PHYSICS
HIGHER LEVEL
PAPER 2

Candidate number

Tuesday 11 November 2003 (afternoon)

2 hours 15 minutes

INSTRUCTIONS TO CANDIDATES

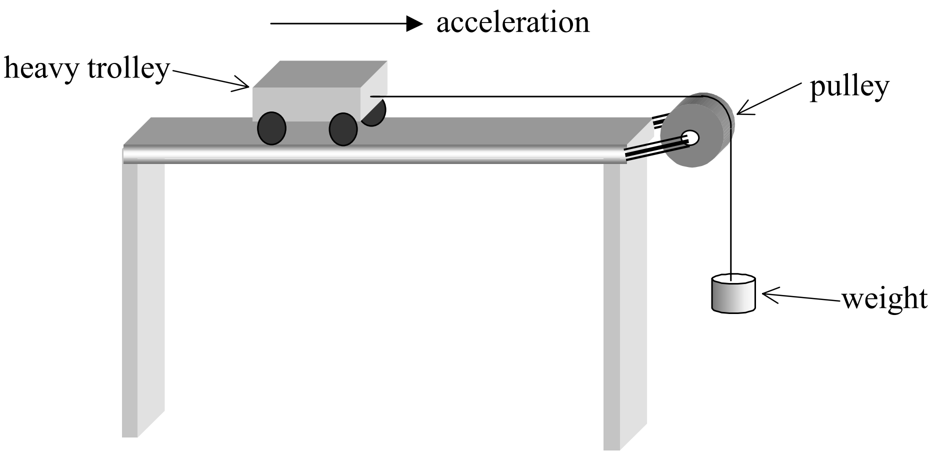
- Write your candidate number in the box above.
- Do not open this examination paper until instructed to do so.
- Section A: answer all of Section A in the spaces provided.
- Section B: answer two questions from Section B in the spaces provided. You may continue your answers on answer sheets. Write your candidate number on each answer sheet, and attach them to this examination paper and your cover sheet using the tag provided.
- At the end of the examination, indicate the numbers of the questions answered in the candidate box on your cover sheet and indicate the number of answer sheets used in the appropriate box on your cover sheet.

SECTION A

*Candidates must answer **all** questions in the spaces provided.*

A1. This question is about an experiment designed to investigate Newton's second law.

In order to investigate Newton's second law, David arranged for a heavy trolley to be accelerated by small weights, as shown below. The acceleration of the trolley was recorded electronically. David recorded the acceleration for different weights up to a maximum of 3.0 N. He plotted a graph of his results.



(a) Describe the graph that would be expected if two quantities are proportional to one another. *[2]*

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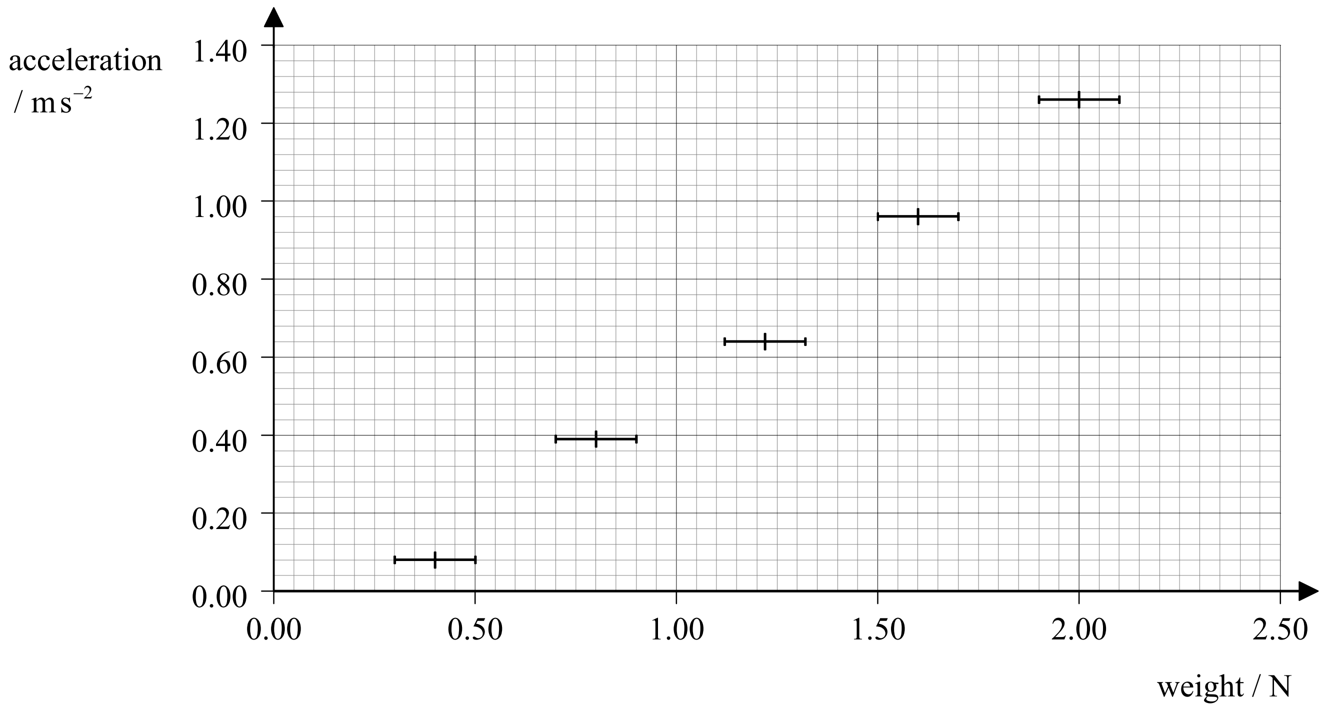
(Question A1 continued)

