Surname	Centre Number	Candidate Number
Other Names		2

GCE A LEVEL

A420U10-1

S18-A420U10-1

PHYSICS – A level component 1
Newtonian Physics

MONDAY, 4 JUNE 2018 – AFTERNOON

2 hours 15 minutes

	For Examiner's use only		
	Question	**Maximum Mark**	**Mark Awarded**
Section A	**1.**	**8**	
	2.	**7**	
	3.	**8**	
	4.	**15**	
	5.	**15**	
	6.	**9**	
	7.	**8**	
	8.	**10**	
Section B	**9.**	**20**	
	Total	**100**	

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ADDITIONAL MATERIALS

In addition to this examination paper, you will require a calculator and a **Data Booklet.**

INSTRUCTIONS TO CANDIDATES

Use black ink or black ball-point pen.

Write your name, centre number and candidate number in the spaces at the top of this page.

Answer **all** questions.

Write your answers in the spaces provided in this booklet. If you run out of space, use the continuation page at the back of the booklet, taking care to number the question(s) correctly.

INFORMATION FOR CANDIDATES

This paper is in 2 sections, **A** and **B.**

Section **A**: 80 marks. Answer **all** questions. You are advised to spend about 1 hour 35 minutes on this section.

Section **B**: 20 marks. Comprehension. You are advised to spend about 40 minutes on this section.

The number of marks is given in brackets at the end of each question or part-question.

The assessment of the quality of extended response (QER) will take place in question **5***(b)*.

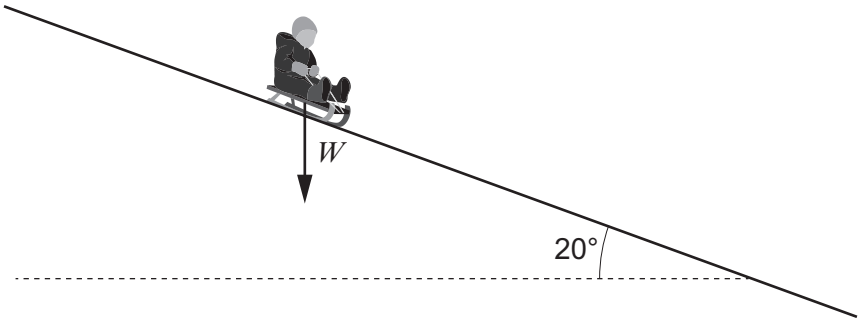
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SECTION A

Answer **all** *questions*.

1. Matthew is sliding down a snow-covered slope on a sledge. The total mass of Matthew and the sledge is 62 kg.



(a) On the diagram the arrow represents the total weight, W, of Matthew and the sledge. **Add two more arrows** to show the normal contact force on the sledge and the frictional force on the sledge. [1]

(b) (i) Show that the component of W parallel to the slope is approximately 200 N. [2]

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(ii) Calculate the magnitude of the normal contact force. [2]

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(c) The sledge's acceleration just after it has started moving is measured to be 2.5 m s^{-2}. Matthew believes that, starting from rest, it will take him less than 9.0 s to slide 100 m down the slope. Evaluate whether or not he is correct, commenting on whether or not your calculation is conclusive. [3]

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2. *(a)* (i) Define the angular velocity, ω, for a body moving in a circle. [1]

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(ii) Two equations giving the acceleration of a body moving at constant speed in a circle are:

$$a = \frac{v^2}{r} \quad \text{and} \quad a = r\omega^2.$$

Show clearly that the equations are equivalent. [2]

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(b) A moon called *Deimos* orbits Mars in a circular path of radius 23 500 km. Astronomers have calculated the mass of Deimos to be 1.48×10^{15} kg, and the force exerted on it by Mars to be 1.15×10^{14} N.

