Module 1: Lecture 2

In the next two lectures we will learn about some of the major air pollutants.

Air pollutants

carbon monoxide CO

sulfur dioxide SO_2

ozone O_3

particulate matter "PM"

Air Pollution is a serious health hazard in the US and around the world. In this class, we will focus primarily on outdoor pollution, but indoor air pollution is also a problem.

Flu, pneumonia, mold

Causes of Death in the US

Actual Cause	1990	2000	
Tobacco	400,000	435,000	
Poor diet, physical inactivity	300,000	400,000	
Alcohol consumption	100,000	85,000	
Microbial agents	90,000	75,000	
Toxic agents / air pollutants	60,000	55,000	← indoor & outdoor pollutants
Motor vehicle	25,000	43,000	
Firearms	35,000	29,000	
Sexual behavior	30,000	20,000	
Illicit drug use	20,000	17,000	

Leading physiological Causes of Death in the US in 2000

Heart Disease	710,760
Malignant neoplasm — (cancer)	553,091
Cerebrovascular disease (stroke)	167,661
Chronic lower respiratory tract disease	122,009
Unintentional injuries	97,900
Diabetes mellitus	65,313
Influenza and pneumonia	49,558
Alzheimer disease	37,251
Nephritis, nephrotic syndrome, nephrosis (kidney disease)	31,224
Septicemia	31,224
Other	499,283

source:
Journal of the American Medical Association, vol. 291, No. 10, pps 1238-1245, 2004

Keep in mind that many of these numbers are difficult to measure and may contain a great deal of uncertainty. In the figure above, the row "Toxic Agents" is highlighted. This category contains estimates of deaths caused by indoor and outdoor air pollution, water pollution, and exposure to materials such as asbestos and lead both in the home and at the work place. It is estimated that 60% of the Toxic Agent deaths are due to exposure to particulate matter, which is something that we will examine briefly in the next lecture.

Causes of Death Worldwide

Unsafe water, poor sanitation & hygiene	1.7 million
Indoor smoke	1.6 million
Malaria	1.2 million
Urban air pollution	800,000
Unintentional acute poisoning	355,000
Climate change ?	150,000

source:
WHO Health and Environment Linkages Initiative
http://www.who.int/heli/risks/en/

Air pollution is a serious hazard worldwide. Indoor air pollution is, in many places, a more serious threat than outdoor air pollution. The Blacksmith Institute listed the Top 10 polluted places in the world in a 2007 report. The report has received a lot of worldwide attention. If you go to this address, you can view the report online or download and print a copy of the report.

We will start with carbon monoxide (CO). Some basic information is shown below. You will find additional information at the Pima County Department of Environmental Quality website and also at the US Environmental Protection Agency website.

problem & indoors / outdoors

Carbon Monoxide (CO)

1

Colorless, odorless, toxic gas. ---> will bond with hemoglobin in blood that normally transports oxygen.

Most abundant pollutant after CO_2. ---> about half of total weight of primary pollutants

2

a primary pollutant comes straight from the source.

75% of CO in Tucson air comes from cars + trucks. ---> "hot spots" in Tucson near congested intersections: 22nd & Alvernon

3

Results from incomplete combustion.

complete: $Fuel + O_2 \rightarrow CO_2 + H_2O + energy$

incomplete: $Fuel + O_2 \rightarrow CO + H_2O + energy$

as if there's not enough oxygen.

Use of catalytic converters and oxygenated fuels is to reduce CO levels. ---> produce CO_2 instead of CO. Also emissions testing and traffic flow control

4

Wintertime morning pollutant ---> trapped in morning surface radiation inversion layers.

