PEARSON EDEXCEL A-LEVEL PHYSICS · 9PH0

PHYSICS



EXAM QUESTION PACK

TOPIC 9: THERMODYNAMICS

KINETIC THEORY AND IDEAL GASES

SCORE	PERCENTAGE
/176	%

STEMUP

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Q1.

A bicycle tyre contains air at 20 °C. The volume occupied by the air is 2.9×10^{-4} m^3. Assume

that this volume remains fixed.

(a) The pressure of the air in the tyre is 5.8×10^5 Pa. In an attempt to improve performance air is pumped into the tyre until the pressure at 20 °C is 6.5×10^5 Pa.

Calculate the number of air molecules that must be pumped into the tyre.

(3)

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Number of molecules = ...

(b) After cycling in a race the air pressure in the tyre has risen from 6.5×10^5 Pa to 6.8×10^5 Pa.

Calculate the increase in temperature of the air in the tyre.

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Increase in temperature = ...

(c) Explain why the pressure increases when the air is heated in a tyre of fixed volume.

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(Total for question = 9 marks)

Q2.

The average kinetic energy of the molecules in an ideal gas is

☒ **A** directly proportional to the square root of the absolute temperature.

☒ **B** directly proportional to the absolute temperature.

☒ **C** independent of the absolute temperature.

☒ **D** inversely proportional to the absolute temperature.

(Total for question = 1 mark)

Q3.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

Air is trapped in a glass tube. When the air is forced into a smaller volume at a constant temperature, the pressure increases.

Which of the following statements about air molecules is a reason why the pressure the trapped air exerts on the tube increases?

☒ **A** The molecules have a greater mean kinetic energy.

☒ **B** The molecules make more frequent collisions with each other.

☒ **C** The molecules make more frequent collisions with the walls of the tube.

☒ **D** The molecules experience a greater change in momentum when they collide with the tube.

(Total for question = 1 mark)

Q4.

For an ideal gas $pV = NkT$ and $pV = \frac{1}{3}Nm\langle c^2\rangle$.

Use these relationships to show that the mean kinetic energy of a gas molecule is proportional to the absolute temperature.

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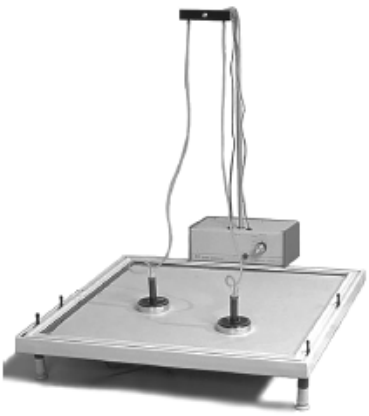
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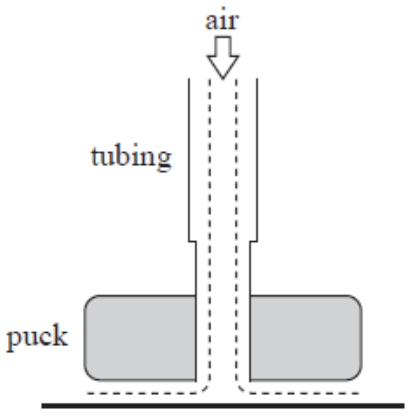
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(Total for question = 2 marks)

Q5.

A teacher is demonstrating the principle of conservation of momentum using a flat glass surface and air pucks. Lightweight tubing supplies compressed air to the pucks which is forced out from the bottom of the pucks. This means that the pucks move with very little friction across the glass surface.





(a) Explain, using ideas about molecular movement, how the puck is able to hover a small distance above the glass surface.

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*(b) Applying Newton's 2nd and 3rd laws of motion to the collision between two pucks leads to the conclusion that momentum is conserved.

Justify this statement.

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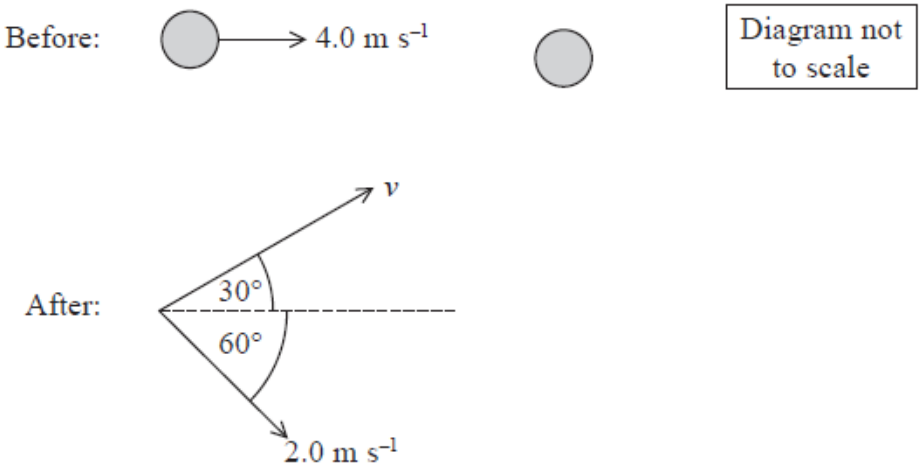
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(c) The teacher uses two identical pucks to investigate collisions. In one collision, one puck moves with a velocity of 4.0 m s^{-1} and collides with a second puck that is stationary.
After the collision, the first puck has a velocity v at an angle of 30° to its original direction, and the second puck moves off with a velocity of 2.0 m s^{-1} at an angle of 60° to the original direction.