(i) Calculate the speed of Deimos around Mars. [2]

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(ii) Explain whether or not a moon of twice the mass of Deimos, but in a circular orbit of the same radius about Mars, would have the same speed as Deimos. [2]

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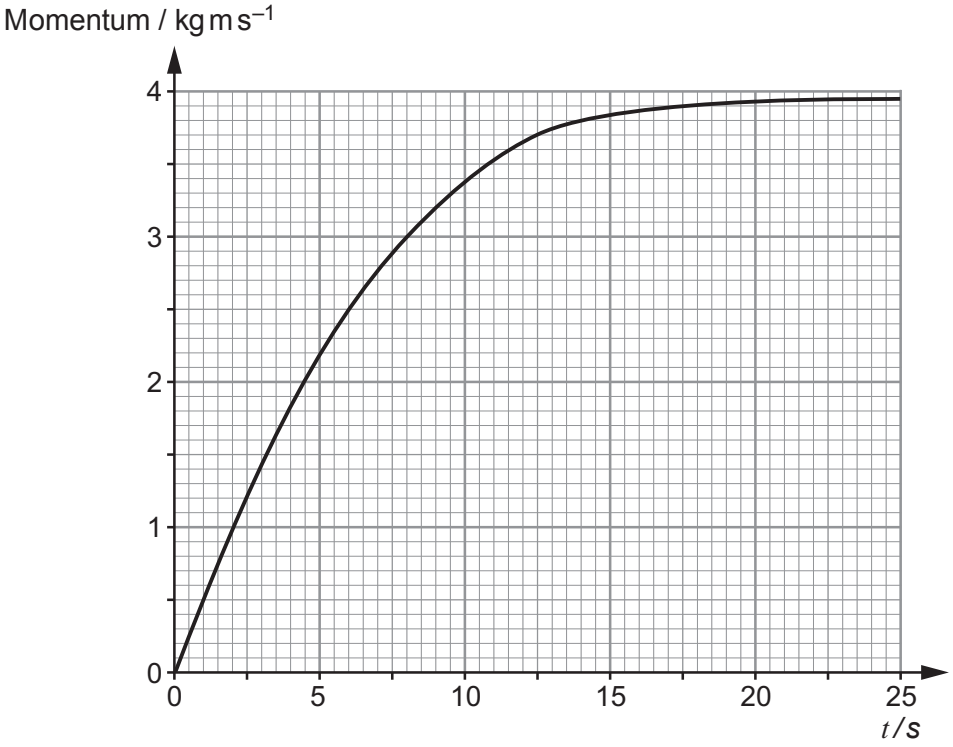
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3. *(a)* State Newton's second law of motion in terms of *momentum*. [2]

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(b) A momentum-time graph is plotted below for an object of mass 0.050 kg dropped (at time t = 0) from the top of a high cliff.



(i) Show clearly that the resultant force on the object at t = 10 s is approximately 0.15 N. [3]

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(ii) Deduce the magnitude of the force of air resistance on the object at t = 10 s. [2]

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(iii) State the magnitude of the force of air resistance on the body when it has reached its terminal velocity. [1]

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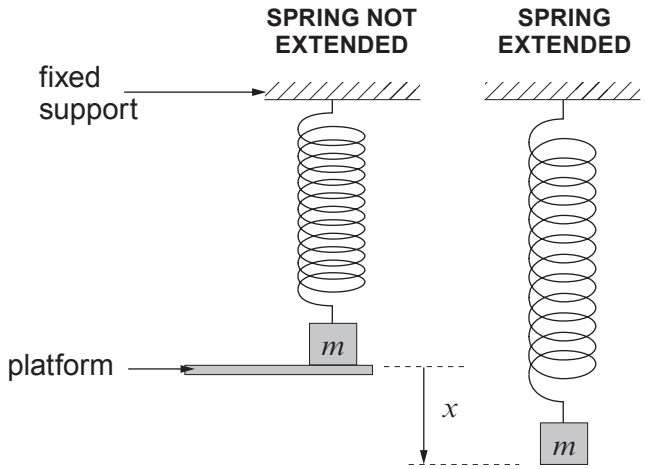
4. *(a)* State the *principle of conservation of energy*. [2]

