred to as the Hagen-Poiseuille equation.

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