(i) Show that the magnitude of the velocity v of the first puck after the collision is about 3.5 m s^{-1}.

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(ii) Use the data to determine if the collision is elastic or inelastic.

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(Total for question = 16 marks)

Q6.

An electric drinks cooler is an appliance consisting of a thermally insulated compartment and a heat pump that transfers heat from the inside of the cooler to the room in which the cooler is

placed.

This maintains the temperature of the inside of the cooler below the temperature of the room.



(Source: http://www.americanas.com.br/produto/110863245/adega-de-vinhos-easycooler-12 garrafas)

On closing the door of the cooler, warm air at atmospheric pressure and at a temperature of 22.5°C is trapped inside. After a time, the internal temperature stabilises at 3.3°C.

A student notices that the door is difficult to open and concludes that this is because the air inside has cooled down and reduced the pressure.

Carry out a calculation to assess the validity of the student's conclusion.

atmospheric pressure = 102 kPa

area of door = 0.15 m^2

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(Total for question = 7 marks)

Q1.

A fine-beam tube is used for investigating properties of electrons.

An electron beam is produced inside a spherical glass bulb. The bulb contains neon gas at a very low pressure.

The neon gas is at a pressure of 1.25 Pa and a temperature of 25 °C.

Calculate the number N of neon atoms inside the bulb.

bulb diameter = 16.0 cm

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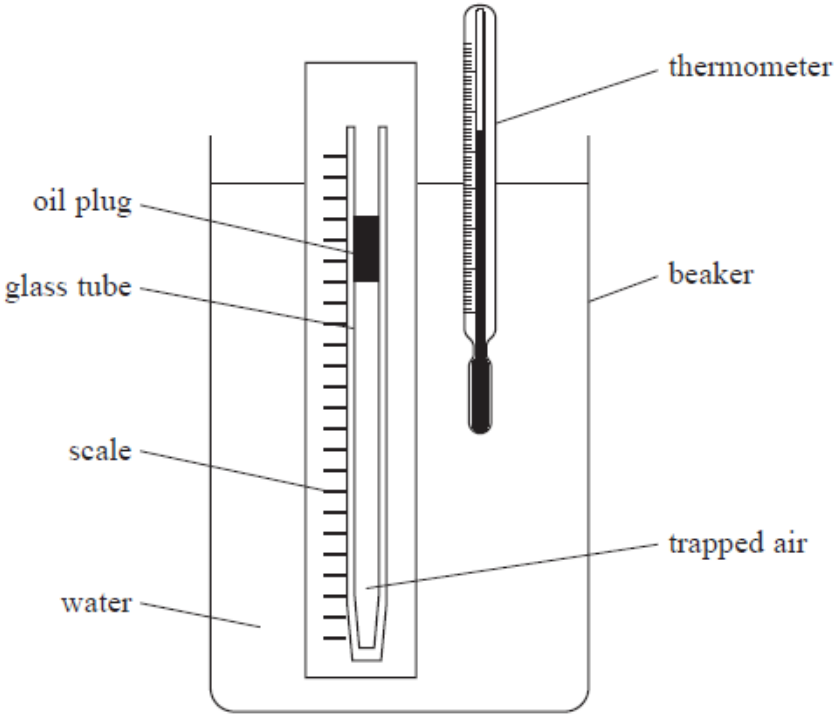
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N = ...

(Total for question = 4 marks)

Q2.

A student investigated how the volume of a fixed mass of air varies with the temperature of the air. She used the apparatus shown.



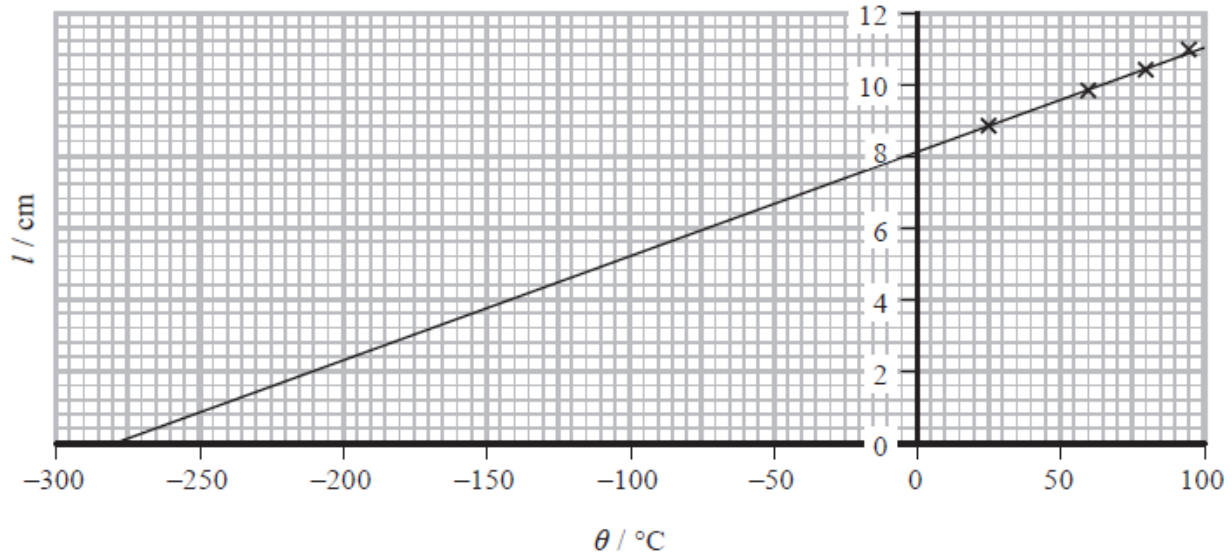
A glass tube was sealed at one end. A plug of oil trapped a length *l* of air in the tube. The water in the beaker was heated to a temperature *θ*. The corresponding value of *l* was measured. This was repeated for a range of temperatures.

