Industrial Chemistry

Energy

Energy is defined as the ability to do work. We rely on it in every aspect of our lives. We need energy for food to live, energy from fuel for transport, energy from electricity for entertainment, cooking and lighting.

The industrial revolution began when scientists discovered how to get energy from burning coal. This led people to move from small self-sufficient farms to cities to work in the big coal consuming factories. Since this time we have been "slaves" to this energy to the point that if it were not for coal and other fossil fuels, people would find it very hard to survive. Currently most people on Earth use 100 times more energy than they need to survive each day.

The sources from which we can obtain energy are quite large. Some of these sources are renewable, they can be regrown, or make use of natural phenomena that will not disappear. Others are not renewable, often mined these sources of energy will not last forever. Some common sources of energy are shown below

Renewable	Non-renewable
Solar	Nuclear
Hydro	Coal
Tidal	Petrol
Wind	Natural Gas
Geothermal	Oil

These sources of energy also fall under different types of energy. Each of those shown in the table above can be used to produce electricity, however they go about it in a different way. Some types of energy are shown below

- Chemical
- Heat
- Electrical
- Kinetic
- Potiential
- Light and Sound

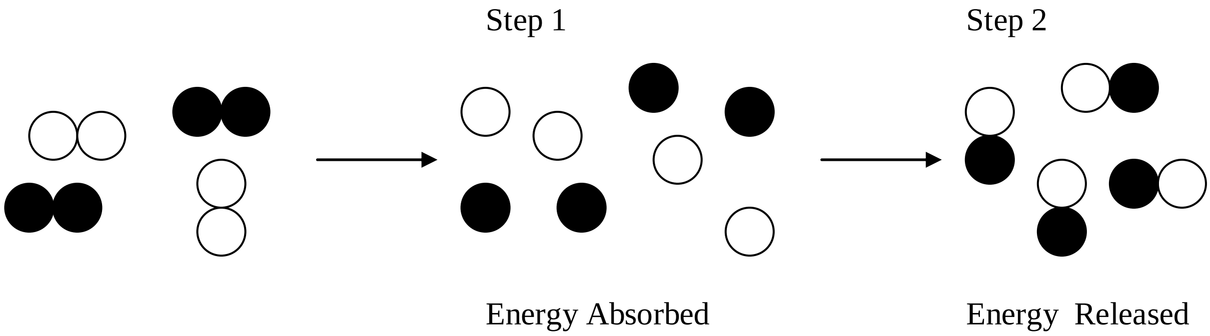
All of the types of energy shown above can be converted from one form to another. In the case of electricity production you can have coal which is chemical energy being transformed into electrical energy. With wind farms kinetic energy of the blades is being converted into electrical energy. In chemistry we are normally only concerned with chemical, heat and electrical energy.

As with most aspects of science, energy needs to be quantified in some way, it must be able to be measured. Energy has its own unit called a **joule (J)** and 1 joule is defined as the energy required to rase the temperature of 1g of water by 0.239^{O}C. In other words 4.18 J is the energy needed to raise 1g of water by 1^{O}C.

Chemical Energy

Chemical energy is the energy that can be obtained from chemical reactions. It is the energy we get from food, the energy we use to generate electricity and the energy used to provide warmth. Some reactions such as explosions release a lot of energy quickly, whilst rusting is a very slow reaction.

To understand where this energy comes from we must first understand how a reaction works or the **reaction mechanism**. Any chemical reaction occurs in two parts. Firstly the bonds between the reactant molecules must split, this requires energy from the surroundings. The second part of this mechanism now involves the split reactant molecules now bonding in a new configuration, this process releases energy. The two steps can be shown in the diagram below.



