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Air Pollution

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Lecture 1

The Atmosphere

1. Introduction

Earth's atmosphere is a critical system for life on our planet. Together with the oceans, the atmosphere shapes Earth's climate and weather patterns and makes some regions more habitable than others.

To see how and why climate fluctuates, we need to learn about the basic characteristics of the atmosphere and some physical concepts that help us understand weather and climate and how physical processes shape the distributions of pressures and temperatures on Earth to create climate zones, weather patterns, and storms, creating conditions suitable for life around the planet.

The atmosphere is a complex system in which physical and chemical reactions are constantly taking place. Many atmospheric processes take place in a state of **dynamic balance**—for example; there is an average balance between the heat input to, and output from, the atmosphere. This condition is akin to a leaky bucket sitting under a faucet: when the tap is turned on and water flows into the bucket, the water level will rise toward a steady state where inflow from the tap equals outflow through the leaks. Once this condition is attained, the water level will remain steady even though water is constantly flowing in and out of the bucket.

Similarly, Earth's climate system maintains a dynamic balance between solar energy entering and radiant energy leaving the atmosphere. Levels of oxygen in the atmosphere are regulated by a dynamic balance in the natural carbon cycle between processes that emit oxygen through photosynthesis and others that consume oxygen, such as respiration. The strength of atmospheric circulation is also controlled by a dynamic balance. Some parts of the planet receive more energy from the sun than others, and this uneven heating creates wind motions that act to move heat from warm to cold regions.

Today human actions are altering key dynamic balances in the atmosphere. Most importantly, humans are increasing greenhouse gas levels in the troposphere, which raises Earth's surface temperature by increasing the amount of heat radiated from the atmosphere back to the ground.

2. The Structure of the Atmosphere

A. chemical composition

The atmosphere is a mixture of gases, suspended particles, and liquid/solid water. Gases and particles are readily exchanged between the Earth's surface and the atmosphere through physical (volcanic) and biological (photosynthesis, respiration) processes. Atmospheric gases are generally classified by their amount and residence time. **The residence time (or removal time or lifetime) is an average amount of time that a particle or substance spends in a particular system (as the atmosphere).** According to residence time, These gases are categorized in **two** types: **permanent and variable gases** and aerosols.(and sometimes highly variable) gases can be distinguished (Table 1).

Table 1: Classification of atmospheric gases

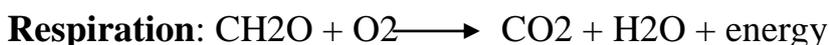
Amount	Main components	Trace gases
Residence time		
Constant gases	nitrogen, oxygen and argon (major components of the atmosphere)	other noble gases
Variable gases	carbon dioxide	other long-lived tracers
Highly variable gases	water vapour	other short-lived tracers

1. Constant (permanent) gases

The constant gases contains nitrogen, oxygen and argon (Table 2). This gases have remained relatively constant throughout much of Earth's history.

Chemical reactions maintain the ratios of major constituents of the atmosphere to each other. For example, oxygen is released into the atmosphere by photosynthesis and consumed by respiration.

The concentration of oxygen in the atmosphere is maintained by a balance between these two processes:



"CH₂O" denotes the average composition of organic matter.

Many gases play critical roles in the atmosphere even though they are present in relatively low concentrations.

Table 2. Shows the Constant (permanent) gases

Constituent	Formula	Percent by Volume	Molecular Weight
Nitrogen	N ₂	78.08	28.01
Oxygen	O ₂	20.95	32.00
Argon	Ar	0.93	39.95
Neon	Ne	0.002	20.18
Helium	He	0.0005	4.00
Krypton	Kr	0.0001	83.80
Xenon	Xe	0.00009	131.30
Hydrogen	H ₂	0.00005	2.02

Permanent gases characteristics

- Stable concentration in the atmosphere.
- account for about 99% of the atmospheric mass
- occur in a constant proportion in the lowest ~80 km of the atmosphere

although individual molecules exchange between the atmosphere and Earth, the total concentration remains the same → *chemical homogeneity*
Lowest 80-100 km is called the **Homosphere** and is sometimes considered to be the entire atmosphere.

The atmosphere above this is called the **Heterosphere**.

- Homosphere: Turbulent mixing causes atmospheric composition to be fairly homogenous from surface to ~80-100 km (i.e., 78% N₂, 21% O₂)
- Heterosphere: Above ~80-100km, much lower density, molecular collisions much less, heavier molecules (e.g., N₂, O₂) settle lower, lighter molecules (e.g., H₂, He) float to top

N₂ + O₂ = 99% of atmospheric volume below 80 km.

They are **chemically active**.

Ar, Ne, He, Xe < 1% and are **chemically inert**.

A.Nitrogen:

Nitrogen (N₂) is a fundamental to all living systems. Through the nitrogen cycle nitrogen is removed from the atmosphere and becomes part of living organisms. This process is realized by nitrogen fixation by soil bacteria, and

by way of lighting through precipitation. Nitrogen returns to the atmosphere mainly by biomass combustion and denitrification

N₂ is added and removed from the atmosphere very slowly – long *residence time*** of ~42 million years.

- N₂ is relatively unimportant for most meteorological and climate processes
- some gases containing N are important to the Earth’s climate such as NO₂.

B. Oxygen: As nitrogen, oxygen (O₂) has also very important relations with life. Oxygen exchange between the atmosphere and biosphere is realized by photosynthesis and respiration .O₂ is crucial to the existence of almost all forms of life currently on the Earth. Its *residence time* is ~5000 years.

C. Argon: (Ar) in the atmosphere is the third most abundant gas. Among noble gases, argon was first detected in the atmosphere in 1894 by Lord Rayleigh and William Ramsay.

2. Variable Gases

Distributions vary both in time and space.

Account for < 1% of the atmosphere below 80 km.

Some of these gases impact the behavior of the atmosphere considerably (table 3).

Table 3 Variable Gases of the Atmosphere			
Constituent	Formula	Percent by Volume	Molecular Weight
Water Vapor	H ₂ O	0.25	18.01
Carbon Dioxide	CO ₂	0.036	44.01
Ozone	O ₃	0.01	48.00

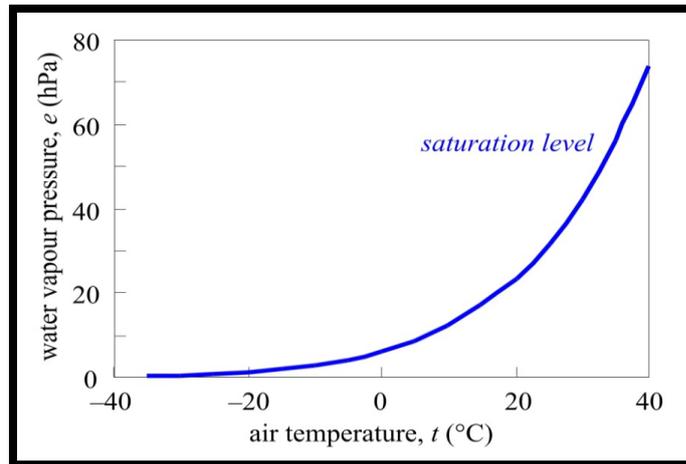
$$\text{H}_2\text{O} + \text{CO}_2 + \text{O}_3 = 0.296\% \text{ of atmospheric volume.}$$

A. Water Vapor (0.25%)

Water vapor (H₂O) is a significant component of the atmosphere. Its concentration varies over a wide range both spatially and temporally. Most

of water vapor concentrated in the lower atmosphere (about 90% of total atmospheric water vapor is found in the lower 5 km atmospheric layer, and more than 99% of it can be found in the troposphere). The capacity of air to hold water vapor (called saturation level) is a function only of the air temperature. The higher the temperature the greater amount of water vapor can be held without condensation (Figure1).

(Figure1)



The highest atmospheric moisture content is observable over equatorial ocean area and tropical rain forests, while the lowest water vapor concentrations can be measured over cold, polar regions, and subtropical deserts. Atmospheric water vapor has several significant direct and indirect effects on both weather and climate. It plays important roles in the radiation and the energy budgets of the atmosphere, and also in the formations of clouds and precipitations. About 70% of total absorption of the incoming shortwave solar radiation, particularly in the infrared region, and about 60% of total absorption of long-wave radiation by the Earth are realized by water vapor (Figure 2) thereby it is the most significant greenhouse gas.

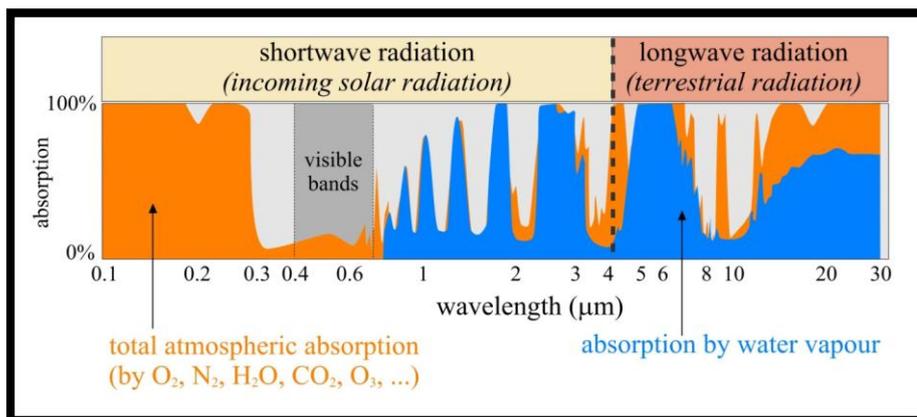


Figure 2: Absorption of solar and terrestrial radiation by all atmospheric components and by water vapor. Water vapor has significant absorption bands both in shortwave (incoming solar radiation) and long wave (outgoing terrestrial radiation) spectra.

–Water vapor is the most abundant variable gas, as it is added or removed from atmosphere through the hydrologic cycle. Continually cycled between atmosphere and earth by evaporation, condensation and precipitation.

–Concentrations exist from nearly 0 percent over desert and Polar Regions to nearly 4 percent near tropics.

–Water vapor is a contributor to Earth’s energy balance and many important atmospheric processes.

- Water vapor varies considerably in both space and time.
- Stores and releases large amounts of heat via evaporation and condensation.

Water vapor has a residence time of only 10 days.

- WV density is greatest at the surface, and decreases rapidly with height.

WV is extremely important for clouds.

WV absorbs radiant energy emitted from the Earth’s surface (*Greenhouse gas*)

B. Carbon Dioxide (0.036%)

Carbon dioxide (CO₂) is a trace gas accounting for 0.036 percent of the atmosphere’s volume. It is an important greenhouse gas as it has a strong absorption capacity in the infrared and near-infrared bands and important to Earth’s energy balance. It has a natural exchange between the atmosphere and biosphere through the photosynthesis and respiration. (CO₂) is supplied to the atmosphere through plant and animal respiration, through decay of organic material, volcanic eruptions, and both natural and *anthropogenic* (human caused) combustion CO₂ is removed through **photosynthesis**, the process of plants converting light energy to chemical energy.

A part of atmospheric CO₂ is dissolved by the seas and oceans. Atmospheric concentration of carbon-dioxide has increased steadily worldwide by over 35% since the beginning of 1800’s. Before the Industrial Era, atmospheric carbon dioxide concentration was 280 ± 10 ppm for several thousand years. The increase has speeded up in the last few decades. (Figure 3). This rapid growth is primarily due to growing anthropogenic activities, like burning of fossil fuels, deforestation, and other forms of land-use change. This man-made increase of atmospheric concentration of carbon-dioxide has definitely contributed to global warming over the last decades with the increase of greenhouse effect. CO₂ has a residence time of ~150 yrs.

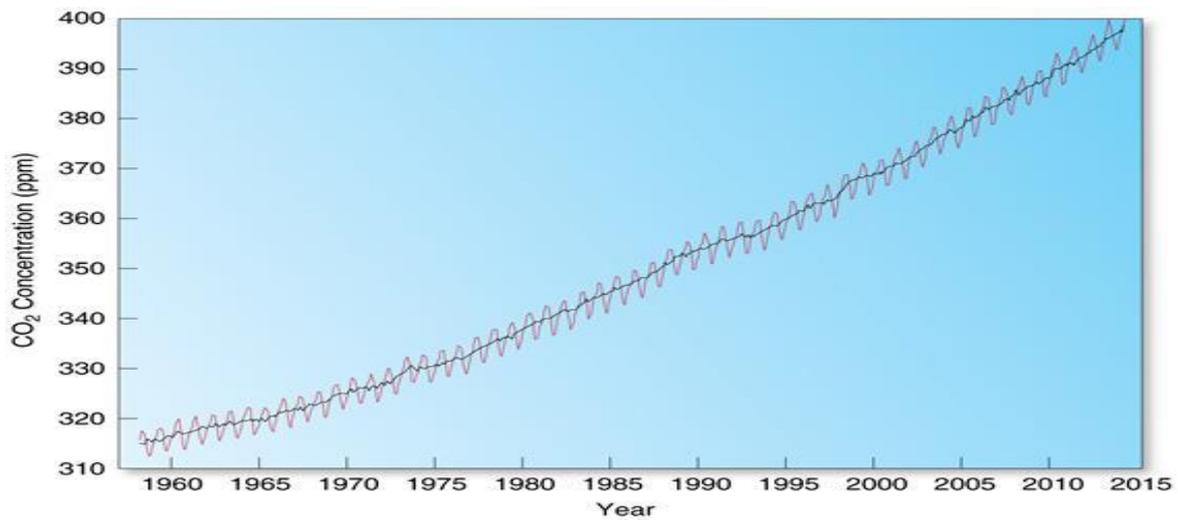
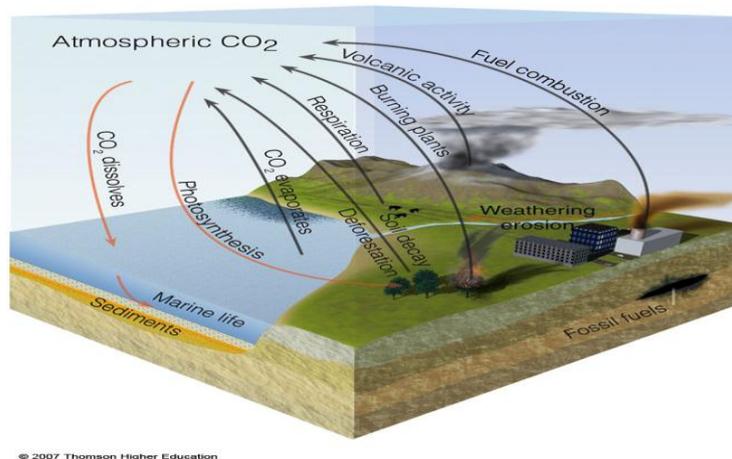


Figure 3: Its concentration in the atmosphere has increased ~18% since 1958. The steady increase of atmospheric CO₂.

Figure 3: Its concentration in the atmosphere has increased ~18% since 1958. The steady increase of atmospheric CO₂.

Earth's greenhouse gases like CO₂ contribute to a ~30C warmer surface temperature than would otherwise exist

Figure 4



Atmospheric CO₂ cycle **Figure 4**. Global climate models used to examine greenhouse warming must be able to account for multiple, complex processes in atmosphere, over land, and in ocean.

C. Ozone (0.01%)

(O₃) is an unusual molecule made up of 3 Oxygen atoms and is essential to life on Earth. It forms when individual O atoms collide with an O₂ molecule and exists in very small concentrations in the *stratosphere* .

O₃ is vital for absorbing lethal UV radiation from the sun. As it does this, it breaks down into its constituent components O + O₂.

Ozone near the surface is a pollutant but–Chlorofluorocarbons (CFCs), specifically chlorine atoms, react with ozone in the stratosphere and destroy ozone.

3. Aerosols

Aerosols are small solid particles or liquid droplets (except water particles) in the air.

They are formed by chemical reactions, wind-generated dust, volcanic ejections, sea spray, and combustion (e.g., fine ash) removed from the atmosphere by precipitation.

Aerosols typically have *residence times* of a few days to several weeks. Due to their small sizes, they can easily remain in suspension for longer periods.

Aerosols have a great impact on several atmospheric phenomena, Earth's climate and on biosphere.

During their atmospheric residence, different size solid and liquid particles influence

The radiation and energy budget of the Earth's.

The hydrological cycle.

Atmospheric circulation .

The abundance of trace gases.

Aerosol particles can be characterized by their concentration, size distribution, structure and chemical composition, which are highly variable both temporally and spatially. Their size are very small, the particle diameters in the range of 10⁻⁹–10⁻⁴ m.

In the lower troposphere, the aerosol mass concentration varies in a range of 1–100 µg m⁻³, and particle number is typically varies from 10² to 10⁵ cm⁻³. Most particles can be found over deserts and urban area, while polar atmosphere and alpine air contains fewer aerosols. Generally, aerosol concentration decreases with altitude.

Atmospheric aerosols have significant effects on different atmospheric processes, climate and human health.

Sources and sinks of atmospheric aerosols

After the emission of aerosol particles, they undergo various physical and chemical processes. During these processes, size, composition and structure of particles can be changed. Finally, they can be removed from the atmosphere to the surfaces by dry or wet deposition processes (Figure 5).

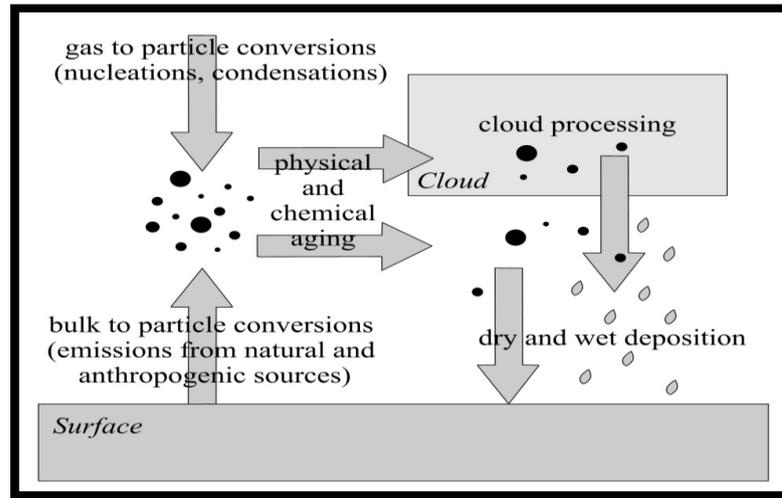


Figure 5: Atmospheric cycles of aerosol particles

Aerosols can be removed from the atmosphere by different ways in the function of their size and disposition. Two main types of removing processes of aerosol particles are wet and dry deposition.