The thermometer had a resolution of 0.5 °C. The scale had mm divisions.

The student's results are shown in the table.

θ / °C	*l* / cm
24	8.8
60	9.8
78.5	10.3
95.5	10.9

The student plotted a graph of *l* against *θ* as shown.



(i) Explain the significance of the intercept on the *x*-axis.

(3)

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(ii) The student wrote a report of the investigation in her lab book. In the conclusion she wrote:

"In this investigation uncertainties were minimised by selecting measuring instruments with a high resolution. The points lie on a perfect straight line, indicating that the investigation is accurate."

Discuss the student's conclusion.

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(Total for question = 7 marks)

Q3.

In 2011, a tsunami was caused by a massive earthquake centred some distance off the coast of Japan. The tsunami caused a cooling system failure at the Fukushima Nuclear Power Plant. This resulted in a nuclear meltdown and radioactive materials were released into the surroundings.

A reservoir beside one of the reactor buildings contained a large volume of water. In 2013, this water was found to have an extremely high concentration of caesium-137.

Caesium-137 is a radioactive isotope of caesium.

The most common radionuclide amongst the fission products in the fuel was iodine-131, which decays with a half-life of 8.0 days to form a stable isotope of the gas xenon.

Deduce whether enough xenon would have collected in 32 days to exert a pressure of 1.0×10^5 Pa in a volume of 450 m^3. Assume that no gas escapes.

temperature = 20 °C

initial number of iodine nuclei = 1.25×10^{28}

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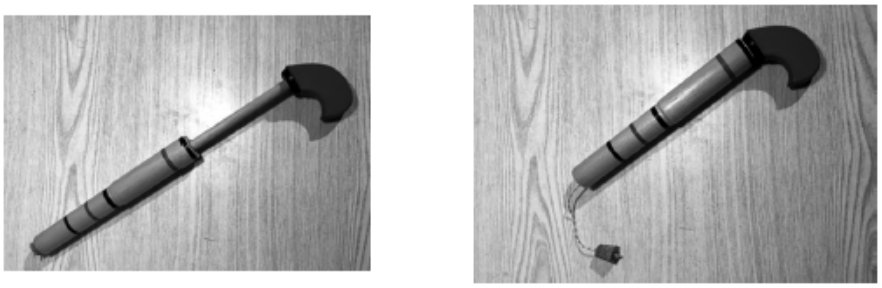
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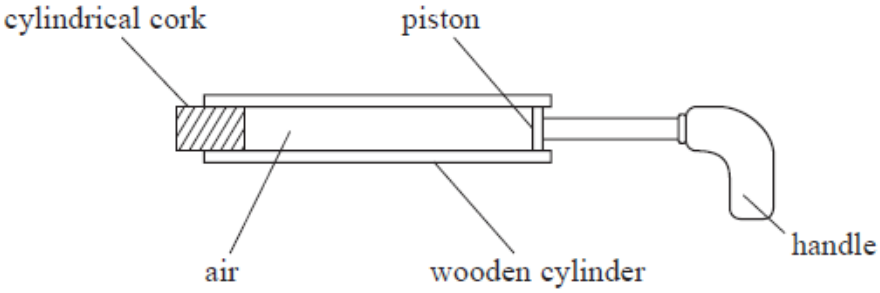
(Total for question = 6 marks)

Q4.

The photographs show a wooden pop gun before and after the cork is popped.



The diagram shows a cross-section through the pop gun.



Initially the piston is at the right-hand end of the cylinder, as shown. Then the cork is pushed into the other end of the cylinder.

When the handle is pushed in, the pressure of the air in the cylinder increases. This exerts an additional force on the cork.

Once the additional force is sufficient to overcome the frictional force between the cork and the cylinder, the cork is pushed out.

Calculate the temperature of the gas in the cylinder at the instant the cork is expelled.

volume of air in the cylinder with the handle pulled out = 1.1×10^{-5} m^3
volume of air in the cylinder at the moment the cork is pushed out = 6.7×10^{-6} m^3
atmospheric pressure = 1.0×10^5 Pa
initial temperature of air = 19 °C

(2)

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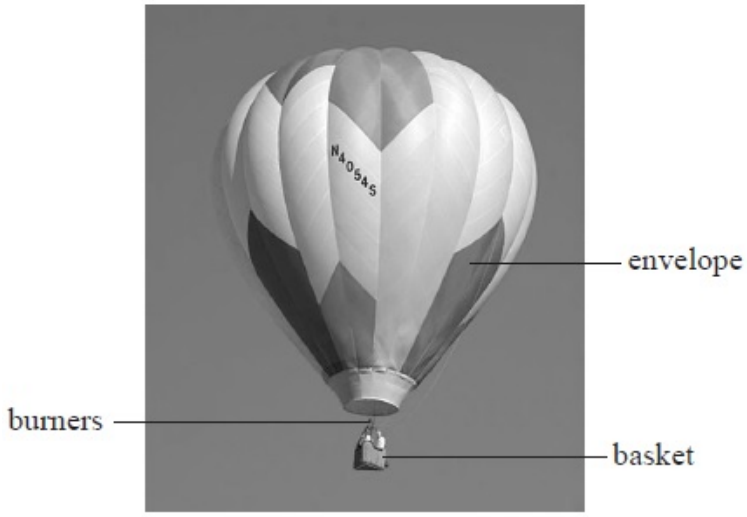
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Temperature = ...

