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Temperature Dependence on Rate of Reactions

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ABSTRACT: Reaction Kinetics deals with the Study of Rates of Chemical Reactions or Processes. It is one of the most advanced studies in the field of physical chemistry. The information about these factors affecting the rate of a chemical reaction help engineers and scientists to economically scale up the reactions to industrial scale in various industries. It is therefore very important for us to know how the rate of a chemical reaction gets affected. Temperature is one of the parameters that can affect the rate of a chemical reaction considerably. We have often seen milk boiling on a gas stove. The rate at which a specific quantity of milk boils depends on the flame of the stove. If the flame height is maximum, the milk boils in less time and if the flame height is minimum, the milk takes more time to boil. Here the flame height resembles temperature. If the temperature is high, the milk attains its boiling point in less time and if the temperature is low, the milk takes more time to attain its boiling point. The boiling of milk is not the only reaction that gets affected by temperature. Most of the chemical reactions show a change in their reaction rate with the varying in temperature.

It has been observed that the rate constant for a chemical reaction gets doubled for every 10°C rise in temperature. Until 1889, there was no fixed way to physically measure the temperature dependence of the rate of a chemical reaction. In 1889, Svante Arrhenius extended the work of J.H van't Hoff and proposed an equation that related temperature and the rate constant for a reaction quantitatively. The proposed equation was named as Arrhenius Equation.

KEYWORDS: temperature, rate, reactions, Arrhenius, chemical, equation, constant, work

I. INTRODUCTION

In chemistry, reaction rate is the frequency at which a chemical reaction proceeds. It is also expressed either in terms of the concentration (amount per unit volume) of a substance produced in a time unit, or the concentration of a reactant absorbed in a time unit.

Here is the Arrhenius Equation on the temperature dependence of the rate of a chemical reaction.

$$k = A e^{-E_a/RT}$$

Where,

k= rate constant of the reaction

A= Arrhenius Constant

E_a= Activation Energy for the reaction (in Joules mol⁻¹)

R= Universal Gas Constant

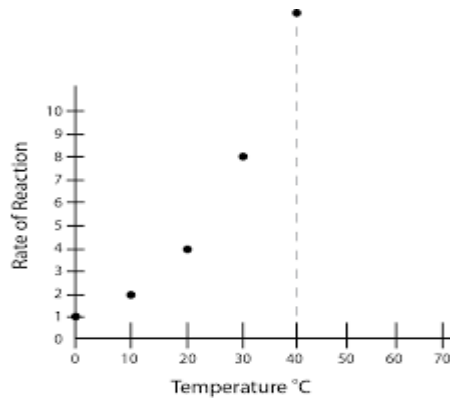
T= Temperature in absolute scale (in kelvins)[1,2]

We knew that the rates of reaction increase with an increase in temperature but it was not known on how to predict the relation between temperature and reaction rates quantitatively. Arrhenius Equation has enabled us to overcome this problem. It is an empirical relation that is used to model the variation of the rate constant with the temperature, that in turn gives information about the rates of chemical reactions at different temperatures.



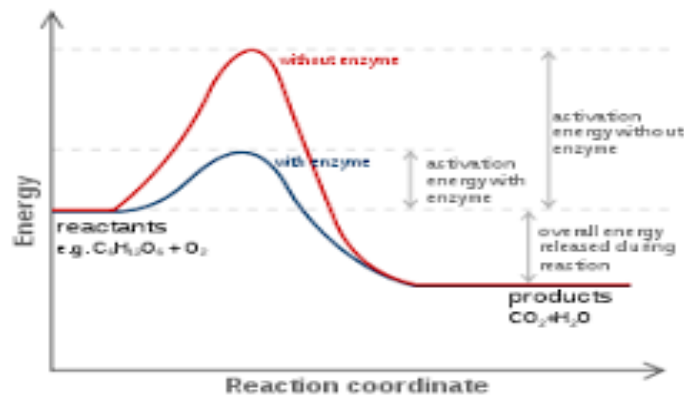
Arrhenius

Usually reaction rates are expressed as the reactant concentration consumed or the product concentration produced per unit time. And the units are moles per unit time per litre, written as M / s, M / min, or M / h. Where (M= mole/lit) Changing pH , temperature, and/or concentration of the substratum may alter the rate of chemical reactions. Substrate is the enzyme complex to which it binds. Optimal pH increases the reaction rate of the enzyme, whereas it reduces by less than optimal pH. It is ultimately damaged by denature of an enzyme. If all the enzymes in the system bind to the substrate, the additional molecules of the substratum must wait before the enzyme becomes active after the reaction is complete. Which means the reaction rate will decrease as the concentration of the enzyme decreases.[3,4]



For example, the time taken to melt a metal will be much higher at a lower temperature but it will decrease as soon as we increase the temperature. It has been found that the rate constant is nearly doubled for a chemical reaction with a rise in temperature by 10°.