(b) David's data are shown below, with uncertainty limits included for the value of the weights. Draw the best-fit line for these data. *[2]*



(c) Use the graph to

(i) explain what is meant by a *systematic* error. *[2]*

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(ii) estimate the value of the frictional force that is acting on the trolley. *[1]*

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(iii) estimate the mass of the trolley. *[2]*

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A2. This question is about the kinematics of an elevator (lift).

(a) Explain the difference between the gravitational mass and the inertial mass of an object. *[3]*

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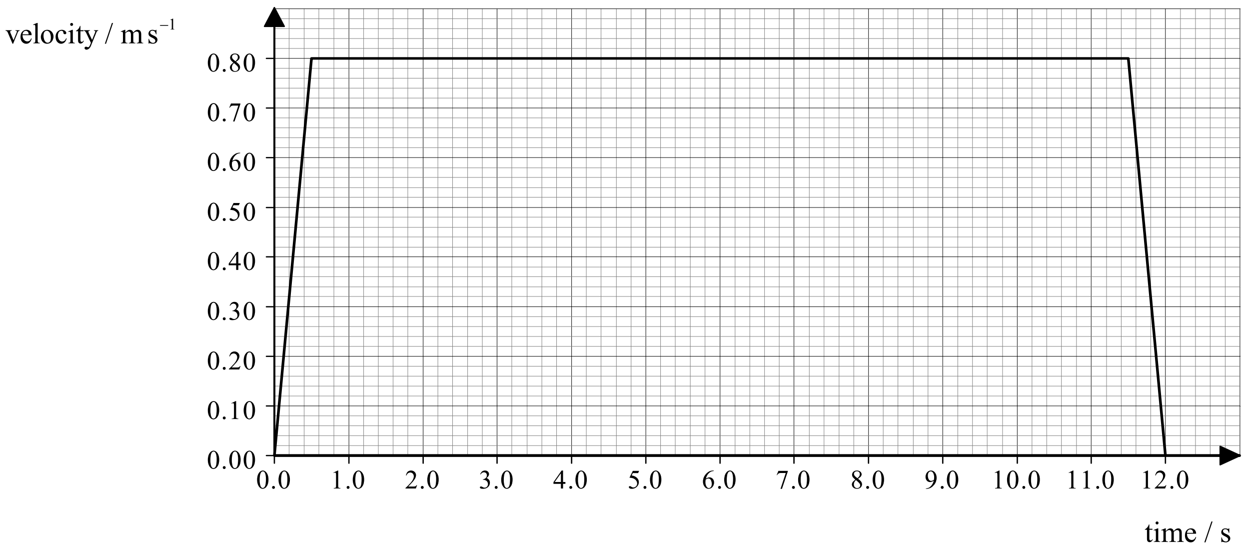
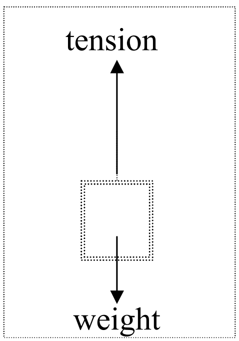
An elevator (lift) starts from rest on the ground floor and comes to rest at a higher floor. Its motion is controlled by an electric motor. A simplified graph of the variation of the elevator's velocity with time is shown below.



The elevator is supported by a cable. The diagram below is a free-body force diagram for when the elevator is moving upwards during the first 0.50 s.



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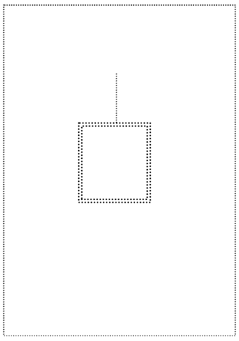
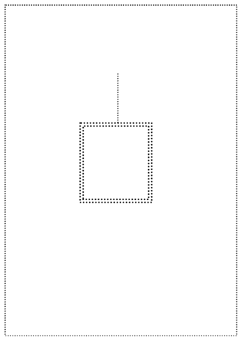
(Question A2 continued)

(b) In the space below, draw free-body force diagrams for the elevator during the following time intervals.