Lecture 2

Physical properties of Atmosphere

Some important numbers for earth's atmosphere are given in Table 4.

atmospheric mass	M_a	5.26×10^{18} kg
global mean surface pressure	p_s	1.013×10^5 Pa
global mean surface temperature	T_s	288 K
global mean surface density	ρ_s	1.235 kg m ⁻³

Table 4 : Some atmospheric numbers.

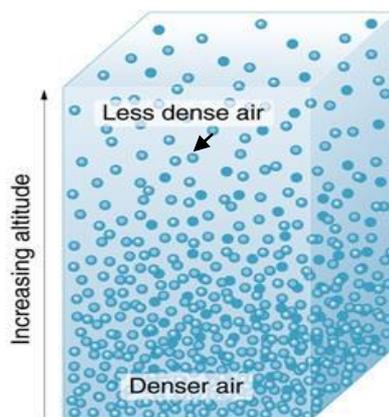
1. Density

–**Density** is mass (kg) per unit volume (m³). **Air density** can be defined as the number of air molecules per unit volume (number density). Near sea level there are about 2.7×10^{19} molecules per cm³ (cubic centimeter) or 4.4×10^{20} molecules per inch³ (cubic inch). Air molecules are held near the earth by *gravity*. In other words, air has weight. Weigh an empty bag, then fill it with air, it now weighs more. In addition gases, like air, are easily compressed, i.e., squeeze a gas together and its number density increases. In other words, we say gases are compressible because they can easily be squeezed into a smaller volume.

–Due to compressibility, near-surface or sea level air is denser than that above (where it is squeezed by the weight of the entire atmosphere above) and decreases as we move up in the atmosphere because the weight of air above becomes less and hence there is less of a squeezing effect .

–This may be expressed in terms of the **mean free path**, or average distance a molecule travels before colliding with another molecule **Figure 6**.

Less overlying weight



More overlying weight

Figure 6: Due to compressibility, atmospheric mass gradually “thins out” with height

- Air density is the *mass* of the air divided by the *volume* of measurement.

$$\rho = \frac{kg}{m^3}$$

As one goes higher in the atmosphere the number of molecules in a given volume decreases, so like pressure, density also decreases monotonically with height.

2. Pressure

Atmospheric air pressure results from the Earth's gravitational pull on the overlying air. Without gravity holding the atmosphere just above the ground surface, air molecules would spread out, and the gas pressure would be close to zero. The weight of the atmosphere acts as a force upon the underlying surface of the Earth. The amount of force exerted over an area of surface is called *atmospheric pressure* or **air pressure**. Near sea level, the average air pressure is about 14.7 pounds per square inch or uses the unit millibars (mb) to specify air pressure. At sea level the average air pressure is 1013 mb. Another way to think of this is that the total weight of all the air above sea levels weighs enough to cause 1013 mb of air pressure.

Since the air (a gas) is a fluid, the pressure force acts in all directions, not just downward. The pressure force pushing downward due to the weight of the air is the same as the pressure force acting sideways and even upward. If you are having trouble understanding this, make an analogy with another fluid liquid water. Consider a deep swimming pool full of water. The water pressure anywhere in the pool depends on the weight of the water above (that is the deeper you dive downward in the pool, the stronger the water pressure.) The pressure force is not just downward though, it pushes in on your body from all directions. The average air pressure at sea level (1013 mb or sometimes called one atmosphere of pressure) is caused by the weight of all the air above sea level. In the same way water pressure is caused by the weight of water above you. At a depth of 32 feet (9.75 meters) below a water surface, the water pressure is about one atmosphere. Thus, the entire column of air from sea level to outer space weighs as much as a 32 foot column of water. Of course diving deeper than 32 feet downward into water means you will encounter an increasing water pressure (enough to crush you if you go too deep).

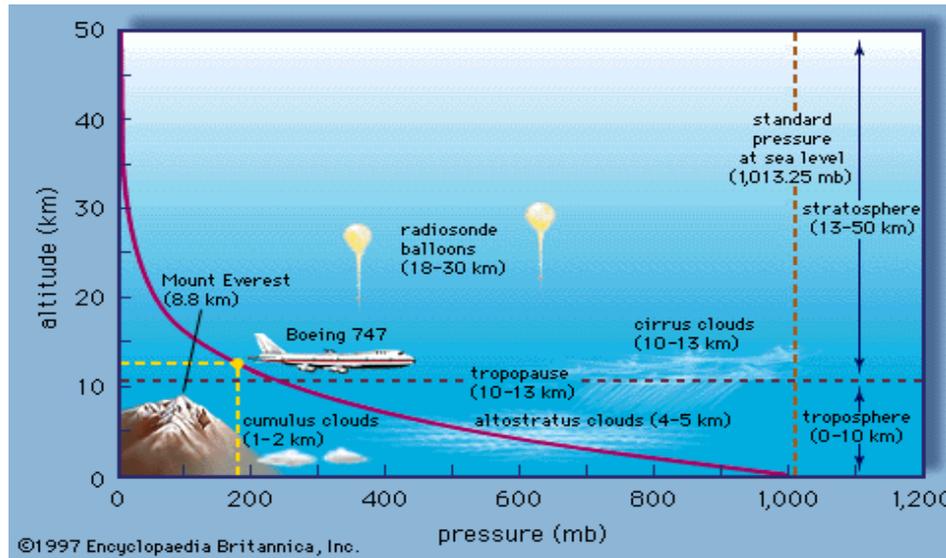
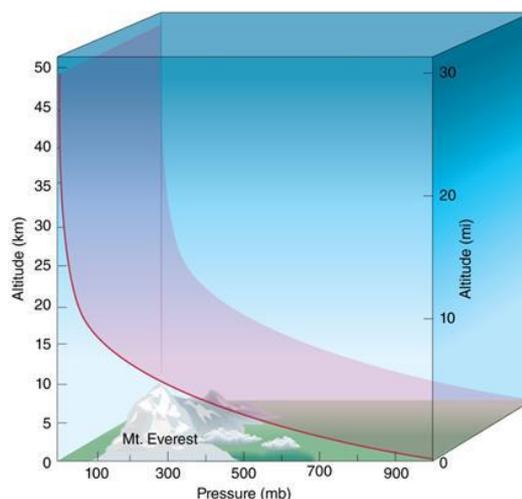


Figure 7: Typical change in air pressure with altitude.

In the atmosphere, the air pressure at any point is caused by the weight per area of the air above that point. As we climb in elevation, fewer air molecules are above us (less weight of air above us); hence, *atmospheric pressure always decreases as you move upward in the atmosphere* .(Figure 7).

Because air is compressed by its own weight, much of the mass of the atmosphere is squeezed into the troposphere where the air is most dense (higher number density), while only a small portion of the mass of the atmosphere remains above the stratosphere where air is less dense (lower number density). Since air pressure is directly related to the weight of air above a given point, a ratio of air pressure is equivalent to a ratio of weight.

- Pressure** is a result of the atmospheres mass.
- Pressure decreases vertically but not at a constant rate.



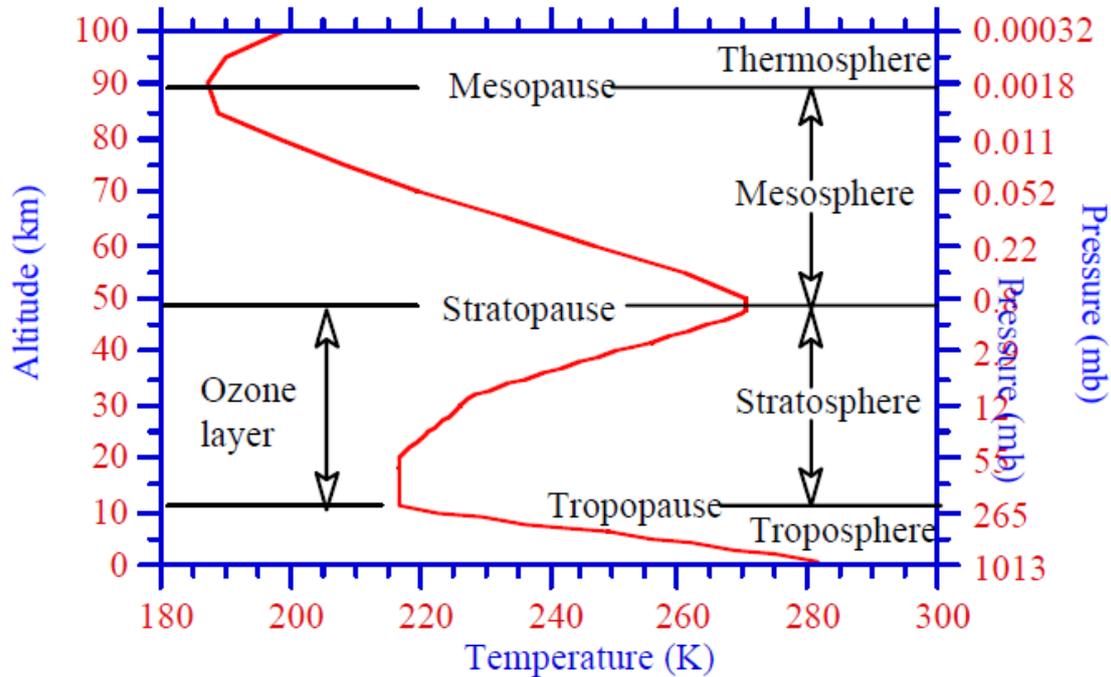
- Air is mostly made up of free molecules in constant motion (gases).
- Air molecules have mass.
- You can feel the mass of the air when the wind is blowing hard.
- Weight (a vertical force) = **Mass x Gravity**
- Air has pressure (weight/area)
- The pressure at the surface is caused by the weight of all the air molecules in the column above the surface.
- Add more air molecules to the column and the pressure goes up. (High Pressure areas) while take away air molecules from the column the pressure goes down. (Low Pressure areas)

Temperature and Processes affecting Temperature:

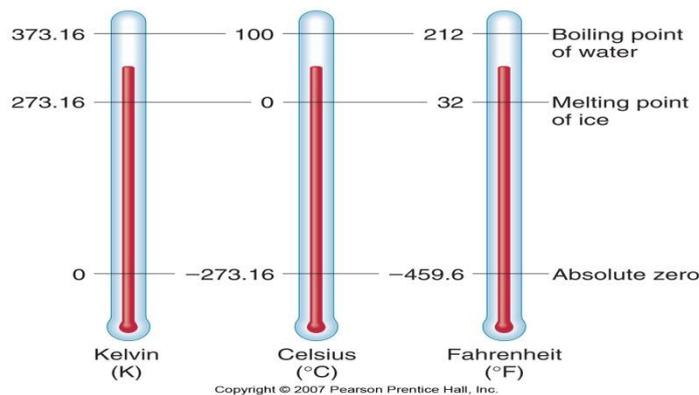
The amount of gas present in the atmosphere, the temperature of the gas, and gravity determine the structure of the Earth's atmosphere. The temperature of the atmosphere differs from location to location, with time, and with altitude. Temperature is proportional to the average kinetic energy of an air molecule. So the higher the temperature, the faster air molecules will travel in the atmosphere. Gravity keeps these molecules from flying out into space. In order for an air molecule to escape the Earth, it must be high enough (so it won't collide with another molecule before escaping), and hot enough (traveling fast enough). Fortunately for us, very few molecules can escape the Earth's gravitational field. Near the surface of the Earth, molecules cannot travel more than 1/10,000,000 meter before colliding with another molecule, making the lower part of the atmosphere well mixed.

The bottom 100 km of the atmosphere is called the homosphere. The homosphere is broken up into layers according to the temperature profile shown below. The transition from one region to another is determined by the rate of temperature change with height.

Temperature Versus Altitude



- Air molecules are moving all around us, bouncing off each other and us.
- When the air molecules have greater kinetic energy (energy of motion), they are moving faster.
- The temperature of the air molecules is a measure of the average speed of the molecules per standard volume.



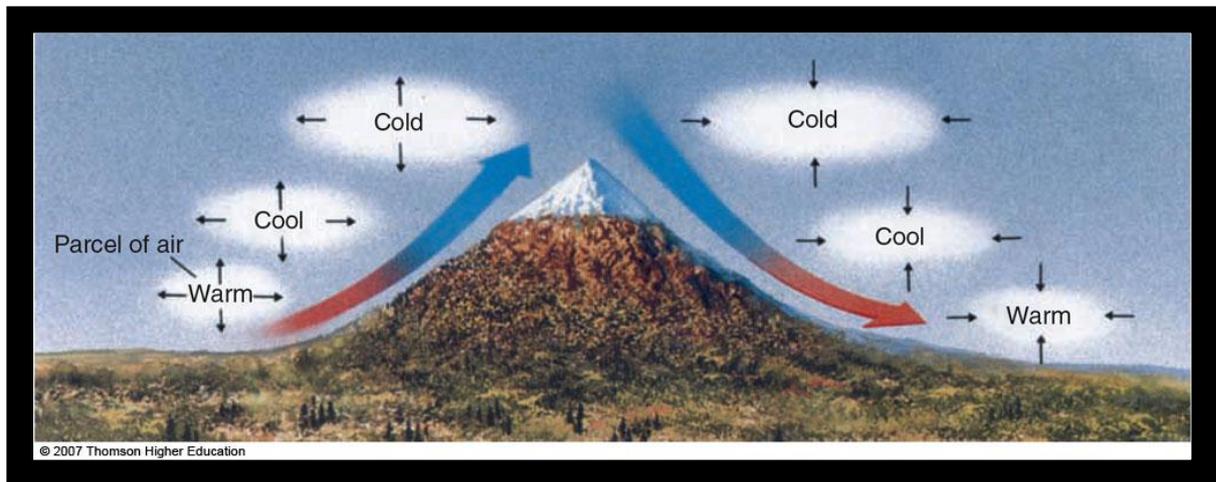
$$K = ^\circ C + 273.16$$

$$F = \frac{9}{5}^\circ C + 32$$

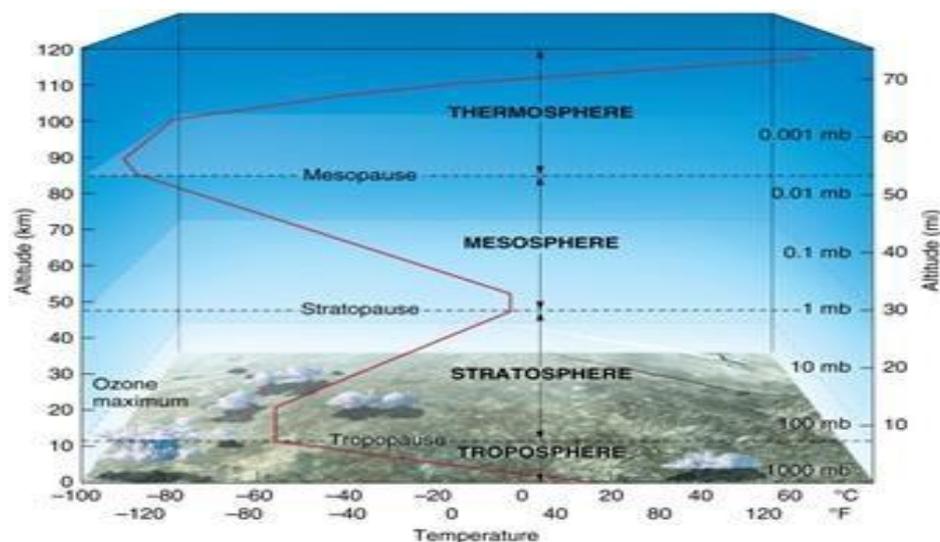
$$C = \frac{5}{9}(^\circ F - 32)$$

Temperature Change w/Altitude

- As a parcel of air rises, it expands due to lower pressure.
- Work done by molecules to expand causes temperature to decrease (cools)
- As air sinks, the parcel experiences compression due to higher pressure
- Air molecules have work done on them, temperature increases (warms)

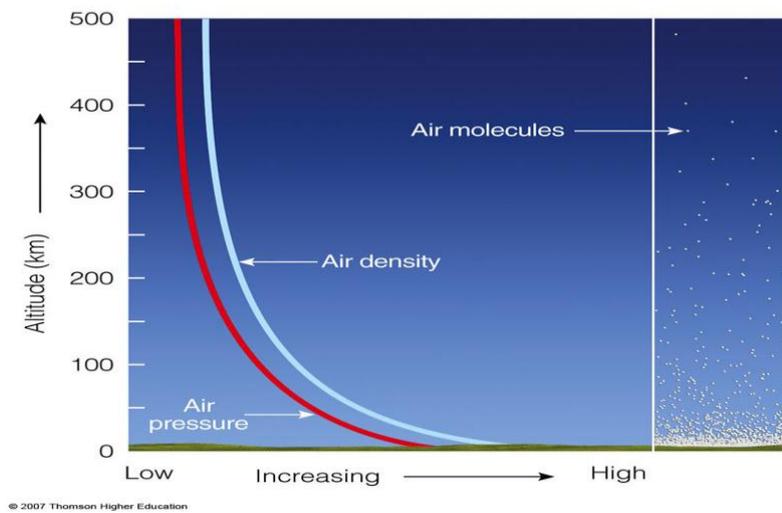


Vertical Structure of the Atmosphere commonly broken into layers
Layers are most often defined by the vertical change of *temperature* within the layer since this is related to the presence of vertical motions (or lack of) in the layer—Four distinct layers of the atmosphere emerge from identifiable temperature characteristics with height.



“Equation of State” or “**Ideal Gas Law**”

- Temperature, pressure and density related
- Pressure = density*gas constant*temperature
 $P = \rho RT$
- If the pressure decreases, the density will decrease for constant Temp.
- If the pressure decreases, the temperature will decrease for constant density, etc.
- It is possible for all three state variables to change at the same time!
- air density (ρ pronounced “row”)
- air pressure (p)
- sea-level pressure (p_s)



Lecture 3

The atmosphere layers

Layers of the Atmosphere

As one travels from the surface to outer space, the atmosphere undergoes various changes, and it is necessary to look at the vertical layers that exist with Earth's atmospheric envelope. There are several systems used to divide the atmosphere into vertical layers. One (1) system uses **temperature and rates of temperature** changes. (2) Another uses the changes in **the content of the gases** in the atmosphere, and (3) yet a third deals with **the functions** of these various layers.

