Chem Factsheet

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The Maxwell-Boltzmann Distribution

To succeed with this topic you need to know:-
- **The factors that affect the rate of chemical reactions.**

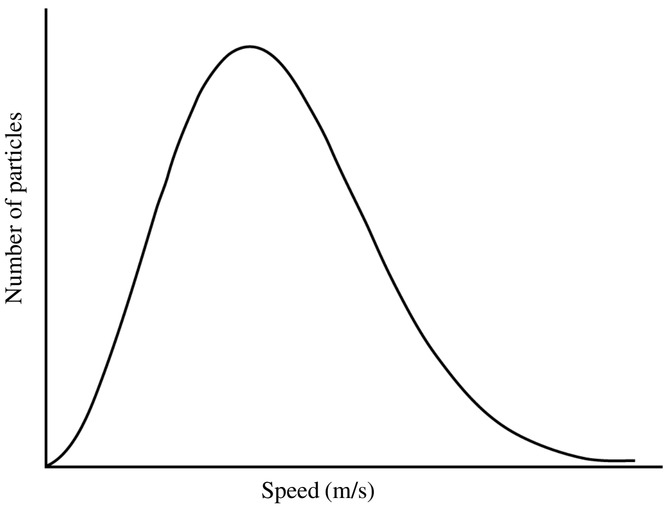
After working through this Factsheet you will understand:-
- **What the Maxwell-Boltzmann Distribution is;**
- **How it changes at different temperatures;**
- **The meaning of the term *activation energy*;**
- **How to use the Maxwell-Boltzmann Distribution to explain factors affecting rates of reaction.**

1. What is the Maxwell-Boltzmann Distribution?

Particles are constantly in motion - they vibrate and rotate, and if they are in liquids, solutions or gases, they move from place to place as well. However, not all the particles in a given substance will be moving with the same speed - some will be moving very slowly, most at around the average speed, and some very fast.

> *The Maxwell-Boltzmann Distribution shows how the speeds of particles are distributed at a particular temperature.*

The diagram below shows an example of a Maxwell-Boltzmann graph.

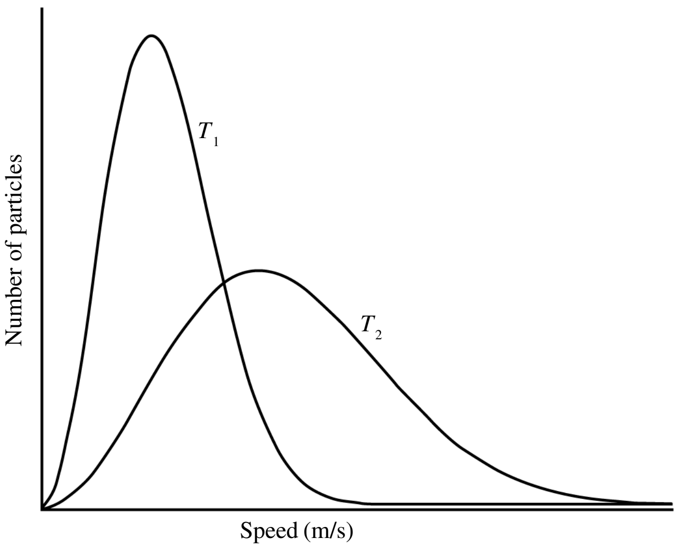


Points to note:-
- The height of the graph shows how many particles have each speed
- The **area under the curve** corresponds to the total number of particles
- No particles have a speed of zero - so the graph does start at the origin
- The most common speed is where the peak is
- Very few particles have very high speeds, but...
- There is **no "speed limit"** - there are always some particles with very high speeds - there is no maximum.
- This means that though the curve gets very close to the x-axis **it never touches it**

> ***Exam Hint: -** The commonest exam mistakes are:-*
> - *Not starting the graph at the origin*
> - *Showing the graph touching the x-axis*
> - *Drawing a "wiggly line" instead of a smooth curve.*
>
> *Double check for these errors - they will lose you marks!*

2. Changes in the Maxwell-Boltzmann Distribution with Temperature

The graph below shows the Maxwell-Boltzmann Distribution for the same sample of gas at two different temperatures, T_1 and T_2, where T_2 is higher than T_1.