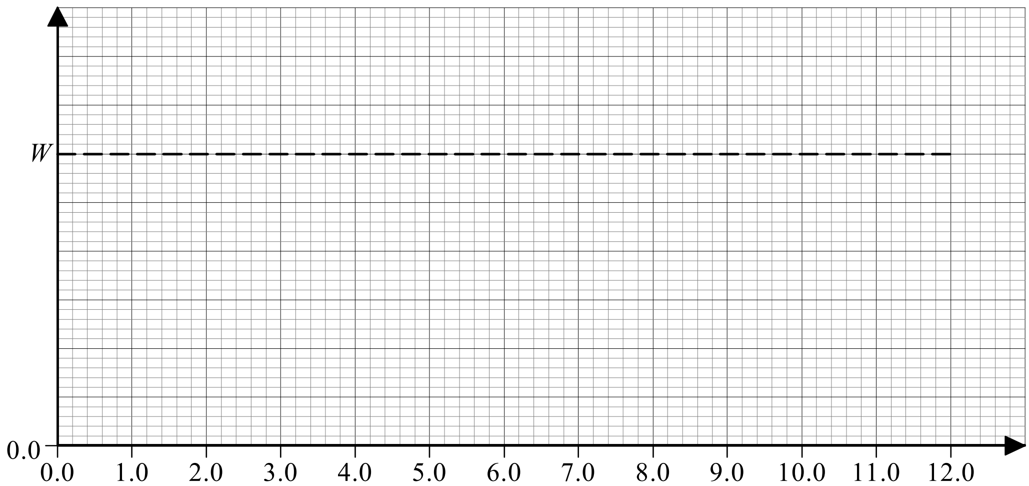
(i) 0.50 to 11.50 s   (ii) 11.50 to 12.00 s   *[3]*





A person is standing on weighing scales in the elevator. Before the elevator rises, the reading on the scales is W.

(c) On the axes below, sketch a graph to show how the reading on the scales varies during the whole 12.00 s upward journey of the elevator. *(Note that this is a sketch graph – you do not need to add any values.)* *[3]*



(d) The elevator now returns to the ground floor where it comes to rest. Describe and explain the energy changes that take place during the whole up and down journey. *[4]*

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A3. This question is about atomic and nuclear structure and fundamental forces.

In a nuclear model of the atom, most of the atom is regarded as empty space. A tiny nucleus is surrounded by a number of electrons.

(a) Outline **one** piece of experimental evidence that supports this **nuclear** model of the atom. *[3]*

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(b) Explain why the protons in a nucleus do not fly apart from each other. *[2]*

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(c) In total, there are approximately 10^{29} electrons in the atoms making up a person. Estimate the electrostatic force of repulsion between two people standing 100 m apart as a result of these electrons. *[4]*

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(Question A3 continued)

(d) Estimate the gravitational force of attraction between two people standing 100 m apart. *[2]*

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(e) Explain why two people standing 100 m apart would not feel either of the forces that you have calculated in parts (c) and (d). *[2]*

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SECTION B

*This section consists of four questions: B1, B2, B3 and B4. Answer any **two** questions in this section.*

B1. This question considers some aspects of the atomic and nuclear physics associated with isotopes of the element helium.

Atomic aspects

(a) The element helium was first identified from the *absorption spectrum* of the Sun.

(i) Explain what is meant by the term *absorption spectrum*. *[2]*

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(ii) Outline how this spectrum may be experimentally observed. *[2]*

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(Question B1 continued)

(b) One of the wavelengths in the absorption spectrum of helium occurs at 588 nm.

(i) Show that the energy of a photon of wavelength 588 nm is 3.38×10^{-19} J. *[2]*

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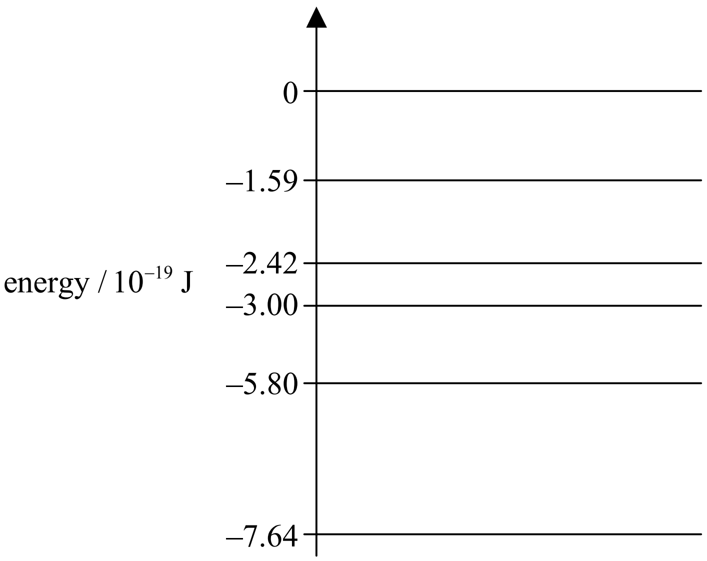
(ii) The diagram below represents some of the energy levels of the helium atom. Use the information in the diagram to explain how absorption at 588 nm arises. *[3]*



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(Question B1 continued)

Two different models have been developed to explain the existence of **atomic** energy levels. The **Bohr model** and the **Schrödinger model** are both able to predict the principal wavelengths present in the spectrum of atomic hydrogen.

(c) Outline

(i) the Bohr model, and

(ii) the Schrödinger model. *[6]*

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(Question B1 continued)

Nuclear aspects

(d) The helium in the Sun is produced as a result of a nuclear reaction. Explain whether this reaction is burning, fission or fusion. *[2]*

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At a later stage in the development of the Sun, other nuclear reactions are expected to take place. One such overall reaction is given below.

$$ {}^{4}_{2}\mathrm{He} + {}^{4}_{2}\mathrm{He} + {}^{4}_{2}\mathrm{He} \rightarrow \mathrm{C} + \gamma + \gamma $$

(e) (i) Identify the atomic number **and** the mass number of the isotope of carbon C that has been formed. *[2]*

Atomic number: . . . .