(Total for question = 2 marks)

Q5.

Hot air ballooning is one way to explore the landscape. Air in a balloon is heated from underneath by a set of burners and the balloon starts to rise.



(a) Explain why heating the air causes the balloon to rise.

(2)

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(b) In 1991, Per Lindstrand and Richard Branson become the first people to cross the Pacific in a hot air balloon.

With a volume of 7.4×10^4 m^3 the balloon was, at the time, the largest ever built.

Calculate the energy supplied by the burners to heat the air from 20.0 °C to 35.0 °C.

average density of air in the balloon = 1.20 kg m^{-3}

specific heat capacity of air = 1010 J kg^{-1} K^{-1}

(3)

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Energy = ...

(c) The first balloons used were filled with hydrogen and sealed to keep the volume constant. As the balloon rose there would be changes in the pressure of the hydrogen due to the temperature changes of the atmosphere.

(i) Calculate the new pressure exerted by the hydrogen if the temperature changed from 20.0 °C to −5.0 °C, as the balloon rose from ground level.

pressure exerted by the hydrogen in the balloon at ground level = 1.01×10^5 Pa

(2)

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New pressure = ...

(ii) State **two** assumptions that you must make to calculate this change.

(2)

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*(iii) By considering the motion of molecules in the gas, explain why the pressure exerted by the gas decreases as it cools.

(3)

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(Total for Question = 12 marks)

Q6.

A sample of an ideal gas at 27 °C is placed in a sealed container. The gas is heated at constant volume to a temperature of 324 °C.
The ratio of the final pressure to the initial pressure exerted by the gas is approximately

☒ **A** 1

☒ **B** 2

☒ **C** 4

☒ **D** 12

(Total for question = 1 mark)

Q7.

A student carries out an experiment to investigate how the volume occupied by a gas depends upon the temperature.

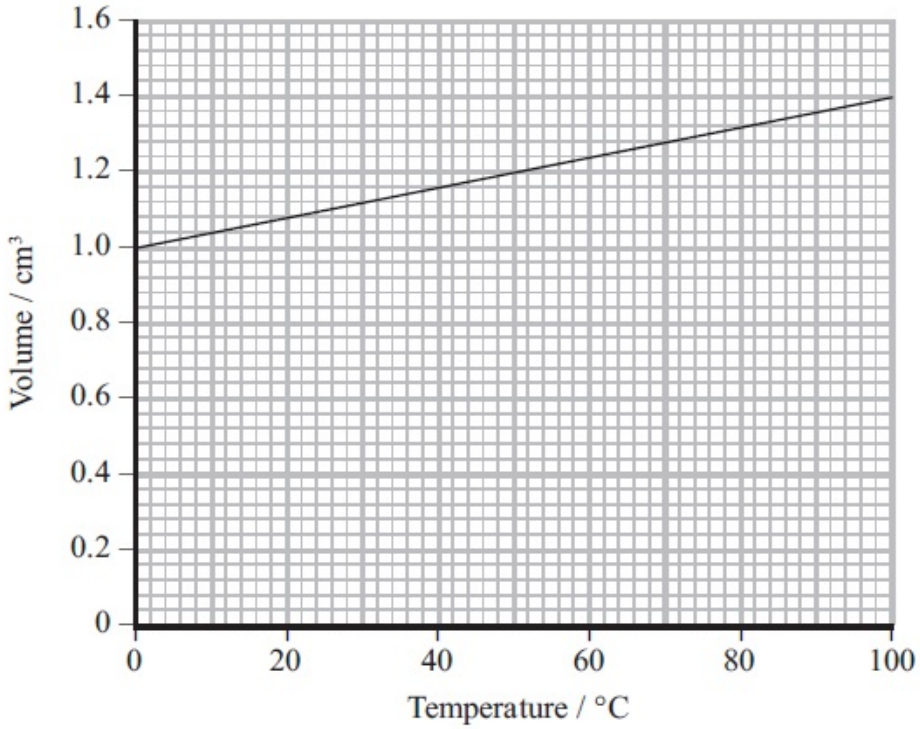
(a) What variables must the student control in this investigation?

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(b) The following graph is obtained.



Explain how graphs such as this provide evidence for an absolute zero of temperature.

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(Total for question = 4 marks)

Q8.

An old type of camping lamp used a 'gas mantle'. The gas mantle is heated by the gas flame on the lamp and emits a bright white light. Gas mantles used to contain thorium-230.

Thorium-230 decays by alpha emission to form an isotope of radium. A student keeps a radioactive gas mantle in a sealed polythene bag. The student suggests that over a period of a year a significant volume of helium gas will be collected, since an alpha particle is a helium nucleus.

A particular gas mantle contains 5.18×10^{-5} g of thorium-230.

(i) Show that the activity of the thorium-230 in the mantle is about 4.0×10^{4} Bq.

230 g of thorium-230 contains 6.02×10^{23} atoms

half-life of thorium-230 = 75 400 years

number of seconds in 1 year = 3.15×10^{7}

(4)

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(ii) Determine the volume of helium gas that could be collected in a year as a result of alpha emission.

Assume that the temperature is 22.0 °C and the pressure is 1.00×10^5 Pa.

(4)

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Volume = ...

(iii) Calculate the root mean square speed of the atoms in the helium gas at a temperature of 22.0 °C.

