5 This question is about the Boltzmann factor, $f = e^{-E/kT}$.

Fig. 5.1 shows how the Boltzmann factor varies with temperature for three processes: **A**, **B** and **C**.

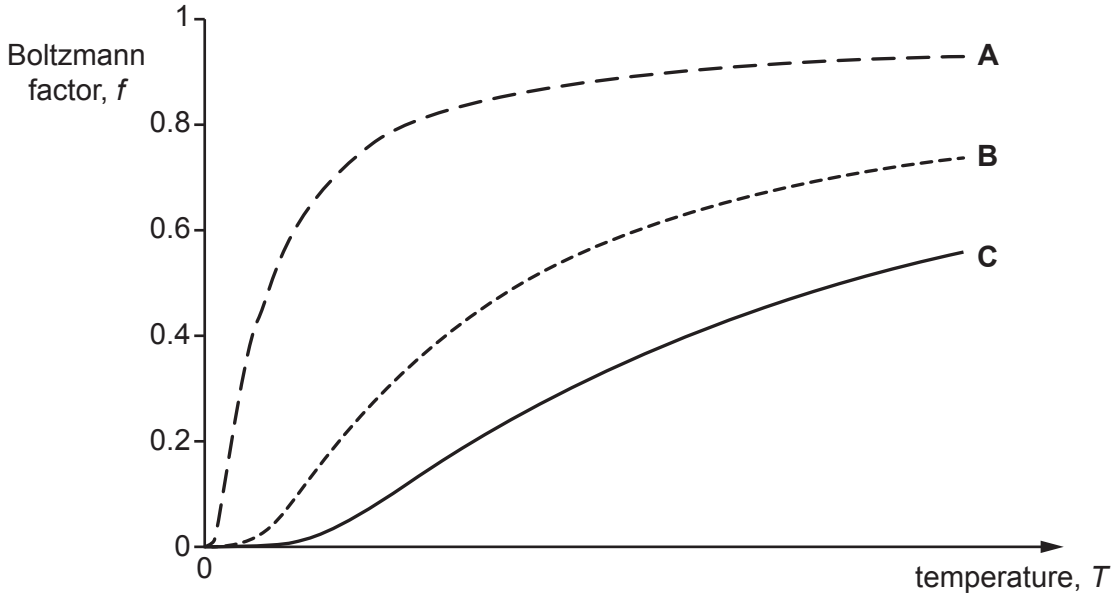

Fig. 5.1

(a) Explain how the graphs in Fig. 5.1 show that line **C** represents the process with the greatest activation energy *E*.

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..... **[3]**

(b) This part of the question is about the evaporation of liquids; the process in which molecules of the liquid gain sufficient energy to enter into the vapour.

(i) The Boltzmann factor for water molecules escaping the liquid and entering the vapour state is 4.9×10^{-8} at 310 K.

Calculate the activation energy required for a water molecule to escape into the vapour state at this temperature.

activation energy = ... J **[3]**

(ii) Explain how particles with an average energy lower than the activation energy gain enough energy to escape into the vapour.

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[2]

(iii)* The activation energy for a molecule of ethyl alcohol to escape into the vapour state is 6.6×10^{-20} J.

Calculate the Boltzmann factor at 310 K for this process and use ideas from the question to explain why a drop of ethyl alcohol feels colder on the skin than a drop of water.

[6]

20 At 300 K a process has an activation energy $E = 10kT$.

The temperature is raised to 330 K.

Which statement about the rate of the process is correct?

It will increase by

A 10% because temperature has increased by 10%.

B 10% because the mean square speed of the particles has increased by 10%.

C 9.1 times because $\frac{E}{kT} = \frac{3000k}{330k} = 9.1$.

D 2.5 times because $e^{\frac{-E}{kT}}$ has increased by $\frac{e^{-9.1}}{e^{-10}} = 2.5$ times.

Your answer ☐ **[1]**

21 Which of the following changes doubles the flux in a magnetic circuit?

1 doubling the permeance

2 doubling the current-turns

3 halving the circuit length

A 1, 2 and 3 are correct

B only 1 and 2 are correct

C only 2 and 3 are correct

D only 1 is correct

Your answer ☐ **[1]**

6 This question is about conduction in metals and in semiconductors.

(a) A copper wire of length 1.5 m and radius 2.5×10^{-4} m has a resistance of 0.13 Ω at 20 °C. Calculate the conductivity of copper at this temperature.

conductivity at 20 °C = ... $S\,m^{-1}$ **[3]**

(b) A simple model of conduction suggests that each copper atom in the wire contributes one or more electrons to a cloud of free electrons that behave rather like particles in a gas. These electrons drift through the wire under the influence of an electric field.