CO is also a problem at high altitude (eg. Denver, Mexico City)

5

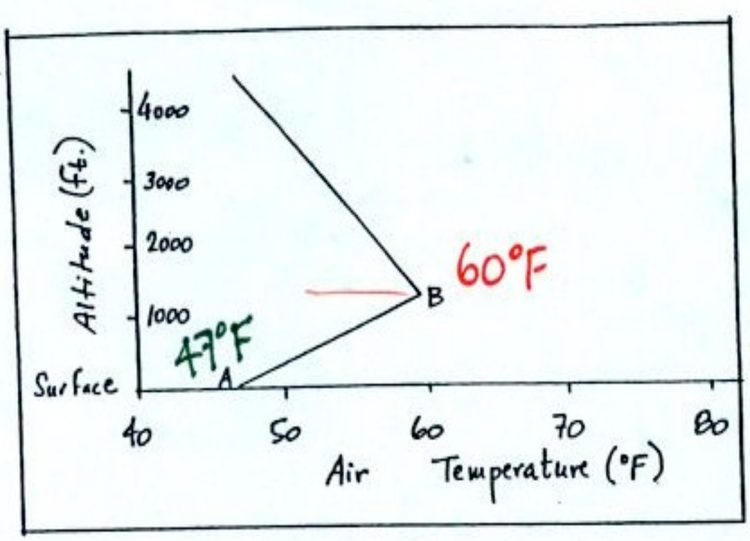
In a temperature invasion, temperature increases with increasing altitude.
Creates very stable atmospheric conditions.
~~not~~ no up or down air motions.
No mixing.

We will be talking about carbon monoxide both outdoors (where it rarely reaches fatal concentrations) and indoors (where it can be deadly). Carbon monoxide is insidious: you cannot smell it or see it but it can kill you (**Point 1** above). Once inhaled, carbon monoxide molecules bond strongly to the hemoglobin molecules in blood and interfere with the transport of oxygen throughout your body.

CO is a primary pollutant (**Point 2** above), which means it travels directly from a source such as an automobile tailpipe into the atmosphere. When insufficient oxygen is present, CO is produced by incomplete combustion of fossil fuels (**Point 3** above). Complete combustion of fossil fuels produces carbon dioxide or CO_2. Cars and trucks produce much of the CO in the atmosphere in Tucson. Vehicles must now be fitted with a catalytic converter that will change CO into CO_2 (and also NO into N_2 and O_2 and hydrocarbons into H_2O and CO_2). In large metropolitan areas such as Pima County vehicles must also pass an emissions test every year. The Clean Air Act requires that special formulations of gasoline (oxygenated fuels) to be used during the winter months to try to reduce CO emissions.

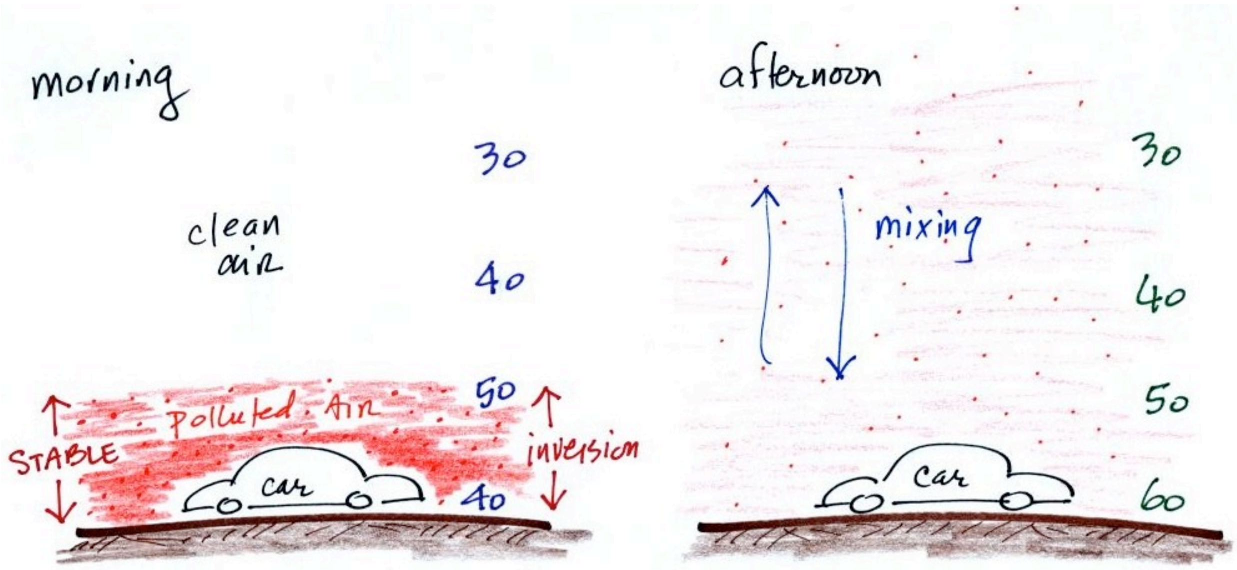
In the atmosphere, CO concentrations peak on winter mornings (**Point 4** above). Surface temperature inversion layers form on long winter nights when the sky is clear and winds are calm. The ground cools quickly and becomes colder than the air above. The air closest to the cold ground ends up colder than air above, which causes a temperature inversion. This means that the air temperature increases with increasing altitude **(Point 5** above). This produces a very stable and stagnant (no vertical motion) layer of air at ground level. At the same time, automobiles burn fuel less efficiently when started on winter mornings because the engines are cold, which creates more CO due to incomplete combustion.