Mass number: . . . .

(ii) Use the information below to calculate the energy released in the reaction.

Atomic mass of helium = $6.648\,325 \times 10^{-27}$ kg
Atomic mass of carbon = $1.993\,200 \times 10^{-26}$ kg *[3]*

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(Question B1 continued)

Another isotope of helium ${}^{6}_{2}\text{He}$ decays by emitting a β^{-}-particle.

(f) (i) State the name of the other particle that is emitted during this decay. *[1]*

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(ii) Explain why a sample of ${}^{6}_{2}\text{He}$ emits β^{-}-particles with a **range of energies**. *[2]*

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(iii) The half-life for this decay is 0.82 s. Determine the percentage of a sample of ${}^{6}_{2}\text{He}$ that remains after a time of 10 s. *[3]*

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(iv) Describe the process of β^{-} decay in terms of quarks. *[2]*

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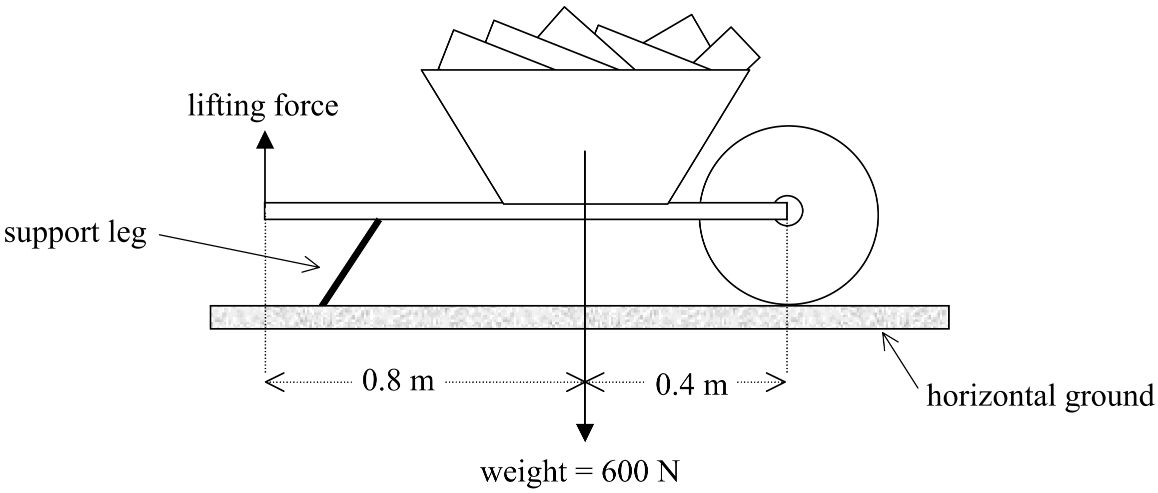
B2. This question is in **two** parts. **Part 1** is about the forces on a wheelbarrow and **part 2** is about the electrical properties of two 12 V filament lamps.

Part 1 The forces on a wheelbarrow

Rachid is using a wheelbarrow to move some blocks. When a lifting force is applied at the handle, its support legs are lifted off the ground. The dimensions of the wheelbarrow are shown in the diagram below.



When loaded, the total weight of the wheelbarrow and the blocks is 600 N. The ground is horizontal.

(a) Determine,

(i) the minimum **vertical** force needed to lift the support legs off the ground. *[3]*

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(ii) the magnitude **and** the direction of the force exerted by the ground on the wheel. *[2]*

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(Question B2 part 1 continued)

Rachid now pushes the wheelbarrow forward **at constant speed**. He applies a force of 260 N to the handles at an angle of 50° to the vertical.

(b) (i) Calculate the **horizontal** component of the force exerted by Rachid. *[2]*

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(ii) Determine the magnitude of the resultant frictional force acting on the wheelbarrow. *[2]*

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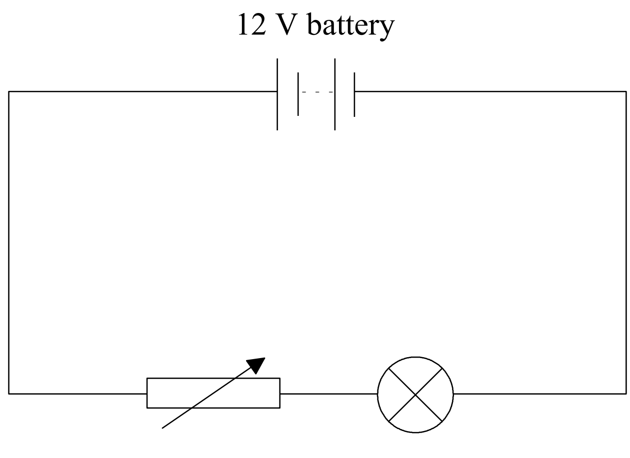
(Question B2 continued)

Part 2 Electrical properties of two 12 V filament lamps

In order to measure the voltage-current *(V-I)* characteristics of a lamp, a student sets up the following electrical circuit.



