8.2 EFFECT OF TEMPERATURE ON THE RATES OF REACTION

Learning outcomes

Candidates should be able to:

1. define activation energy, E_A, as the minimum energy required for a collision to be effective
2. sketch and use the Boltzmann distribution to explain the significance of activation energy
3. explain qualitatively, in terms both of the Boltzmann distribution and of frequency of effective collisions, the effect of temperature change on the rate of a reaction

Introduction

At higher temperature, molecules have more kinetic energy, so a **higher percentage of successful collisions** occur between reactant molecules.

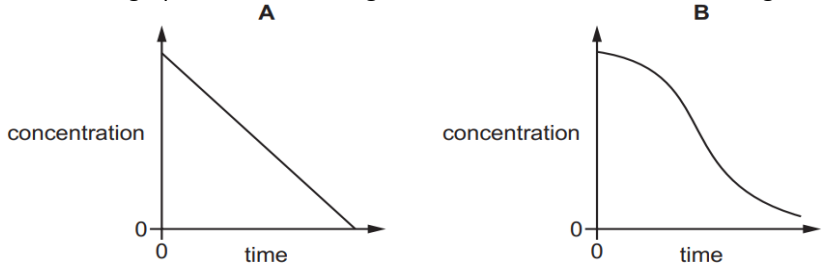
Remember that increasing temperature increases the rate of reaction because of two factors:
1. The frequency of effective collisions is greater because of the greater kinetic energy of the molecules
2. A greater proportion of the molecules have kinetic energy greater than the activation energy.

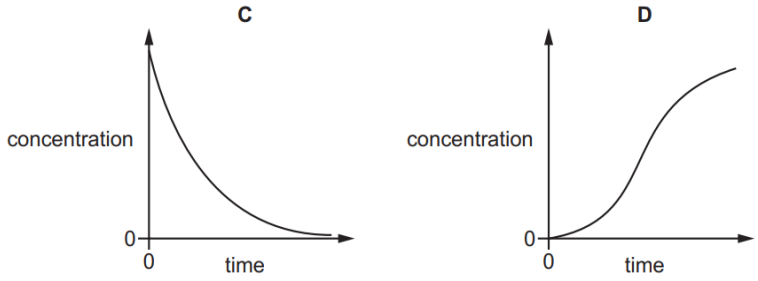
The second reason has a far greater effect.

1. Explain, in terms of activation energy, $\mathbf{E}_a$, and the collision of particles, how an increase in temperature affects the rate of a chemical reaction. [2]

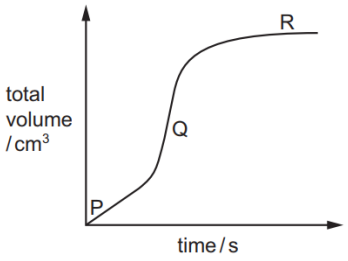
2. Cold water reacts slowly with a piece of Mg to produce bubbles of $H_2(g)$.
   Cold water reacts rapidly with burning Mg to produce $H_2(g)$ in an explosive mixture.
   $Mg + 2H_2O \rightarrow Mg(OH)_2 + H_2$
   Explain why the rate of reaction of cold water with burning magnesium is greater. [2]

1. The rate of an exothermic reaction is followed by measuring the concentration of a reactant at regular time intervals.
   During the experiment, the temperature of the reaction mixture is not controlled.
   Which graph shows the change in concentration of the reactant against time?





2. A large excess of magnesium ribbon is added to dilute hydrochloric acid and the volume of hydrogen gas produced is measured as the reaction proceeds. The reaction is exothermic.
The results are shown.



Which row explains the changes in the rate of reaction between points P and Q and between points Q and R?

	between points P and Q	between points Q and R
A	the reaction temperature is increasing	the acid concentration is falling
B	the reaction temperature is increasing	the magnesium has been used up
C	magnesium's surface area is decreasing	the acid concentration is falling
D	magnesium's surface area is decreasing	the magnesium has been used up

3. In the reaction shown, the concentrations of both X and Y are reduced to half of their original values whilst keeping the total volume of the solution constant.
$X(aq) + Y(aq) \rightarrow XY(aq)$
Simultaneously, the temperature is increased from 298 K to 348 K.
Which prediction is definitely true?

A A smaller proportion of collisions between particles of X and particles of Y will be successful.
B The average kinetic energy of particles of X and particles of Y will increase.
C The rate of the reaction will be unaffected.
D The frequency of collisions between particles of X and particles of Y will halve.