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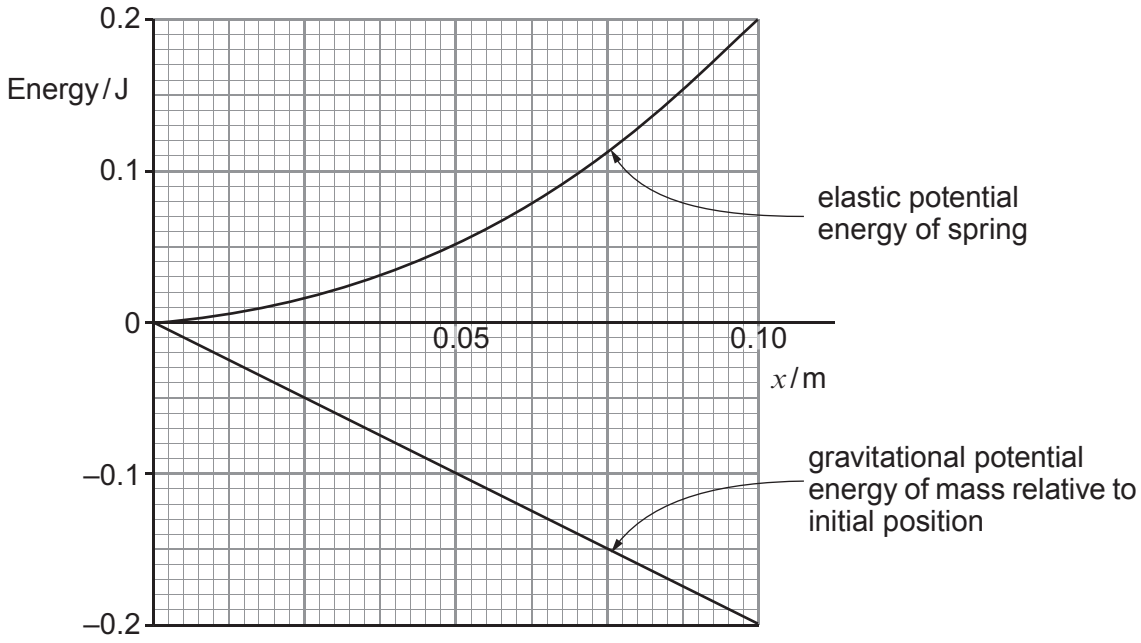
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(b) A mass, m, is attached to a light spring whose top end is held firmly. Initially the mass is supported by a platform with the spring unextended. The platform is suddenly removed so the mass falls.



The graphs show how the elastic potential energy of the spring and the gravitational potential energy of the mass vary with the distance, x, of the mass below the platform (see diagrams).



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(i) Assuming that resistive forces are negligible, use data from the graphs to calculate:

I. the spring constant, k; [3]

II. the mass, m; [2]

III. the kinetic energy of m when x = 0.050 m. [2]

(ii) Sketch a graph of the kinetic energy of the mass, m, against x **on the same grid as the other graphs**. [2]

(c) In the arrangement described in *(b)*, the furthest distance, x_{max}, that m falls is 0.10 m. However, a larger mass would fall further. In theory, x_{max} is directly proportional to the mass, m. Describe briefly how you would verify this relationship by experiment. [4]

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5. *(a)* Rachel investigates a simple pendulum consisting of a small metal sphere suspended by a thread. She determines its period to be 2.40 s.

(i) Calculate the length of the pendulum. [2]

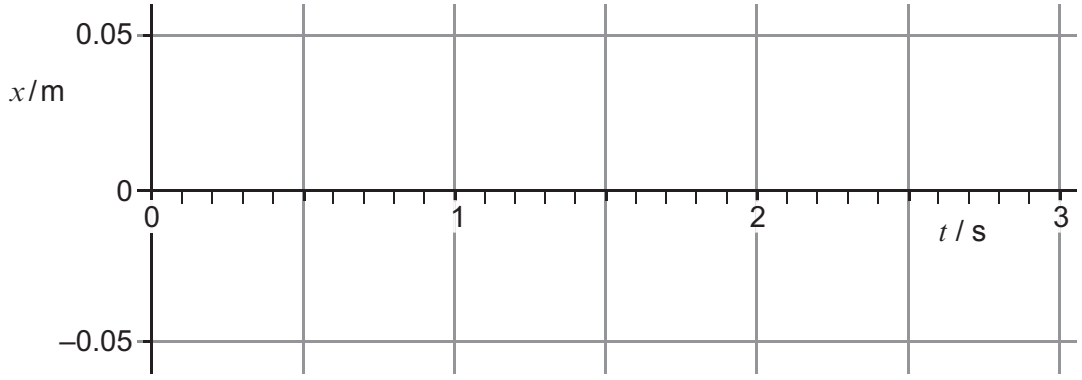
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(ii) Rachel now displaces the sphere by 0.050 m to one side of its equilibrium position and releases it at time t = 0.