(a) On the circuit above, add circuit symbols showing the correct positions of an ideal ammeter **and** an ideal voltmeter that would allow the *V-I* characteristics of this lamp to be measured. *[2]*

The voltmeter and the ammeter are connected correctly in the circuit above.

(b) Explain why the potential difference across the lamp

(i) cannot be increased to 12 V. *[2]*

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(ii) cannot be reduced to zero. *[2]*

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(Question B2 part 2 continued)

An alternative circuit for measuring the *V-I* characteristic uses a *potential divider*.

(c) (i) Draw a circuit that uses a potential divider to enable the *V-I* characteristics of the filament to be found. *[3]*

(ii) Explain why this circuit enables the potential difference across the lamp to be reduced to zero volts. *[2]*

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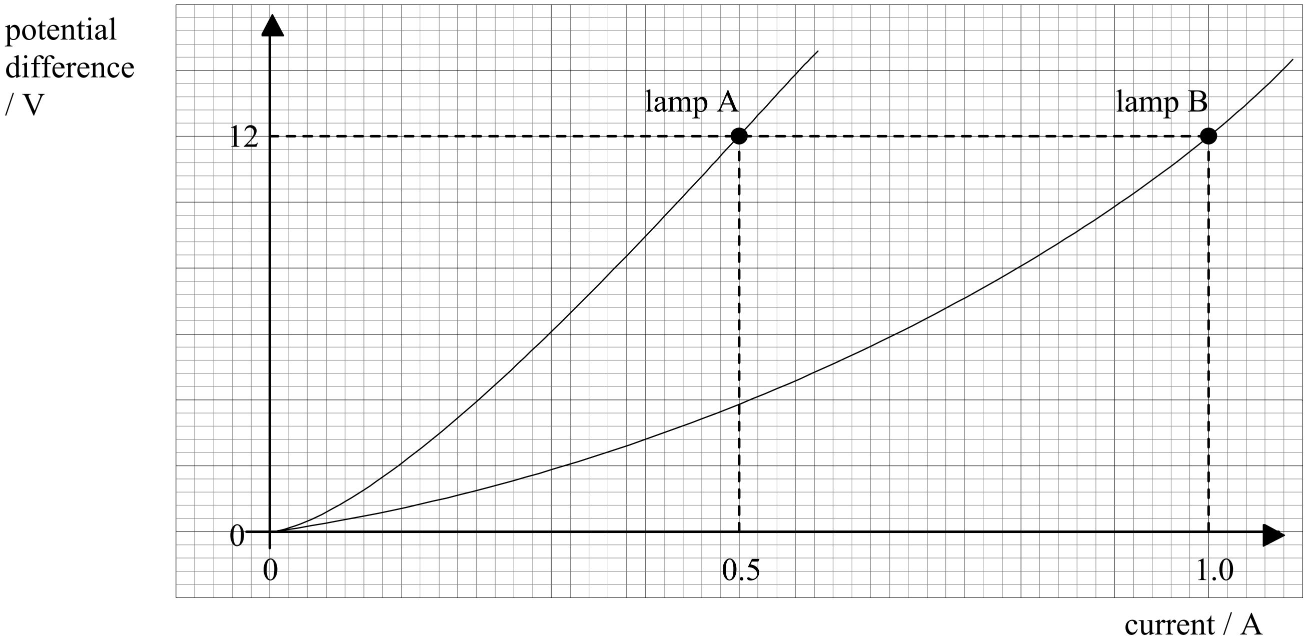
(Question B2 part 2 continued)

The graph below shows the *V-I* characteristic for two 12 V filament lamps A and B.



(d) State and explain which lamp has the greater power dissipation for a potential difference of 12 V. *[3]*

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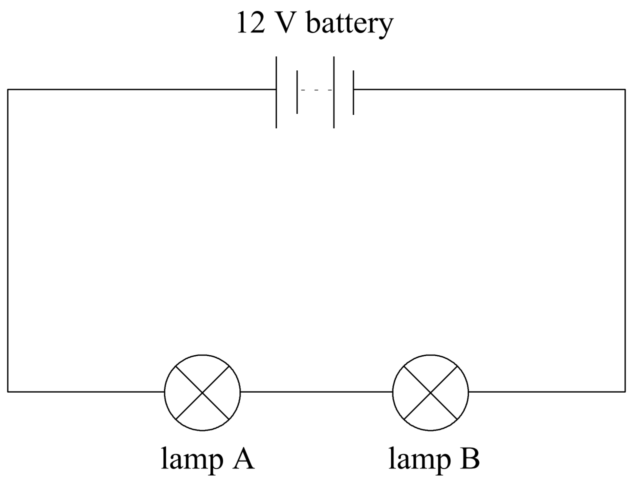
(Question B2 part 2 continued)

The two lamps are now connected in series with a 12 V battery as shown below.