4. When the temperature of a particular reaction is increased by 10°C (e.g. from 20°C to 30°C) the rate of the reaction approximately doubles.
What is the most significant reason for this increase?

A a different mechanism for the reaction
B an increased collision frequency of the reactant molecules
C more collisions have energy greater than the activation energy
D a reduced activation energy for the reaction

5. The catalysed formation of ammonia by the Haber process can be represented by the equation shown.
$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ $\Delta H = -92$ kJ mol^{-1}
Which change in conditions will increase both the rate of formation and the equilibrium yield of ammonia?

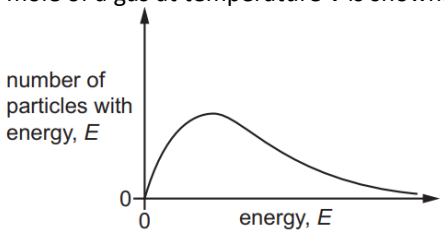
A decrease in the temperature
B increase in the temperature
C increase in the pressure
D increase in the surface area of the catalyst

Boltzmann distribution: a graph showing the number of molecules with a particular kinetic energy plotted against the kinetic energy. The exact of the curve varies with temperature. The curve shows that only a very small proportion of the molecules have very high energies.

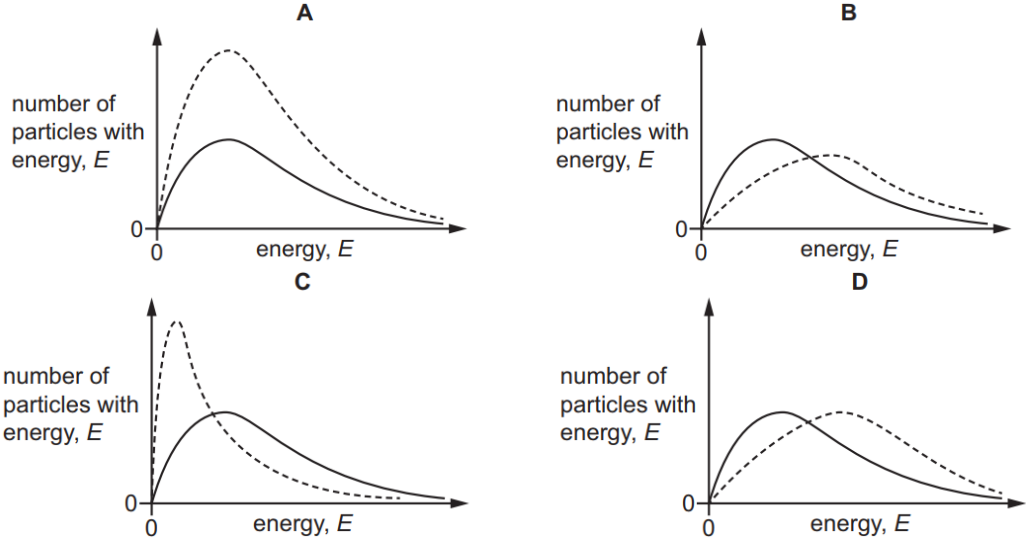
Video explanation:
https://www.youtube.com/watch?v=YacsIU97OFc

The Boltzmann distribution represents the number of molecules in a sample with particular energies. The change in the Boltzmann distribution as the temperature is increased shows that more molecules have energy greater than the activation energy. This, in turn, leads to an increase in reaction rate.

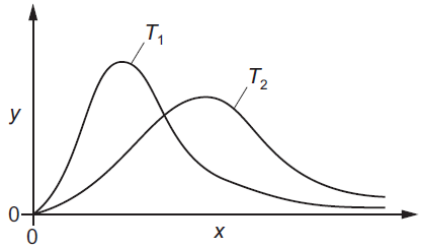
6. The Boltzmann distribution for one mole of a gas at temperature **T** is shown.



One mole of the same gas is added, and the gas remains at temperature T.
Which dotted curve shows the distribution with the added gas?