I. Sketch a graph of displacement, x, against time, t, for the sphere between t = 0 and t = 3.00 s **on the grid provided**. Take the initial value of x to be positive. [2]

II. Use an appropriate equation to calculate the sphere's displacement at t = 1.60 s. [2]

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III. Calculate the sphere's velocity at t = 1.60 s. [2]

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IV. State the next time at which the sphere has the same velocity. [1]

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(b) Explain what is meant by *resonance*, and how its effects can be reduced in a particular case where resonance should be avoided. [6 QER]

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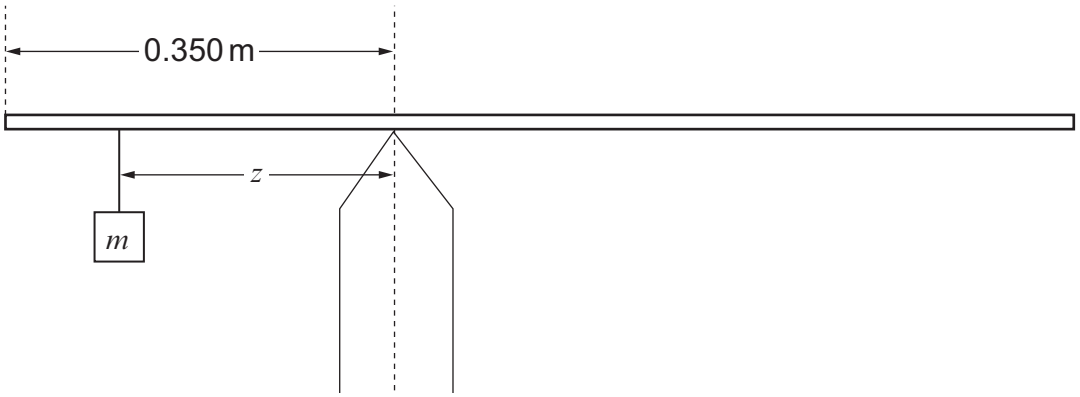
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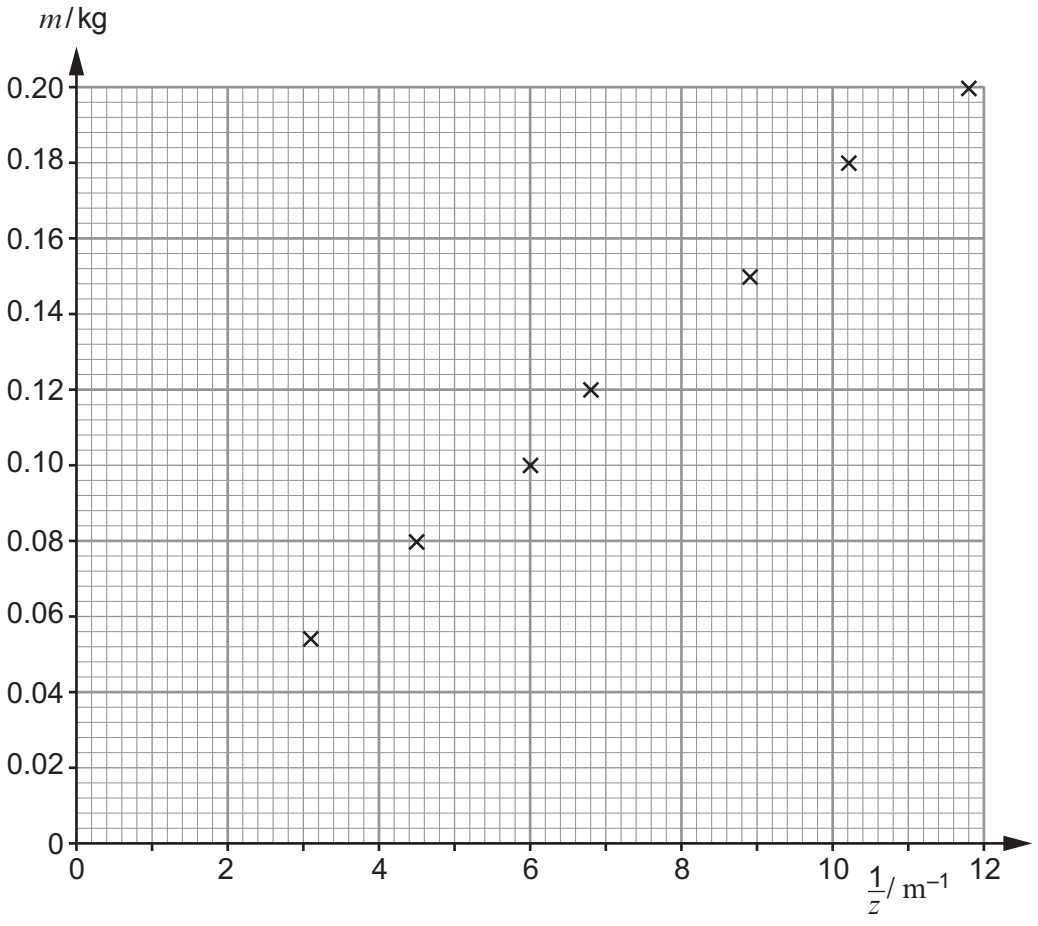
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6. Nathan pivots a uniform metre ruler at 0.350 m from one end. He hangs a mass, m, from the ruler and moves the mass along until the ruler balances.