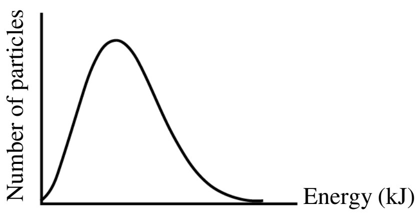
Points to note:-
- The total area under each graph is the same, as the number of particles does not change just because the sample is heated
- The graph becomes more "spread out" at higher temperatures
- The peak of the graph moves to the right as the temperature increases - the most common speed is higher
- There are a greater proportion of particles at high speed for a higher temperature

3. Using the Maxwell-Boltzmann Distribution

For a chemical reaction to occur, we need the particles involved to collide; not only that, they must collide with enough energy. If particles do not have enough energy, then even if they collide, no reaction occurs.

> *The **activation energy** for a particular reaction is the minimum energy the colliding particles need to have for the reaction is to occur.*

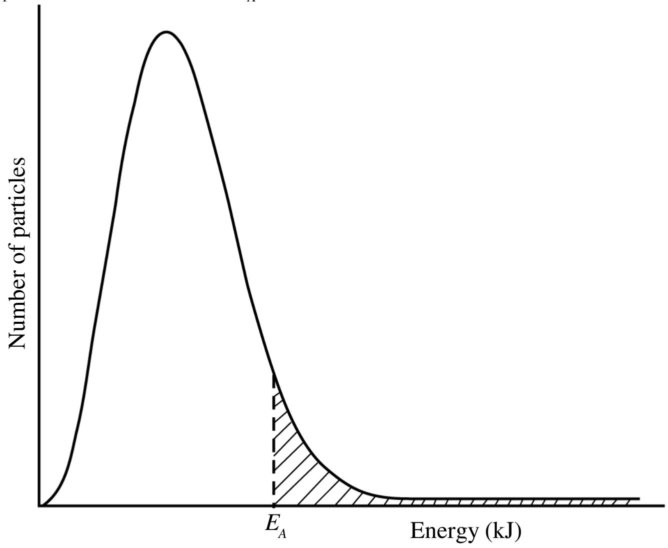
The energy that the particles have is the kinetic energy due to their speed. So particles travelling at a higher speed have a higher energy. You will sometimes see the Maxwell-Boltzmann graph with the x-axis labelled "energy" instead of "speed".



This means that the Maxwell-Boltzmann distribution can tell us about the proportion of particles that will have the activation energy.

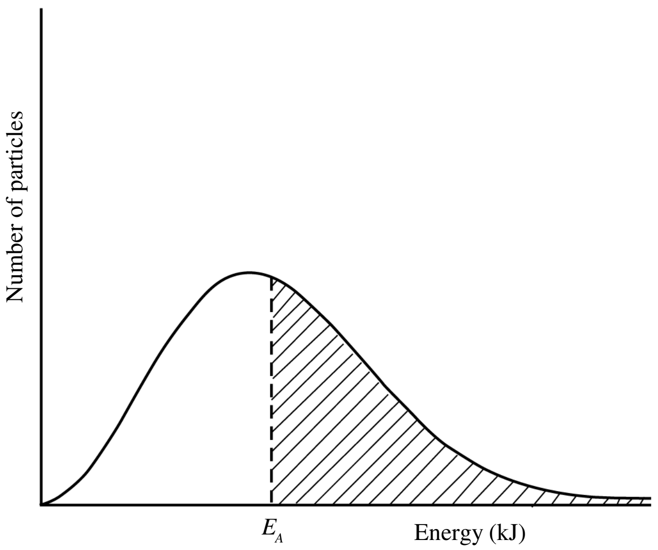
(a) Temperature

We will consider again the distributions at two different temperatures. The diagram below shows the distribution for a substance at temperature T_1. The activation energy E_A for a reaction is marked on the *x*-axis.



In this diagram, the shaded area gives us the number of particles with energy equal to or above the activation energy - in other words, the number of particles with enough energy to react.

Now consider the same diagram for temperature T_2.