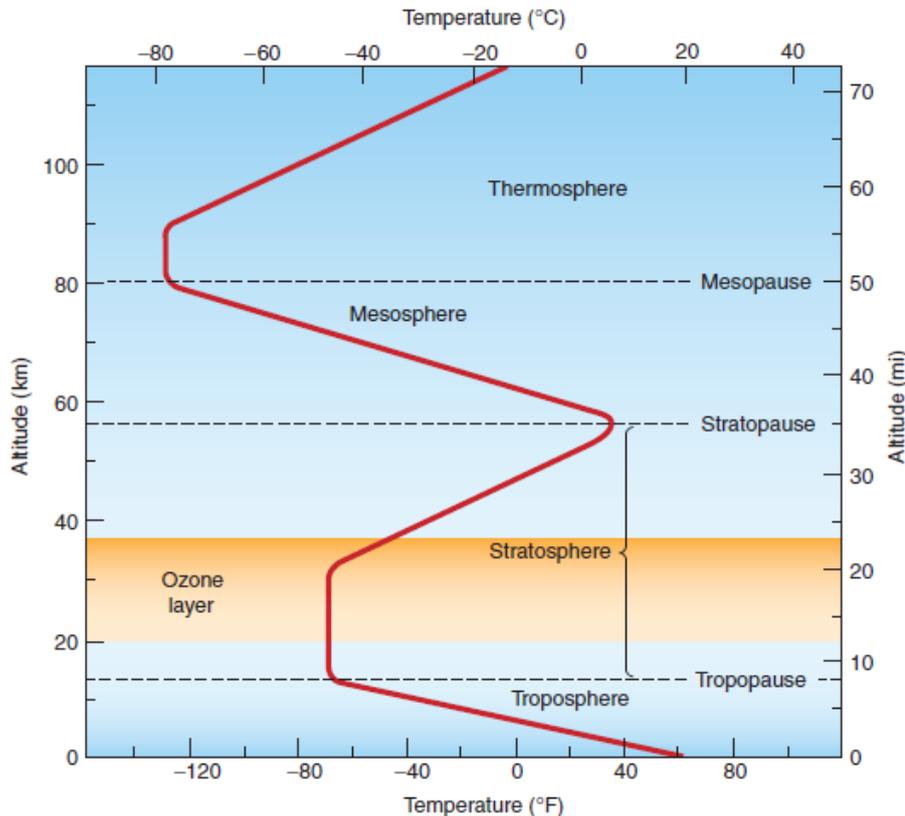
System of Layering by Temperature Characteristics

The atmosphere can be divided into four layers according to differences in temperature and rates of temperature change (Fig. 4.8). The first of these layers, lying closest to Earth's surface, is the **troposphere**.

● **FIGURE 4.8**

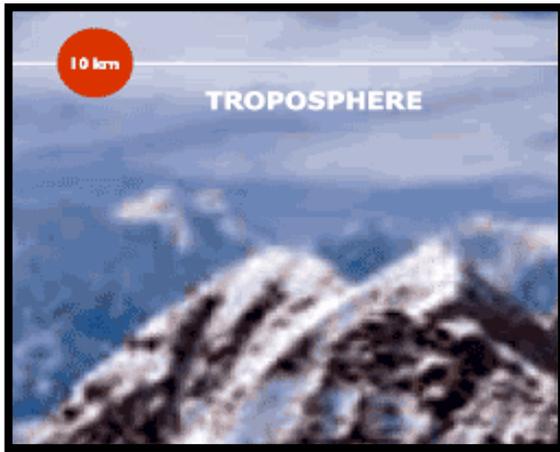
Vertical temperature changes in Earth's atmosphere are the basis for its subdivision into the troposphere, stratosphere, mesosphere, and thermosphere.

At what altitude is our atmosphere the coldest?



1. The troposphere (from Greek: *tropo*, turn—the turning or mixing zone), which extends about 8–16 kilometers (5–10 mi) above Earth. Its thickness, which tends to vary seasonally, is least at the poles and greatest at the equator. It is within the troposphere that people live and work, plants grow, In fact, most clouds form in this layer and virtually all Earth’s weather and climate take place.

The troposphere has **two** distinct characteristics that differentiate it from other layers of the atmosphere. One is that the water vapor and particulates of the atmosphere are concentrated in this one layer; they are rarely found in the atmospheric layers above the troposphere. The other characteristic of this layer is that temperature normally decreases with increased altitude. The average rate at which temperatures within the troposphere decrease with altitude is called the



normal lapse rate (or the environmental lapse rate); it amounts to 6.5°C per 1000 meters (3.6°F/1000 ft).

The altitude at which the temperature ceases to drop with increased altitude is called the **tropopause**. It is the boundary that separates the troposphere from the **stratosphere**—the second layer of the atmosphere.

The constant motion in this layer is significant in discussing air quality because it results in the dispersion of

pollutants. In one respect this dispersion is considered beneficial because it has the effect of diluting pollutants, which can reduce harmful impacts on a local level. On the other hand, this dispersion also results in the movement of air pollutants (and therefore air pollution problems) from areas of high pollution production to areas of lower production.

2. The stratosphere

The second layer of the atmosphere. The temperature of the lower part of the stratosphere remains fairly constant (about -57°C , or -70°F) to an altitude of about 32 kilometers (20 mi). It is in the stratosphere that we find the ozone layer that does so much to protect life on Earth from the sun’s UV radiation. As the ozone layer absorbs UV radiation, this absorbed energy results in the release of heat, and thus temperatures increase in the upper parts of the stratosphere.

Some water is available in the stratosphere, but it appears as stratospheric ice clouds. These thin veils of ice clouds have no effect on weather as we experience it. Temperatures at the *stratopause* (another boundary), which is about 50 kilometers (30 mi) above Earth, are about the same as temperatures found on

Earth's surface, although little of that heat can be transferred because the air is so thin.

In the Earth's stratosphere, the temperature increases with altitude (as opposed to the troposphere, where it gets colder with altitude).



The increasing temperature in the stratosphere is caused by the presence of a layer of ozone near an altitude of 30 kilometers. The ozone molecules absorb high---energy UV rays from the sun, which warm the atmosphere at that level.

The terrestrial stratosphere is the region between the tropopause, or the end of the troposphere, and the level at which the maximum warming due to the presence of ozone takes place, which is at an altitude of about 50 kilometers.

Ozone

The Ozone Hole. Pollution. Skin Cancer. The topic of ozone makes headlines on a regular basis. How important is the ozone in our atmosphere and why are scientists so concerned about its increase near the surface of the Earth and its disappearance higher up in the atmosphere?

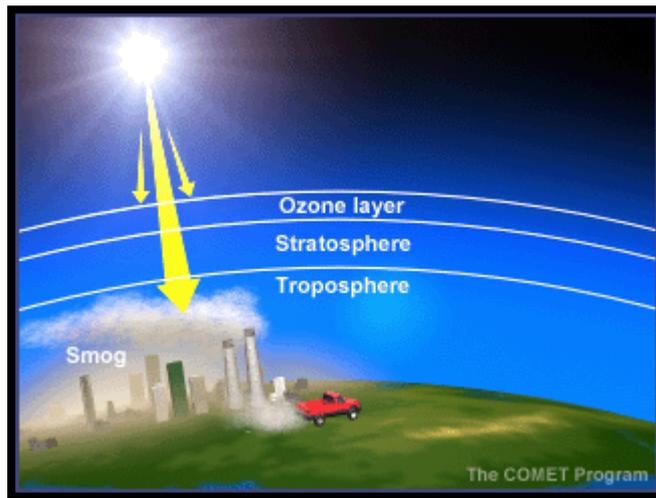
First things first --- what is ozone? Ozone is made of three oxygen atoms (O₃). The oxygen in our atmosphere that we breathe is made up of two oxygen atoms (O₂). Because of its chemical formulation, a single atom of oxygen (O) is unstable. That is, it wants to combine with something else. That is why oxygen is almost always found in pairs, in its (diatomic) form, where it is more stable. (O₃) is less stable than (O₂), because it wants to return to the diatomic state by giving up an oxygen atom.

About 90% of the ozone in the Earth's atmosphere lies in the stratosphere. When enough ozone molecules are present, it forms a pale blue gas. Ozone has the same chemical structure whether it is found in the stratosphere or the troposphere.

- It lies at an altitude between **30 km and 50 km** from the earths Because of the presence of ozone molecules; this layer reflects the harmful ultraviolet radiation.
- The ozonosphere is also called **chemosphere** because; a lot of chemical activity goes on here.
- The temperature rises at a rate of **5°C per kilometer** through the ozonosphere.

In the troposphere, the ground-level or "bad" ozone is an air pollutant that damages human health, vegetation, and many common materials. It is a key ingredient of urban smog. In the stratosphere, we find the "good" ozone that protects life on Earth from the harmful effects of the Sun's ultraviolet rays. Although simplistic, the saying "Good up high and bad nearby,"

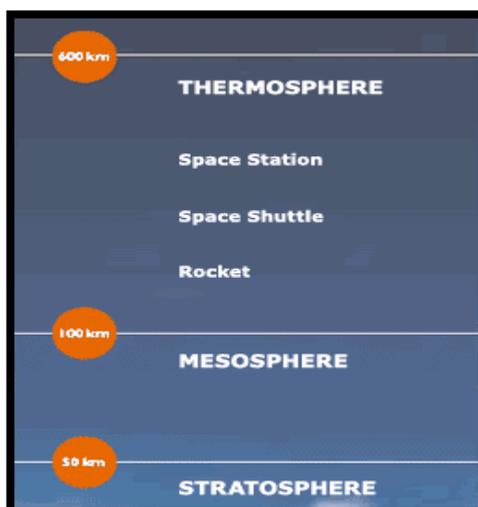
While both oxygen and ozone together absorb 95 to 99.9% of the Sun's ultraviolet radiation, only ozone effectively absorbs the most energetic ultraviolet light, known as UV-C and UV-B, which causes biological damage.



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3. The mesosphere

In the Earth's mesosphere, the air masses are relatively mixed together and the temperature decreases with altitude. Atmospheric temperatures reach the lowest average value of around -90°C in the mesosphere. This is also the layer in which a lot of meteors burn up while entering the Earth's atmosphere.



The mesosphere extends from the top of the stratosphere (the stratopause, located at about 50 kilometers) to an altitude of about 90 kilometers. In fact it is colder than Antarctica's and recorded lowest temperature degrees. It is cold enough to freeze water vapor into ice clouds. You can see these clouds if sunlight hits them after sunset. They are called

Noctilucent Clouds (NLC). Above the stratopause is the **mesosphere**, in which temperatures tend to drop with increased altitude; the *mesopause* (the last boundary) separates the mesosphere from the **thermosphere**.

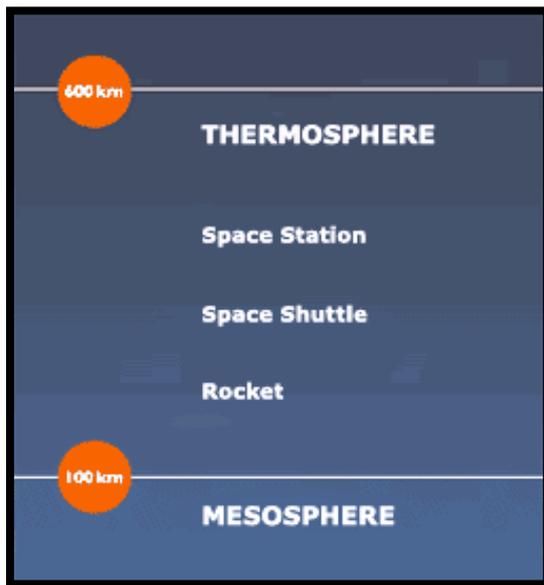
4. The Thermosphere

The Earth's thermosphere is the layer of the atmosphere which is first exposed to the Sun's radiation and so is first heated by the Sun. The air is so thin that a small increase in energy can cause a large increase in temperature.

The temperature in the thermosphere is very dependent on solar activity. When the

Sun is active, temperatures can reach up to 1,500°C or higher!

Because of the thin air in the thermosphere, scientists can't measure the temperature directly. They measure the density of the air and then use the density to find the temperature.



The thermosphere also includes the region of the Earth's atmosphere called the ionosphere. The ionosphere is the region of the atmosphere that is filled with charged particles. Elevated temperatures can sometimes cause a molecule to become ionized, therefore, the ionosphere and thermosphere can

overlap.

The Ionosphere

Scientists call the ionosphere an extension or a part of the thermosphere. So technically, the ionosphere is not another atmospheric layer, but a region of the atmosphere. The ionosphere represents less than 0.1% of the total mass of the Earth's atmosphere. Even so, it is extremely important!

The upper atmosphere is ionized by solar radiation. Under normal conditions free electrons and ions tend to recombine and a balance is established between electron and ion production and loss.

Ionization processes release energy which heat up the upper atmosphere. So temperature increases with height in the ionosphere region to the extent that by 150-200km, the Earth's atmosphere is extremely hot compared to surface temperatures.

Different regions of the ionosphere make long distance radio communication possible by reflecting the radio waves back to Earth. It is also home to auroras.

Regions of the Ionosphere

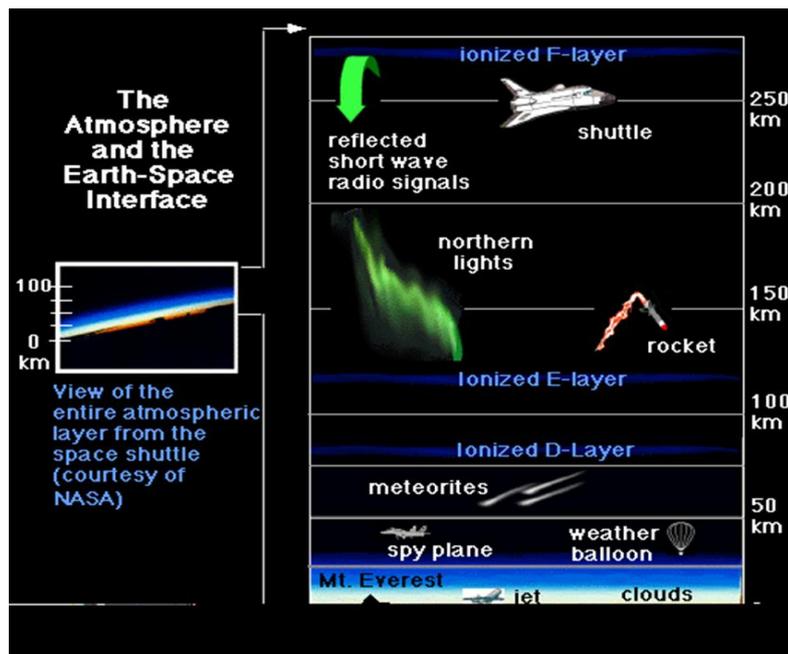
The ionosphere can be further broken down into the D, E and F regions. The breakdown is based on what **wavelength of solar radiation is absorbed in that region most frequently** .

The D region is the lowest in altitude, though it absorbs the most energetic radiation, hard x-rays.

The D region doesn't have a definite starting and stopping point, but includes the ionization that occurs below about 90km (or ionization that occurs below the E region).

The E region peaks at about 105km. It absorbs soft x-rays.

The F region starts around 105km and has a maximum around 600km. It is the highest of all of the regions. Extreme ultra-violet radiation (EUV) is absorbed there.



Layers (D, E, and F) of Earth's Ionosphere

On a more practical note, the D and E regions (the lower parts of the ionosphere), reflect standard AM radio waves back to Earth. Radio waves with shorter lengths are reflected by the higher F region. Visible light, radar, television and FM wavelengths are all too short to be reflected by the ionosphere. So these types of global communication are made possible by satellite transmissions.

The Exosphere

At very high altitudes, the atmosphere becomes very thin. The region where atoms and molecules escape into space is referred to as the exosphere. This is the true upper limit of the Earth's atmosphere. The exosphere extends from the thermosphere out to space

System of Layering by Functional Characteristics

Astronomers, geographers, and communications experts sometimes use a different method of layering the atmosphere, one based on the protective function these layers provide. In this system, the atmosphere is divided into two distinct layers, the lowest of which is the **ozonosphere**.

This layer lies approximately between 15 and 50 kilometers (10–30 mi) above the surface.

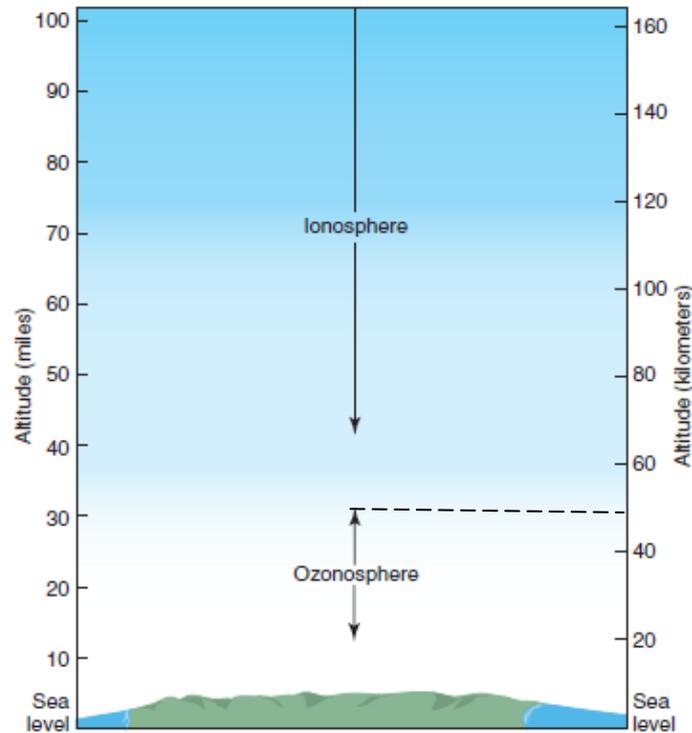
The ozonosphere is another name for the ozone layer mentioned previously. Again, ozone effectively filters the UV energy from the sun and gives off heat energy instead. As we have noted, although ozone is a toxic pollutant at Earth's surface, aloft, it serves a vital function for Earth's life systems.