He records the distance, z (see diagram) and repeats the experiment with different masses, keeping the pivot in the same position on the ruler.

He plots m against $\frac{1}{z}$ on the grid below.



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(a) Nathan correctly believes that m and z are related by the equation:

$$mz = M \times 0.150$$

in which *M* is the mass of the ruler and z is in metres.

Explain, in terms of moments, why this equation is correct. [3]

(b) Determine from the graph the best value for M, showing your working. The uncertainty is **not** required. [4]

(c) Discuss whether or not Nathan could have obtained readings for lower values of m than 0.050 kg, for the pivot in the same position on the ruler. [2]

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7. *(a)* State **two** assumptions that must be made about the molecules of an ideal gas in order to derive the kinetic theory equation: [2]

$$p = \frac{1}{3}\rho\overline{c^2}$$

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(b) A cylinder of volume 5.0×10^{-2} m^3 contains 2.20 mol of argon gas (relative molecular mass, M_r = 39.9) at a pressure of 250 kPa.

(i) Calculate the rms speed of the argon molecules. [3]

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(ii) I. State what would happen to the rms speed if the kelvin temperature of the gas in the cylinder were doubled, justifying your answer. [2]

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II. Explain briefly whether or not your answer to *(b)* (ii) I. would still apply if some gas escaped from the cylinder while the temperature was being raised. [1]