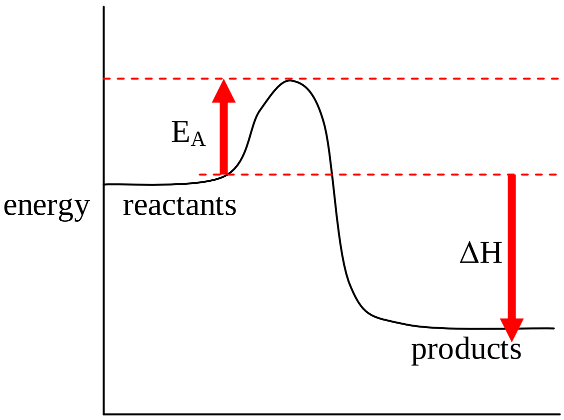
In most cases the energy released and absorbed is done so in the form of heat. This transfer of heat, the release of heat to the surroundings and the absorption of heat from the surroundings is known as the **enthalpy (ΔH)**. Enthalpy can be calculated using the following formula

$$\Delta H = \pm 4.18 \times \Delta T \times V(H_2O)$$

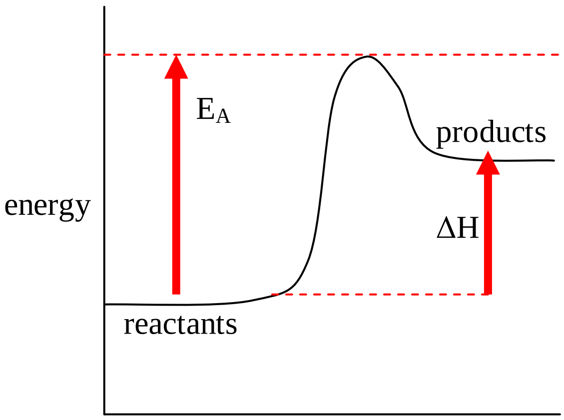
Therefore we can find out the enthalpy or energy released or absorbed from a reaction given the change in temperature and the volume of water used (in mL)

In some reactions the energy released when forming bonds is much greater than the energy needed to break them. In this case a great deal of heat energy will be released to the surroundings therefore increasing the temperature. These reactions that produce heat are known as **exothermic** reactions. Other reactions require a lot more energy to break the bonds than is released when bonds are formed, this means that more heat is being taken out of the surroundings than being returned to it. This causes a temperature drop and these are known as endothermic reactions.

The transfer of energy in reactions can be demonstrated in an **energy profile diagram**. They show the energy changes as the reaction occurs and they are shown below. In these graphs E_A represents the activation energy. Activation energy is the minimum amount of energy required for the reaction to occur, or the minimum energy required to break the bonds to initiate the reaction mechanism.



Exothermic – Energy Released



Endothermic – Energy Absorbed

Rate of Reaction

Rate of reaction is the speed at which a chemical reaction occurs. Some reactions are fast like explosions and some are slow such as rusting. Learning about rate of reaction is essentially about learning how to control a chemical reaction so that we can speed it up to make more of the required product faster, or slow it down to make the reaction safer. Often in many industrial processes it is a matter of balance, speeding up the reaction to the point where it is occurring quicker whilst still retaining control.

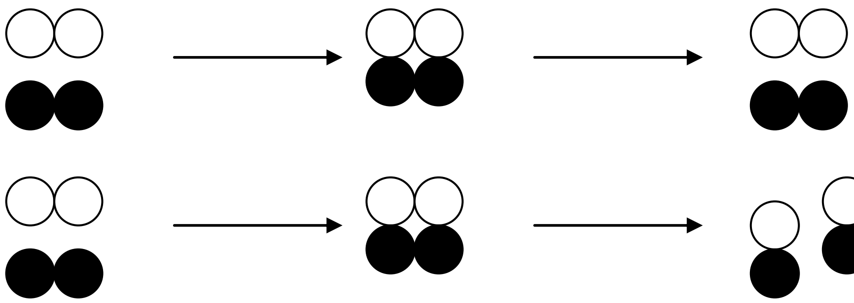
<u>Collision theory</u>

Rate of reaction is essentially about collision theory. Collision theory ties closely to what we have been looking at in terms of the reaction mechanism and activation energy. Collision theory states two things

1. For molecules to react they must collide.

2. They must collide with sufficient energy to overcome the activation energy.

The picture below will help to demonstrate this concept



Collision energy lower than E_A. Molecules bounce off each other (non-productive collision)

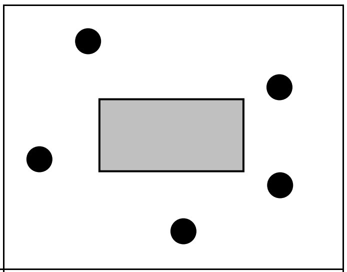
Collision energy higher than E_A. Molecules react (productive collision)

