pH Calculations

All aqueous solutions (water) contain some H^+ ions and some OH^- ions.

- *Neutral* solutions contain equal concentrations of each
- *Acidic* solutions contain more H^+ ions
- *Basic* solutions contain more OH^- ions

pH = -log[H^+] where [H^+] is the hydrogen ion concentration in mol L^{-1} — $[H^+] = 10^{-pH}$
pOH = -log[OH^-] where [OH^-] is the hydroxide ion concentration in mol L^{-1} — $[OH^-] = 10^{-pOH}$
pH + pOH = 14 — $[H^+]\times[OH^-] = 10^{-14}$ at 25°C

When hydrogen ions (H^+) are in aqueous solution they 'attach' themselves to the unbonded electron pair and hence are also known as hydronium ions (H_3O^+).

Acid Rain

Rain is naturally acidic (a pH between 6.5 and 5.6) because CO_2 dissolves in it to make carbonic acid:
$H_2O + CO_2 \rightarrow H_2CO_3$
The acid then partially ionises to produce acidic solution:

$$2H_2O_{(l)} + H_2CO_{3\,(aq)} \rightleftharpoons 2H_3O^+_{(aq)} + CO_3^{2-}{}_{(aq)}$$

Rain becomes “acid rain” when its pH drops below 5.6. It usually occurs when oxides of nitrogen and sulfur dissolve in water in the atmosphere.

Nitrogen dioxide (produced when nitric oxide NO reacts with O_2 in the atmosphere):
$2NO_{2\,(g)} + H_2O_{(l)} \rightarrow HNO_{2\,(aq)} + HNO_{3\,(aq)}$
Sulphur dioxide (an impurity in carbon-based fuels):
$SO_{2\,(g)} + H_2O_{(l)} \rightarrow H_2SO_{3\,(aq)}$
Sulphur trioxide (produced by some of the released SO_2 reacting with O_2 in the atmosphere):
$SO_{3\,(g)} + H_2O_{(l)} \rightarrow H_2SO_{4\,(aq)}$

Nitric acid (HNO_3) and sulfuric acid (H_2SO_4) are strong acids, so are the major contributors to acid rain.

Acid rain has harmful environmental effects:

- Corrodes metals and carbonates. Example equations:
  - $Fe_{(s)} + 2H^+_{(aq)} \rightarrow Fe^{2+}_{(aq)} + H_{2\,(g)}$
  - $CaCO_{3\,(s)} + 2H^+_{(aq)} \rightarrow Ca^{2+}_{(aq)} + CO_{2\,(g)} + H_2O_{(l)}$
- Causes mobilisation in the soil (leaching) of toxic cations such as aluminium, lead and cadmium
  - Example: $Al^{3+}_{(soil)} + H^+_{(aq)} \rightarrow Al^{3+}_{(aq)} + H^+_{(soil)}$
  - Free aluminium ions disrupt defense mechanisms in plants and damage necessary bacteria
  - Free aluminium ions adhere to gills of fish and restrict oxygen supply leading to suffocation
  - Toxic cations (lead, cadmium, etc) can enter human drinking water and cause disease or death
- Reduces the pH in lakes and rivers, reducing fish populations
  - Eggs and fry (recently-hatched fish) are sensitive to low pH
  - Low pH leads to excessive loss of sodium from the gills
- Damages the foliage of plants

Photochemical Smog

Photochemical smog is a form of lower atmosphere pollution which is visible as a yellow-brown haze, and is made up of many primary and secondary pollutants.

High temperature engines and furnaces can allow N_2 to react with O_2, producing NO, which spontaneously reacts with O_2 to produce NO_2:

$$N_{2\,(g)} + O_{2(g)} \xrightarrow{\text{heat}} 2NO_{\,(g)}$$
$$2NO_{(g)} + O_{2(g)} \longrightarrow 2NO_{2\,(g)} \quad \text{(spontaneous)}$$

Nitrogen oxides lead to the formation of ozone in the lower atmosphere (troposphere). Nitrogen dioxide absorbs UV and breaks into nitric oxide (NO) and atomic oxygen (O).

$$NO_{2\,(g)} \xrightarrow{\text{UV}} NO_{\,(g)} + O_{(g)}$$

The atomic oxygen is then able to react with O_2 present and form O_3. This reaction releases excess energy which must be absorbed by a 'stabilising' molecule (commonly N_2 or O_2 but represented as M in the equation below). The * represents that the molecule is absorbing the excess energy.

$$O_{2(g)} + O_{(g)} + M_{(g)} \longrightarrow O_{3\,(g)} + M^{*}_{\,(g)}$$

'Primary pollutants' are released directly into the atmosphere. They commonly come from sources such as combustion engines and furnaces, and include NO, CO, CO_2, SO_2 and unburnt hydrocarbons.
'Secondary pollutants' are formed when primary pollutants react with air, water or sunlight. Examples are O_3, NO_2, SO_3, HNO_3, and H_2SO_4.
Note: Ozone is a pollutant in the troposphere but not in the stratosphere (where the ozone layer is).

Harmful effects of ozone:

- Health problems in animals (adverse effects on respiratory system)
- Reduction of photosynthesis in plants (yellowing of leaves)
- Break chains in long molecules (e.g. rubber, polymers) causing cracking and perishing

Harmful effects of oxides of nitrogen:

- Similar effects on plants and animals as ozone
- Forms acid rain

Catalytic Converters

A catalytic converter contains platinum or a similar element which acts as a catalyst for reactions which reduce the quantity of nitrogen oxides and carbon monoxide emitted.

$$2NO_{(g)} + 2CO_{(g)} \longrightarrow N_{2\,(g)} + 2CO_{2\,(g)}$$
$$2CO_{(g)} + O_{2\,(g)} \longrightarrow 2CO_{2\,(g)}$$

Water Treatment

Flocculation is a process by which suspended particles in water can be removed. Salts containing highly charged cations (such as Al^{3+}) are added to the water. Clay particles in water are negatively charged so the cations will attract them and join them together in larger clumps which are too large to stay suspended and will settle. The clay can then be removed as a sediment or filtered out.

For water to be potable (suitable for drinking) the bacteria in it must be killed. One way of achieving this is to treat the water with an oxidising agent such as Cl_2 (chlorine gas) or OCl^- (hypochlorite ions).
One equilibrium that occurs in pool water is shown below.

$$Cl_{2\,(g)} + H_2O_{(l)} \rightleftharpoons HOCl_{(aq)} + HCl_{\,(aq)}$$

This equilibrium depends on the pH and the temperature.

Chlorine, hypochlorous acid and hypochlorite ions are all oxidising agents. They oxidise bacteria (killing it) and are in the process reduced to chloride ions.