(e) (i) State how the current in lamp A compares with that in lamp B. *[1]*

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(ii) Use the *V-I* characteristics of the lamps to deduce the total current from the battery. *[4]*

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(iii) Compare the power dissipated by the two lamps. *[2]*

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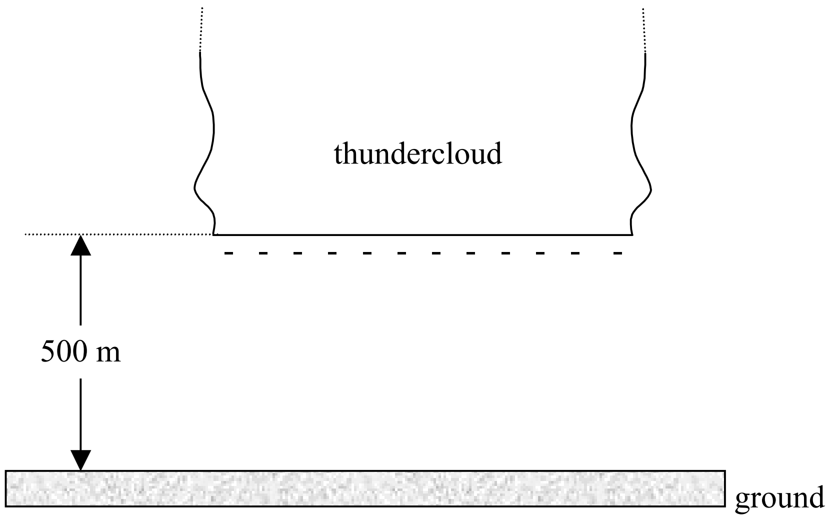
B3. This question is in **two** parts. **Part 1** is about the physics of a lightning strike and **part 2** is about sound waves.

Part 1 The physics of a lightning strike

In a simple model of a thundercloud, a negative charge is built up on the base of the cloud by the process of *charge separation*. The resulting *electric field* between the cloud and the ground is approximately the same as that between two infinite parallel charged plates. When the charge on the base of the cloud reaches a certain value, a lightning strike occurs between the ground and the base of the cloud.



(a) Explain what is meant by the term *charge separation*. *[2]*

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(b) Define *electric field strength*. *[2]*

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(c) On the above diagram, draw the electric field pattern between the ground and the base of the cloud. *[3]*

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(Question B3 part 1 continued)

The electric field strength E between two infinite, parallel charged plates is given by

$$E = \frac{\sigma}{\varepsilon_0}$$

where σ is the charge on an area of 1 m^2 of one plate.

Just before a lightning strike, a particular thundercloud carries a charge of 20 C spread over its base. The area of the base of the cloud is $7 \times 10^6\ m^2$.

(d) (i) Show that the magnitude of the electric field between the base of the cloud and the ground is approximately $3 \times 10^5\ V\,m^{-1}$. *[3]*

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(ii) State **two** assumptions made when applying this formula. *[2]*

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(e) The base of the cloud is at an average height of 500 m. Calculate the potential difference between the ground and the cloud base just before the lightning strike. *[2]*

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(This question continues on the following page)

(Question B3 part 1 continued)

When a lightning strike occurs between the ground and the base of this thundercloud, the cloud completely discharges in a time of 20 ms.

(f) (i) Calculate the average current in the lightning strike. *[1]*

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(ii) Estimate the energy released during the lightning strike. *[3]*

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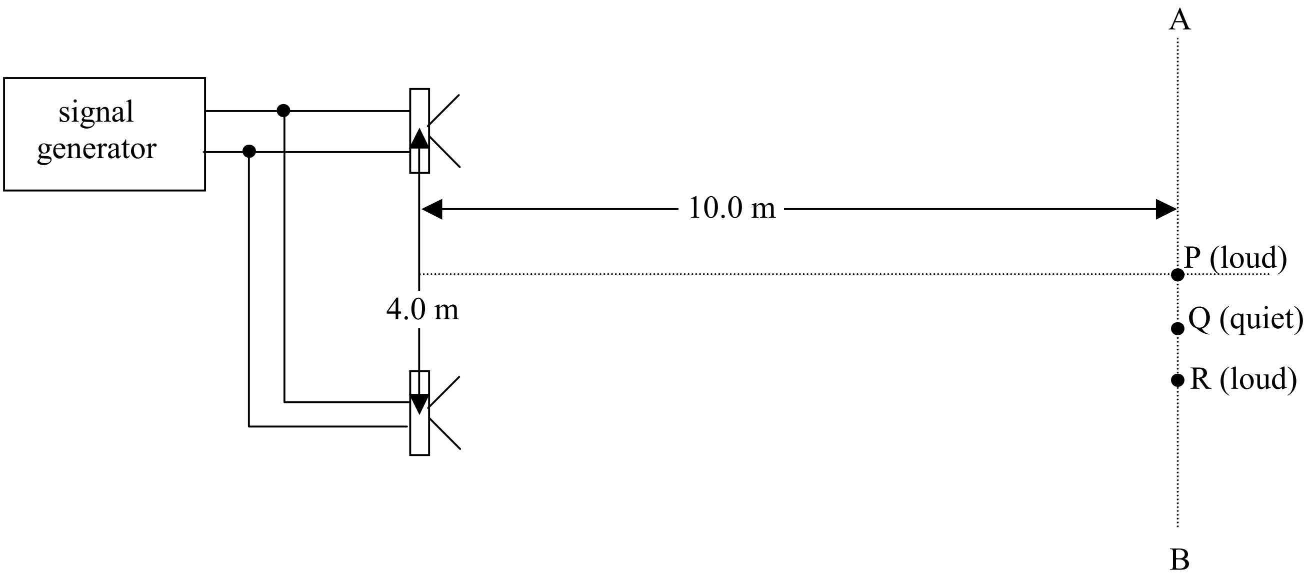
(Question B3 continued)

Part 2 Sound waves

In order to demonstrate two-source interference of sound waves, two loudspeakers are connected to the same output of a signal generator. The loudspeakers are fixed 4.0 m apart.