Therefore as explained above no reaction will occur if the reactant particles do not collide. Even if they do collide if they don’t have sufficient energy then they will just bounce off of each other

Factors Influencing Rate of Reaction

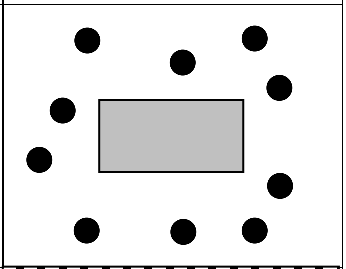
There are many factors that influence rate of reaction and they are all in some way based on collision theory above. Knowing how to control a reaction using these factors is critical in industry in producing maximum product for minimum cost.

We will be basing our comparison on the reaction shown opposite →



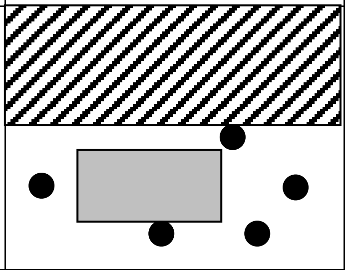
Concentration

By increasing the concentration you are increasing the number of reactant particles. This increases the chance of a collision as there are more molecules to bump into and refers to part 1 of collision theory.



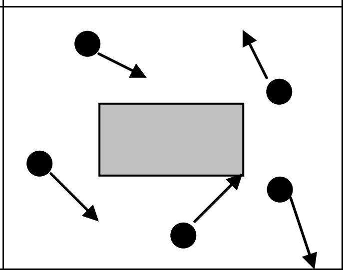
Pressure

By increasing the pressure you are effectively decreasing the volume of the container. This means you have the same number of particles in a smaller volume and therefore you have increased concentration. This increases the chance of a collision (collision theory part 1)



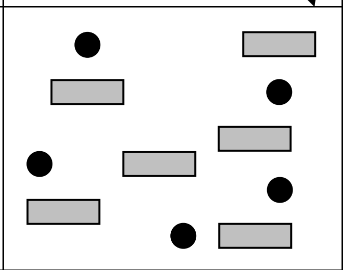
Temperature

Increasing the temperature will increase the energy of the reactant particles so when they collide it is more likely that they will have overcome the activation energy and it will be a productive collision (collision theory part 2).



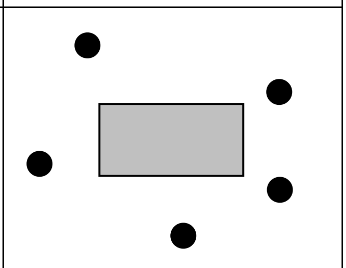
State of Subdivision

By using a greater state of subdivision you are increasing the surface area and therefore increasing the area that is exposed to the reactant particles. This will increase the chance of a collision therefore increasing reaction rate (collision theory part 1)



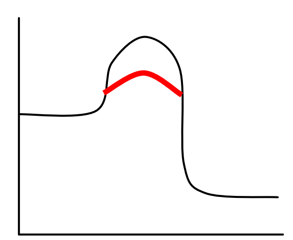
Intensity of Light

Increasing the intensity of lightwill increase the energy of the reactant particles **in a photochemical reaction** so when they collide it is more likely that they will have overcome the activation energy and it will be a productive collision (collision theory part 2).



Catalyst

Catalysts neither increase the chance of a collision or increase the energy of reactant particles. Instead what they do is provide an alternative pathway for the reaction to proceed in which has a lower energy than the activation energy. This is shown on the energy profile diagram opposite.



To explain a few of the terms above a photochemical reaction is a type of reaction that is initiated by light. An example of this is photosynthesis, without light this reaction will not occur.

Catalysts are chemical species that can increase the rate of a chemical reaction, but they do not take part in it, they are not consumed. One group of very important catalysts are **enzymes.** Enzymes are biological catalysts that are found very commonly within living things. The advantage of enzymes is that they are much faster than any other inorganic catalyst. They are often up to 1 million times faster than the reaction would normally occur at. Enzymes however have only a very specific function. One enzyme will only speed up one particular type of chemical reaction. Therefore we must have one enzyme for almost every chemical reaction that takes place in the body. Hence the body has about 700 different enzymes to deal with the various chemical reactions taking place every day.