From about 60–400 kilometers (40–250 mi) above the surface lies the layer known as the **ionosphere**. This name denotes the ionization of molecules and atoms that occurs in this layer, mostly as a result of UV rays, X-rays, and gamma radiation. Ionization refers to the process whereby atoms are changed to ions through the removal or addition of electrons, giving them an electrical charge. The ionosphere in turn helps shield Earth from the harmful shortwave forms of radiation. This electrically charged layer also aids in **transmitting communication** and broadcast signals to distant regions of Earth. It is in the ionosphere that the **auroras occur**. The ionosphere gradually gives way to interplanetary space (Fig. 4.9).

● **FIGURE 4.9**

Vertical changes in Earth's atmosphere based on functions of the gases cause the atmosphere to be subdivided into the ozonosphere and the ionosphere.

How do these layers protect life on Earth?



System of Layering by Chemical Composition

Atmospheric chemists and physicists are at times concerned with the actual chemical makeup of the atmosphere. To this end, there is one more system to divide the atmosphere into two vertical layers. The first is termed the **homosphere** (from Greek: *homo*, same throughout). This layer begins on the surface and extends to an altitude of 80 kilometers (50 mi). In this layer, the gases in our atmosphere maintain the same percent by volume. There are a few areas of concentration of specific gases, like the **water vapor** near Earth's surface and the **ozone** layer aloft, but for the most part the mixture is homogeneous. Other than rapid decreases in pressure and density while ascending through this layer, this is essentially the same air that we breathe on the surface.

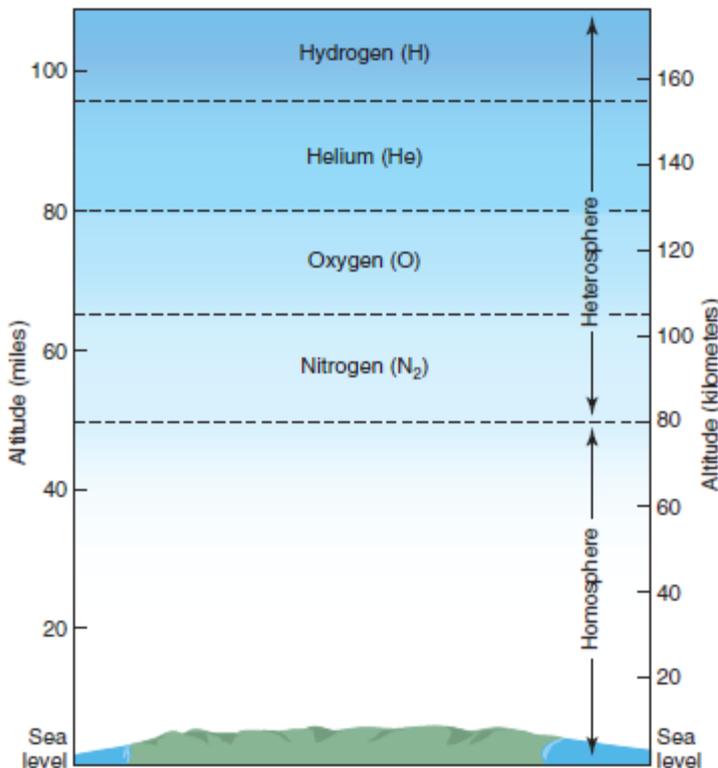
From an altitude of about 80 kilometers (50 mi) and reaching into the vacuum of outer space lies the **heterosphere** (from Greek: *hetero*, different). In this layer, atmospheric gases are no longer evenly mixed but begin to separate out into distinct sublayers of concentration. This separation of gases is caused by Earth's gravity in

which heavier gases are pulled closer to the surface and the lighter gases drift farther outward. The regions of concentration and their corresponding gases occur in the following order: nitrogen gas (N₂) is the heaviest and therefore the lowermost, followed by atomic oxygen (O), then by helium (He), and finally atomic hydrogen (H)—the lightest element that concentrates at the outermost region (● Fig. 4.10).

● **FIGURE 4.10**

The changes in chemical composition of the gases allow for the subdivision of the atmosphere into the homosphere and the heterosphere.

What gas in the atmosphere is the last to reach into outer space?



It is interesting to note that, when watching television news reports from the International Space Station. The background appears black, making it look like interplanetary space, but in reality these missions still take place within the realm of the outer atmosphere. One should also keep in mind that these different layering systems can focus on the same regions.

For example, note that the thermosphere, the ionosphere, and the heterosphere all occupy the same altitudes above Earth—that is, from 80 kilometers (50 mi) and outward. The names are different because of the criteria used in the differing systems.

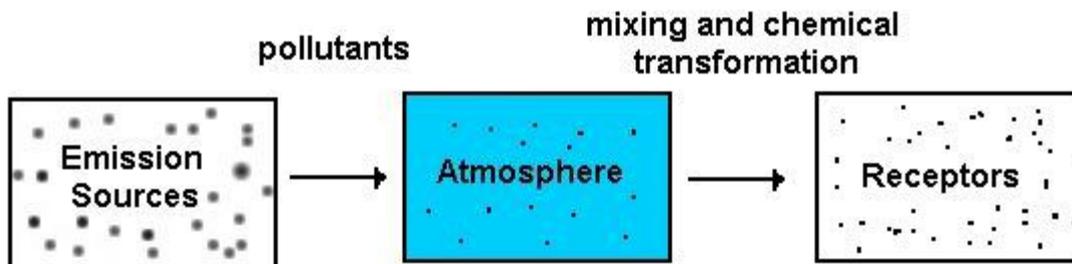
Lecture 4

Air pollution

May be defined as any atmospheric condition in which *substances* are present at concentrations high enough above their normal ambient levels to produce a *measurable effect* on man, animals, vegetation, or materials (**receptors**).

Substances mean any natural or anthropogenic (man-made) chemical compounds capable of being airborne (**emission sources**). They may exist in the atmosphere as gases, liquid drops, or solid particles through (**atmosphere**).

The air pollution problem can be schematically presented as a system consisting of three basic components:



Air pollutants

Airborne **particles** and **gases** that occur in concentrations that danger to the health and well-being of organisms.

Primary pollutants

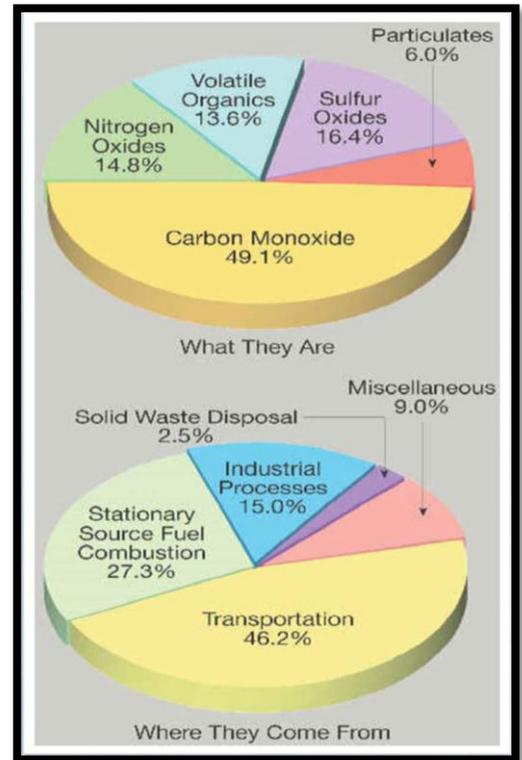
Primary air pollutants (PAPs) are that enters the atmosphere directly from (anthropogenic) and natural sources. Examples – Sulphur dioxide, nitrogen oxides, carbon monoxide, volatile organic matter, particulate matters, lead, ammonia etc.

Secondary pollutant A secondary air pollutant (SAPs) is not directly emitted as such, but forms when other pollutants (primary pollutants) react in the atmosphere.

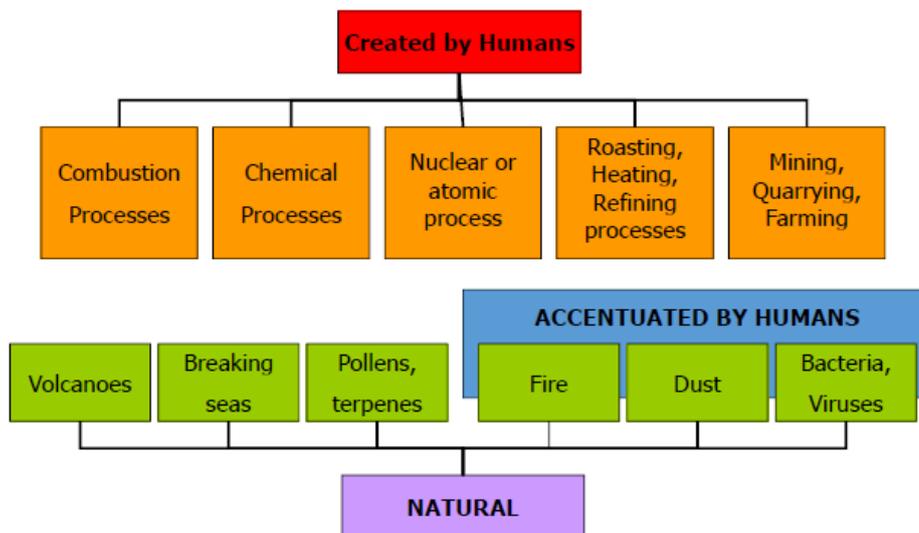
Examples of a secondary pollutant include **ozone**, which is formed when hydrocarbons (HC) and nitrogen oxides (NO_x) combine in the presence of sunlight and **acid rain**, which is formed when sulfur dioxide or nitrogen oxides react with water.

Primary Pollutants

- Sulfur Dioxide (SO₂)
- Nitrogen Oxides (NO_x)
- Carbon Monoxide (CO)
- Volatile Organic Compounds (VOCs)
- Particulate Matter (solid and liquid)
 - *Fine* are 2.5 um or less (PM 2.5)
 - *Coarse* are 10 um or greater (PM 10)
- Lead (Pb)



Sources of Primary Pollutants



1. Sulfur dioxide (SO₂)

Sulfur Dioxide (SO₂) Colorless and corrosive gas that comes primarily from burning of coal and oil. SO₂ is a gas formed when sulfur is exposed to oxygen at high temperatures during fossil fuel combustion, oil refining, or metal smelting. SO₂ is toxic at high concentrations, but its principal air pollution effects are associated with the formation of acid rain and aerosols. SO₂ dissolves in cloud droplets and oxidizes to form sulfuric acid (H₂SO₄), which can fall to Earth as acid rain or snow or form sulfate aerosol particles in the atmosphere.

• **Sources include:**

- Power plants
- Smelters
- Petroleum refineries
- Pulp and paper mills
- Through Chemical reactions in the atmosphere can ultimately form **ACID RAIN (sulfuric acid)**.

Natural Sources of Sulfur Dioxide Emissions

There are also significant sulfur emissions generated by natural sources.

The **main** natural sulfur emissions come in the **reduced forms of sulfur compounds** such as :

- hydrogen sulfide (H₂S)
- carbon disulfide (CS₂)
- carbonyl sulfide (COS)
- and in the organic forms of:
 - methyl mercaptan (CH₃SH)
 - dimethyl sulfide (DMS) (CH₃SCH₃)
 - dimethyl disulfide (DMDS) (CH₃SSCH₃)

Most of these compounds get oxidized to sulfur dioxide or to sulfate aerosols in the atmosphere. **Marine phytoplankton** produce dimethyl sulfide (DMS) which is then oxidized to SO₂ in the atmosphere; **decay processes** in soil and vegetation produce H₂S (as one of sulfur compounds); and SO₂ is emitted into the atmosphere by **volcanoes**.

- Around 90% of all natural sulfur emissions come in the form of DMS.
- Most recently the natural sources have been by far surpassed by anthropogenic sources. Natural sources have been estimated to produce around **24%** of all sulfur dioxide emissions, whereas human-caused emissions made up around **76%**.

Effects of Sulfur Dioxide Emissions

Environmental effects

When sulfur dioxide combines with water and air, it forms sulfuric acid, which is the main component of acid rain. Acid rain can:

- cause deforestation
- acidify waterways to the detriment of aquatic life
- Corrode building materials and paints.

In Queensland, there is less heavy industry than in Europe or North America, where the potential for forming acid rain from sulfur dioxide emissions is higher.

Health effects

sulfur dioxide affects the respiratory system, particularly lung function, and can irritate the eyes.

Sulfur dioxide irritates the respiratory tract and increases the risk of tract infections. It causes coughing, mucus secretion and aggravates conditions such as asthma and chronic bronchitis.

2. Nitrogen oxides (NO and NO₂, referred together as NO_x)

NO_x are highly reactive gases formed when oxygen and nitrogen react at high temperatures during combustion or lightning strikes. Nitrogen present in fuel can also be emitted as NO_x during combustion. Emissions are dominated by fossil fuel combustion at northern mid-latitudes and by biomass burning in the tropics.

In the atmosphere NO_x reacts with volatile organic compounds (VOCs) and carbon monoxide CO to produce ground-level ozone through a complicated chain reaction mechanism.

It is eventually oxidized to nitric acid (HNO₃). Like sulfuric acid, nitric acid contributes to acid deposition and to aerosol formation which fall to earth as rain, fog, snow or dry particles. Some may be carried by wind. Can be harmful to respiratory and Cardiovascular systems and is carcinogenic.

Sources include; Motor vehicles, Power plants and some bacteria

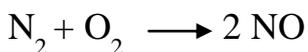
Seven (7) oxides of nitrogen are known to occur – NO, NO₂, NO₃, N₂O, N₂O₃, N₂O₄ and N₂O₅.

- Nitric oxide (NO) and Nitrogen dioxide (NO₂) are important in air pollution study.

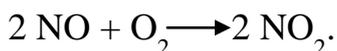
- There are two sources of nitrogen oxides (or NO_x):
 - i. **Thermal NO_x** are created when nitrogen and oxygen in the combustion air are heated to a high enough temperature ($> 1000 \text{ K}$) to oxidize nitrogen.
 - ii. **Fuel NO_x** result from the oxidation of nitrogen compounds that are chemically bound in the fuel molecules themselves. Natural gas almost has no nitrogen in them and some coal can have 3% N by weight. Fuel NO_x is often the dominant source of NO_x .
- Almost all NO_x emissions are in the form of **NO**, which has **no adverse health effects**.
- However, NO can oxidise to **NO_2** , which in turn may react with hydrocarbons in the presence of sunlight to form photochemical smog, which is injurious.
- **NO_2** also reacts with **hydroxyl radical** (HO) in the atmosphere to form **nitric acid** (HNO_3) and results in acid rain.
- NO_2 is an **acute** irritant at higher concentrations. Prolonged exposure to relatively low concentrations is linked to increased bronchitis in children. It can also damage plants. When converted to nitric acid it causes corrosion of metal surfaces.
- NO is a colorless gas, but NO_2 gives smog its reddish brown color.
- When mobile source controls are introduced, modifications to the combustion process that improve emissions of CO tend to make the NO_x problem worse and vice-versa. To control CO, it helps to increase the combustion air supply and to raise the temperature. To control NO_x , the opposite is true.

The NO- NO_2 - O_3 photochemical reaction sequence

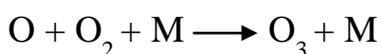
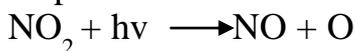
- NO is formed during combustion



- The nitric oxide thus emitted, can oxidise to NO_2 .

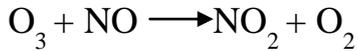


- If sunlight is available, NO_2 can photolyse, and the freed atomic oxygen can then help to form ozone:



where $h\nu$ represents a photon ($\lambda < 0.38 \mu\text{m}$) and M represents a molecule (usually O_2 or N_2) whose presence is necessary to absorb excess energy from the reaction.

- Ozone can then convert NO back to NO_2 :



- Thus, NO concentrations rise as early morning traffic emits its load of NO. Then as morning progresses, there is a drop in NO and a rise in NO_2 as NO gets converted to NO_2 .

As the sun's intensity increases toward noon, the rate of photolysis of NO_2 increases; thus NO_2 begins to drop while O_3 rises. Ozone is so effective in its reaction with NO that as long as O_3 is present, NO concentrations do not rise through the rest of the afternoon, even though there may be new emissions.

If only NO_2 photolytic cycle is involved, O_3 cannot accumulate in sufficient quantity in photochemical smog to account for the actual measured data. The introduction of hydrocarbons upsets the balance in production and destruction of ozone, thus allowing more O_3 to accumulate.

3. Carbon monoxide (CO)

It is the **MOST** abundant primary pollutant .CO is an odorless, colorless and tasteless gas formed by **incomplete combustion of carbon in fuel**.

Incomplete combustion, yielding CO instead of CO_2 , results when any of the following variables are not kept sufficiently high:

- i. Oxygen supply
- ii. Flame temperature
- iii. Gas residence time at high temperature
- iv. Combustion chamber turbulence.

The main **source** of the CO emissions are from the **transportation sector**. Hourly atmospheric concentrations of CO often reflect city driving patterns. Peaks occur on week days during the morning and late afternoon rush hours. Along with industrial processes and biomass burning. The CO, at levels that occur in urban air has no detrimental effect on materials or plants; but adversely affects human health.

In cities incomplete combustion of gasoline. Carbon monoxide binds to hemoglobin in red blood cells, reducing their ability to transport and release oxygen throughout the body. Low exposures can aggravate cardiac ailments, while high exposures cause

central nervous system impairment. People who breathe high levels of CO can develop vision problems, reduced ability to work or learn, reduced manual

dexterity, and difficulty performing complex tasks at extremely high levels, CO is poisonous and can cause death. Even small amounts of CO can seriously reduce the amount of oxygen conveyed throughout the body brain function is affected and heart rate increased in an attempt to offset the oxygen deficit. It also plays a role in the generation of ground-level ozone.