In the diagram below, the line AB is parallel to the loudspeakers and at a distance of 10.0 m from the loudspeakers. Point P is midway between the loudspeakers.



Katerina walks along the line AB carrying a microphone connected to a detector. She registers a sound that alternates in intensity from loud to quiet.

(a) Describe the conditions necessary for a sound of minimum intensity to be registered at Q. *[3]*

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(Question B3 part 2 continued)

As Katerina runs along the line AB she counts the number of loud sounds registered in a given time. The frequency of the sound emitted by both loudspeakers is 360 Hz and the speed of sound in air is $330\,\text{m}\,\text{s}^{-1}$.

(b) Estimate the speed at which she is running if the maximum sounds occur with a frequency of about 2 Hz. *[6]*

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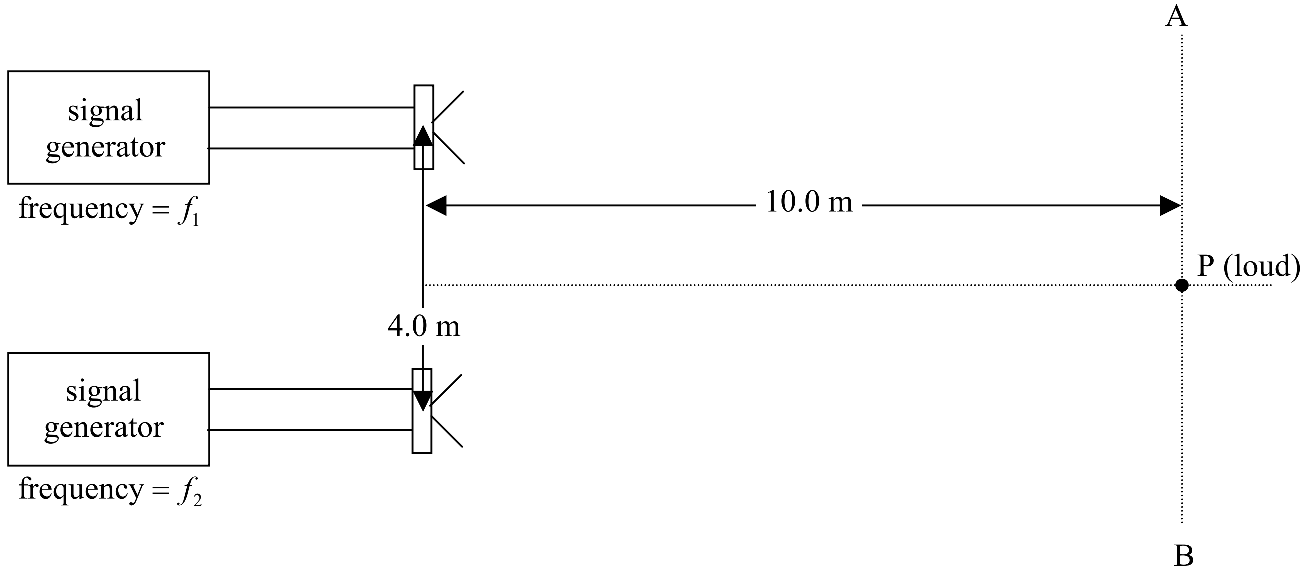
(Question B3 part 2 continued)

One of the loudspeakers is now disconnected from the source and connected to another signal generator as shown below.



(c) The frequencies of **both** generators are altered. With this new arrangement, Katerina now stands at the point P and registers a sound of frequency 360 Hz that varies in amplitude at a frequency of 2.0 Hz. Explain quantitatively how this observation arises. *[3]*

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B4. This question is in **two** parts. **Part 1** is about modelling the thermal processes involved when a person is running and **part 2** is about the thermodynamics of a heat engine.

Part 1 Modelling the thermal processes involved when a person is running

When running, a person generates *thermal energy* but maintains approximately constant *temperature*.

(a) Explain what *thermal energy* and *temperature* mean. Distinguish between the two concepts. *[4]*

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The following simple model may be used to estimate the rise in temperature of a runner assuming no thermal energy is lost.

A closed container holds 70 kg of water, representing the mass of the runner. The water is heated at a rate of 1200 W for 30 minutes. This represents the energy generation in the runner.

(b) (i) Show that the thermal energy generated by the heater is 2.2×10^6 J. *[2]*

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(ii) Calculate the temperature rise of the water, assuming no energy losses from the water. The specific heat capacity of water is $4200\,\text{J kg}^{-1}\,\text{K}^{-1}$. *[3]*

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(Question B4 part 1 continued)

(c) The temperature rise calculated in (b) would be dangerous for the runner. Outline **three** mechanisms, other than evaporation, by which the container in the model would transfer energy to its surroundings. *[6]*

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A further process by which energy is lost from the runner is the evaporation of sweat.