A very reasonable wintertime morning temperature profile in Tucson is shown below. There is very little mixing in a stable layer of air. In the afternoon, the ground warms, the inversion layer disappears, and the atmosphere becomes more unstable. CO emitted into air at the surface mixes with cleaner air above. The CO concentrations are effectively diluted. Temperature increases from 47° F at the ground (Point A) to about 60° F at 1000 feet altitude (Point B), that's the stable inversion layer. Temperature begins to decrease with increasing altitude above Point B. There is very little vertical mixing in a stable air layer.

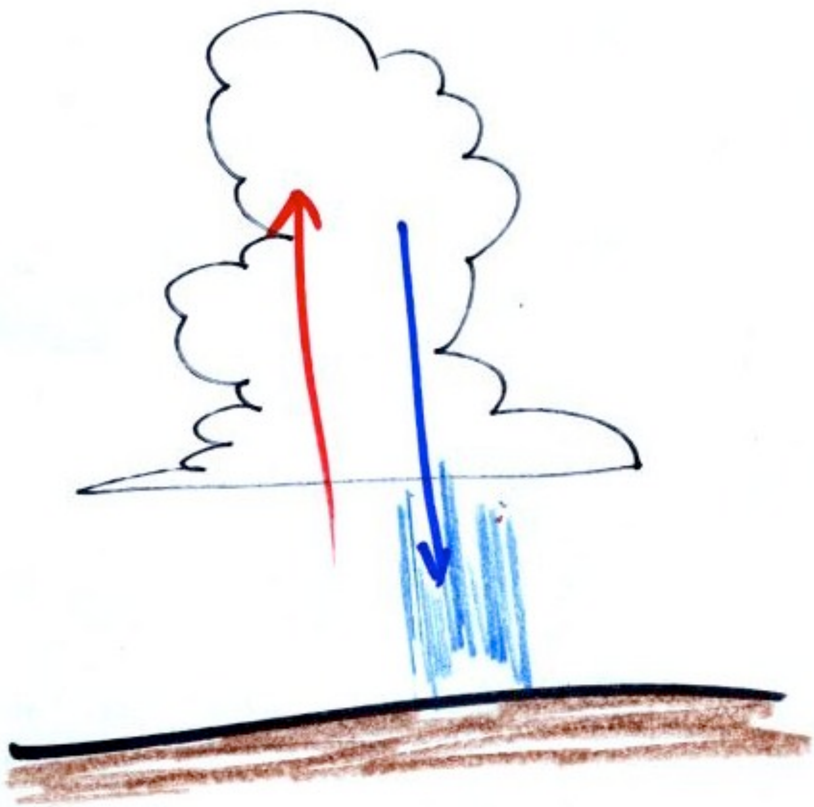


A typical wintertime, early morning, surface inversion layer. The inversion, a stable air layer, is where the air temperature is increasing with increasing altitude; between points A and B. The inversion will usually disappear later in the day as the ground is warmed by sunlight.