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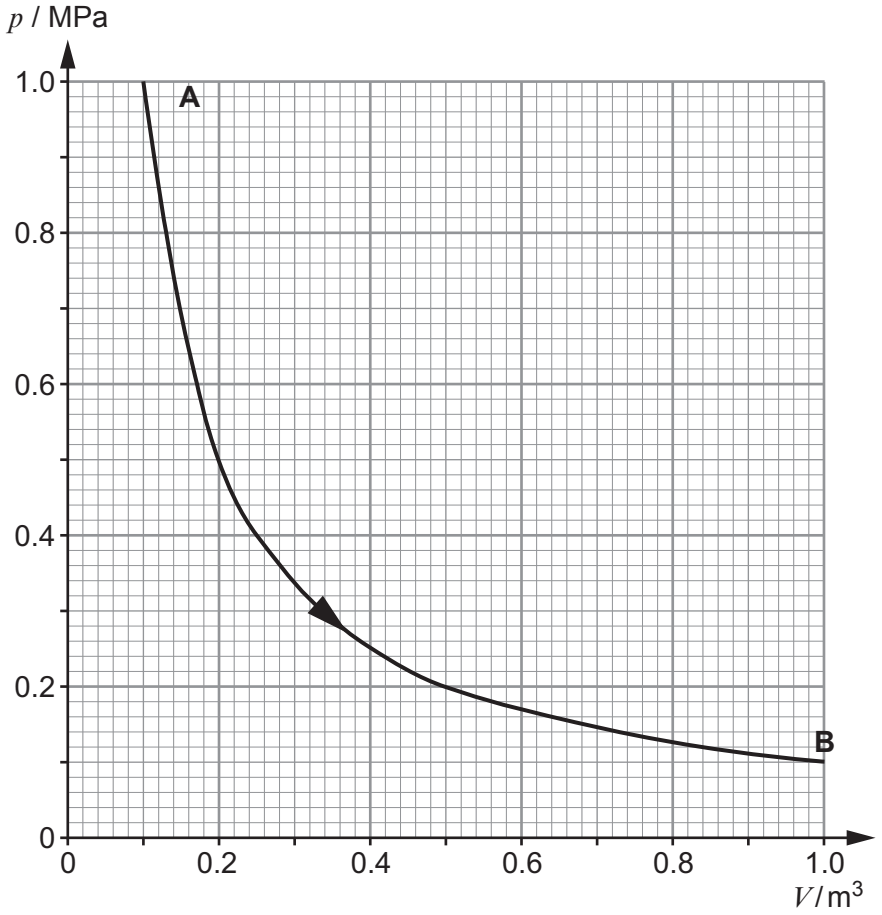
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8. *(a)* 33.2 mol of nitrogen gas is contained in a cylinder fitted with a piston. The gas is allowed to expand from A to B, doing work against the piston. A p–V graph for the expansion is given below.



(i) Show that the expansion occurs at a constant temperature of approximately 360 K. [3]

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(ii) Determine the approximate amount of work done by the gas during the expansion. [2]

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(iii) Rini claims that the work done by the gas results in an equal amount of internal energy being lost by the gas. Give the *correct* application of the first law of thermodynamics to this isothermal expansion. [2]

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(b) An estimated 600 MJ of work can be produced by an ordinary car engine burning 0.10 m^3 (100 litre) of petrol. An estimated 15 MJ of work can be produced by the expansion of the same volume of air compressed to the highest safe (initial) pressure.

Discuss the advantages and disadvantages of powering cars by compressed air rather than petrol. Calculations are not required. [3]

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SECTION B

Answer **all** *questions.*

Read through the following article carefully.

Conduction in more detail
by Iustiniano Luigi Maurizio

Paragraph

Georg Ohm is credited with establishing the most famous of electrical laws. His law is used in the design of electrical devices that enhance our 21st century living. Can we learn more about the law by looking at the conduction of electricity on the atomic level? 1

As a starting point, one can try to apply the laws of classical physics to the motion of fast-moving electrons as they negotiate pathways through a metal lattice. An applied potential difference provides an electric field which will accelerate electrons until they collide, a fraction of a pico-second later, with an unsuspecting metal ion. This collision then has the effect of randomising the motion of the electron once again and all the good work of the electric field is lost. However, the acceleration commences again immediately and the process repeats over and over again. 2

The question is "Can we model this behaviour using A level physics?" The answer is "Yes we can!" 3

The first thing to do is to obtain a value for the rms speed of an electron (mass, m_e) at room temperature. This can be done quite easily by applying the kinetic theory of gases to "free" electrons in a metal. 4

$$\frac{1}{2}m_e\bar{c^2} = \frac{3}{2}kT \qquad \text{Equation 1}$$

It is relatively straightforward to show that the rms speed of electrons at room temperature is over 100 km s^{-1}. An estimate can also be made of the distance travelled by an electron in between collisions – let's say this distance is 10 atomic diameters which is around 3 nm. This then leads to a time between collisions of a few tens of femtoseconds. 5

