I Must Have That Formula

There are a number of formulas that you must know for the AP Environmental Exam. The following formulas are not the only formulas, but can be considered some of the most important.

Air Pollution Formulas:

$$4FeS_2 + 11O_2 \rightarrow 2Fe_2O_3 + 8SO_2$$

Impurities such as pyrite or iron pyrite are found in coal, when we burn coal it interacts with atmospheric oxygen to form iron oxide and sulfur dioxide (a **primary** air pollutant).

$$2SO_2 + O_2 \rightarrow 2SO_3$$

The **primary** air pollutant, sulfur dioxide, is *oxidized*, once in the atmosphere, to sulfur trioxide.

$$SO_x$$

The generalized representation of sulfur oxides, whether it be sulfur dioxide or sulfur trioxide. The Sulfur oxides are considered **primary** air pollutants.

$$SO_3 + H_2O \rightarrow H_2SO_4$$

Sulfur trioxide dissolves it atmospheric water droplets to form sulfuric acid. Sulfuric acid is a major component of acid rain. Sulfuric acid is considered a **secondary** air pollutant.

$$N_2 + O_2 \rightarrow 2NO$$

Molecules of nitrogen and atmospheric oxygen combine AT VERY HIGH TEMPERATURES to form nitric oxide, a colorless gas. The high temperatures of natural processes like lightening or those of the combustion chambers of an engine are effective in causing this conversion. Nitric oxide is a **primary** air pollutant

$$2NO + O_2 \rightarrow 2NO_2$$

Once in the atmosphere, nitric acid reacts with additional oxygen to form nitrogen dioxide, a red-brown toxic gas that causes irritation to the eyes and respiratory system

$$NO_2 + H_2O \rightarrow HNO_3$$

Further reaction of nitrogen dioxide with water can produce nitric acid, another component of acid rain. Nitric acid is considered a **secondary** air pollutant

Photochemical Smog

Photochemical smog is a condition that develops when **primary pollutants** (oxides of nitrogen and volatile organic compounds created from fossil fuel combustion) interact under the influence of **sunlight** to produce a mixture of hundreds of different and hazardous chemicals known as **secondary pollutants**.

To begin the chemical process of photochemical smog development the following conditions must occur:

- Sunlight.
- The production of oxides of nitrogen (NOx).
- The production of volatile organic compounds (VOCs).
- Temperatures greater than 18 degrees Celsius.

If the above criteria are met, several reactions will occur producing the toxic chemical constituents of photochemical smog. The following discussion outlines the processes required for the formation of two most dominant toxic components: **ozone (O3)** and **peroxyacetyl nitrate (PAN)**. **Note** the **symbol R** represents a **hydrocarbon** (a molecule composed of carbon, hydrogen and other atoms) which is primarily created from volatile organic compounds.

O3 + NO »»» NO2 + O2

NO + RO2 »»» NO2 + other products

Nitrogen dioxide can be formed by one of the above reactions. Notice that the **nitrogen oxide** (NO) acts to remove ozone (O3) from the atmosphere and this mechanism occurs naturally in an unpolluted atmosphere.

$$N_2 + O_2 + Energy \rightarrow 2NO$$

Nitrogen oxide is an essential ingredient of photochemical smog that is produced during the high temperatures associated with combustion of vehicle's engines.

$$NO_2 \xrightarrow{\text{sunlight}} NO + O$$

Initial reaction of nitrogen dioxide with sunlight. Sunlight can break down **nitrogen dioxide** (NO2) back into **nitrogen oxide** (NO).

$$O + O_2 \rightarrow O_3$$

The oxygen atom generated from the initial reaction reacts with atmospheric, diatomic oxygen, to form ozone. This is not the good, protective ozone of the stratosphere, this is the polluting ozone of the lithosphere, which traps heat and contributes to thermal inversions.

NO2 + R »»» products such as PAN

Nitrogen dioxide (NO2) can also react with radicals produced from volatile organic compounds in a series of reactions to form toxic products such as **peroxyacetyl nitrates** (PAN). **Note** the **symbol R** represents a **hydrocarbon** (a molecule composed of carbon, hydrogen and other atoms) which is primarily created from volatile organic compounds.

$$Hydrocarbons + Sunlight + O_2 + CO + NO_x \rightarrow O_3 + NO_x + \text{Organic Compounds} + CO_2 + H_2O$$

(auto exhaust/VOC's) (oxidizing agents and irritants)

This simplified equation represents the key ingredients and products of photochemical smog. Hydrocarbons (including VOC's), carbon monoxide, and nitrogen oxides from vehicle exhausts are irradiated by sunlight in the presence of oxygen gas. The resulting reactions produce a potentially dangerous mixture that include other nitrogen oxides, ozone, and irritating organic compounds, as well as carbon dioxide and water vapor.

Acid Rain

$$CO_2 + H_2O \rightarrow H_2CO_3$$

The pH of rainwater is normally slightly acidic, at about 5.6, due mainly to reaction of carbon dioxide with water to form carbonic acid.

$$SO_2 + H_2O \rightarrow H_2SO_3$$

$$SO_3 + H_2O \rightarrow H_2SO_4$$

$$2NO_2 + H_2O \rightarrow HNO_3 + HNO_2$$

Other natural events can contribute to the acidity of precipitation. Volcanic eruptions, forest fires, and lightning bolts produce sulfur dioxide, sulfur trioxide, and nitrogen dioxide. These gases can react with atmospheric water in much the same way that carbon dioxide does to produce sulfurous acid, sulfuric acid, nitric acid and nitrous acid.