(d) (i) Percentage of generated energy lost by sweating: 50 %
Specific latent heat of vaporization of sweat: 2.26×10^{6} J kg^{-1}

Using the information above, and your answer to (b)(i), estimate the mass of sweat evaporated from the runner. *[3]*

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(ii) State and explain **one** factor that affects the rate of evaporation of sweat from the skin of the runner. *[2]*

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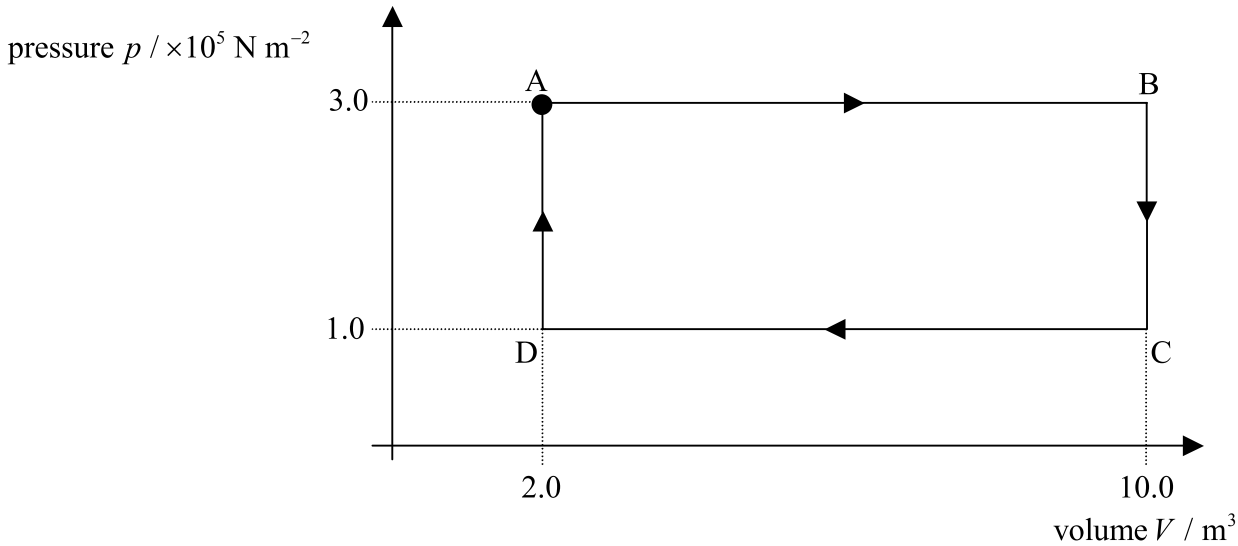
(Question B4 continued)

Part 2 The thermodynamics of a heat engine

In an idealized heat engine, a fixed mass of a gas undergoes various changes of temperature, pressure and volume. The *p*-*V* cycle (A→B→C→D→A) for these changes is shown in the diagram below.



(a) Use the information from the graph to calculate the work done during **one** cycle. *[2]*

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(b) During one cycle, a total of 1.8×10^6 J of thermal energy is ejected into a cold reservoir. Calculate the efficiency of this engine. *[2]*

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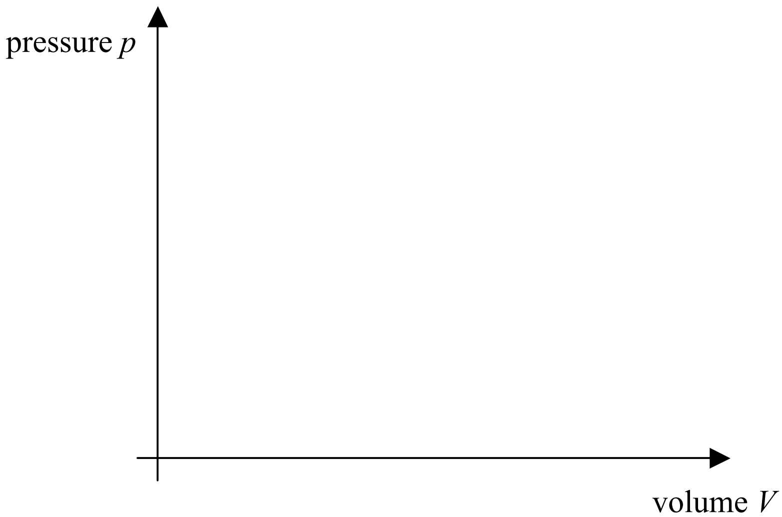
(Question B4 part 2 continued)

(c) Using the axes below, sketch the *p-V* changes that take place in the fixed mass of an ideal gas during one cycle of a *Carnot engine*. *(Note this is a sketch graph – you do not need to add any values.)* *[2]*



(d) (i) State the names of the **two** types of change that take place during one cycle of a Carnot engine. *[2]*

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(ii) Add labels to the above graph to indicate which parts of the cycle refer to which particular type of change. *[2]*