7. The diagram shows the Boltzmann distribution for the same gas at two different temperatures, T_1 and T_2.

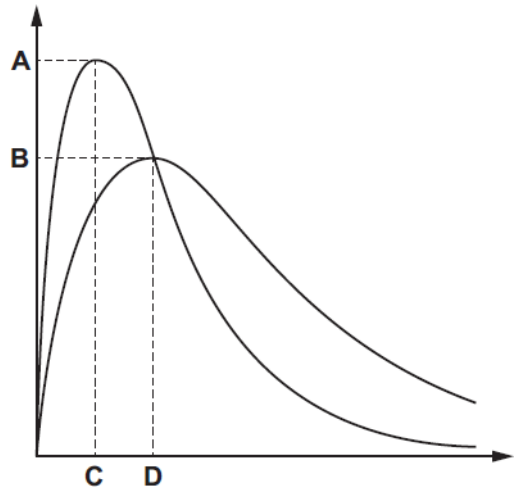


What is plotted on the y-axis and which line represents the higher temperature?

	plotted on *y*-axis	higher temperature
A	number of molecules	T_1
B	number of molecules	T_2
C	molecular energy	T_1
D	molecular energy	T_2

8. The diagram shows the Boltzmann energy distribution curves for molecules of a sample of a gas at two different temperatures.

Which letter on the axes represents the most probable energy for molecules of the same sample of gas at the **lower** temperature?



9. The temperature of a sample of an inert gas is increased.
What effect does this have on the number of molecules with the most probable energy and on the number of molecules with higher energy?

	number of molecules with higher energy	number of molecules with the most probable energy
A	decreases	decreases
B	decreases	increases
C	increases	decreases
D	increases	increases

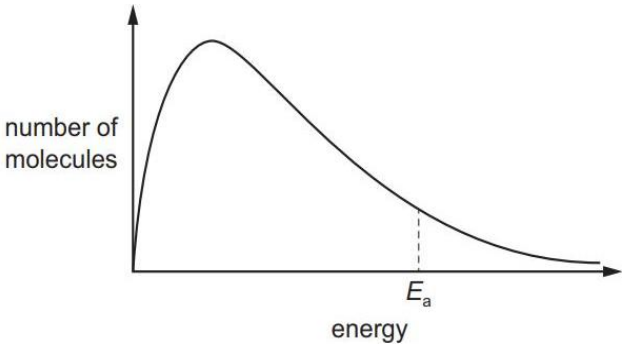
10. The height of the peak of the curve in a Boltzmann distribution represents the number of molecules with the most probable energy.
A sample of gas has its temperature decreased without changing the number of molecules present.
Which statement correctly describes a feature of the Boltzmann distribution for the gas when the temperature decreases?

A The value of the most probable energy would stay the same.
B The number of molecules with the most probable energy would increase.
C The area under the molecular energy distribution curve would decrease.
D The number of molecules at the very high energy end of the distribution would stay the same.

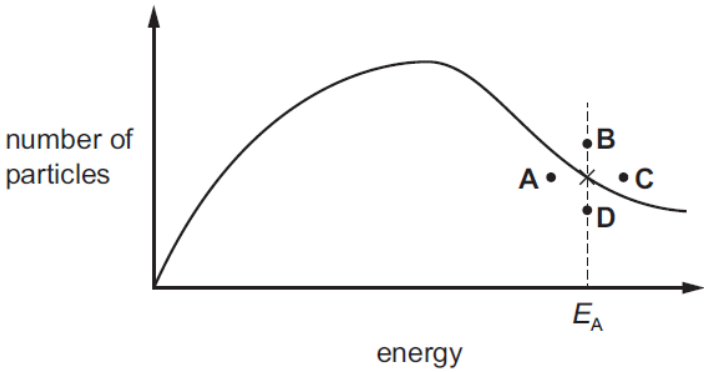
3. The rate of chemical reactions is affected by changes in temperature and pressure.
(i) Draw a curve on the axes to show the Boltzmann distribution of energy of particles in a sample of gaseous krypton atoms at a given temperature.
Label the curve $\mathbf{T_1}$ and label the axes. [2]

(ii) On the diagram in **(i)**, draw a second curve to show the distribution of energies of the krypton atoms at a higher temperature.
Label the second curve $\mathbf{T_2}$. [1]

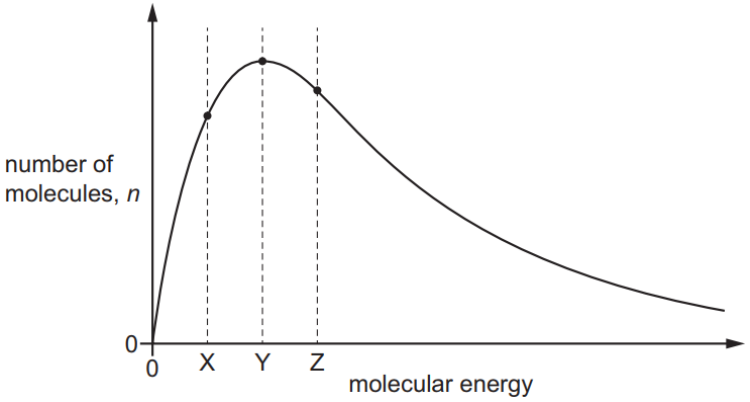
4. Fig. 3.2 shows the Boltzmann distribution of energies for molecules of **G,** $C_4H_{10}O$, at constant temperature, T°C.
Sketch, on Fig. 3.2, the Boltzmann distribution of energies for molecules of **G** at a higher temperature, (T+100)°C.