When CO is emitted into the thin stable layer, the CO remains in the layer and does not mix with cleaner air above. CO concentrations build.

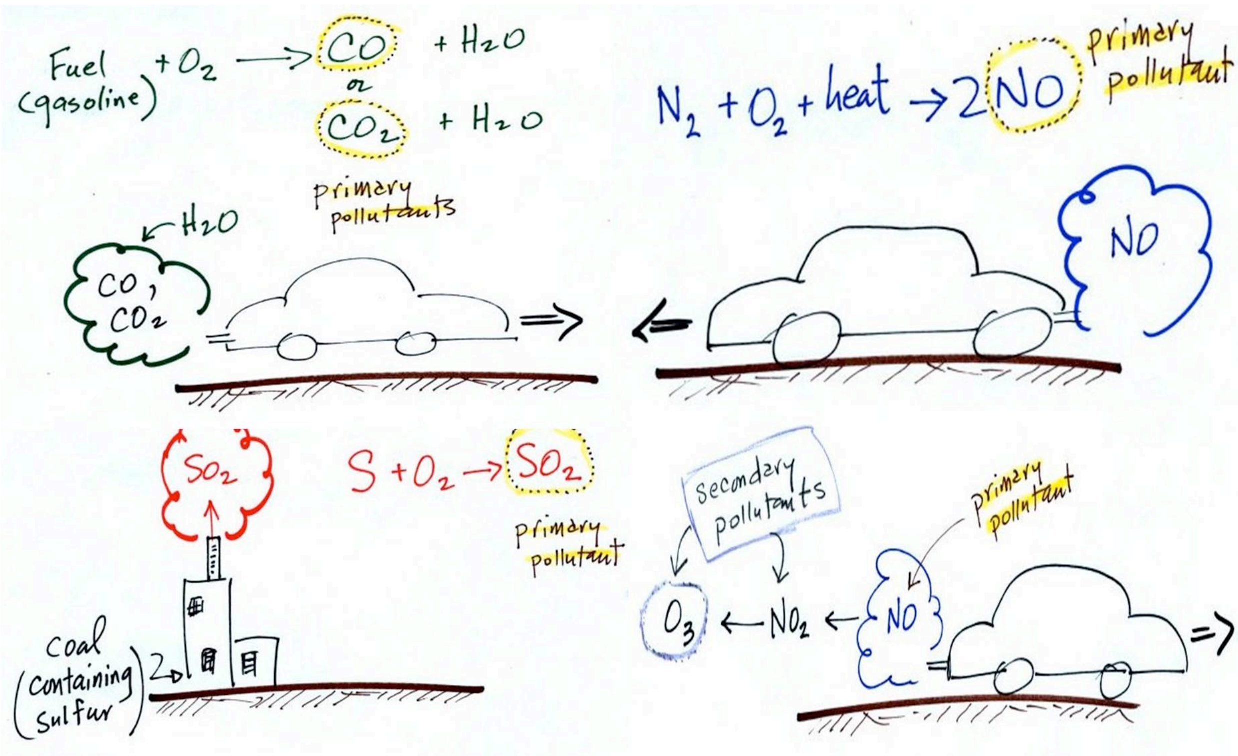


Thunderstorms contain strong up (updraft) and down (downdraft) air motions. Thunderstorms are a sure indication of <u>unstable</u> atmospheric conditions. When the downdraft winds hit the ground they spread out horizontally. These surface winds can sometimes reach 100 MPH, stronger than many tornadoes.