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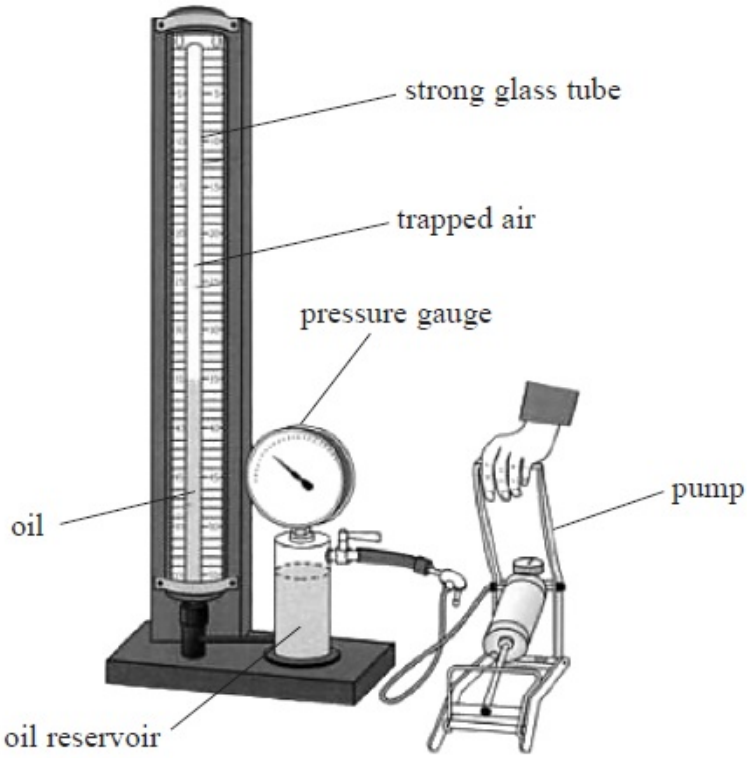
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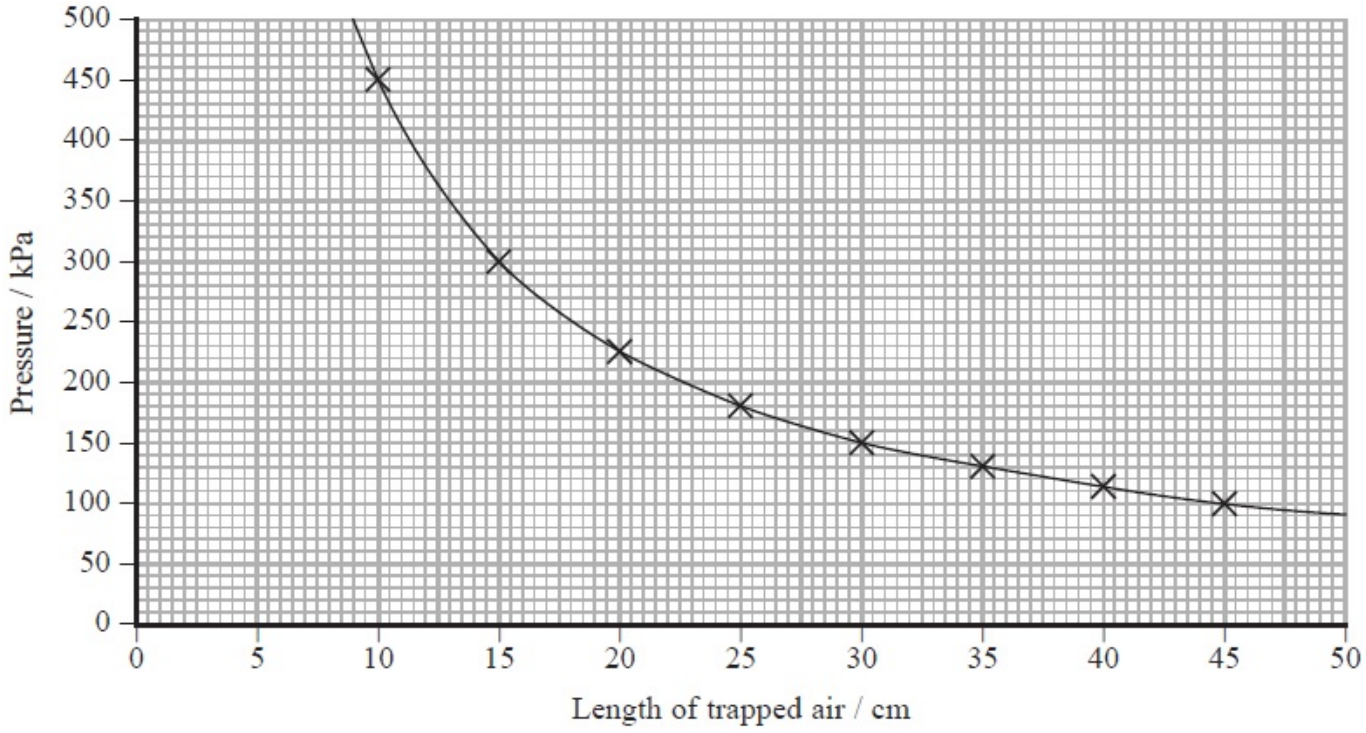
Root mean square speed = ...

(Total for question = 11 marks)

Q9. A student uses the apparatus shown to investigate the relationship between pressure and volume of a gas.



Air is trapped in a glass tube of uniform cross-sectional area. As the pressure of the trapped air is increased, the length of trapped air decreases. The student collects data and plots the following graph.