Equilibrium

Since you have started looking at any chemical reaction in science you would have been told that you add these things together and they turn into these things. It indicated that what you added together was no longer there, it had been completely been changed into new substances. However this is not always the case. There are quite a few reactions around where there is not a complete change of reactants into products but rather a balance set up between reactants and products. This balance is called an equilibrium.

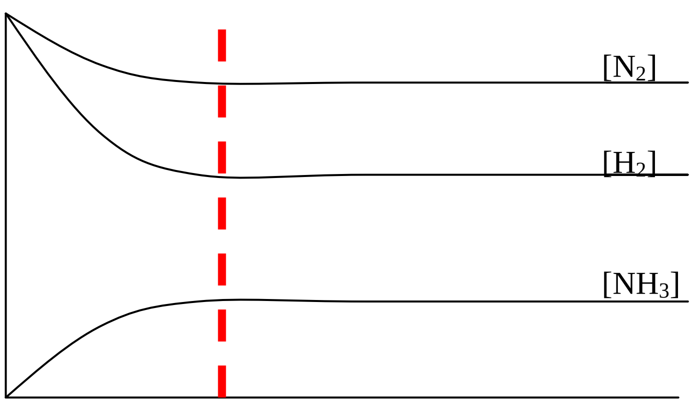
Equilibrium reactions are those where the reactants are consumed until a balance is set up. Once this balance is set up, since it is a dynamic equilibrium, there is no change in the concentration of reactants and products, however the reaction is still occurring, the forward and reverse reactions are occurring at the same rate.

Equilibrium can only be achieved in a closed system. A closed system is defined as one where there can be no change in the concentration of any of the reactants or products.

Let us take an example of an equilibrium process below

$$3H_{2(g)} \quad + \quad N_{2(g)} \rightleftharpoons 2NH_{3(g)} \qquad \Delta H = -92 \text{ kJ}$$

If we take a look at how the reaction proceeds we would see a graph as shown below



As you can see at the start the concentration of reactants is decreasing at the start and the products are increasing as expected however afre a while there is a point at which the concentration levels out for all lines this is where equilibrium has occurred and will continue like this until altered.

Since it is an equilibrium any external change to this system will change the position of the equilibrium. This is best explained by Le Chateliers Principle which is shown below.

> If an external change is made to a system at equilibrium then the equilibrium will shift to counteract the change.

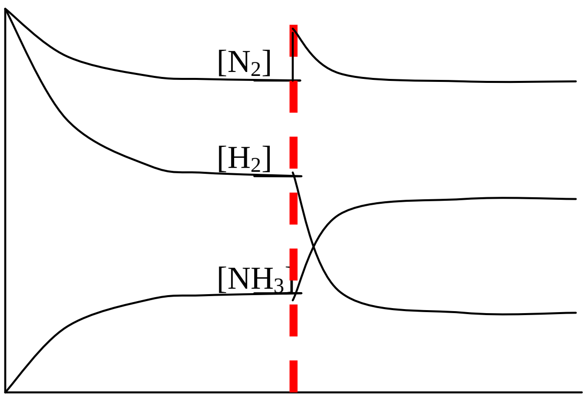
Therefore if the temperature is increased then the equilibrium will shift to decrease it, if the pressure is decreased the equilibrium will try to increase it and if more of one reactant is added it will shift to decrease it. We will examine each of these individually, it is important to note that equilibrium will always be established again..

<u>Effect of concentration</u>

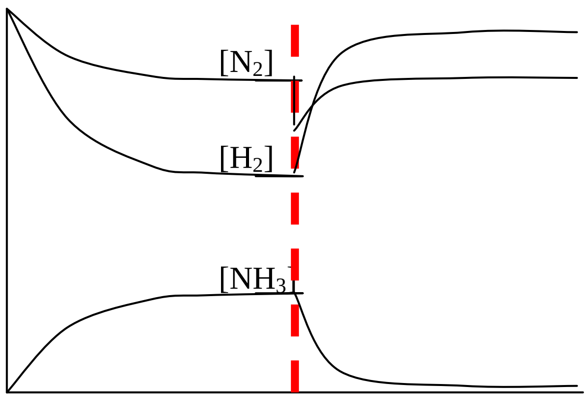
Increasing or decreasing the concentration of any substance in an equilibrium to shift. If you increase the concentration of a species the equilibrium will shift to consume it and will therefore produce more of the other side of the reaction. Whereas on the other hand if you decrease the concentration of a species it will shift to that end.