CO, nitric oxide (NO) and sulfur dioxide (SO_2) are all primary pollutants which are emitted directly by sources into the atmosphere. Ozone is a secondary pollutant (and here we are referring to trophospheric ozone, not stratospheric ozone). Ozone does not come directly from an automobile tailpipe or other pollution. Instead ozone appears in the atmosphere only after the primary pollutants have undergone a very complex series of reactions.

The difference between primary and secondary pollutants is illustrated below.



The concentrations of several of the main pollutants are monitored in large cities in the US and around the world. In Tucson, carbon monoxide, ozone, and particulate matter are of primary concern and daily measurements are reported in the city newspaper. The Air Quality Index value is reported instead of the actual concentration (which most people would not know how to interpret). The AQI is the ratio of the measured to regulatory limits multiplied by 100%. Air becomes unhealthy when the AQI value exceeds 100%.

For carbon monoxide, concentrations up to 35 ppm (parts per million) for a 1 hour period and 9 ppm for an 8 hour period are allowed. If the observed CO concentration were 4.5 ppm averaged over an 8 hour period the AQI would be

$$AQI = 100\% \times (4.5ppm / 9ppm) = 50\%$$

and the air quality would be considered good. [Current Air Quality Index values] for Tucson are available online.

The regulatory limits for important pollutants are shown below. The atmospheric concentration of lead has decreased significantly since the introduction of unleaded gasoline.

Environmental Protection Agency

EPA has established concentration levels for 6 pollutants:

CO, NO_2, SO_2, Pb, PM, and O_3. ozone

nitrogen dioxide, lead, particulate matter.

These are know as the National Ambient Air Quality Standards (NAAQS).

eg.	CO	9 ppm	8-hr average
		35 ppm	1-hr average

parts per million.

Air Quality Index, AQI =

$$\frac{\overset{\text{measured value}}{8\ hr\ value}}{\underset{\text{allowed}}{9\ ppm}} \times 100\ \%$$

AQI Values			
	0 - 50%	Good	
	51 - 100	Moderate	
	101 - 199	Unhealthful	
	200 - 299	very Unhealthful	Stage 1 advisory: alert
	300 - 399	Hazardous	Stage 2 advisory: warning
	400 - 499	Hazardous	Stage 3 advisory: emergency

AQI values are often reported in newspapers in large cities

Air quality

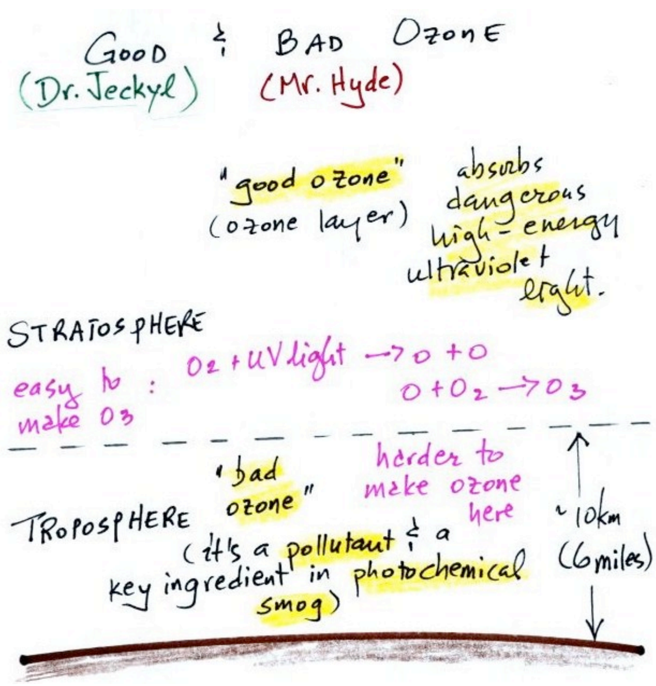
Particulates (mostly dust and smoke): 50; ozone (automotive pollutants): 39; carbon monoxide (automotive pollutants): 29.

Zero to 50 is good; 51 to 100 moderate; 101 to 199 unhealthful; 200 to 299 very unhealthful; and 300 and above constitutes an emergency.