Let's apply some more physics to the motion of the electrons. Although electrons have a mean **speed** of 100 km s^{-1} their motion is random and there is no preferred direction of motion. However, all this changes as soon as an electric field, E, is applied. It is easy to show that the acceleration experienced by the electrons is 6

$$a = \frac{eE}{m_e} \qquad \text{Equation 2}$$

in the usual physics notation. By applying $v = u + at$, with $u = 0$ you can obtain

$$v = \frac{eE}{m_e}\tau \qquad \text{Equation 3}$$

where τ is the mean time spent by electrons in between collisions. This gives a final mean drift velocity of

$$\bar{v}_{drift} = \frac{eE}{2m_e}\tau \qquad \text{Equation 4}$$

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Paragraph

When this equation is combined with the drift velocity equation that students learn to derive for A level, you get:

$$I = nA\bar{v}_{\text{drift}}e = nA\left(\frac{eE}{2m_{\text{e}}}\right)\tau e = \frac{nAe^2\tau E}{2m_{\text{e}}} \qquad \text{Equation 5}$$

But if you remember that, for a uniform electric field:

$$E = \frac{V}{d} \qquad \text{Equation 6}$$

and substitute this into Equation 5, you will find you've just derived Ohm's Law,

$$I = \frac{nAe^2\tau}{2m_{\text{e}}d}V \qquad \text{Equation 7}$$

with the resistance of the metal given by:

$$R = \frac{2m_{\text{e}}d}{nAe^2\tau} \qquad \text{Equation 8}$$

You should also be able to see that the last equation for the resistance leads to the equation for resistivity, (ρ):

$$\rho = \frac{2m_{\text{e}}}{ne^2\tau} \qquad \text{Equation 9}$$

These are all very powerful equations and enhance the meaning of Ohm's law. For instance, the condition for Ohm's law is that the temperature must remain constant. We can now explain this in detail – the temperature affects the mean speed of the electrons, which in turn affects their time between collisions which will then change the resistance. 7

However, there is a very important limit to this theory – the laws of physics at the atomic level are governed by quantum theory. In our simplified theory, the distance between collisions is a constant. This leads to a resistivity which is proportional to the square root of temperature and, unfortunately, this is not what happens in experiments. 8

Another important disagreement between this theory and practice is superconductivity. This theory would suggest that resistivity decreases gradually and eventually arrives at zero at a temperature of absolute zero. Again, this doesn't happen in practice and the superconductors lose their resistance suddenly at the superconducting transition temperature. Even more spectacular is the behaviour of electrons below this temperature – they almost cease to be individual electrons but team up in pairs held together by a lattice vibration. These pairs of electrons feel an attractive force due to the lattice vibration between them and travel freely through the lattice without ever experiencing collisions. This means that the mean time between collisions tends to infinity. 9

To answer the original question about Georg Ohm's spectacular law, it seems that there is a lot to be learned from looking at conduction of electricity at the atomic level. When combined with quantum physics the possibilities seem to be endless or perhaps even infinite. 10

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9. Answer the following questions in your own words. Direct quotes from the original article will not be awarded marks.

(a) In your own words, describe the motion of electrons both with and without the application of an electric field (see paragraphs 2 and 6). [4]

(b) Calculate the temperature at which electrons are expected to have an rms speed of $100\,\text{km}\,\text{s}^{-1}$ (see Equation 1). [2]

(c) Show that the acceleration of an electron in an electric field, of strength E, is:

$$a = \frac{eE}{m_e} \qquad \text{(Equation 2)} \qquad [2]$$

(d) Use a mean time of 40 fs to calculate the electric field strength, E, when the mean drift velocity of electrons is $0.25\,\text{mm}\,\text{s}^{-1}$ (see Equation 4). [2]

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(e) Explain briefly how the author can derive Equation 9 from Equation 8. [2]

(f) Copper has a resistivity of $1.68 \times 10^{-8}\ \Omega$ m and has 8.5×10^{28} free electrons per m^3. Use equation 9 to calculate the mean time between collisions for copper. [2]

(g) Explain why resistivity should be proportional to the square root of temperature (see paragraph 8 and Equation 9). [4]

(h) State and explain what charge you would expect a lattice vibration to carry (see paragraph 9). [2]

END OF PAPER

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