We will again examine the example of the equilibrium given below

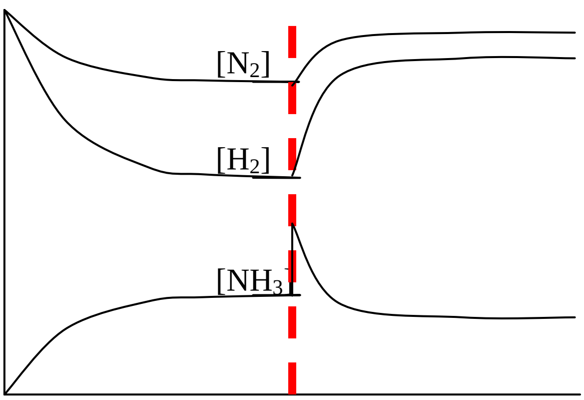
$$3H_{2(g)} + N_{2(g)} \rightleftharpoons 2NH_{3(g)} \qquad \Delta H = -92 \text{ kJ}$$



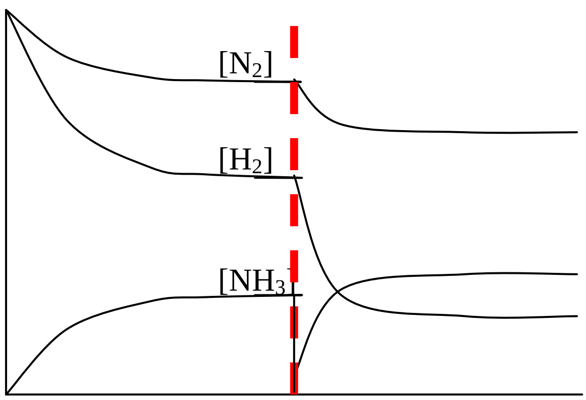
Increase [N₂]



Decrease [N₂]



Increase [NH₃]

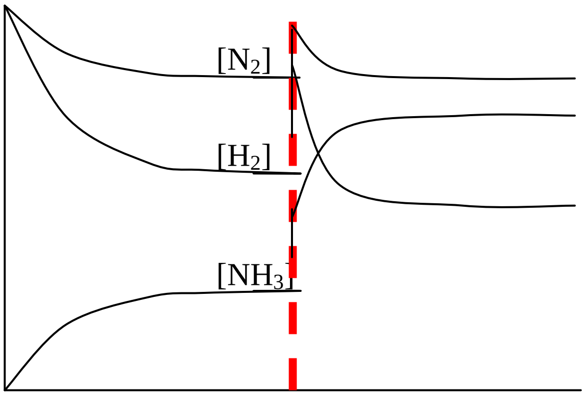


Decrease [NH₃]

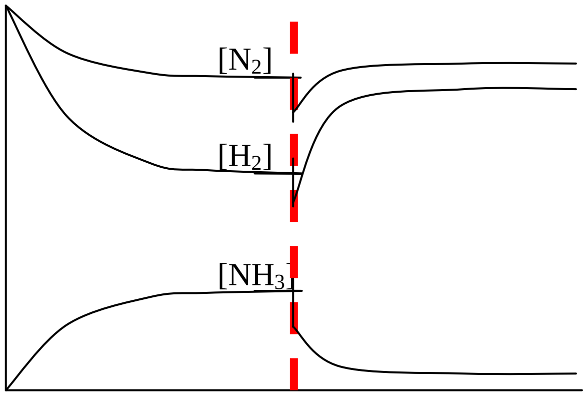
Effect of Pressure

When the pressure of a system at equilibrium is increased the equilibrium will want to counteract this. The way that it does it is to shift it so that you minimise the amount of gas molecules in the system. Conversely if the pressure of the system was decreased then the equilibrium would shift to increase the number of gas molecules and hence increase the pressure. In the equation below there are 4 gas molecules on the reactants side and 2 gas molecules on the products side. Therefore an increase in pressure would favour the production of the products, whereas a decrease in pressure would favour the reactants We will again examine the example of the equilibrium given below