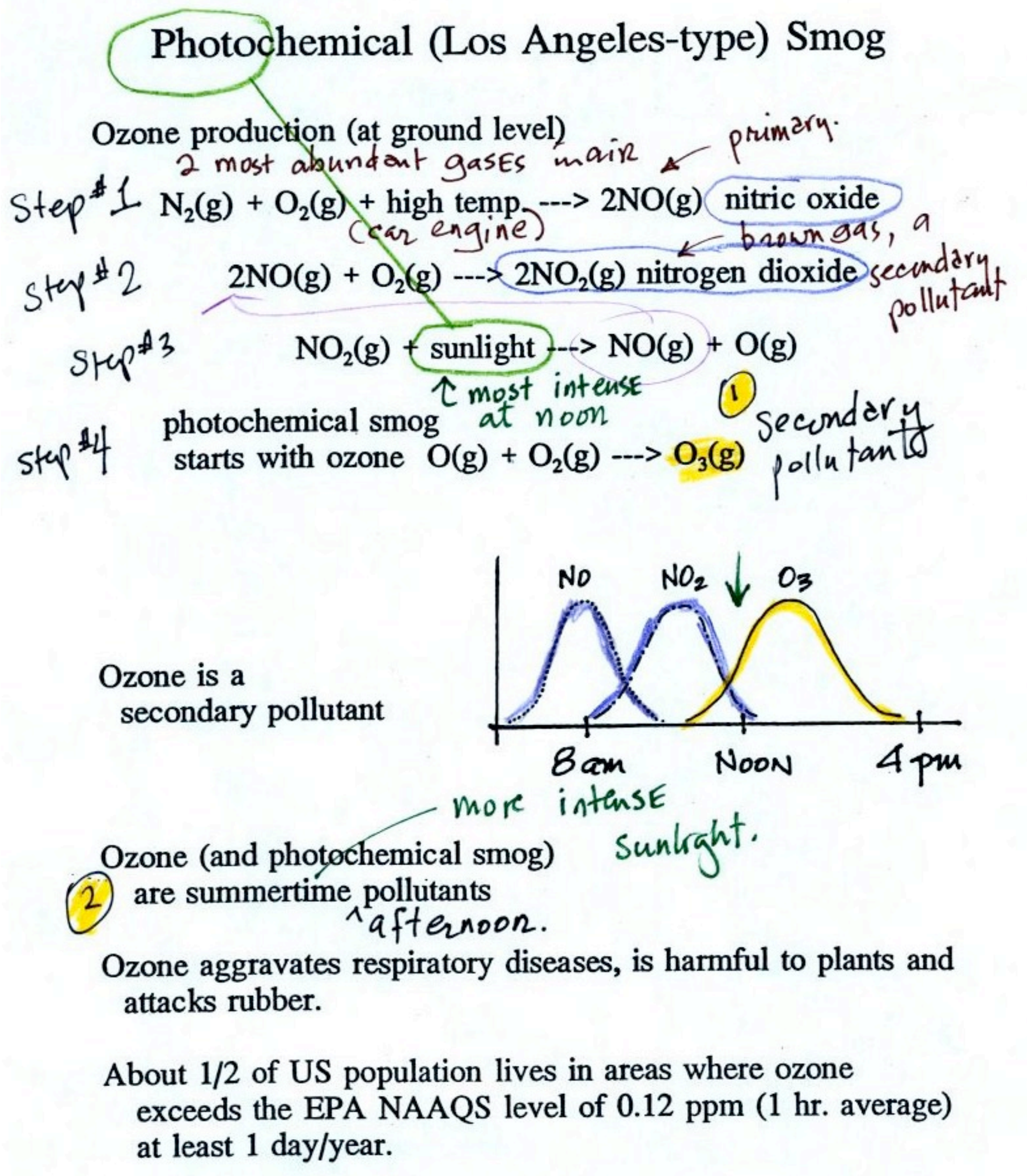
So far we have been talking about carbon monoxide found in the atmosphere. Carbon monoxide is also a serious hazard indoors, where it can build to much higher levels than would ever be found outdoors. You may remember having heard about an incident at the beginning of the school year in 2007 in which [carbon monoxide from a malfunctioning hot water heater sickened 23 Virginia Tech students] in an apartment complex. The indoor CO concentration were thought to have reached 500 ppm.