4. Volatile organic compounds (VOCs)

VOCs including hydrocarbons (C_xH_y) but also other organic chemicals are emitted from a very wide range of sources, including fossil fuel combustion, industrial activities, and natural emissions from vegetation and fires. Some anthropogenic VOCs such as benzene are known carcinogens.

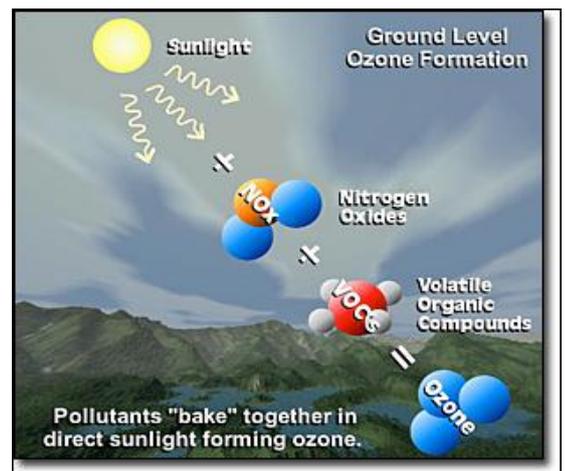
VOCs are also of interest as chemical precursors of ground-level ozone and aerosols. Large VOCs oxidize in the atmosphere to produce nonvolatile chemicals that condense to form aerosols. Short-lived VOCs interact with NO_x to produce high ground-level ozone in polluted environments. Methane (CH₄), the simplest and most long-lived VOC, is of importance both as a greenhouse gas and as a source of background tropospheric ozone. Major anthropogenic sources of methane include natural gas production and use, coal mining, livestock, and rice paddies.

Health Effects from VOCs

The harmful effects of exposure to VOCs vary according to the specific compound – ranging from no effects to highly toxic effects. This variance is related to the nature of the VOC, the level of exposure to the VOC, and the length of exposure to it.

With short-term exposure, the consequences can encompass eye and respiratory tract irritation, headaches, dizziness, visual disorders, fatigue allergic skin reactions, and memory impairment.

Long-term contact with VOCs can damage the liver, kidneys and central nervous system.



5. Particulate Matter

Particle pollution (also called particulate matter or PM) is the term for a mixture of solid particles and liquid droplets found in the air. Some particles, such as dust, dirt, soot, or smoke, are large or dark enough to be seen with the naked eye. Others are so small they can only be detected using an electron microscope. Particle pollution includes “**inhalable coarse particles**,” with diameters larger than 2.5 micrometers and smaller than 10 micrometers and “**fine particles**,” with diameters that are 2.5 micrometers and smaller.

These particles come in many sizes and shapes and can be made up of hundreds of different chemicals. Some particles, known as **primary particles** are emitted directly from a source, such as **construction sites, unpaved roads, fields, smokestacks or fires**. Others form in complicated reactions in the atmosphere of chemicals such as sulfur dioxides and nitrogen oxides that are emitted from power plants, industries and automobiles. These particles, known as **secondary particles**, make up most of the fine particle pollution in the country.

Particulate Matter Solid particles and liquid droplets that are small enough to remain suspended in the air Particles less than 10 microns are more likely they are to get into the lungs and affect the body.

- **Fine are 2.5 um or less (PM 2.5)**
- Fuel combustion, fireplaces, and wood stoves
- Get deep into lungs, cause serious health problems
- Can cause premature death
- **Coarse are 10 um or greater (PM 10)**
- Crushing and grinding operations, dust, soot
- Aggravate asthma and other respiratory conditions
- Main cause for **REDUCED VISIBILITY** .
- Midwest is a big problem due to regions with a lot of industry
- Lots of coal burning power plants cause a problem because they emit SO₂ which turns into fine particles.

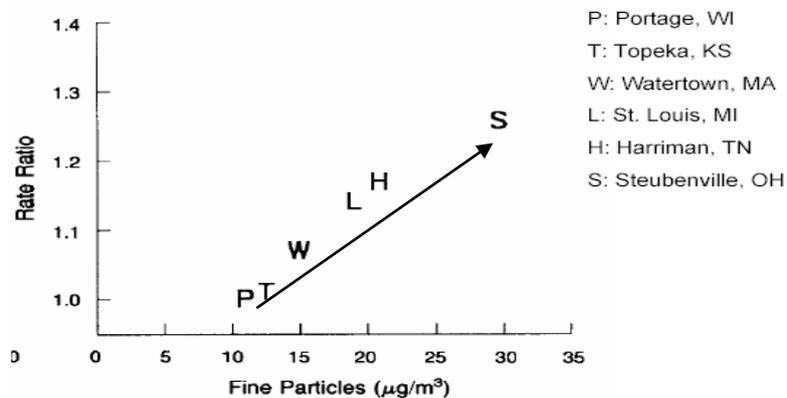
Effects of PM 2.5

Many scientific studies have linked breathing PM to a series of significant health problems, including:

- Aggravates **asthma**
- Increases in respiratory symptoms like

coughing and difficult or painful breathing

- Chronic bronchitis
- Decreased lung function
- Premature death



Six Cities Study

- They found that PM_{2.5} correlated very strongly with increased mortality. That's not to say that other pollutants aren't harmful; they just don't lead to shortened life-spans.

Dust

- Visibility reduction
- Breathing issues

Volcanic Ash

- Ash reflects sunlight back to space (cools Earth)
- Dangerous to breathe
- Covers the land surface

The ability of the human respiratory system to defend itself against particulate matter is, to a large extent, determined by the size of the particles.

Particles larger than 10 μm

- Large particles that enter respiratory system can be trapped by the hairs and lining of the nose. Once captured, they can be driven out by a cough or sneeze. Smaller particles that make it into the tracheobronchial system can be captured by mucus, worked back to the throat by tiny hair like cilia, and removed by swallowing or spitting.

Particles smaller than 10 μm

- These particles may make it into the lungs, but depending on their size, they may or may not be deposited there.
- Some particles are so small that they tend to follow the air stream into the lungs and then right back out again.
- Particles roughly between 0.5 and 10 μm may be large enough to be deposited in the lungs by sedimentation. Sedimentation is most effective for particles between 2 and 4 μm .
- High particulate concentration in the atmosphere, especially in conjunction with oxides of sulfur→ respiratory infection, cardiac disorders, bronchitis, asthma, pneumonia ...
- Some particles are toxic. Many carbonaceous particles, especially those containing polycyclic aromatic hydrocarbons (PAHs) are suspected carcinogens.
- Particulate emissions have decreased substantially in the past few decades, due to tremendous reductions in combustion emissions (especially by electric utilities).

6. Lead

In the past, **motor vehicles** were the major contributor of lead emissions to the air. As a result of regulatory efforts to reduce lead in on-road motor vehicle gasoline, air emissions of lead from the transportation sector, and particularly the automotive sector, have greatly declined over the past two decades.

Major sources of lead emissions to the air today are ore and **metals processing** and **piston-engine aircraft operating on leaded aviation gasoline**. The highest air concentrations of lead are usually found near lead **smelters**. Other stationary sources are **waste incinerators, utilities, paints** and **lead-acid battery** manufacturers.

Lead causes damage to the kidneys, liver, brain and nerves, and other organs. Exposure to lead may also lead to osteoporosis (brittle bone disease) and reproductive disorders. Lead affects the brain and nerves, the Excessive exposure to lead causes seizures, mental retardation, behavioral disorders, memory problems, and mood changes. Low levels of lead damage the brain and nerves in fetuses and young children, resulting in learning deficits and lowered IQ.

Most lead emissions in the past have been from motor vehicles burning gasoline containing the antiknock additive, tetraethyl lead, $(\text{C}_2\text{H}_5)_4\text{Pb}$.

- Lead is emitted to the atmosphere primarily in the form of inorganic particulates.
- Much of this is removed from the atmosphere by settling in the immediate vicinity of the source.

- Air borne lead may affect human populations by direct inhalation, in which case people living nearest to highways are at greatest risk, or it can be ingested after the lead is deposited onto food stuffs.
- Most of human exposure to airborne lead is the result of inhalation. It has been estimated that about one third of the lead particles inhaled are deposited in the respiratory system and that about half of those are absorbed by the blood stream.
- The NAAQS standard for lead – $1.5 \mu\text{g}/\text{m}^3$.
- Blood lead levels associated with neurobehavioral changes in children appear to begin at 50-60 μg per decilitre ($\mu\text{g}/\text{dL}$). Encephalopathy, with possible brain damage or death occurs at levels some what 80 $\mu\text{g} / \text{dL}$.

Lecture 5

Secondary Pollutants

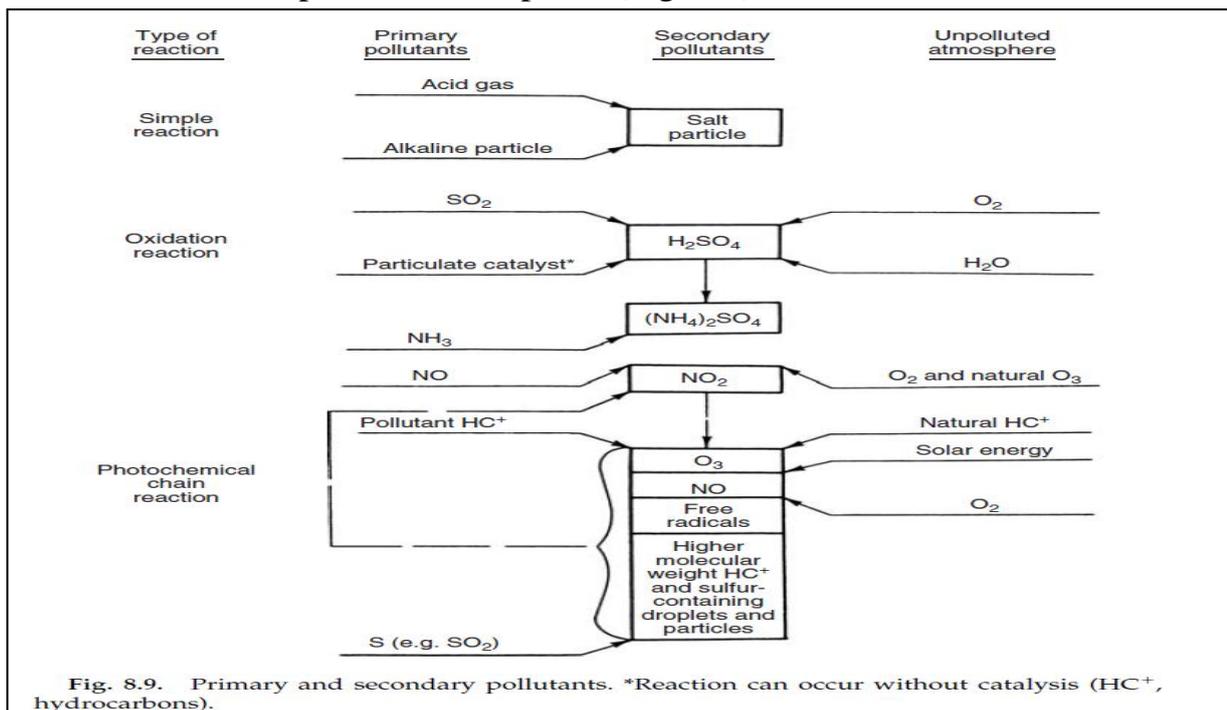
Secondary Pollutants are produced in the atmosphere by chemical reactions between primary pollutants (**precursors**) not emitted directly to the atmosphere. These reactions take place either by photo-activation (especially UV), or without it. The harmfulness of these substances is not less than their initial products may be even more than the previous ones. The rate, at which primary pollutants react together, is influenced by:

1. Their concentrations in the atmosphere;
2. The degree of photo-activation;
3. Particle size.
4. Meteorological factors variance and humidity.

Table 1. Chemical kinetics in the atmosphere.

Type of reaction	Process	Notation
Bimolecular	Two reactants combine to produce two products.	$A + B \rightarrow C + D$
Three-body	Two reactants combine to form one new product. A third, inert molecule (M) stabilizes the end product and removes excess energy.	$A + B + M \rightarrow AB + M$
Photolysis	Solar radiation photon breaks a chemical bond in a molecule	$A + h\nu \rightarrow B + C$
Thermal decomposition	A molecule decomposes by collision with an inert molecule (M)	$A + M \rightarrow B + C$

Chemical reactions may occur among the primary pollutants and the constituents of the unpolluted atmosphere (Fig. 8.9).



Secondary pollutants may be formed by thermal, chemical or photochemical reactions.

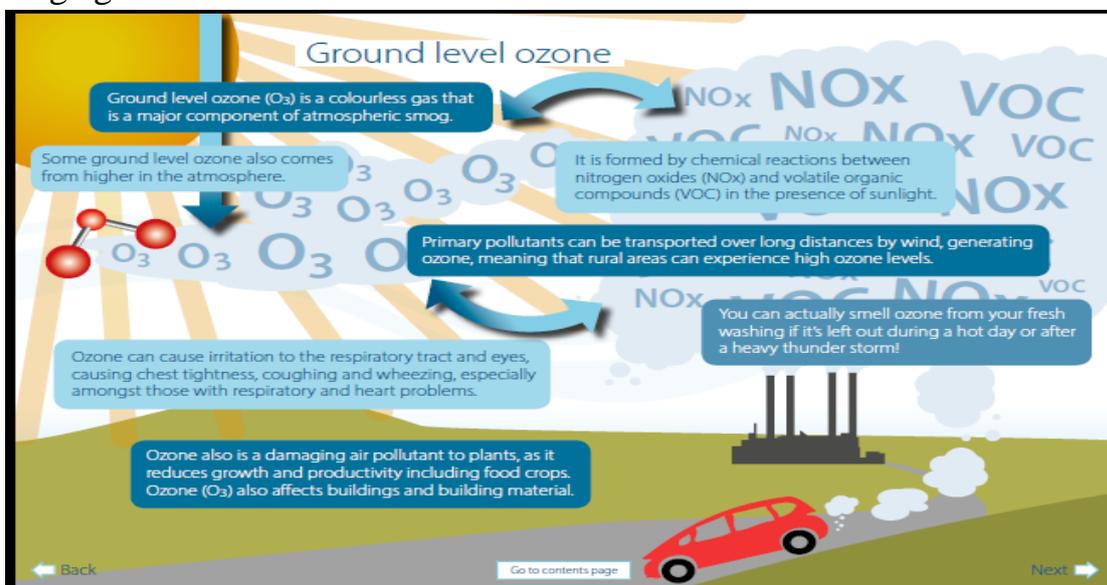
For example, by **thermal action** sulphur dioxide(SO_2) can oxidize to sulphur trioxide(SO_3) which, dissolved in water, gives rise to the formation of sulphuric acid mist (catalysed by manganese and iron oxides). **Photochemical reactions** between nitrogen oxides(NO_x)and reactive hydrocarbons(Hc) can produce ozone (O_3), formaldehyde and peroxyacetyl nitrate (PAN); reactions between HCl and formaldehyde can form bis-chloromethyl ether.

Different types of secondary pollutants include:

- Ozone (O_3)
- Sulfuric acid and nitric acid (component of acid rain)
- Particulate matter
- Nitrogen dioxide (NO_2)
- Peroxyacyl nitrates (PANs)
- and more

Ozone

Colorless, poisonous gas with a sharp, cold, irritating odor (acid), sweet smell, oxidizing agent.



Ozone is a highly reactive compound that irritates airways in the lungs and interferes with host defense mechanisms in the body. It also has an unusual effect on breathing patterns as the result of changes in the reflex breathing mechanism.

In the lower atmosphere, **oxygen**, with light from the sun as a source of energy, reacts with **nitrogen compounds** and volatile **hydrocarbons** to create **ozone**. This occurs especially in stagnant weather conditions and inversions under conditions of sunshine, where there is ample time for the photochemical reactions to take place.

A photochemical smog (of brown-yellow color) which results in the formation of ozone and airborne particles. The process of ozone formation may take several days to complete, and ozone itself may turn out to be far from the sources of original primary pollutant emissions.

Ozone is chemically unstable, and will react with a variety of substances.

The way in which ozone affects humans appears to be complicated, and dependent on activity level and pollutant concentration, among other factors. Ozone appears to attack the epithelial cells in the bronchial tree, which in turn may cause airway inflammation .

The WHO guidelines are 150–200 $\mu\text{g}/\text{m}^3$ (0.076–0.1 ppm) for one hour exposure and 100–200 $\mu\text{g}/\text{m}^3$ (0.05-0.06 ppm) for 8 hour exposures.

Effects of Ozone as an Air Pollutant

Ozone in the troposphere can have the following negative effects on animals, humans and the natural environment

- Irritation of the respiratory system causing coughing, throat irritation and an uncomfortable sensation in the chest
- Susceptibility to respiratory infections
- Compromised lung function harming the breathing process which may become more rapid and more shallow than normal
- Inflammation and damage to the lining of the lungs
- aggravation of asthma
- Reduction in agricultural yields
- Interference with photosynthesis and suppression of growth of some plant species

Photochemical Smog Source

This term refers to an atmosphere laden with secondary pollutants that form in the presence of sunlight as a result of chemical reactions in the atmosphere. Photochemical smog arises in urban areas, where there is a heavy build-up of vehicle exhausts. It is greatly exacerbated by weather conditions. Under normal conditions, the primary air pollutants are dispersed over a large region or to the upper atmosphere. A good prevailing wind is

important for cities and large urban areas to help reduce smog. At certain times of the year, when the wind is very still, the primary pollutants build up over cities. Autumn tends to be worse for photochemical smog than other times of the year.