(a) State the variables that should be controlled in this investigation.

(2)

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(b) Theory suggests that, for the air trapped in the tube, the pressure p is inversely proportional to the volume V.

Use the graph to show that this relationship is correct. State an assumption that you are making.

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(c) the day that the investigation was carried out, the temperature in the laboratory was 20 °C.

Calculate the number of air molecules trapped in the tube.

cross-sectional area of tube = 7.5×10^{-5} m^2

(3)

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Number of air molecules = ...

(d) State how the graph would change if

(i) the air molecules in the tube were replaced by the same number of molecules of hydrogen gas.

(1)

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(ii) the temperature of the laboratory was substantially higher.

(2)

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(Total for Question = 12 marks)

Q10.

A bicycle tyre contains air at 20 °C. The volume occupied by the air is 2.9×10^{-4} m^3. Assume that this volume remains fixed.

(a) The pressure of the air in the tyre is 5.8×10^5 Pa. In an attempt to improve performance air is pumped into the tyre until the pressure at 20 °C is 6.5×10^5 Pa.

Calculate the number of air molecules that must be pumped into the tyre.

(3)

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Number of molecules = ...

(b) After cycling in a race the air pressure in the tyre has risen from 6.5×10^5 Pa to 6.8×10^5 Pa.

Calculate the increase in temperature of the air in the tyre.

(3)

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Increase in temperature = ...

(c) Explain why the pressure increases when the air is heated in a tyre of fixed volume.

(3)

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(Total for question = 9 marks)

Q11.

Answer the question with a cross in the box you think is correct (☒). If you change your mind about an answer, put a line through the box (☒) and then mark your new answer with a cross (☒).

A sample of an ideal gas has pressure p, volume V and absolute temperature T.

The volume of the gas is decreased to $\frac{2}{3}V$ and the temperature increased to $\frac{6}{5}T$.

Which of the following is the new pressure of the gas?

☐ **A** $\frac{5}{9}p$

☐ **B** $\frac{4}{5}p$

☐ **C** $\frac{5}{4}p$

☒ **D** $\frac{9}{5}p$

(Total for question = 1 mark)

Q12.

At the Culham Centre for Fusion Energy (CCFE) experiments are carried out to investigate nuclear fusion and the properties of plasmas. A plasma consists of ionised gas, containing positive ions and electrons.

In a plasma experiment 5.0 mg of deuterium, an isotope of hydrogen, occupies a volume of 98 m^3. The temperature of deuterium is raised to 1.3×10^8 K. In this experiment, the deuterium behaves as an ideal gas.

(i) Calculate the pressure due to the deuterium ions.

mass of deuterium ion = 3.3×10^{-27} kg

(3)

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Pressure = ...

(ii) Calculate the root mean square speed of the deuterium ions at this temperature.

(2)

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Root mean square speed = ...

(iii) The temperature of the plasma is monitored using the Doppler effect. Light from a laser is directed into the plasma and the wavelength of the light reflected is measured.

The Doppler shift observed when light is reflected by a deuterium ion is twice the Doppler shift that would be observed for a source of light moving at the same speed as the deuterium ion.

Calculate the maximum wavelength of light that would be detected after reflection from a deuterium ion moving at $1.5 \times 106\,\text{m}\,\text{s}^{-1}$.

wavelength of laser light = 1064 nm

(3)

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Maximum wavelength detected = ...

(Total for question = 8 marks)

Q13.

When an ideal gas reaches the absolute zero of temperature, the gas

☒ **A** becomes a superfluid.

☒ **B** condenses to a liquid.

☒ **C** has maximum molecular potential energy.

☒ **D** exerts no pressure.

(Total for question = 1 mark)

Q14.

For an ideal gas $pV = NkT$ and $pV = \frac{1}{3}Nm\langle c^2\rangle$.

Use these relationships to show that the mean kinetic energy of a gas molecule is proportional to the absolute temperature.

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(Total for question = 2 marks)

Q15.

A gas cylinder of volume 0.052 m^3 contains oxygen gas at a temperature of 22°C and a pressure of 2.0×10^5 Pa.
Some of the oxygen in the cylinder is used and the gas pressure falls to 1.6×10^5 Pa.
The temperature remains constant.

Calculate the number of molecules removed from the cylinder

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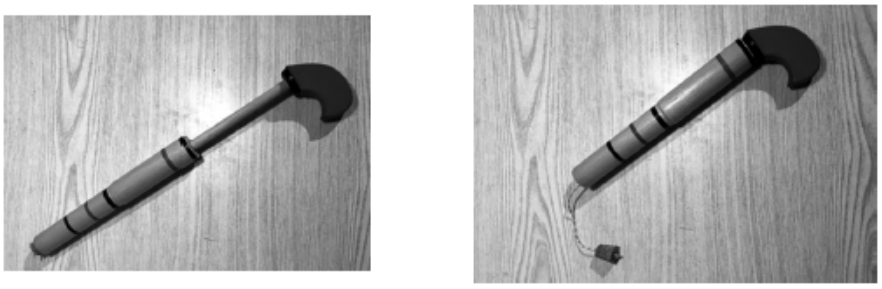
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Number of molecules removed = ...

