pH Notes

Acid = substance which in solution can break down other substances by donating hydrogen ions to them

Base = substance which in solution can break down other substances by accepting (or taking) hydrogen ions from these substances. If you like a base is like a 'hoover' for H+ ions.

What is pH?

The term 'pH' means 'power of hydrogen'. It is based on the concentration of hydrogen ions (H+ ions) in a solution. It is a measure of acidity or basicity (corrosiveness) of a substance

Why just focus on hydrogen ions?

There are 2 reasons;

1) the hydrogen atom is the **smallest atom** you can get (i.e. it is 1 proton surrounded by 1 electron). This means that when it loses its electron (to form a H+ ion) it becomes just a proton. Because of its small size it is very easy for a H+ to move around to attack molecules and break them down ie to corrode things. Also because it is just a single proton with one unit of charge (i.e. one positive charge) this means it has a **high amount of charge** for its size when you compare it to other ions e.g. the Na^+ ion has a total of 23 neutrons and protons for the <u>same charge</u>. This is like having the same engine in a small light sports car verses being in a heavy truck so H+ ions can easily be attracted (or repelled) by things which furthers its ability to do damage. The result is hydrogen ions are potentially much more damaging than other ions, particularly when they are in excess.

2) H+ ions are **extremely common** particularly in water based solutions. Water is an excellent solvent, occurring throughout the natural world and it is also the most common solvent when making up solutions in chemistry. In any volume of water (even in pure water) there are always a tiny amount of molecules that will go through the reversible reaction

(a) $H_2O \leftrightarrow H^+ + OH^-$

(ie they will split into ions) so it contains a tiny no of moles of H+ ions (10^{-7} mol/l). All of this has led to the focus on H+ ions and in turn to the creation of the pH scale.

The H+ ion concentration of 10^{-7} mol/l is the default concentration of H+ against which the H+ concentration of other solutions are comparted. If a solution has a concentration greater than this, eg 10^{-5} mol/l, then it is acidic. If the concentration is less it is basic.

It should be noted that even though pure water contains H+ ions it isn't corrosive. This is because there are *equal numbers of H+ and OH^-*. Think of it as if the other ion acts like a parent of the first keeping it out of trouble; the H+ ions are prevented from reacting with other molecules by OH^- ions and H+ ions in turn prevent OH^- ions from reacting with other substances. However when you add an acid (e.g. HCl) to the water it results in a change in the balance of numbers of H+ ions over the number of OH^- ions. This means there aren't enough OH^- ions to prevent the H+ ions from reacting with other substances and corrosion can occur. [When you add molecules of HCl to water HCl splits into H+ and Cl^- ions. Because Cl^- discards the H+ so strongly and there aren't enough OH- ions to keep it under control the H+ ions are essentially free to attack other molecules]. The more concentrated HCl acid is (HCl *solution* is known as hydrochloric acid, HCl by itself

is a gas) the greater the concentration of H+ ions available to react and so the more corrosive it is. The result of this is when you pour concentrated HCl on something, e.g. a metal, it can easily corrode it.
But not all acids are this corrosive. Acidic molecules can vary in how much they want to discard their H+. When a weakly acidic molecule e.g. ethanol (C_2H_5OH) is put in water it will split a little into a negative ion ($C_2H_5O^-$) and H+. But because $C_2H_5O^-$ still has a good attraction to H+ the H+ ion remains close to it and isn't really free to attack other substances (a bit like the OH- in equation (a) above). Therefore C_2H_5OH isn't very corrosive.

(Note that in water the concentration of H+ ions will increase as you increase it's temperature i.e. it pushes equation (a) above over to the right. This doesn't mean that water becomes corrosive at higher temperatures because as the concentration of H+ increases the concentration of OH^- increases by the same amount. It is only when other substances are added to water that this balance of H+ and OH- ions is upset. It also alters the direction of equation (a) above).

What happens with bases?

In the case of bases, which readily accept H+ ions, when you add a base to water this affects equation (a) by the base binding to the H+ ions which causes the concentration of H+ to decrease below 10^{-7} mol/l and leaves an excess of OH- ions. This means there are few H+ ions available to prevent the OH- ions reacting. OH- ions are reactive and also small which is why bases are also corrosive. This is what happens when you dissolve ammonia (NH_3) in water; NH_3 binds to H+ (from equation (a)) as follows:

$$NH_3 + H^+ \leftrightarrow NH_4^+$$

and OH- ions are left behind which can attack molecules causing corrosion.

Another effect of removing H+ is it causes equation (a) to go to the right i.e. more water molecules will dissociate into H+ and OH-. More NH_3 will bind to these H+ ions leaving behind more OH-.

In the case of NaOH which is a strong base and so dissociates fully into Na+ and OH- ions when you put it in water (ie it provides its own OH-) the concentration of H+ in the water decreases because the OH- ions from the NaOH will react with them (which forces equation (a) over to the left). But because NaOH is added in excess this means there is an excess of OH- ions available and little H+ ions to help neutralise them. Therefore the OH- is free to react with other molecules.

Note that water with NaOH in it will still have small concentrations of H+ because the equation (a) will still occur ie further H_2O will breakdown. Because there is so much OH- ions around the concentration of H+ tends to be small (less than 10^{-7} mol/l) but there are still H+ present. Hence the pH scale can still apply to basic solutions but in that case the corrosiveness is due to OH- ions.

The pH scale

Another way of looking at the pH scale is it is a way of measuring the 'corrosiveness' of a solution where this is due to either the H+ ion of the OH- ion being in excess.

As mentioned above in pure water there are H+ ions. The concentration of these is 0.0000001 (or 10^{-7}) moles per litre of water i.e. only a small number of the water molecules at any one time splits into H+ and OH-ions. In concentrated sulphuric acid the concentration of H+ ions is around 0.1 (or 10^{-1}) moles per litre of solution. Writing these concentrations involves dealing with awkward numbers and in the chemical industry when you have to write them repetitively in this way it is very inconvenient. It also can be difficult to compare them with each other if needed. A guy called Soren Peter Sorenson devised a simpler way which was based on the indice (the power or 'Log') of the concentration of the H+ ions. For example in pure water, which is neutral (non-reactive) due to the equal numbers of H+ and OH-, the concentration is 10^{-7} moles per litre. He took the indice which is –7 and multiplied it by –1 to get rid of the negative sign to get a pH value of 7 i.e. pure water has a pH of 7. If you take a solution of HCl with a H+ concentration of 1 (or 10^{0}) mole per litre and use the same approach this has a pH of 0.

However let's say the concentration of H+ is 7.1×10^{-7} moles per litre. Another way of writing this is by finding the log of it which is $10^{-6.15}$ i.e. the indice (or power) that 10 would be under to get 7.1×10^{-7} is -6.15. So the pH is 6.15.

Whenever you need to find the pH of a solution you use the formula:

(b) $pH = -1 \times \text{Log}_{10}\,[H+]$

where [H+] is the concentration of H+ in the solution.

(Note that in an exam if you asked what is pH you can use this formula as a definition)

This is how you calculate the pH (or corrosiveness) of a solution. In bases as far as we are concerned there are very very few H+ ions. It's easier to measure the concentration of OH- using a formula similar to (b) above. That is

$$pOH = -1 \times \text{Log}_{10}\,[OH-]$$

where [OH-] is the concentration of OH-.

The pOH is then subtracted from 14 to give the pH

i.e. pH + pOH = 14 therefore 14 – pOH = pH