The current I is given by the equation $I = nave$ where:

n is the number of free electrons in the material per m^3
a is the cross-sectional area of the wire
v is the drift velocity of the electrons
e is the electronic charge.

Calculate the drift velocity of the electrons when the copper wire in part **(a)** carries a current of 2.3 A. The number of free electrons per m^3 in copper = $8.5 \times 10^{28}\,m^{-3}$

drift velocity = ... $m\,s^{-1}$ **[2]**

(c)* The conductivity σ of semiconductors such as ntc thermistors increases dramatically with temperature T. The relationship is given by the equation

$$\sigma = C\, e^{-E/kT}$$

where C is a constant, k is the Boltzmann constant and E is the energy required to ionise an atom in the semiconductor.

Use the relationships given in the question to explain the effect of increasing temperature on the conductivity of metals and semiconductors, referring to the microscopic structure of the materials. No calculations are required. **[6]**

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39 (a)* Boyle's Law states that at constant temperature, pressure is proportional to $\frac{1}{\text{volume}}$.

Explain how the random motion of particles gives rise to Boyle's law.

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..... **[6]**

(b) Here are some data about trace gases in the atmosphere:

H_2 molar mass 2 grams
Xe molar mass 132 grams

(i) Calculate the ratio: $\frac{\text{speed of hydrogen molecule with average kinetic energy}}{\text{speed of xenon atom with average kinetic energy}}$.

Make your reasoning clear.

ratio = ... **[3]**

(ii) The escape velocity for planet Earth is $11.2\,\text{km}\,\text{s}^{-1}$.

Use the Boltzmann factor to estimate the number of H_2 molecules per mole with sufficient energy to escape the atmosphere and the Earth's gravitational field at a temperature of 288 K.

number = ... mole^{-1} **[4]**

SECTION C

Answer **all** the questions.

36 This question considers some of the evidence for a Hot Big Bang start to our expanding universe.

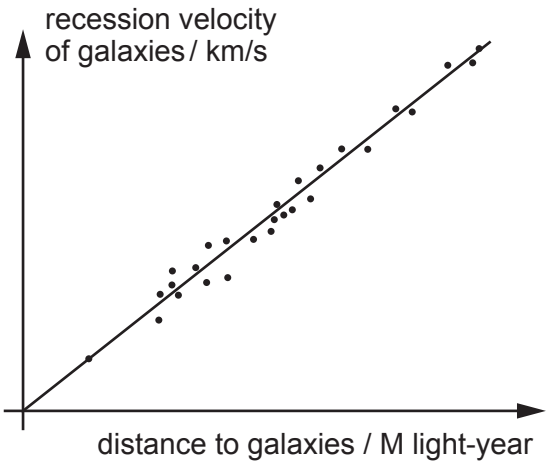

Fig. 36.1

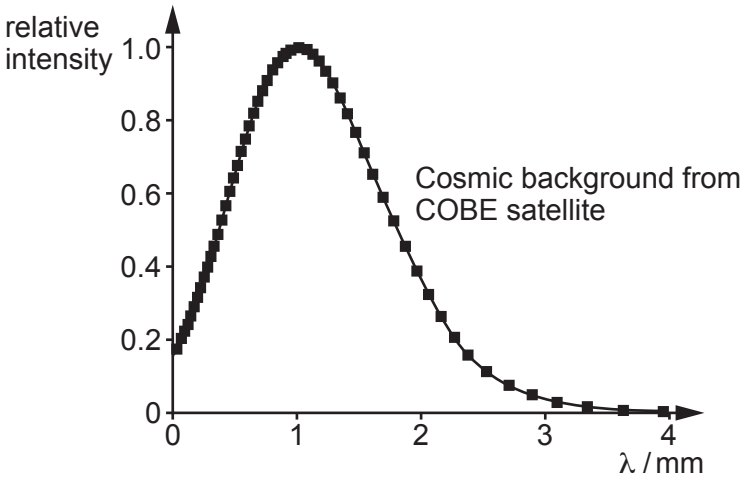

Fig. 36.2

(a) Explain how the graph(s) show evidence that the universe started from:

(i) a big bang expansion

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..... **[2]**

(ii) a hot state.

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..... **[2]**

(b) The intensity spectrum of thermal radiation depends on temperature T. Photons at the **peak** of intensity have energy $\varepsilon \approx 5kT$.

Use this approximation and data from **Fig. 36.2** to estimate the temperature of the cosmic microwave background radiation (CMBR).

temperature = ... K **[4]**