11. A Boltzmann distribution for a sample of a reacting gas at a constant temperature is shown. The activation energy, E_A, for the reaction is marked.
Point × shows the number of particles whose energy is equal to the activation energy.
The temperature of the sample of gas is decreased. The shape of the distribution curve changes.
Which point could show the number of particles whose energy is the same as the activation energy at the new temperature?



12. The Boltzmann distribution for a gas at a constant temperature of 50 °C is shown.

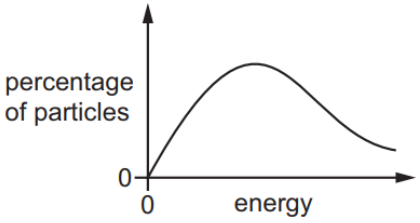


If the temperature of the gas is **reduced** by 10 °C, the graph changes shape.
What happens to the values of *n* for the molecular energies X, Y and Z?

	X	Y	Z
A	higher	lower	higher
B	higher	lower	lower
C	lower	higher	lower
D	lower	lower	lower

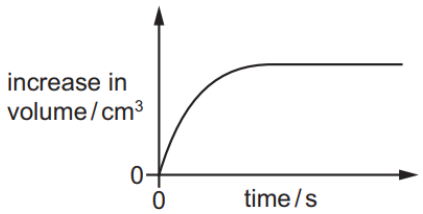
13. The Boltzmann distribution of the particles in a mixture of gas X and gas Y is shown in diagram 1.

diagram 1



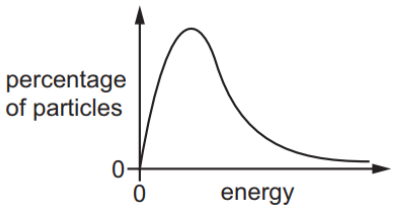
14. X and Y react and the reaction causes an increase in gas molecules present. The reaction goes to completion.
In experiment 1, the increase in volume is measured every 10 seconds. During the reaction, the temperature and pressure remain constant. The increase in volume is shown in the volume–time graph in diagram 2.

diagram 2

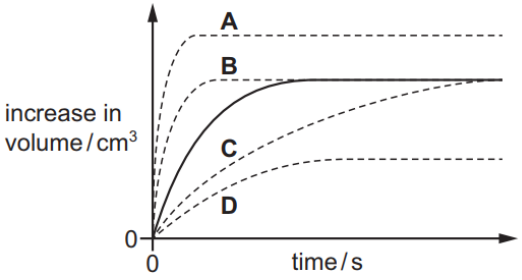


In experiment 2, the experiment is repeated using identical amounts of X and Y. A different temperature is used compared to experiment 1. The same pressure is used. The Boltzmann distribution of the second mixture of X and Y is shown in diagram 3. During the reaction the temperature and pressure remain constant.

diagram 3

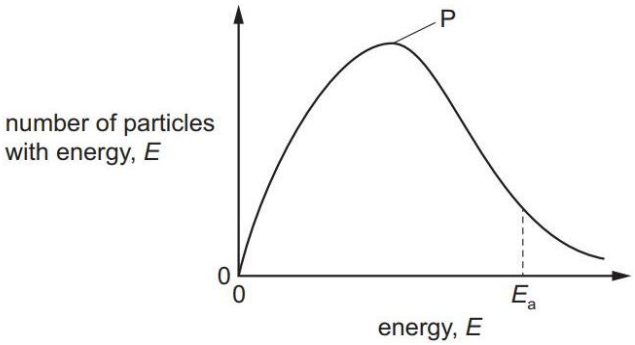


Which curve on the volume–time graph would show the increase in volume against time for experiment 2? (The original line for experiment 1 is redrawn as a solid line.)



Problems involving activation energy

15. The diagram shows the Boltzmann distribution for one mole of a gas. The gas takes part in a reaction with an activation energy, Ea.