Air Pollution Control and Prevention

$$SO_2 + Ca(OH)_2 \rightarrow CaSO_3 + H_2O$$

Formula that represents the process of "scrubbing" products of industrial combustion processes. Sulfur dioxide gas is removes by using an aqueous solution of calcium hydroxide, also called limewater. The sulfur dioxide reacts with the limewater to form solid calcium sulfite. Scrubbers that utilize this "wet" scrubbing method can remove up to 95% of sulfur oxides.

$$SO_2 + Mg(OH)_2 \rightarrow MgSO_3 + H_2O$$

$$MgSO_3 \rightarrow SO_2 + MgO$$

Another process for scrubbing that utilizes magnesium hydroxide instead of limewater. The sulfur dioxide dissolves in the water and reacts with the magnesium hydroxide to form a salt. The magnesium sulfite that is formed can be isolated and heated to regenerate sulfur dioxide. The recovered sulfur dioxide can be collected and used as a raw material in other commercial processes.

Ozone Formation and Destruction

When ultraviolet light waves (UV) strike CFC* (**CFCl3**) molecules in the upper atmosphere stratosphere, a carbon-chlorine bond breaks, producing a chlorine (**Cl**) atom. The chlorine atom then reacts with an ozone (**O3**) molecule breaking it apart and so destroying the ozone. This forms an ordinary oxygen molecule(**O2**) and a chlorine monoxide (**ClO**) molecule. Then a free oxygen** atom breaks up the chlorine monoxide. The chlorine is free to repeat the process of destroying more ozone molecules. A single CFC molecule can destroy 100,000 ozone molecules.

* CFC - chlorofluorocarbon: it contains chlorine, fluorine and carbon atoms.
** UV radiation breaks oxygen molecules (**O2**) into single oxygen atoms.

CFCl3 + UV Light ==> CFCl2 + Cl
Cl + O3 ==> ClO + O2
ClO + O ==> Cl + O2

The free chlorine atom is then free to attack another ozone molecule

Cl + O3 ==> ClO + O2
ClO + O ==> Cl + O2

and again ...

Cl + O3 ==> ClO + O2
ClO + O ==> Cl + O2

and again... for thousands of times.

The Carbon Cycle

CO_2

$CaCO_3$

CH_4

The different forms and compounds in which carbon atoms are found are considered chemical reservoirs of carbon. These reservoirs include atmospheric carbon dioxide, calcium carbonate (in limestone), natural gas, and organic molecules, to name a few.

$6CO_2 + 6H_2O \xrightarrow[Photosynthesis]{Light} C_6H_{12}O_6 + 6O_2$: Plants use carbon dioxide and energy from the sun to form carbohydrates in photosynthesis. The carbohydrates are consumed by other organisms, and are eventually broken down, or “oxidized”.

$C_6H_{12}O_6 + O_2 \rightarrow 6CO_2 + 6H_2O$: The process of respiration. The chemical representation of how carbohydrates are broken down, or oxidized, thereby releasing energy for use by the consuming organisms. The carbon used and circulated in photosynthesis represents only a tiny portion of the available global carbon.

Burning Coal: $C(s) + O_2 \rightarrow CO_2$

Burning Natural Gas: $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

Burning Gasoline: $2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$

Atmospheric carbon dioxide levels have increased by 30% since the 1800's (industrial revolution).This increase can be explained, primarily, but several human activities. The most significant of these activities is the burning of fossil fuels.

Nitrogen Cycle

1) $N_2 \xrightarrow[\text{nitrogen-fixing bacteria}]{} NH_3$ or NH_4^+

Atmospheric nitrogen is converted to ammonia or ammonium ion by nitrogen-fixing bacteria that live in legume root nodules or in soil, or atmospheric nitrogen is converted to nitrogen oxides by lightening.

2) NH_3 or $NH_4^+ \xrightarrow[\text{Soil bacteria}]{} NO_2^-$

$NO_2^- + H_2O \rightarrow NO_3^- + 2H$

Ammonia and Ammonium are oxidized by soil bacteria first to nitrite ions and then to nitrate ions

6) NH_3 or NO_3^- or $NO_2^- \xrightarrow[\text{Denitrifying Bacteria}]{} N_2$: After plants have taken up nitrogen from the soil in the form of nitrate ions, the nitrogen is passed along the food chain. When those plants and animals dies, bacteria and fungi take up and use some of the nitrogen from the plant/animal protein and other nitrogen containing molecules. The remaining nitrogen is released as ammonium ions or ammonia gas. Denitrifying bacteria convert some ammonia, nitrite, and nitrate back to nitrogen gas, which returns to the atmosphere.

$N_2 + 3H_2$ ½½½½ $2NH_3$

Heat + $CH_4 + H_2O \rightarrow 3H_2 + CO$

$CO + H_2O \rightarrow H_2 + CO_2$

Haber-Bosch Process: A technique for making ammonia from hydrogen and nitrogen, according to the first equation. To get the reactants, nitrogen gas is liquefied form air and hydrogen gas is obtained chemically from methane (natural gas). First natural gas is treated to remove sulfur-containing compounds; then the present methane is allowed to react with steam. Carbon monoxide, a product of methane reacting with steam, is converted to carbon dioxide which allows for the additional production of nitrogen gas.