KE and RMS Questions

Q1.

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

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)

Q2.

The formulae sheet for this paper includes the equation

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

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

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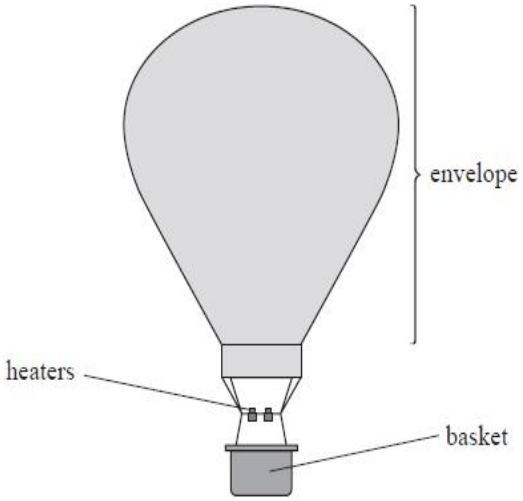
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(Total for question = 2 marks)

Q3.

A hot air balloon consists of a fabric envelope, heaters and a basket, as shown.



When the balloon is set up, the envelope is partly filled with air at 20°C. The air is then heated to 120°C and expands to fill the envelope and becomes less dense.

The air pressure inside the envelope is always equal to the air pressure outside the envelope because the envelope is open at the bottom.

The balloon takes off when the upthrust is more than the total weight of the balloon, the air in the envelope and the passengers.

Deduce whether the balloon can take off.

volume of air at 120°C in inflated envelope = 2800 m^3
density of air at 20°C = 1.2 kg m^{-3}
mass of balloon = 380 kg
mass of passengers = 340 kg
upthrust when the envelope is full = 33 000 N

(i) State one assumption of the kinetic theory of gases.

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(ii) Derive an equation to show that, for a gas at temperature *T*,

the mean kinetic energy of the molecules $= \frac{3}{2} kT$

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(iii) Calculate the root-mean-square speed of nitrogen molecules at a temperature of 120°C.

mass of nitrogen molecule = 28 u

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Root-mean-square speed = ...

(Total for question = 6 marks)

Q4.

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.

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

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Mean kinetic energy = ...

(Total for question = 2 marks)

Q5.

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

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Pressure = ...

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

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Root mean square speed = ...

(Total for question = 5 marks)

Q6.

The fuel used in a camping stove is butane, which is stored in a canister as shown.



The pressure inside the canister is 220 kPa and the temperature of the gas is 21 °C.

Number of molecules of butane gas = 4.74×10^{23}

(ii) Calculate the r.m.s. speed of the molecules of butane gas.

mass of butane molecule = 9.6×10^{-26} kg

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rms speed = ...

(Total for question = 2 marks)

Q7.

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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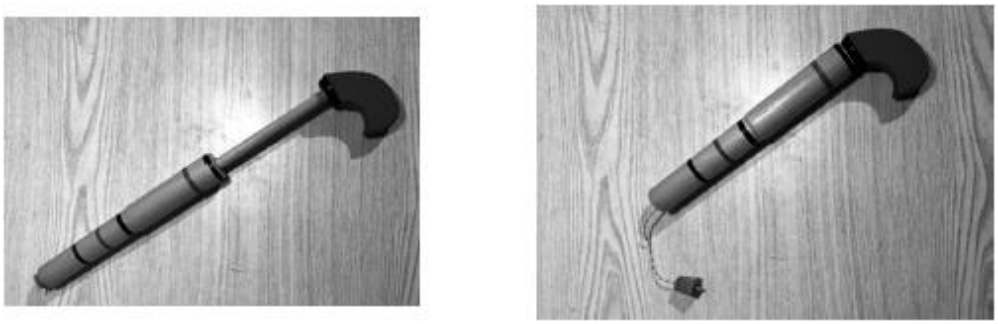
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Root-mean-square speed = ...

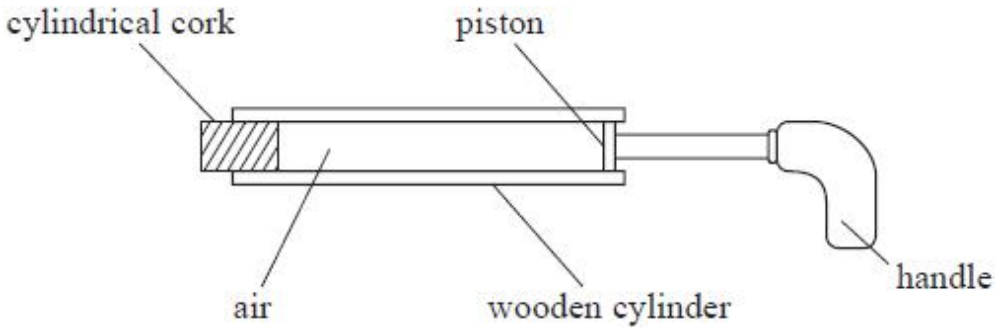
(Total for question = 3 marks)

Q8.

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

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Root mean square speed = ...

(Total for question = 2 marks)

Q9.

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.

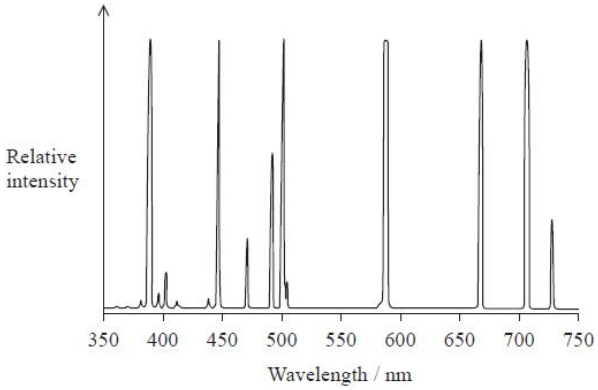
Hydrogen:



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.

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.

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Temperature = ...

(Total for question = 3 marks)

Q10.

Air is a mixture of mostly nitrogen and oxygen molecules. The mass of an oxygen molecule is slightly greater than the mass of a nitrogen molecule.

On average, in a sample of air at a given temperature

- ☒ **A** the nitrogen and oxygen molecules have the same speed.
- ☒ **B** the nitrogen molecules are travelling more slowly than the oxygen molecules.
- ☒ **C** the oxygen molecules are travelling more slowly than the nitrogen molecules.
- ☒ **D** the molecules have relative speeds that depend upon the amount of each gas present.

(Total for Question = 1 mark)

Q11.

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}

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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.

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Volume = $5.09 \times 10^{-14} m^3$

(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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Root mean square speed = ...

(Total for question = 11 marks)