$$3H_{2(g)} + N_{2(g)} \rightleftharpoons 2NH_{3(g)} \qquad \Delta H =-92\ kJ$$



Increase Pressure

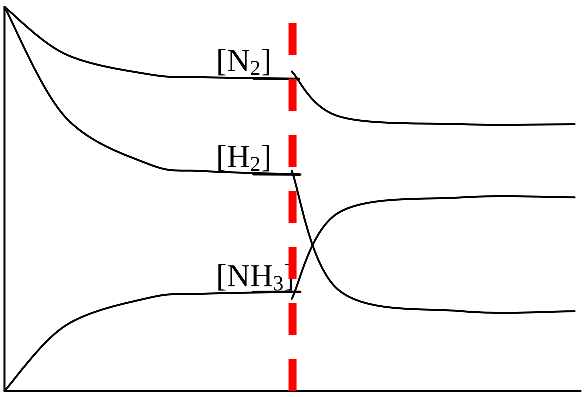


Decrease Pressure

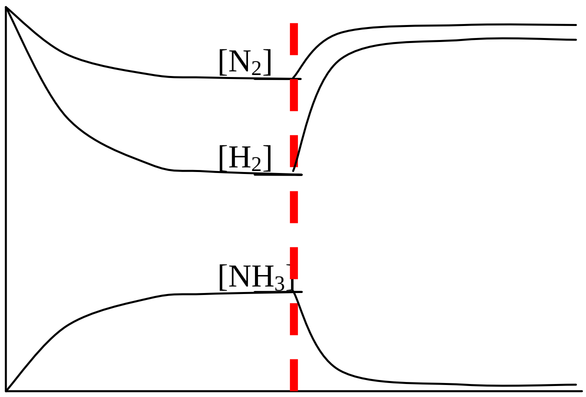
Effect of Temperature

An increase in temperature of the system will mean that the equilibrium will shift to decrease the heat. Therefore an endothermic reaction will be favoured as they absorb heat. Looking at the reaction below it is an exothermic reaction in the forward reaction and therefore the reverse reaction is endothermic and will be favoured. On the other hand if the temperature was decreased it would favour the forward reaction as there would be an increase in temperature. We will again examine the example of the equilibrium given below

$$3H_{2(g)} + N_{2(g)} \rightleftharpoons 2NH_{3(g)} \qquad \Delta H =-92\ kJ$$



Decrease Temp



Increase Temp

Industrial Chemical Processes

Industrial and Chemical plants need to make a lot of considerations before deciding to build. Some of these considerations include

• Land Cost	Chemical plants often occupy large areas of land
• Availability of Labour	Preferable to have a plant near a trained or skilled work force.
• Access to Energy and Raw Materials	Costs of energy supply and transport of raw materials must be kept to a minimum
• Cooling Water	If large quantities of cooling water are required, plant should be sited near a river, lake or the sea
• Access to Markets	Important to ensure that you can sell your product
• Availability of Equipment	Transporting large items of equipment to site can be expensive.
• Regulatory Restrictions	Government regulations on emissions of gases or disposal of liquid or solid wastes can strongly influence the choice of site of a plant.
• Safety	When processes produce toxic, flammable or explosive materials, the OHS&W of workers and people living nearby is important
• Transport	Must be easy to access various modes of transport (road, rail, sea) and must be situated in a way that minimises these costs.

Often the major cost for any industrial process is the cost of energy. It often outweighs the cost of raw materials and labour. Energy use must be kept to a minimum to maximise profit. There are many ways that energy costs can be minimised.

- Transfering heat energy – heat energy release by an exothermic reaction can be transferred to another part of the process requiring heat using heat exchangers.
- Operating chemical processes at lower temperatures – using a catalyst allows the same rate of reaction at a lower temperature. There must also be a negotiation between increased product and increased energy costs normally there is a balance struck having a moderately high temperature and pressure.
- Running a process continuously – Stopping and starting a process regularly not only uses a lot of energy to start up but also costs a lot of time, therefore most plants elect to run their process continously