AP Environmental Science ***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.

$SO_3 + H_2O \rightarrow H_2SO_4$
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

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

$N_2 + O_2 \rightarrow 2NO$
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

Photochemical Smog

$N_2 + O_2 + Energy \rightarrow 2NO$ 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

$O + O_2 \rightarrow O_3$ 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 troposphere, which traps heat and contributes to thermal inversion.

Photochemical Smog (cont)

$$\underset{\text{(auto exhaust/VOC's)}}{Hydrocarbons} + Sunlight + O_2 + CO + NO_x \rightarrow O_3 + NO_x + \underset{\text{(oxidizing agents and irritants)}}{\text{Organic Compounds}} + CO_2 + H_2O$$

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 includes other nitrogen oxides, ozone, and irritating organic compounds, as well as carbon dioxide and water vapor.

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.

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 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.

Ozone Formation and Destruction

$O_2 +$ high-energy UVphoton $\rightarrow O + O$

$O_2 + O + M \rightarrow O_3 + M$

As sunlight penetrates into the stratosphere, high-energy UV photons react with oxygen gas molecules, splitting them into individual oxygen atoms. These highly reactive oxygen atoms are examples of *free radicals*; they quickly enter into chemical reactions that allow them to attain stable arrangements of electrons. In the stratosphere free radicals can combine with oxygen molecules to form ozone. A third molecule, typically nitrogen gas or atmospheric oxygen (represented by *M* in the equation), carries away excess energy from the reaction but remains unchanged.

$O_3 +$ medium-energy UV photon $\rightarrow O_2 + O$

$O_2 + O + M \rightarrow O_3 + M$

Each ozone molecule formed in the stratosphere can absorb a UV photon with a wavelength of less than 320nm. This energy absorption prevents potentially harmful UV rays from reaching the earth's surface. The energy also causes the ozone to decomposed, producing an oxygen molecule and an oxygen free radical. These products can then carry on the cycle by replacing ozone in the protective stratospheric layer.

$Cl + O_3 \rightarrow ClO + O_2$

$ClO + O \rightarrow Cl + O_2$

CFC's (chlorofluorocarbons) are highly stable molecules in the troposphere, however, high-energy UV photons in the stratosphere split chlorine radicals from CFC's by breaking their C-Cl bond. The freed chlorine radicals are very reactive and can participate in a series of reaction that destroy ozone by converting it to diatomic oxygen. Every chlorine radical that participates in the first reaction can later be regenerated. Thus each chlorine radical acts as a catalyst participating in not just one, but also an average of 100,000 ozone –destroying reactions. In doing so, it speeds up ozone destruction but remains unchanged.