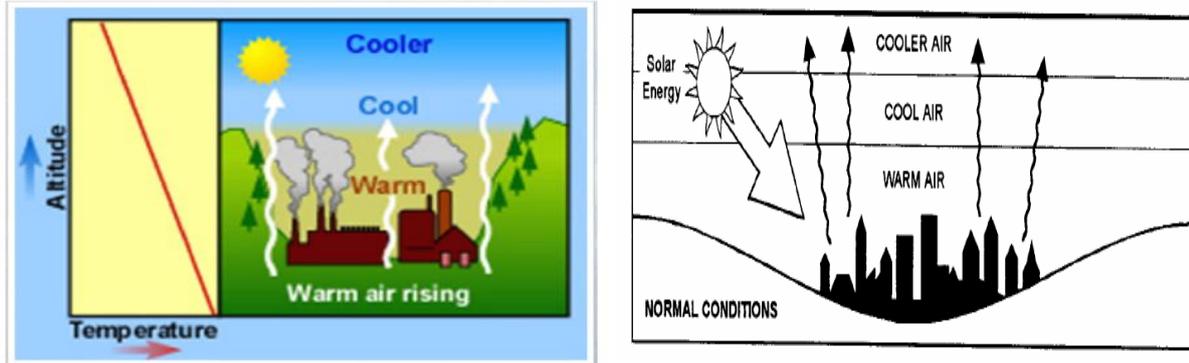


Figure 2.10 – Normal dispersion pattern of pollutants from a large urban area²

In autumn, the days are sunny and warm, with cool nights. Under still conditions, a warm inversion layer forms under a layer of higher cooler air. Large urban areas store heat, which provides the warmth for the inversion layer. The inversion layer limits air mixing and dispersal trapping primary pollutants at lower altitudes over urban areas.

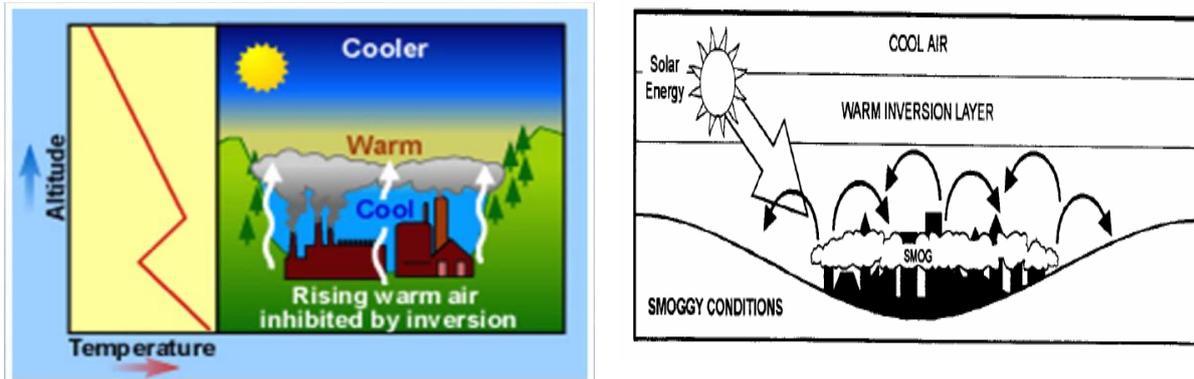
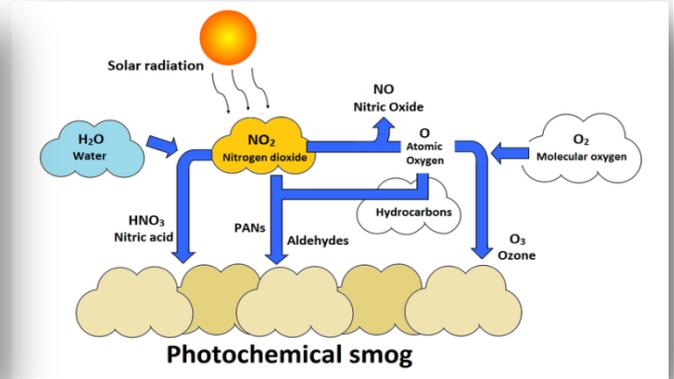
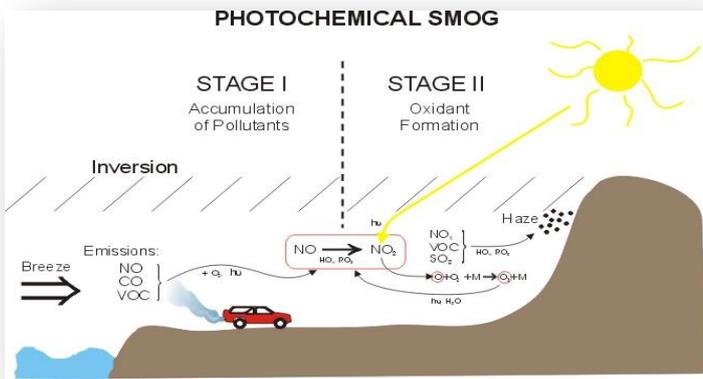


Figure 2.11 – Conditions which favour smog formation in a large urban area²

When primary pollutants such as NO_x and hydrocarbons are trapped in the lower atmosphere and subjected to UV radiation from the sun – photochemical smog forms.

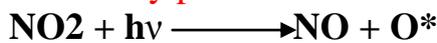
These ingredients produce the pollutants that characterize photochemical smog.

These products are termed **gross photochemical oxidants**, they include **ozone (O₃)**, **hydrogen peroxide (H₂O₂)**, **organic peroxides (ROOR')**, **organic hydroperoxides (ROOH)** and by far the most serious to health, **peroxyacyl nitrates (RCO₃NO₂)**, known as **PAN's**. The latter are formed by the irradiation of mixtures of alkenes, ozone and nitrogen dioxide.

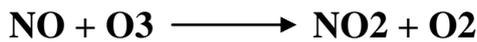
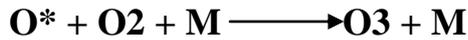


A quick **summary** of the reactions involved in smog formation can be compressed into four stages. This also explains the time variations in levels of hydrocarbons, ozone, NO₂ and NO

1. Primary photochemical reaction producing oxygen atoms:

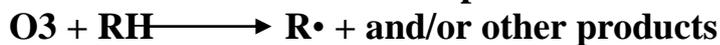


2. Reactions involving oxygen species (M is an energy-absorbing third body):



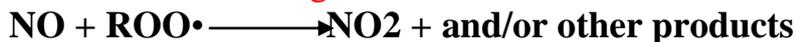
Because the latter reaction is rapid, the concentration of O₃ remains low until that of NO falls to a low value. Automotive emissions of NO tend to keep O₃ concentrations low along freeways.

3. Production of organic free radicals from hydrocarbons, RH:

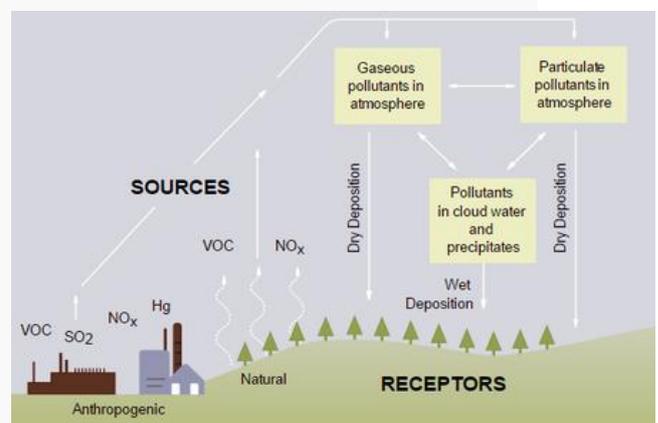
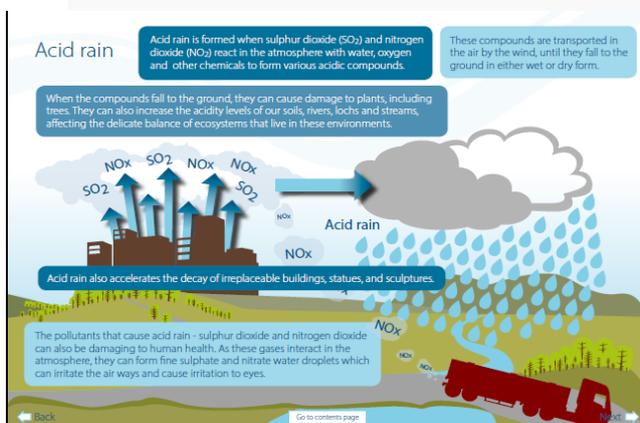


(R[•] is a free radical that may or may not contain oxygen.)

4. Chain propagation, branching, and termination by a variety of reactions such as the following:



Acid rain

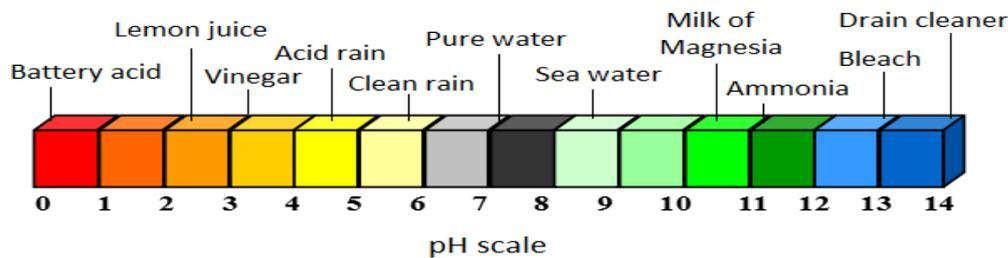


Acid rain formation

Acid deposition is any type of precipitation - rain, snow, sleet, hail, or fog - that has a lower pH (and is therefore more acidic) than normal. However, the term almost always used for all of these is **acid rain**. This higher acidity can cause problems in ecosystems and the environment, and remains one of the major environmental concerns from fuel use since the 1970s. Acid rain is produced when water in the air combines with nitrogen oxides and sulfur dioxide, two types of pollutants, and then falls down the surface of the Earth. These pollutants may also collect on the Earth's surface and the rain may combine with it upon arrival to the Earth, so the term "**acid deposition**" is often preferred over acid rain.

Acidity

Normal rain has a pH of around 5.6 so it is slightly acidic, and this is due to the combination of carbon dioxide with the water in the air to form carbonic acid. Acid rain, however, has a pH of around 4.2. This means that acid rain is around **25 times more acidic** than normal rain due to the logarithmic nature of the pH scale. This higher acidity can be harmful to the environment as will be explored below.



Acid rain relative to other acidic and basic substances on the pH scale.

Impacts

Acid rain has many damaging effects on vegetation, lakes, fish, buildings and other structures. It can also cause respiratory diseases in humans, especially those that have bad health. When lakes and other bodies of water become too acidic, typically less than a pH of 6.0, plants and aquatic life begin to suffer. Fish reproduction ability falters, with death or deformity being widespread among younger fish. Amphibians and invertebrates suffer similarly. The most notable impacts have been measured in northeastern sections of North America and Western Europe, with the sources being traced

primarily to coal-fired power plants which emit large amounts of NO_x and SO₂. The acid rain levels can be seen in (Figure a) in the United States, and due to a combination of wind flows from the US and the production of pollutants within Canada, Eastern Canada also suffers largely from acid rain.

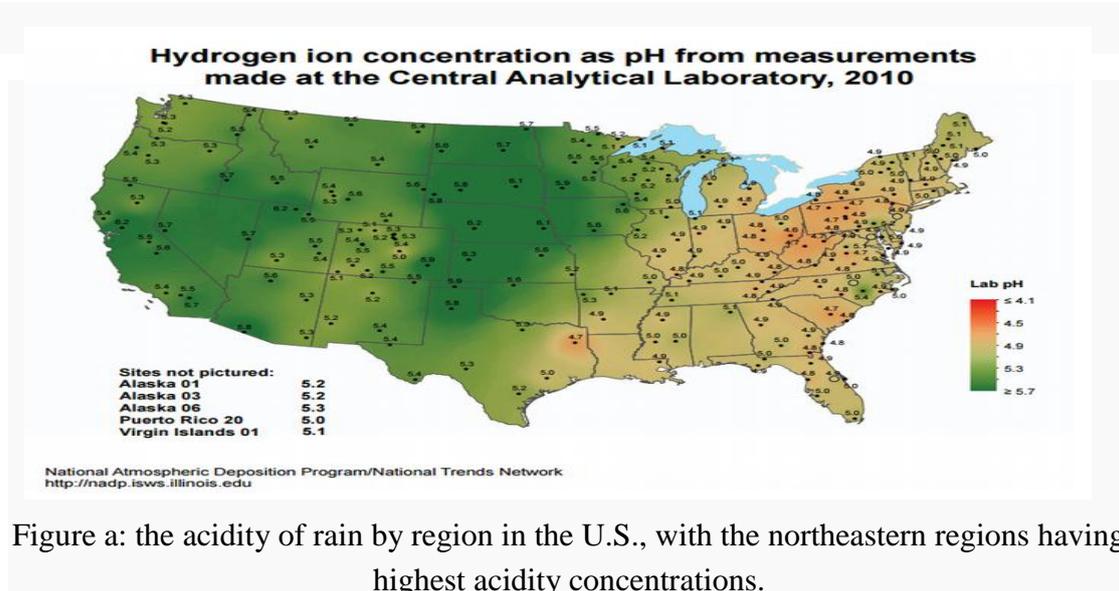


Figure a: the acidity of rain by region in the U.S., with the northeastern regions having highest acidity concentrations.

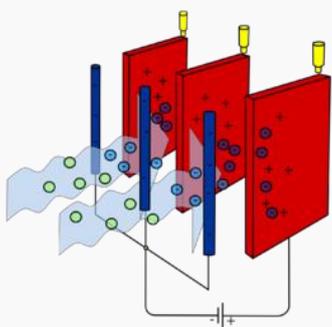
After acid rain falls to the Earth, the effects depend on the type of rock and soil it encounters. Limestone is able to neutralize the acid content of the rain, while bedrocks consisting of granite, quartz, and gneiss are not able to. The northeastern regions of Figure 2 are made up largely of bedrocks of this type; therefore they are very vulnerable to acid rain. Lakes at higher elevations in these regions tend to be more acidic, and are considered "dead" if they are not able to support life.

The buildup of acid snow on mountains is also a negative consequence, especially since a large amount of the acidic content may be released all at once during the spring in mountain runoff. This chemical shock is devastating to plant life downstream. Many high mountain lakes have been known to lose their fish populations due to increased acidity.

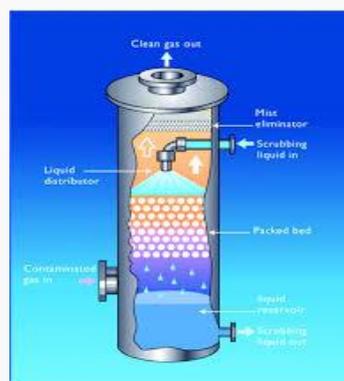
Prevention

Following harsh (severe) realizations of the effects of acid rain, many limits to pollution were put in place around the world since the 1980s. The emissions of SO₂ have decreased by 40% in the United States, with acid rain levels down about 65% in 2005. The same is true for NO_x. The acidity of lakes has been found to have decreased in these chemical concentrations, and fish life is

expected to gradually recover. This is made possible by the use of various air pollution control devices, such as **scrubbers** (is a system that is used to remove harmful materials from industrial exhaust gases before they are released into the environment) and **electrostatic precipitators** (is a type of filter that uses static electricity to remove soot and ash from exhaust fumes before they exit the smokestacks). Coal power plants and other pollution producing plants require these devices in order to meet restrictions on emissions, which can reduce the emissions of some harmful pollutants by 99%.

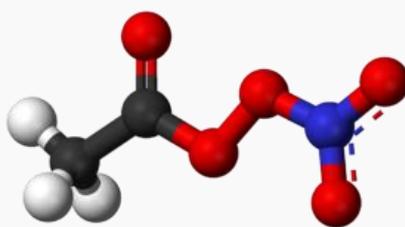


A model of an electrostatic precipitator using metal wires as the negative electrodes and large plates as the positive electrodes.



scrubbers

Peroxyacyl nitrate



Structure of a PAN called peroxyacetyl nitrate. Red: oxygen, Blue: nitrogen, Grey: Carbon, White: Hydrogen.

Peroxyacyl nitrates or **PANs** are a component of photochemical smog, produced in the atmosphere when oxidized volatile organic compounds combine with nitrogen oxide. They are a secondary pollutant since they form in the atmosphere *after* the emission of primary pollutants. Sources of the pollutants required to create PANs include motor vehicles, tobacco smoke, and the burning of fossil fuels.

Effects

PANs have many adverse effects in the human body such as reduced respiratory function and eye irritation, and may also be linked to emphysema, impaired breathing and other lung problems. Human exposure to PANs.

PANs have a lifetime of about 3 months in atmosphere at cold temperatures of around -20°C, however in warmer areas it is typically only a few hours. The implications of PANs that remain in the atmosphere for extended periods of time are of concern, since they can be transported large distances thereby spreading their environmental impact to other regions. Under these conditions PANs can contribute to air pollution in places far away from their source. Upon decomposition it can produce a variety of chemicals like carbon monoxide and carbon dioxide.

Lecture 6

The Greenhouse Effect

The “Greenhouse Effect” is a term that refers to a physical property of the Earth's atmosphere. If the Earth had no atmosphere, its average surface temperature would be very low of about -18C. The difference in temperature is due to a suite of gases called greenhouse gases which affect the overall energy balance of the Earth's system by absorbing **infrared radiation**. In its existing state, the Earth atmosphere system balances absorption of solar radiation by emission of infrared radiation to space (Fig. 1). Due to greenhouse gases, the atmosphere absorbs more infrared energy than it reradiates to space, resulting in a net warming of the Earth atmosphere system and of surface temperature. This is the “Natural Greenhouse Effect”. With more greenhouse gases released to the atmosphere due to human activity, more infrared radiation will be trapped in the Earth's surface which contributes to the “Enhanced Greenhouse Effect”.

Types of Greenhouse gases

Greenhouse gases form less than 1% of the atmosphere. Their levels are determined by a balance between “sources” and “sinks”. Sources and sinks are processes that generate and destroy greenhouse gases respectively.

Human affect greenhouse gas levels by introducing new sources or by interfering with natural sinks.

The major greenhouse gases in the atmosphere are carbon dioxide (CO₂), methane, (CH₄), nitrous oxide (N₂O), chlorofluorocarbons (CFCs) and ozone (O₃). Atmospheric water vapour (H₂O) also makes a large contribution to the natural greenhouse effect but it is thought that its presence is not directly affected by human activity.

Water vapour (H₂O): The main greenhouse gas is water vapour (H₂O), which is responsible for about **two-thirds** of the natural greenhouse effect. In the atmosphere, water molecules capture the heat that the earth radiates and then re-radiate into all directions, warming earth's surface, before it is eventually radiated back to space.