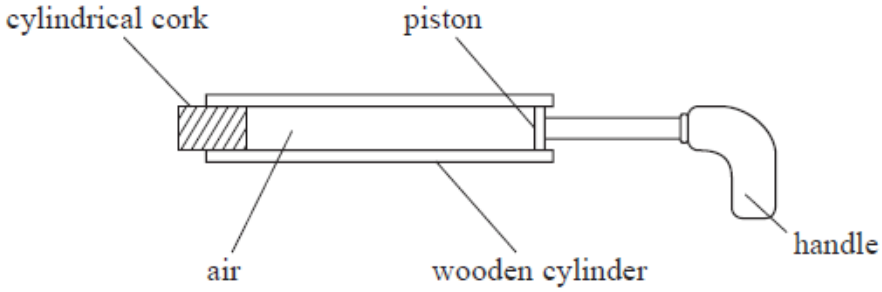
(Total for question = 3 marks)

Q1.

The photographs show a wooden pop gun before and after the cork is popped.



The diagram shows a cross-section through the pop gun.



Initially the piston is at the right-hand end of the cylinder, as shown. Then the cork is pushed into the other end of the cylinder.

When the handle is pushed in, the pressure of the air in the cylinder increases. This exerts an additional force on the cork.

Once the additional force is sufficient to overcome the frictional force between the cork and the cylinder, the cork is pushed out.

Calculate the root mean square speed of the molecules of air in the cylinder before the handle is pushed in.

average mass of molecule of air = 4.8×10^{-26} kg
temperature of air = 19 °C

(2)

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Root mean square speed = ...

(Total for question = 2 marks)

Q2.

When a large potential difference is applied to a discharge tube, the gas in the discharge tube emits coloured light. When this light is passed through a diffraction grating, an emission spectrum which is made up of a series of lines of different wavelengths may be seen.

The photographs show the spectra produced from a tube containing hydrogen and a tube containing helium.

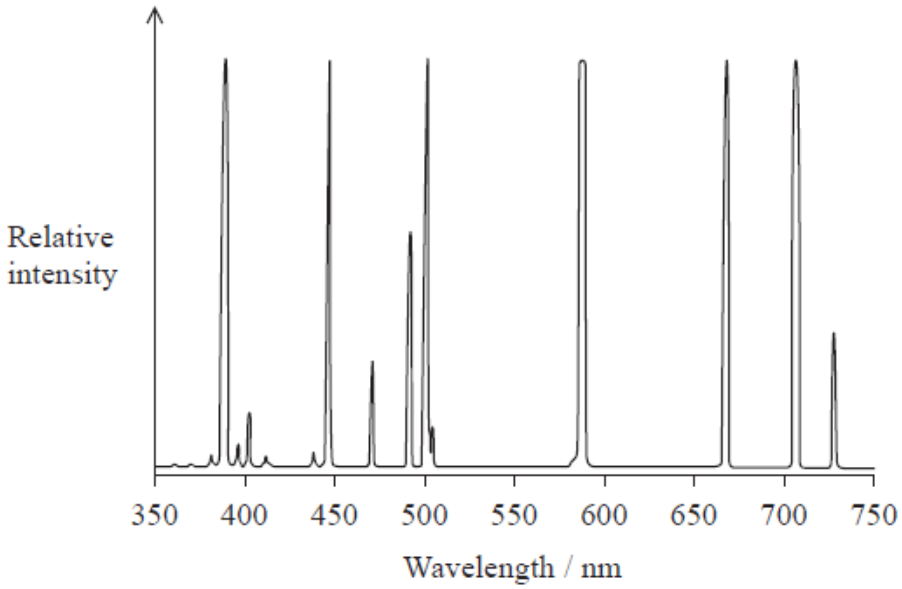
Hydrogen:



Helium:



The graph shows the relative intensities of different wavelengths of light in the spectrum of a sample of helium.



The graph shows that the lines are not at a single wavelength. This effect is known as thermal Doppler broadening and occurs because of the random motion of the helium atoms.

(i) Explain why the thermal motion of the helium atoms causes the broadening of the spectral lines.

(2)

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(ii) The width of a line may be used to determine the speed of the atoms in the gas and hence the temperature of the gas.

The spectral line with wavelength 587 nm for a particular tube containing helium has a width of 6×10^{-3} nm.

(1) Show that this corresponds to a speed, for a helium atom, of about 1500 m s^{-1}.

(2)

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(2) Assuming that this is the root mean square speed for the helium (He 4) atoms in the tube, calculate the temperature of the gas in the tube.

(3)

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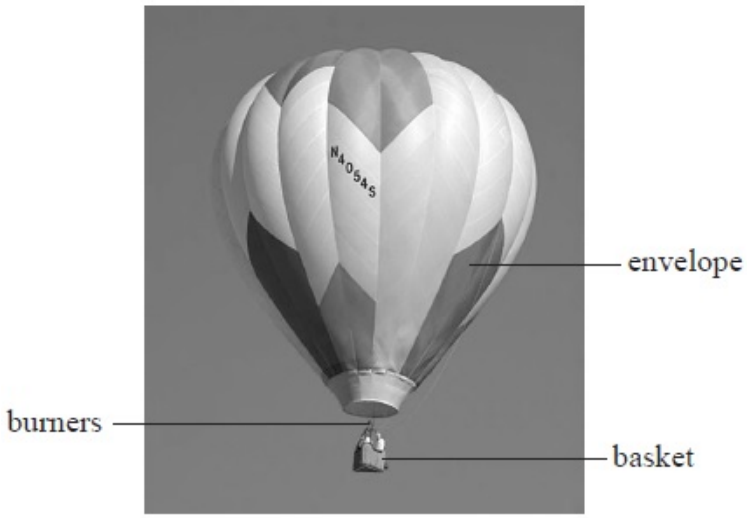
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Temperature = ...