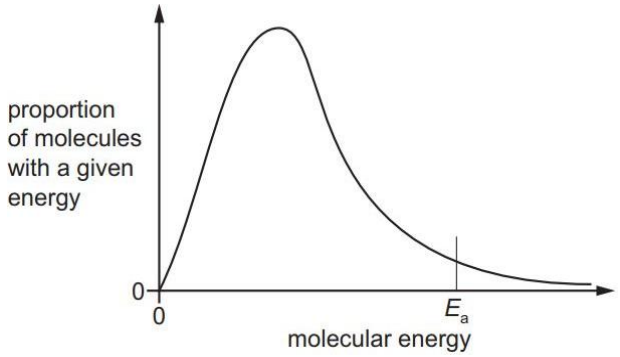
Which statement correctly describes the effect of an increase in temperature?

A	Peak P will be higher and fewer molecules will have energy > Ea.
B	Peak P will be higher and more molecules will have energy > Ea.
C	Peak P will be lower and fewer molecules will have energy > Ea.
D	Peak P will be lower and more molecules will have energy > Ea.

5. A large excess of 2-bromo-2-methylpropane is added to 0.0010mol of NaOH(aq), which contains a few drops of phenolphthalein indicator. A stopwatch is started as soon as the substances are mixed. The time taken for the pink colour to disappear is recorded.
The experiment is repeated at different temperatures, keeping all concentrations and volumes of reagents constant.

Temperature, /°C	time taken for pink colour to disappear, /s
20	300
25	65
35	20

(b) The graph shows the energy distribution of molecules in a sample of 2-bromo-2-methylpropane at 25°C. E_a represents the activation energy for the reaction.

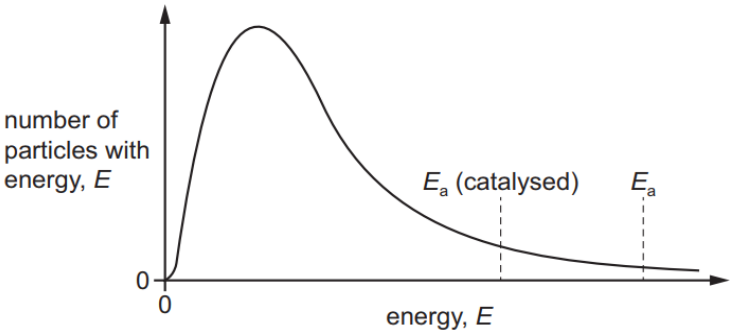


(i) Label the graph to show the proportion of 2-bromo-2-methylpropane molecules that have sufficient energy to react. [1]

(ii) Use the same axes to sketch the distribution of energies of molecules in a sample of 2-bromo-2-methylpropane at 50°C. [2]

(iii) State the effect of an increase in temperature on E_a for this reaction. [1]

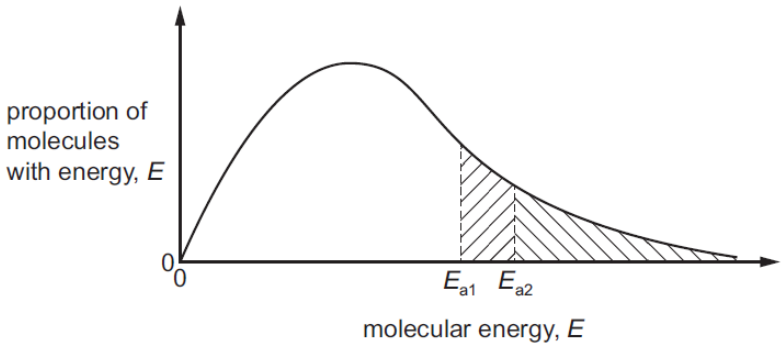
16. The Boltzmann distribution curve for a gaseous mixture of ethene and hydrogen is shown. Nickel is an effective catalyst for the reaction that occurs.



How does the diagram appear if the same reaction mixture is at a higher temperature?

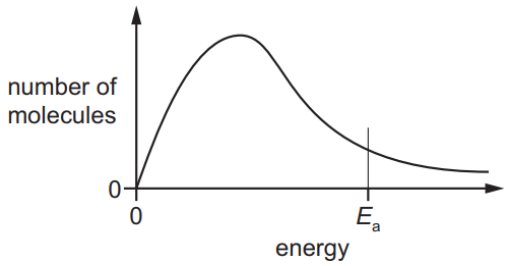
A The curve is unchanged.
B The values of both E_a (catalysed) and E_a decrease.
C The values of both E_a (catalysed) and E_a increase.
D The values of both E_a (catalysed) and E_a remain the same.