Water vapour in the atmosphere is part of the hydrological cycle, a closed system circulating water – of which there is a finite amount on earth - from the oceans and land to the atmosphere and back again through evaporation and transpiration, condensation and precipitation.

Human activities do not add water vapour to the atmosphere. However, warmer air can hold much more moisture, so increasing temperatures further intensify climate change.

Carbon dioxide (CO₂): The main contributor to the enhanced (manmade) greenhouse effect is carbon dioxide (CO₂). Globally, it accounts for over 60% of the enhanced greenhouse gas effect. In industrialized countries, CO₂ makes up more than 80% of greenhouse gas emissions.

There is a finite amount of carbon on earth, which, like water, is part of a cycle – the carbon cycle.

This is a very complex system in which carbon moves through the atmosphere, the terrestrial biosphere and oceans. Plants absorb CO₂ from the atmosphere during photosynthesis. They use the carbon to build their tissue, and they release it back to the atmosphere when they die and decompose. The bodies of animals (and humans) also contain carbon since they are built from carbon taken in from eaten plants - or animals that eat plants. This carbon is released as CO₂ when they breathe (respiration) and when they die and decompose.

Fossil fuels are the fossilized remains of dead plants and animals formed over millions of years under certain conditions, and that's why they contain a lot of carbon. Broadly speaking, coal is the remnant of buried forests while oil is converted oceanic plant life. (Oceans absorb CO₂ which, in dissolved form, is used by marine life in photosynthesis.)

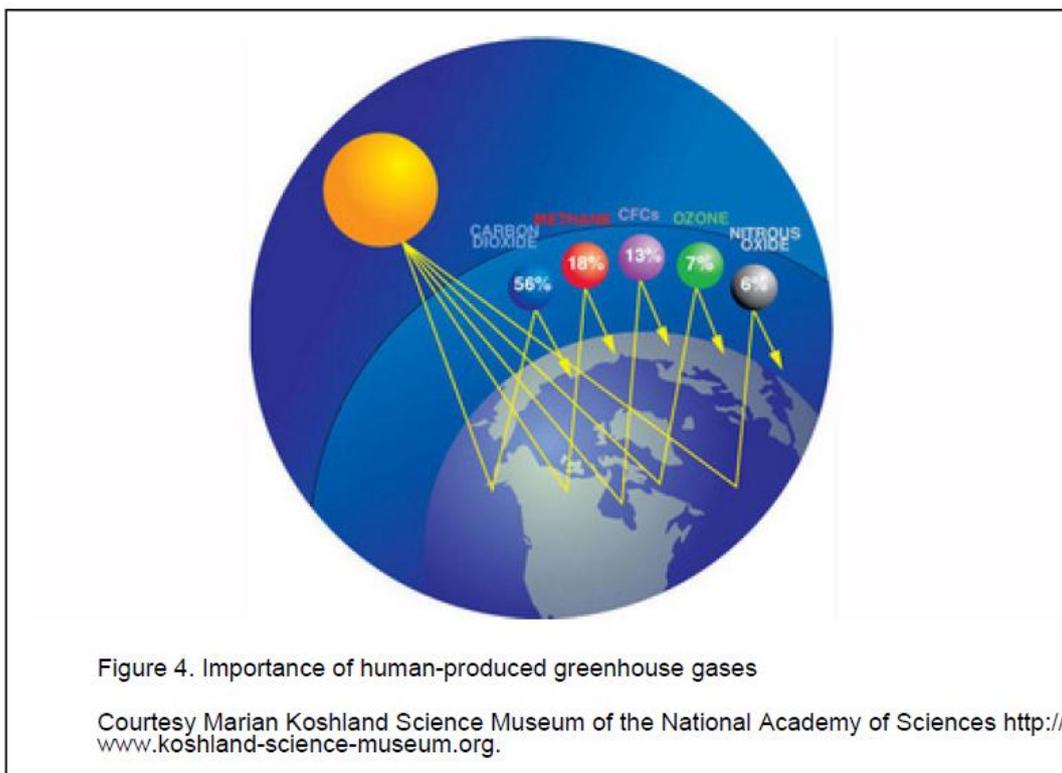
Many billions of tonnes of carbon are exchanged naturally each year between the atmosphere, the oceans and land vegetation. Carbon dioxide levels in the atmosphere appear to have varied less than 10% during the 10,000 years before the Industrial Revolution. Since 1800, however concentrations have risen by about 30% as massive amounts of fossil fuels are burned to produce energy – mostly in developed countries. Currently we are emitting more than 25 billion tonnes of CO₂ into the atmosphere each year.

Methane(CH₄): The second-most important greenhouse gas for the enhanced greenhouse effect is methane (CH₄). Since the beginning of the Industrial Revolution, atmospheric methane concentrations have doubled and contributed some 20% to the enhancement of the greenhouse gas effect. In industrialised countries, methane accounts typically for 15% of greenhouse gas emissions.

Methane is created predominantly by bacteria that feed on organic material where there is a lack of oxygen. It is therefore emitted from a variety of natural and human-influenced sources, with manmade emissions accounting for the majority. Natural sources include wetlands, termites, and oceans. Human-influenced sources include the mining and burning of fossil fuels, livestock .In the atmosphere, methane traps heat and is 23 times more effective at that than CO₂. Its lifetime is however shorter, between 10 and 15 years.

Nitrous oxide: Nitrous oxide (N₂O) is released naturally from oceans and rainforests and by bacteria in soils. Human-influenced sources include

nitrogen-based fertilisers, fossil fuel combustion and industrial chemical production using nitrogen, such as sewage treatment. In industrialised countries, N₂O accounts for around 6% of greenhouse gas emissions. Like CO₂ and methane, nitrous oxide is a greenhouse gas whose molecules absorb heat trying to escape to space. **N₂O is 310 times more effective than CO₂ absorbing heat.** Since the beginning of the Industrial Revolution, nitrous oxide concentrations in the atmosphere have increased by about 16% and contributed 4 to 6% to the enhancement of the greenhouse effect.



Fluorinated greenhouse gases: These are the only greenhouse gases that do not occur naturally, but have been developed by man for industrial purposes. Their share of greenhouse gas emissions from industrialised countries is around 1.5%. But they are extremely powerful – they can trap heat up to 22,000 times more effectively than CO₂ - and they can stay in the atmosphere for thousands of years.

Fluorinated greenhouse gases include hydrofluorocarbons (HFCs) which are used in cooling and refrigeration, including air conditioning; sulphur hexafluoride (SF₆), which is used, for example, in the electronics industry; and perfluorocarbons (PFCs), which are emitted during the manufacture of aluminium and also used in the electronics industry. the best known of these

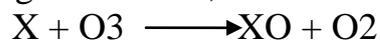
gases are chlorofluorocarbons (CFCs), which are not only fluorinated greenhouse gases, but also deplete the ozone layer. They are being phased out under the 1987 Montreal Protocol on Ozone- Depleting Substances.

Stratospheric pollution

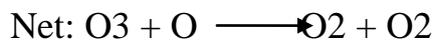
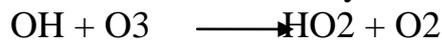
Synthetic chemicals deplete stratospheric ozone

- **Ozone layer**= ozone in the lower stratosphere
- 12 ppm concentrations effectively block incoming damaging ultraviolet radiation

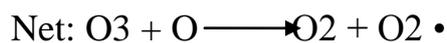
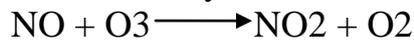
Stratospheric Ozone Depletion Ozone. In the stratosphere, however, ozone
In general form, the ozone destruction in a catalytic cycle is



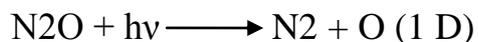
where X is the free radical catalyst. X can be H, OH, NO, Cl and Br. Example, if X = OH we have OH catalytic ozone destruction cycle



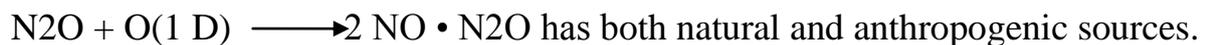
where HO₂ is the hydroperoxy radical. Let's consider NO catalytic ozone destruction cycle



The principal source of NO_x in the stratosphere is N₂O. How it works: About 90% of N₂O in the stratosphere is destroyed by photolysis



The remainder reacts with the singlet-D oxygen atom, O(1 D):



NOTE: N₂O is an important greenhouse gas (Thus, if N₂O emission from anthropogenic sources increases => more NO in the stratosphere => ozone depletion (because of NO catalytic ozone destruction cycle) • Another potential sources of NO in the stratosphere: supersonic transport (SST)

Chlorofluorocarbons (CFCs)= chemicals that attack ozone

- 1 million metric tons/year were produced
 - Releases chlorine atoms that split ozone
- Ozone hole**= ozone levels over Antarctica had declined by 40-60%
- Depletion also in the Arctic and globally

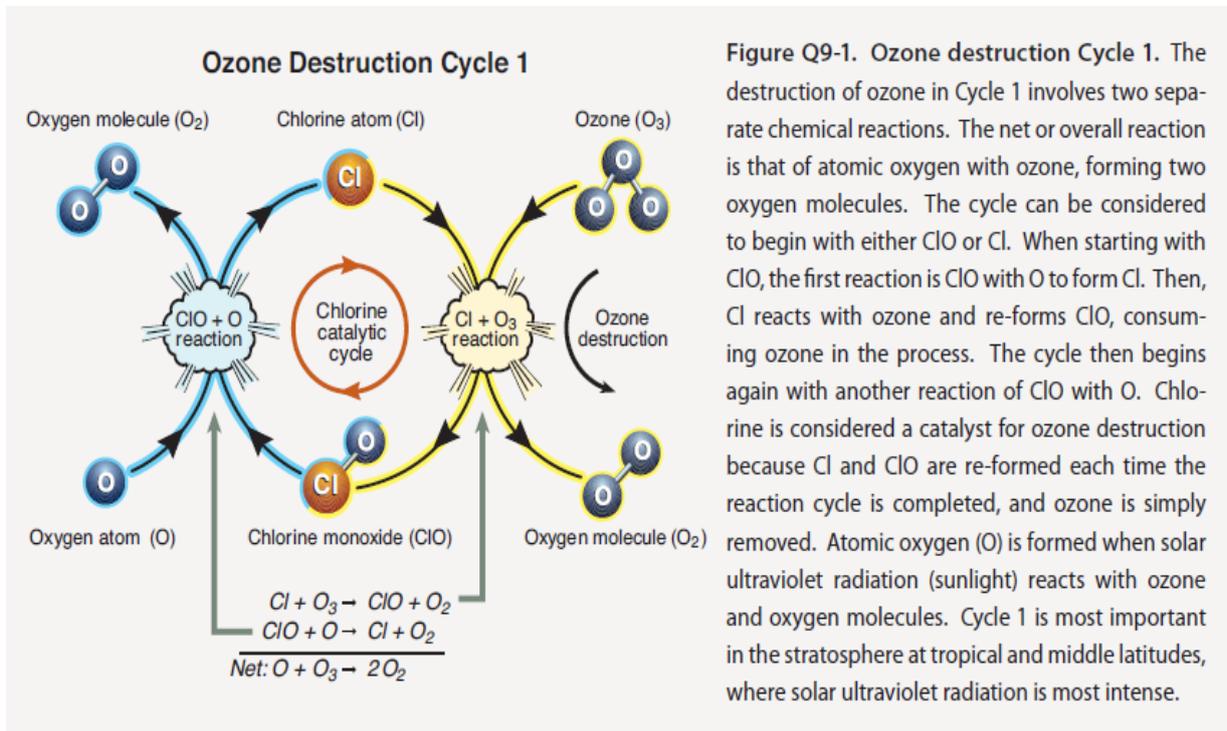
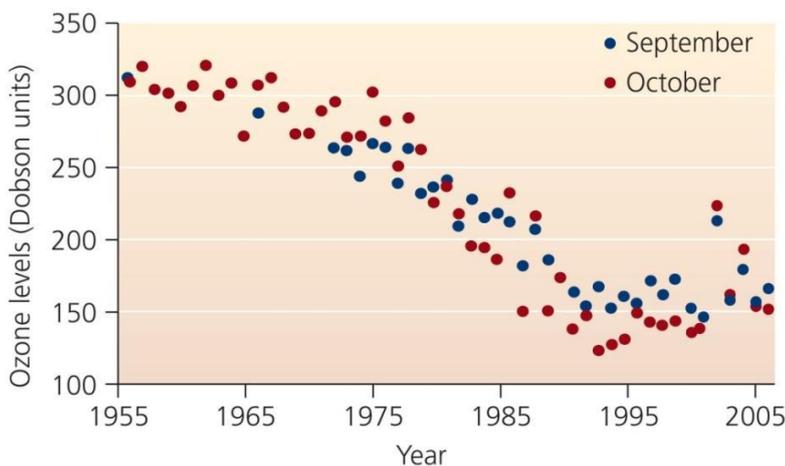
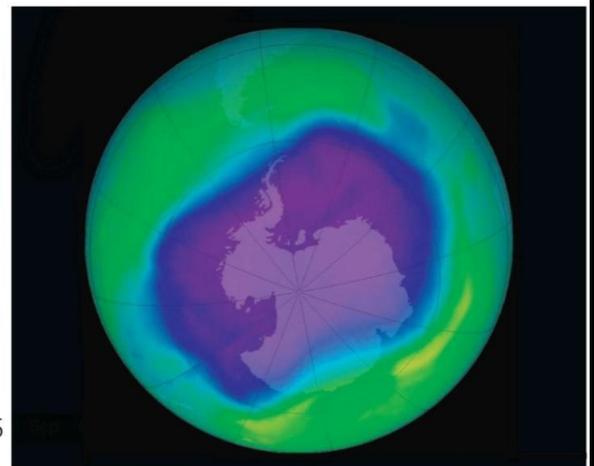


Figure Q9-1. Ozone destruction Cycle 1. The destruction of ozone in Cycle 1 involves two separate chemical reactions. The net or overall reaction is that of atomic oxygen with ozone, forming two oxygen molecules. The cycle can be considered to begin with either ClO or Cl. When starting with ClO, the first reaction is ClO with O to form Cl. Then, Cl reacts with ozone and re-forms ClO, consuming ozone in the process. The cycle then begins again with another reaction of ClO with O. Chlorine is considered a catalyst for ozone destruction because Cl and ClO are re-formed each time the reaction cycle is completed, and ozone is simply removed. Atomic oxygen (O) is formed when solar ultraviolet radiation (sunlight) reacts with ozone and oxygen molecules. Cycle 1 is most important in the stratosphere at tropical and middle latitudes, where solar ultraviolet radiation is most intense.



(a) Monthly mean ozone levels at Halley, Antarctica

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(b) The "ozone hole" over Antarctica, September 24, 2006

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Lecture 7

Air pollution effects

Air Pollution exposure and Damage

Exposure

An exposure is any contact between a receptor and the air pollutant . The receptor can be human, other species, ecosystems, or even inanimate objects, eg, buildings and monuments. For chemical and biological pollutants, this contact can come about from a number of exposure pathways (eg, air, water, and soil) and routes (eg, inhalation, ingestion, dermal, and nasal).

The exposure process begins with the release of a substance. The air pollutant released toward the receptor. Thus, there are three possibilities after release:

- (1) an air pollutant is released and remains an air pollutant when it reaches the receptor;
- (2) a nontoxic substance is released but due to physical, chemical, and biological conditions in the atmosphere is transformed into air pollutant;
- (3) an air pollutant is released but due to physical, chemical, and biological conditions in the atmosphere is transformed into a nontoxic substance.

The primary route of exposure is **inhalation** for air pollutants, but other routes are often involved. For example, suspended dust may be inhaled, but settled dust may be **ingested** when it deposits on food or semi volatile air pollutants may sorb to surfaces whereupon a person's skin, eyes, and nose come into contact with what was previously an air pollutant.

Exposure can be calculated by multiplying the concentration of the agent (eg, air pollutant) with the duration of the contact exposure (*E*) expressed in mass per volume (eg, mg m³)

The target may be the receptor (eg, the amount of the contaminant that is applied or absorbed by a person). The target may also be an organ or other tissue in the receptor (eg, the amount of the contaminant that reaches the bloodstream). It may be indicated by a **biomarker**, such as the concentration of benzene in urine.

For example, if benzene is found in urine, this is the amount that has been eliminated following intake, absorption, distribution, and metabolism. The biomarker is not the exposure, but is merely an indicator of exposure.

Indeed, the biomarker may not be parent compound, but a metabolite of the compound, eg, a person exposed to nicotine would have a certain amount of its metabolite, cotinine, and a person exposed to PAHs may have 1-hydroxypyrene in urine.

TOTAL BODY BURDEN

Air pollutant interacts with the human body provides the most useful information about the dose to a target organ or bodily system.

The human body and other biological systems have a tremendous capacity to take in all types of chemicals and either utilize them to support some bodily function or eliminate them. As analytical capabilities have improved, lower and lower concentrations of chemicals have been observed in various parts of the body. Some of these chemicals enter the body by inhalation.

The concept of **total body burden** refers to the total accumulation of [toxins in your body](#). This can include anything from dangerous metals like lead or mercury, to pesticides, or fluoride – just to name a scant few.

The components of the body that can store these materials are the blood, urine, soft tissue, hair, teeth, and bone.

certainly your body has self-cleansing mechanisms, but if you expose yourself to [more toxins than your body can eliminate](#), they will accumulate in your fatty tissue and organs. The greater the accumulation, the greater the stresses on your health.

Air pollution may damage every organ in the human body

Respiratory disorders

Because most of the pollutants enter the body through the airways, the respiratory system is in the first line of progression of diseases resulted from air pollutants. Depending on the dose of inhaled pollutants, and deposition in target cells, they cause a different level of damages in the respiratory system. In the upper respiratory tract, the first effect is irritation, especially in trachea which induces voice disturbances. Air pollutants, especially PMs and other respirable chemicals such as dust, O₃, and benzene cause serious damage to the respiratory tract asthma and lung cancer. Some studies have validated associations between both traffic-related and/or industrial air pollution and increasing the risk of COPD.

Respiratory System.