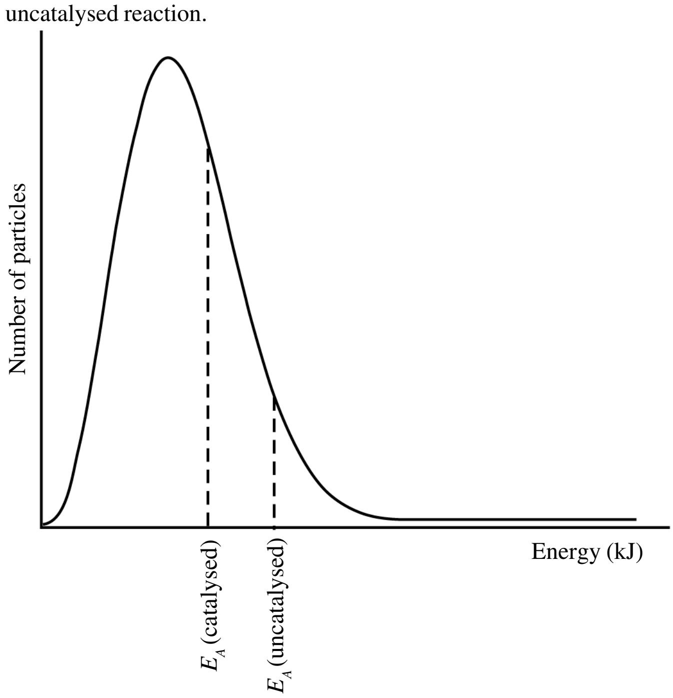
We can see that now a much greater proportion of the particles have energy equal to or above the activation energy. This means that many more particles are now able to react if a collision occurs - so more collisions will result in reactions, and hence the rate of reaction increases.

> ***Exam Hint: -*** *It is important to remember that increasing the temperature only increases the proportion of particles that can react - however high the temperature, some particles will not have the activation energy.*

(b) Catalysts

When we use a catalyst in a reaction, it does not affect the shape of the Maxwell-Boltzmann distribution - only temperature will do that. So why does it make the reaction proceed faster? A catalyst works by lowering the activation energy required for a reaction. It does that by providing an alternative pathway by which the reaction can proceed.

The diagram below shows the activation energies for a catalysed and uncatalysed reaction.



We can see that the proportion of particles with energies above E_A is much higher for the catalysed reaction - hence more collisions will result in reaction, increasing the rate of reaction.

> ***Exam Hint: -*** *You will also need to be able to explain the effect of factors such as concentration and pressure on the rate of a reaction - these* ***do not*** *involve the Maxwell-Boltzmann distribution.*

Questions

1. A tube contains a mixture of methane and chlorine gas. Initially it is at a temperature of 0^oC. It is then heated to 100^oC.
(a) Sketch, on one axis, graphs showing how the distribution of speeds of molecules changes between these two temperatures.
(b) Use your graph to describe and explain the effect of temperature on the rate of the reaction between methane and chlorine (you may assume UV light is present in both cases)

2. The Haber Process, to produce ammonia, is catalysed by iron. Explain why the catalyst increases the rate of the reaction (you do not need to give detailed chemistry of any reactions)

3. Decide whether each of these statements is true of false:-
If you increase the temperature of a substance,
(a) the average speed of the particles increases.
(b) the number of particles at any particular speed increases
(c) the number of particles with speeds above any particular speed increases
(d) the area under the Maxwell-Boltzmann graph increases
(e) the height of the peak on the Maxwell-Boltzmann graph increases.

Acknowledgements: This Factsheet was researched and written by Cath Brown.. ***Curriculum Press, Bank House, 105 King Street, Wellington, Shropshire, TF1 1NU. ChemistryFactsheets*** *may be copied free of charge by teaching staff or students, provided that their school is a registered subscriber. No part of these Factsheets may be reproduced, stored in a retrieval system, or transmitted, in any other form or by any other means, without the prior permission of the publisher.* ***ISSN 1351-5136***

Answers

1. (a) Your graph should look like the one on the 2nd column of page 1. You need to label which is which - the T_2 graph should be the 100^oC
(b) See 1st column of 2nd page of Factsheet.
2. See 2nd column of 2nd page of Factsheet.
3. (a) T (b) F (c) T (d) F (e) F