II. DISCUSSION






According to the Arrhenius equation, a reaction can only take place when a molecule of one substance collides with the molecule of another to form an unstable intermediate. [5,6] This intermediate exists for a very short time and then breaks up to form two molecules of the product. The energy required to form this intermediate is known as activation energy (E_a).

Chemical Kinetics toppr

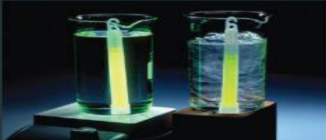
Factors Influencing Rate of a Reaction

Nature of Reactants



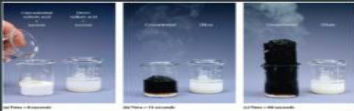
- Faster rate when both the reactants are in liquid phase.
- Collision frequency is more in liquid phase
- The reaction rate of a heterogeneous reaction depends on the surface area of the more condensed phase.

Temperature



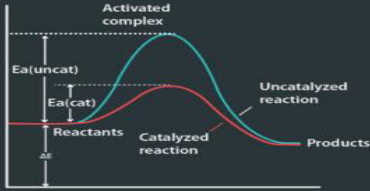
- The reaction rate of virtually all reactions increases with increase in temperature
- Temperature increases Average kinetic energy of the particle increasing the collision frequency of the constituent particles.

Concentration of the Reactants



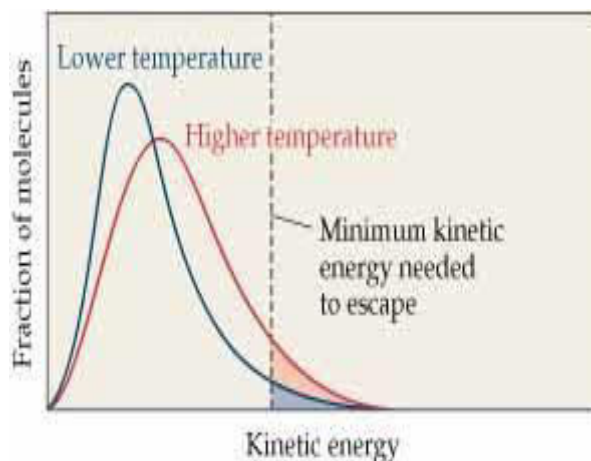
- The reaction rate usually increases as the concentration of the reactants increases.
- The more reactant particles that collide per unit time, the more often a reaction between them can occur.

Presence of a Catalyst



- The catalyst provide an alternate pathway to the reaction to proceed.
- The catalysed pathway has a lower Activation Energy.
- Because of its lower Activation Energy, the reaction rate of a catalysed reaction is faster than the reaction rate of the uncatalyzed reaction at the same temperature

Obviously, all the molecules do not have the same energy. The distribution of kinetic energy can be described by plotting the fraction of molecules with given kinetic energy vs kinetic energy. The peak of the curve in the graph corresponds to the most probable kinetic energy. When the temperature increases, the maximum of the curve moves to the higher energy value. Therefore, the curve broadens.[7,8]





Increasing the temperature increases the fraction of molecules, which collide with energies greater than the activation energy E_a .

In Arrhenius equation, the factor $e^{-E_a/RT}$ corresponds to the fraction of molecules colliding with activation energies more than E_a . Taking natural logarithms of both sides of the equation I, we get,

$$\ln k = -E_a/RT + \ln A \dots\dots\dots(II)$$

Therefore, from the Arrhenius equation, we can find that increasing the temperature or decreasing the activation energy will result in an increase in the rate of the reaction and an exponential increase in the rate constant. In a graph of activation energy vs rate of reaction, slope = $-E_a/R$ and intercept = $\ln A$.