Q3.

Hot air ballooning is one way to explore the landscape. Air in a balloon is heated from underneath by a set of burners and the balloon starts to rise.



(a) Explain why heating the air causes the balloon to rise.

(2)

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(b) In 1991, Per Lindstrand and Richard Branson become the first people to cross the Pacific in a hot air balloon.

With a volume of 7.4×10^4 m^3 the balloon was, at the time, the largest ever built.

Calculate the energy supplied by the burners to heat the air from 20.0 °C to 35.0 °C.

average density of air in the balloon = 1.20 kg m^{-3}

specific heat capacity of air = 1010 J kg^{-1} K^{-1}

(3)

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Energy = ...

(c) The first balloons used were filled with hydrogen and sealed to keep the volume constant. As the balloon rose there would be changes in the pressure of the hydrogen due to the temperature

changes of the atmosphere.

(i) Calculate the new pressure exerted by the hydrogen if the temperature changed from 20.0 °C to −5.0 °C, as the balloon rose from ground level.

pressure exerted by the hydrogen in the balloon at ground level = 1.01×10^5 Pa

(2)

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New pressure = ...

(ii) State **two** assumptions that you must make to calculate this change.

(2)

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*(iii) By considering the motion of molecules in the gas, explain why the pressure exerted by the gas decreases as it cools.

(3)

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(Total for Question = 12 marks)

Q4.

The formulae sheet for this paper includes the equation

$$pV = \frac{1}{3}Nm\langle c^2\rangle$$

Derive the equation $\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$

(2)

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(Total for question = 2 marks)

Q5.

An old type of camping lamp used a 'gas mantle'. The gas mantle is heated by the gas flame on the lamp and emits a bright white light. Gas mantles used to contain thorium-230.

Thorium-230 decays by alpha emission to form an isotope of radium. A student keeps a radioactive gas mantle in a sealed polythene bag. The student suggests that over a period of a year a significant volume of helium gas will be collected, since an alpha particle is a helium nucleus.

A particular gas mantle contains 5.18×10^{-5} g of thorium-230.

(i) Show that the activity of the thorium-230 in the mantle is about 4.0×10^4 Bq.

230 g of thorium-230 contains 6.02×10^{23} atoms

half-life of thorium-230 = 75 400 years

number of seconds in 1 year = 3.15×10^7

(4)

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(ii) Determine the volume of helium gas that could be collected in a year as a result of alpha emission.

Assume that the temperature is 22.0 °C and the pressure is 1.00×10^5 Pa.

(4)

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Volume = ...

(iii) Calculate the root mean square speed of the atoms in the helium gas at a temperature of 22.0 °C.

(3)

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Root mean square speed = ...

(Total for question = 11 marks)

Q6.

Our understanding of the atom has developed over time, from early models in which atoms were considered to be hard incompressible spheres, through to the nuclear model of the atom and the ladder model in which electrons exist in a discrete number of allowed energy states.

* The model of atoms as hard incompressible spheres, moving rapidly and randomly, can be used to explain why gases exert a pressure.

Explain, using ideas of momentum, why the pressure exerted by a gas increases as the temperature of the gas increases.

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(Total for question = 6 marks)

Q7.

Barnard's star is a red dwarf star in the vicinity of the Sun. The wavelength of a line in the spectrum of light emitted from Barnard's star is measured to be 656.0 nm. The same light produced by a source in a laboratory has a wavelength of 656.2 nm.

Visible light from the star originates from the photosphere. In the photosphere of Barnard's star,

hydrogen and helium atoms are at a temperature of 3100 K.

(i) Calculate the mean kinetic energy of an atom in the photosphere at a temperature of 3100 K.

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Mean kinetic energy = ...

(ii) Describe how these atoms emit visible light.

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(Total for question = 4 marks)

Q8.

At the Culham Centre for Fusion Energy (CCFE) experiments are carried out to investigate nuclear fusion and the properties of plasmas. A plasma consists of ionised gas, containing positive ions and electrons.

In a plasma experiment 5.0 mg of deuterium, an isotope of hydrogen, occupies a volume of 98 m^3. The temperature of deuterium is raised to 1.3×10^8 K. In this experiment, the deuterium behaves as an ideal gas.

(i) Calculate the pressure due to the deuterium ions.

mass of deuterium ion = 3.3×10^{-27} kg

(3)

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Pressure = ...

(ii) Calculate the root mean square speed of the deuterium ions at this temperature.

(2)

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Root mean square speed = ...

(iii) The temperature of the plasma is monitored using the Doppler effect. Light from a laser is directed into the plasma and the wavelength of the light reflected is measured.

The Doppler shift observed when light is reflected by a deuterium ion is twice the Doppler shift that would be observed for a source of light moving at the same speed as the deuterium ion.

Calculate the maximum wavelength of light that would be detected after reflection from a deuterium ion moving at $1.5 \times 106\,\text{m}\,\text{s}^{-1}$.

wavelength of laser light = 1064 nm

(3)

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Maximum wavelength detected = ...

(Total for question = 8 marks)

Q9.

For an ideal gas $pV = NkT$ and $pV = \frac{1}{3}Nm\langle c^2\rangle$.

Use these relationships to show that the mean kinetic energy of a gas molecule is proportional to the absolute temperature.

(2)

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(Total for question = 2 marks)

Q10.

The molecules in a sample of gas have a mass of 5.0×10^{-26} kg.

Calculate the root-mean-square speed of gas molecules in the gas at 25 °C.

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Root-mean-square speed = ...