Carbon monoxide alarms are relatively inexpensive and readily available at any hardware store. They will monitor CO concentrations indoors and warn you when concentrations reach hazardous levels. Indoors CO is produced by gas furnaces and water heaters that are either operating improperly or aren't being adequately vented to the outdoors. A few hundred people are killed indoors by carbon monoxide every year in the United States. You can learn more about carbon monoxide hazards and risk prevention at the [Consumer Product Safety Commission web page].

Before discussing trophospheric ozone, which is a pollutant, here is a quick reminder that there are both "good" and "bad" types of ozone. Whether ozone is good or bad depends upon where the ozone is found. Ozone has a Dr. Jekyll and Mr. Hyde personality. Ozone in the stratosphere (the ozone layer) is beneficial, it absorbs dangerous high energy ultraviolet light (which would otherwise reach the ground and cause skin cancer, cataracts, and many other problems). It is also easy to make ozone in the stratosphere; molecular oxygen and ultraviolet light are all that are required. Ozone in the troposphere is bad because it is a pollutant. Trophospheric ozone is a key component of photochemical smog (also known as Los Angeles-type smog).



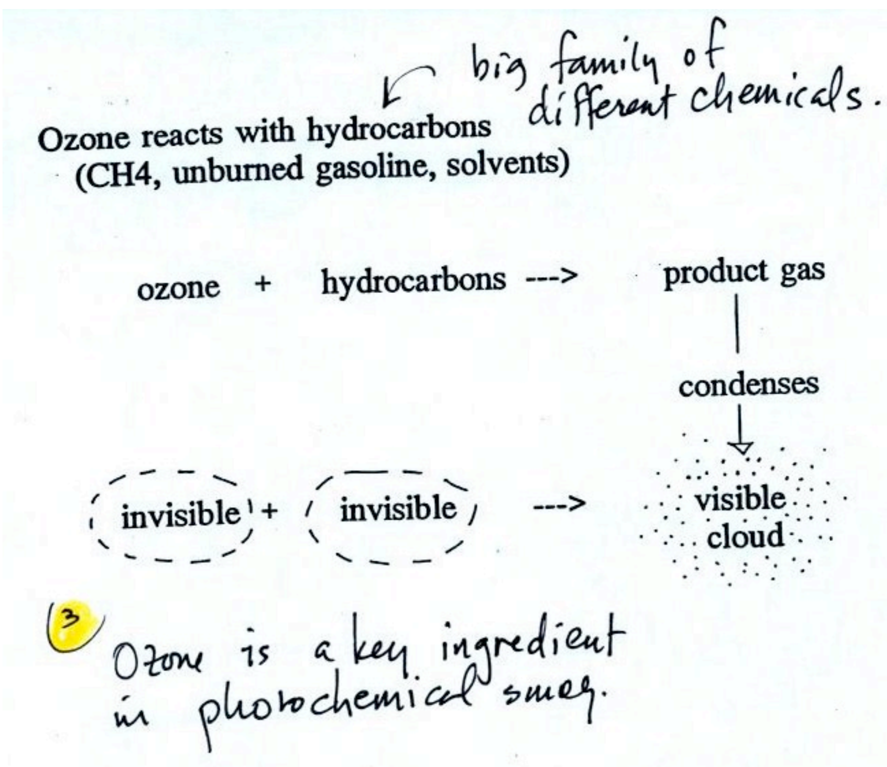
Making ozone in the troposphere is also a more complex process as we will see below.