At temperature T_1 , equation II will be

$$\ln k_1 = -E_a/RT_1 + \ln A \dots\dots\dots(III)$$

At temperature T_2 , equation II will be

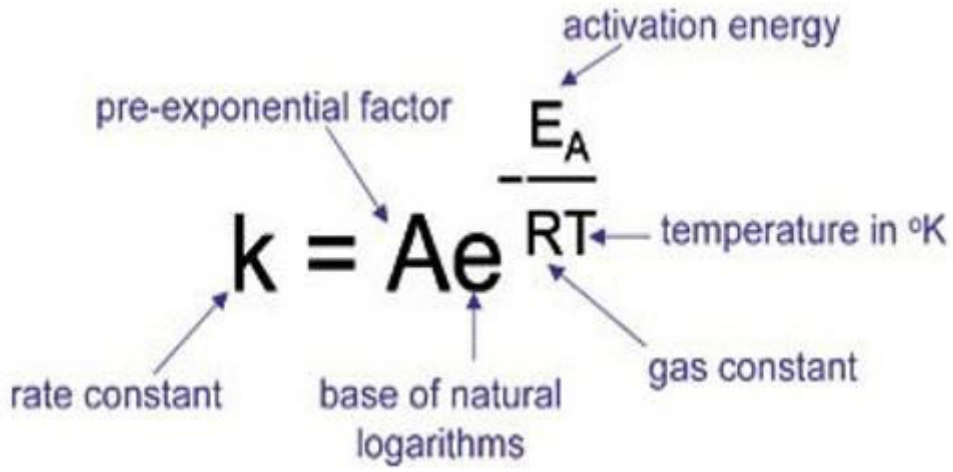
$$\ln k_2 = -E_a/RT_2 + \ln A \dots\dots\dots(IV) \text{ (} k_1 \text{ and } k_2 \text{ are the rate constants at temperature } T_1 \text{ and } T_2 \text{)}$$

Subtracting equation III from equation IV, we get[9,10]

$$\ln k_2 - \ln k_1 = E_a/RT_1 - E_a/RT_2$$

$$\therefore \ln k_2 / k_1 = (E_a/R)[1/T_1 - 1/T_2]$$

$$\therefore \log k_2 / k_1 = (E_a/2.303R)(T_2 - T_1)/T_1T_2]$$





III. RESULTS

A catalyst is a material that enhances the rate of a reaction while not undergoing any lasting chemical changes. Intermediate Complex Idea: A catalyst makes transient bonds with reactants to produce an intermediate complex, according to this theory. This complex decomposes over time, releasing products and the catalyst.[11]

A catalyst decreases the potential energy barrier by lowering the activation energy. As a result, the catalyst gives an alternative reaction pathway. Catalyze a large number of reactants with a minimal amount of catalyst. Gibbs' energy is not changed by a catalyst. A catalyst can only catalyze spontaneous reactions and not non-spontaneous reactions. Furthermore, a catalyst does not alter the equilibrium constant; rather, it aids in the speedier attainment of equilibrium.

Chemical reactions can be speed up or slowed down by changing the pH, temperature, or concentration of the substratum. The enzyme complex to which it interacts is referred to as the substrate. The enzyme's reaction rate increases at appropriate pH, but decreases at less than optimal pH. It is eventually harmed when an enzyme is denatured.[12]

IV. CONCLUSIONS

Both the Arrhenius activation energy and the rate constant k are experimentally determined, and represent macroscopic reaction-specific parameters that are not simply related to threshold energies and the success of individual collisions at the molecular level. Consider a particular collision (an elementary reaction) between molecules A and B. The collision angle, the relative translational energy, the internal (particularly vibrational) energy will all determine the chance that the collision will produce a product molecule AB. Macroscopic measurements of E and k are the result of many individual collisions with differing collision parameters. To probe reaction rates at molecular level, experiments are conducted under near-collisional conditions and this subject is often called molecular reaction dynamics. Another situation where the explanation of the Arrhenius equation parameters fall short is in heterogeneous catalysis, especially for reactions that show Langmuir-Hinshelwood kinetics. Clearly, molecules on surfaces do not "collide" directly, and a simple molecular cross-section does not apply here. Instead, the pre-exponential factor reflects the travel across the surface towards the active site. There are deviations from the Arrhenius law during the glass transition in all classes of glass-forming matter. The Arrhenius law predicts that the motion of the structural units (atoms, molecules, ions, etc.) should slow down at a slower rate through the glass transition than is experimentally observed. In other words, the structural units slow down at a faster rate than is predicted by the Arrhenius law. This observation is made reasonable assuming that the units must overcome an energy barrier by means of a thermal activation energy. The thermal energy must be high enough to allow for translational motion of the units which leads to viscous flow of the material.[13]

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