17. The diagram shows a Boltzmann distribution of the energies of gaseous molecules and the activation energies, *E*a, of a reaction with and without a catalyst.

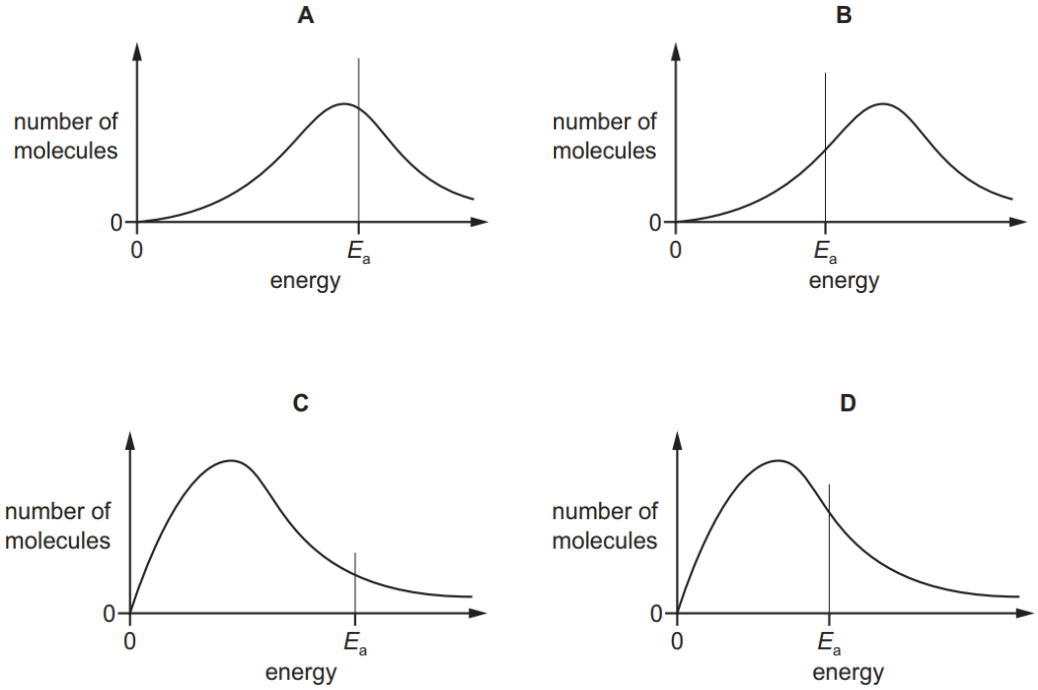


Which statement about this distribution curve is correct?
A If the temperature of the gas is increased, the maximum of the curve becomes higher.
B If the temperature of the gas is increased, the maximum of the curve moves to the left.
C The fraction of molecules that react in the presence of a catalyst is shown by  .
D The fraction of molecules that react in the absence of a catalyst is shown by  .

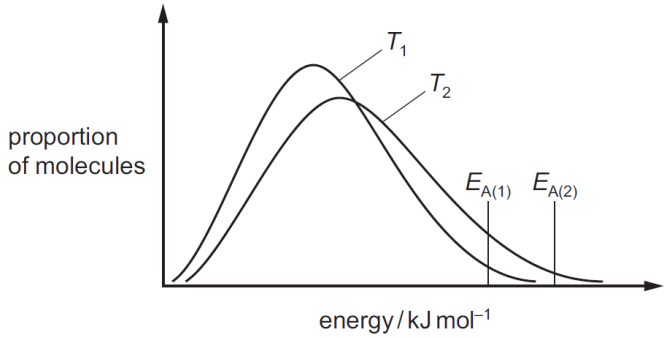
18. Measurements are made to determine the activation energy, E_a, of a reaction. The diagram shows E_a on the Boltzmann distribution at temperature T_1.



Measurements are then made at a higher temperature, T_2.
Which diagram correctly shows the Boltzmann distribution and Ea at T2?



19. The diagram shows a Boltzmann distribution of molecular energies for a gaseous reaction at two different temperatures and two different activation energies.



Which combination of temperature and activation energy will give the highest reaction rate?

A T_1 and EA(1) B T_1 and EA(2) C T_2 and EA(2) D T_2 and EA(1)

*****This is not a complete note. It is just to guide you. It is recommended to study the prescribed textbooks along with this material. *****