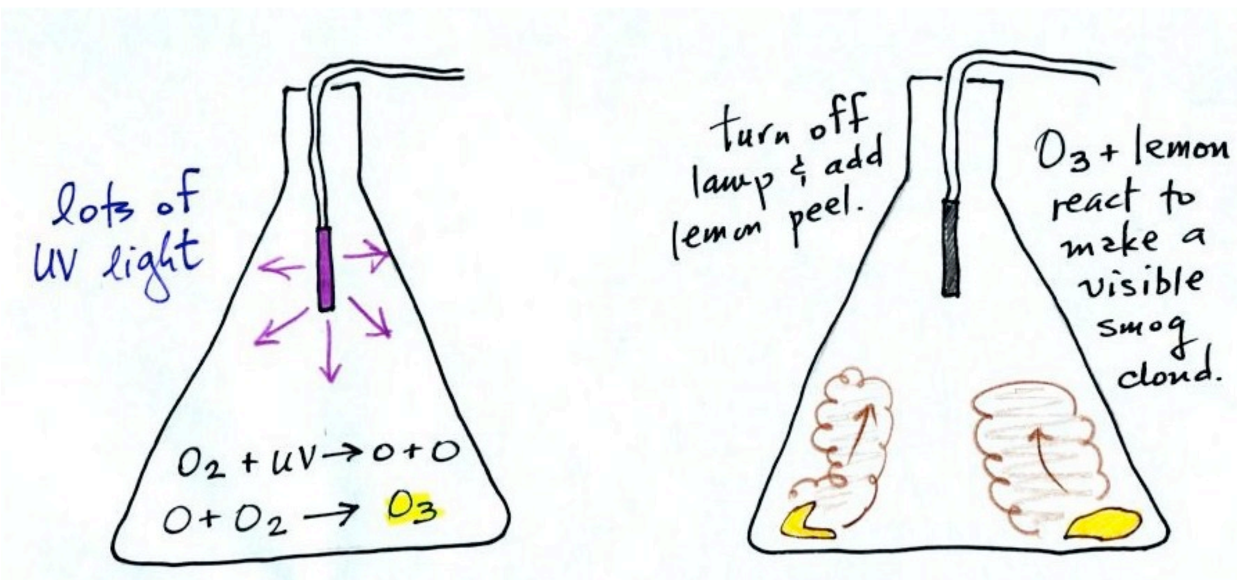
In the figure above, you see that a complex series of reactions is responsible for the production of trophospheric ozone. The production of trophospheric ozone begins with nitric oxide (NO). NO is produced when nitrogen and oxygen in air are heated (in an automobile engine for example) and react. The NO can then react with oxygen to make nitrogen dioxide, a poisonous brown-colored gas.. Sunlight can dissociate (split) the nitrogen dioxide molecule producing atomic oxygen (O) and NO. O and O_2 react in a 4th step to make ozone (O_3). Because ozone does not come directly from an automobile tailpipe or factory chimney, but only shows up after a series of reactions, it is a secondary pollutant. Nitric oxide would be the primary pollutant in this example.

NO is produced early in the day during the early morning rush hour. The concentration of NO_2 peaks somewhat later. Peak ozone concentrations are usually found in the afternoon. Ozone concentrations are also usually higher in the summer than in the winter. This is because sunlight plays a role in ozone production and summer sunlight is more intense than winter sunlight.

As shown in the figure below, invisible ozone can react with a hydrocarbon of some kind which is also invisible to make a product gas. This product gas sometimes condenses to make a visible smog cloud or haze. The cloud is composed of very small droplets or solid particles.
The particles are too small to be seen but they are able to scatter light - that is why you can see the cloud.



Ozone and photochemical smog as summarized below in the picture. We begin by using the UV lamp to create and fill the flask with ozone. Then a few pieces of fresh lemon peel were added to the flask. A whitish cloud quickly became visible (the cloud is colored brown in the figure below).



lots of UV light
O_2 + UV → O + O
O + O_2 → O_3
turn off lamp & add lemon peel.
O_3 + lemon react to make a visible smog cloud.