The anatomy of the respiratory system is shown in Figure 12. This system may be divided into three regions, namely,

1. **The nasal region** is composed of the nose and mouth cavities and the throat
2. **The tracheobronchial** region begins with the trachea and extends through the bronchial tubes to the alveolar sacs
3. **Pulmonary region** is composed of the terminal bronchi and alveolar sacs, where gas exchange with the circulatory system occurs.

The trachea branches into the right and left bronchi. Each bronchus divides and subdivides at least 20 times; the smallest units, bronchioles, are located deep in the lungs. The bronchioles end in about 3 million air sacs, the alveoli.

The behavior of particles and gases in the respiratory system is greatly influenced by the region of the lung in which they are located. After the air is channeled through the trachea to the first bronchi, the flow is divided at each subsequent bronchial bifurcation until very little apparent flow is occurring within the alveolar sacs.

Particle behavior in the lung is dependent on the aerodynamic characteristics of particles in flow streams. In contrast, the major factor for gases is the solubility of the gaseous molecules in the linings of the different regions of the respiratory system. The aerodynamic properties of particles are related to their size, shape, and density. The behavior of a chain type or fiber may also be dependent on its orientation to the direction of flow. The deposition of particles in different regions of the respiratory system depends on their size.

The nasal openings permit very large dust particles to enter the nasal region, along with much finer airborne PM. Particles in the atmosphere can range from <0.01 to >50mm in diameter. The relationship between the aerodynamic size of particles and the regions where they are deposited is shown in Figure 1.

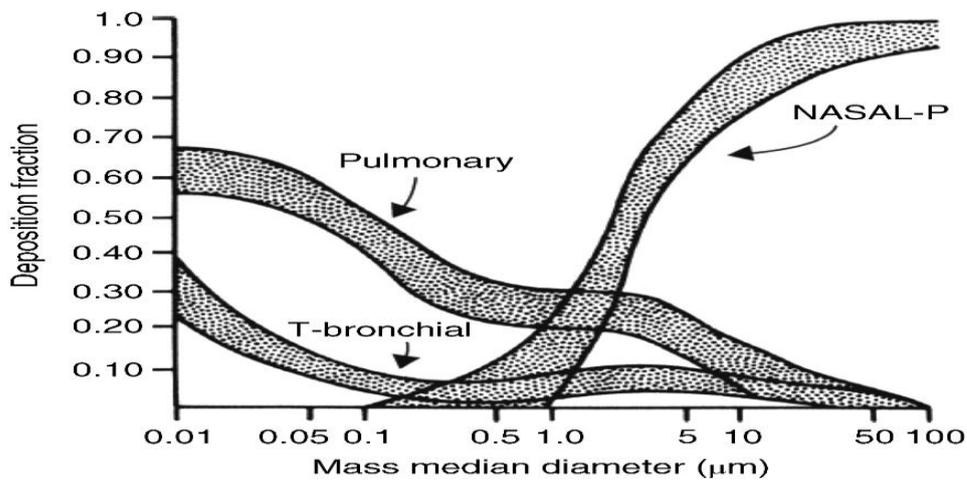


Fig.1. Particle deposition as a function of particle diameter in various regions of the lung.

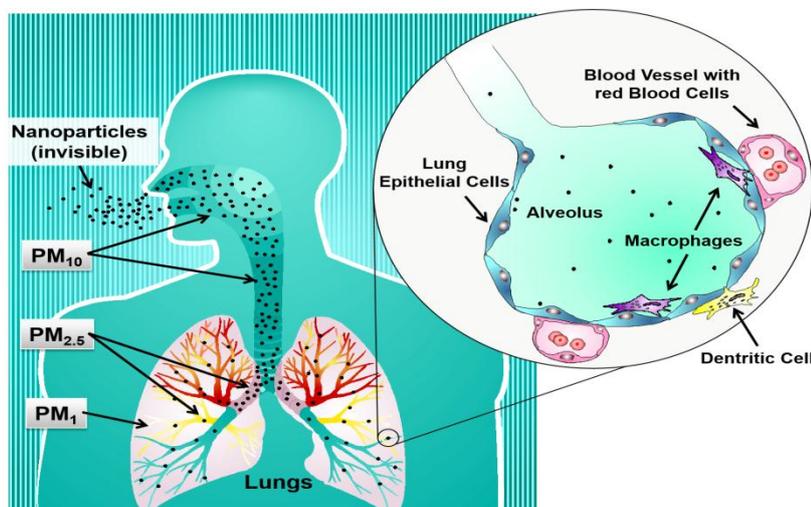
Larger particles are deposited in the nasal region by **impaction** on the hairs of the nose or at the bends of the nasal passages. Smaller particles pass through the nasal region and are deposited in the tracheobronchial and pulmonary regions. As the airflow decreases near the terminal bronchi, the smallest particles are removed by Brownian motion, which pushes them to the alveolar membrane .

The respiratory system has several mechanisms for removing deposited Aerosols. The walls of the nasal and tracheobronchial regions are coated with a mucous fluid. Nose blowing, sneezing, coughing, and swallowing help remove particles from the upper airways. The tracheobronchial walls have fiber cilia that sweep the mucous fluid upward, transporting

particles to the top of the trachea, where they are swallowed.

This mechanism is often referred to as the mucociliary escalator. In the pulmonary region of the respiratory system, foreign particles can move across the epithelial lining of the alveolar sac to the lymph or blood systems, or they may be engulfed by scavenger cells called alveolar

macrophages. The macrophages can move to the mucociliary escalator for removal Fig. 2



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Fig. 2. Possible transport pathway for particles differing in size in the lung

For gases, solubility controls removal from the airstream. Highly soluble gases such as SO₂ are absorbed in the upper airways, whereas less soluble gases such as NO₂ and O₃ may penetrate to the pulmonary region. Irritant gases are thought to stimulate neuro receptors in the respiratory walls and cause a variety of responses, including sneezing, coughing, bronchoconstriction, and rapid, shallow breathing. The dissolved gas may be eliminated by biochemical processes or may diffuse to the circulatory system .

Larger particles (>5 mm) tend to deposit before reaching the lungs, especially being captured by ciliated cells that line the upper airway. Moderately sized particles (1–5 mm) are more likely to deposit in the central and peripheral airways and in the alveoli but are often scavenged by macrophages. Particles with an aerodynamic diameter <1mm remain suspended in air and are generally exhaled.

Cardiovascular dysfunctions

Many experimental and epidemiologic studies have shown the direct association of air pollutant exposure and cardiac-related illnesses. Air pollution is also associated with changes in white blood cell counts which also may affect the cardiovascular functions. On the other hand, a study on animal models suggested the close relationship between hypertension and air pollution exposure. The traffic-related air pollution, especially exposure to high levels of NO₂, is associated with right and left

ventricular hypertrophy. In addition to the antidote therapy that exists only for a few cardiotoxic substances like CO.

Nerve system complications

The relationship between exposure to air suspended toxic materials and nerve system has always been argued.

The toxic effect of air pollutants on nerve system includes neurological complications and psychiatric disorders. Neurological impairment may cause devastating consequences, especially in infants. In contrast, psychiatric disorders will induce aggression and antisocial behaviors. Recent studies have reported the relationship between air pollution and neurobehavioral hyperactivity, criminal activity, and age- inappropriate behaviors. Studies have also

revealed the association between air pollution and higher risk of neuroinflammation, Alzheimer's and Parkinson's diseases .Some studies showed that aggression and anxiety in megacities are in close relationship with the high level of air pollutants.

Other long- term complications

The skin is a target organ for pollution in which the absorption of environmental pollutants from this organ is equivalent to the respiratory uptake. Research on the skin has provided evidence that traffic- related air pollutants, especially PAHs, VOCs, oxides, and PM affect skin aging and cause pigmented spots on the face.

There are some data which highlighted the role of air pollutants, especially traffic- related air pollution on the incidence of autism and its related disorders in fetus and children. Disrupting endocrine by chemical components of pollutants has been described as a possible mechanistic pathway of autism or other neurological disorders. Some studies showed that there are relationships between air pollution exposure and fetal head size in late pregnancy, fetal growth, and low birth weight.

The eye is a neglected vulnerable organ to the adverse effects of air suspended contaminants even household air pollution. Clinical effects of air pollution on the eyes can vary from asymptomatic eye problems to dry eyesyndrome. Chronic exposure to air pollutants increases the risk for retinopathy ,adverse ocular outcomes irritation of the eyes, dry eye syndrome, and some of the major blinding.

Effects on Plant Life

The effects of air pollution on plants have been classified as visible symptoms and non visual or subtle effects. Visible symptoms are deviations from the normal healthy appearance of the leaves. For roadleaf plants, a healthy leaf has good color, with a normal cell structure in the various layers. Deviations from this healthy appearance include tissue collapse and various degrees of loss of color. Extensive tissue collapse or necrosis results from injury to the spongy or palisade cells in the interior of the leaf. The leaf is severely discolored and loses structural integrity. Dead tissue may fall out of the leaf, leaving holes in the structure. Less dramatic discolorations are caused by a reduction in the number of chloroplasts, a symptom referred to as chlorosis. Injury to the outer or epidermal layer is referred to as glazing or silvering of the leaf surface.

Other forms of visible injury are related to various physiological alterations.

This type of injury is often related to low level, long-term chronic exposure to air pollution.



The major air pollutants that are phytotoxic to plants are ozone, sulfur dioxide, nitrogen dioxide, fluorides, and peroxyacetyl nitrate (PAN). Physiological or biochemical changes have been observed in plants exposed to air pollutants, including alterations in net photosynthesis,



Peroxyacetyl nitrate (PAN): Causes a collapse of tissue on the lower leaf

stomata response, and metabolic activity. Such exposure studies have been conducted under controlled laboratory conditions. An understanding of the processes involved will help to identify the cause of reduction in yield. Laboratory studies have also investigated the interaction of air pollutants and the reproductive cycle of certain plants. Subtle changes in reproduction in a few susceptible species can render them unable to survive and prosper in a given ecosystem.

Material Damage

Material damage results from a wide range of air pollutants in all physical phases. Gases and vapors may be corrosive inherently, or they may be transformed chemically in the atmosphere into highly reactive substances, such as the formation of acids from oxides of sulfur and nitrogen. Material damage may also result from exposure to chemicals in aerosols that are deposited on materials and subsequently react with surfaces and crevices as acid aerosols and the dissolution of many types of materials by acid-forming gases.

dry deposition of acidic compounds can coat buildings and other structures, which can lead to very high cleaning and maintenance costs. Coatings and paints are also vulnerable to air pollution, especially sulfur dioxide (SO₂), which reacts in the atmosphere to become sulfuric acid (H₂SO₄).



Lecture 8

Indoor air pollution: a global health concern

Indoor air pollution is ubiquitous, and takes many forms, ranging from smoke emitted from solid fuel combustion, especially in households in developing countries, to complex mixtures of volatile and semi-volatile organic compounds present in modern buildings. Various indoor chemical pollutants, from a historical and global perspective. Health effects are presented for individual compounds or pollutant mixtures based on real-world exposure situations. Health risks from indoor air pollution are likely to be greatest in cities in developing countries, especially where risks associated with solid fuel combustion coincide with risk associated with modern buildings. Everyday exposure to multiple chemicals, most of which are present indoors, may contribute to increasing prevalence of asthma, autism, childhood cancer, medically unexplained symptoms, and perhaps other illnesses. Given that tobacco consumption and synthetic chemical usage will not be declining at least in the near future, concerns about indoor air pollution may be expected to remain.

Indoor smoke from burning solid fuels

Combustion of solid fuels in households often takes place in simple, poorly designed and maintained stoves. This kind of combustion contributes directly to low energy efficiency, adding pressure on fuel resources. **Low combustion efficiency** means that a large fraction of fuel carbon is converted to compounds other than carbon dioxide (CO₂)—i.e. products of incomplete combustion. These incomplete combustion products mainly comprise CO and fine (respirable) particles, as well as a large suite of VOCs and SVOCs. Daily exposure to products of incomplete combustion poses both acute and chronic health risks^{4,5}. A recent World Health Organization (WHO) report estimated that indoor smoke from solid fuels ranked as one of the top ten risk factors for the global burden of disease, accounting for an estimated 1.6 million premature deaths each year. Among all environmental risk factors, it ranked second only to poor water/sanitation/hygiene. In this estimate, **the burden of disease** is defined as lost healthy life years, which includes those lost to premature death and those lost to illness as weighted by a

disability factor (severity). It needs to be recognized, however, that such estimates are associated with relatively large uncertainties, because the data available on exposure and on exposure-effects relationships are limited, despite the apparently large risks and populations involved. The existing literature provides strong evidence that smoke from solid fuels is a risk factor for

1. acute respiratory infections (ARI),

2. chronic obstructive pulmonary disease (COPD)

3. lung cancer (from coal smoke) .

Evidence from 13 studies in developing countries indicates that young children living in solid-fuel using households have two to three times more risk of serious ARI than unexposed children after adjustment for potential confounders including socio-economic status. An evaluation of eight studies in developing countries indicates that women cooking over biomass fires for many years have two to four times more risk of COPD than those unexposed after adjustment for potential confounding factors. Excess lung cancer mortality rates are reported in Chinese women who had been exposed to the smoke from household use of so-called 'smoky coal' which has high sulphur content and emits a large quantity of smoke and PAHs compared to other types of coals.

The existing epidemiological literature provides moderate evidence that solid fuel smoke is a risk factor for cataracts, tuberculosis, asthma attacks and adverse pregnancy outcomes. Household coal combustion produces the same kinds of pollutants as biomass fuels, but the amounts vary according to such parameters as the content of volatiles and fixed carbon. Depending on the geological conditions of coal formation, household use of coal can also produce differing levels of sulphur dioxide (SO₂) and certain toxic elements. Chronic fluorine and arsenic poisoning are, for example, particular problems in parts of China relying on local dirty coal deposits used for household fuel.

Environmental tobacco smoke (ETS)

Tobacco smoke has been an accepted and well-documented cause of ill health for more than half a century. Tobacco accounted for an estimated 4% of the global burden of disease in 2000, mainly as a result of active

smoking exposure. However, there has been growing concern about the health effects of exposure to ETS, also called **passive smoking**, involuntary smoking, or second-hand smoking. ETS refers to the mixture of primary smoke exhaled by smokers and the secondary smoke produced by the burning tobacco between puffs. ETS exposure is lower than that experienced by active smokers, but the smoke is generally similar and contains the same gases and particles including a wide range of irritating compounds and carcinogens. Available data show that ETS exposure is a significant health risk factor in adults, children and infants. In addition to the health outcomes, breast cancer and pulmonary tuberculosis have been suggested, with limited evidence, to be associated with ETS exposure.

In a recent cross-sectional study of 1718 school-age children whose mothers were never smokers, a monotonic exposure–response relationship was observed between paternal smoking and decline of pulmonary function. Estimates indicate that 3000 lung cancer deaths each year can be attributed to passive smoking in the USA along with hundreds of thousands of childhood respiratory disease cases.

Globally, ETS is perhaps the largest modern source of indoor air pollution, reflecting the alarmingly high levels of smoking prevalence (29% in adults worldwide).

It is true that the direct health impacts of passive smoking are much smaller than those of active smoking. Efforts to control ETS, however, can have a much larger health benefit than just the reduction in ETS exposure itself, because they are also one of the best Indoor inorganic contaminants Inorganic gases found in contaminated indoor air include CO₂, CO, SO₂, NO₂, ozone (O₃), hydrogen chloride (HCl), nitrous acid (NHO₂), nitric acid vapour (HNO₃) and radon.

In residences where combustion appliances are present, major indoor sources of **CO₂** are fuel combustion and occupants' expired air. Exposure to CO₂ itself is normally not a health concern. However, indoor CO₂ levels can be used as an indicator of the presence of other human bioeffluents in occupied facilities (e.g. office building, workshops, theatres, commercial buildings) and also are often employed as an indicator of whether the facilities have adequate ventilation. It is generally accepted that CO₂ levels inside an occupied building, when no

combustion source is present, should be no more than 650 ppm above outdoor levels.

Household combustion is mainly responsible for elevated indoor levels of **CO, SO₂ and NO₂**. If properly operated and maintained, appliances that burn gaseous fossil fuels have high combustion efficiencies and thus generate insignificant amounts of CO. However, the high combustion temperature associated with gas combustion favours the formation of NO₂. Epidemiological studies suggest that long-term exposure to NO₂ (through the use of gas stoves) is a modest risk factor for respiratory illnesses compared to the use of electric stoves. The concern about CO, on the other hand, is primarily for its acute poisoning—i.e. its ability to bind strongly to haemoglobins . Acute exposure to high levels of CO from improperly operated and maintained appliances is the leading cause of poisoning death in USA and claims many lives worldwide.

Ozone (O₃) is a strong oxidizing agent. For this reason, some so-called air purifiers are intended to produce ozone indoors in order to ‘purify’ the air, on the largely erroneous belief that O₃ may ‘kill’ odorous contaminants³⁵. Besides this intentional indoor O₃ source, use of photocopiers and laser printers may generate O₃. However, the amount of O₃ created through typical office activities will normally not significantly elevate indoor O₃ concentrations. Exposure to O₃ may cause breathing problems, reduce lung function, exacerbate asthma, irritate eyes and nose, reduce resistance to colds and other infections, and speed up ageing of lung tissue. Importantly, indoor O₃, whether penetrating from the outdoors or derived indoors, can drive chemical reactions among chemical species present indoors, generating secondary pollutants that may be of greater health concern compared to primary pollutants³⁶. For example, several terpenes are present indoors at concentrations several orders of magnitude higher than their outdoor concentrations because of the wide use of these terpenes as solvents in consumer products (e.g. d-limonene contained in lemon scented detergents, α -pinene contained in pine scented paints). Under typical indoor conditions, these terpenes can react with O₃ at a rate faster than, or comparable to, the air exchange rate, to form ultra-fine and fine particles, aldehydes, hydrogen peroxide, carboxylic acids, reactive intermediates, and free radicals including the hydroxyl radical. The hydroxyl radical can, in turn, further react with

almost all the organics present in the air. It is clear that some of the secondary products from O₃-initiated indoor reactions are strong airway irritants and that exposure to ultra-fine and fine particles have respiratory and cardiovascular effects⁴¹. Therefore, it is not desirable, and can be problematic, to use ozone generators indoors because of the risk associated both with O₃ exposure and with secondary pollutants resulting from indoor O₃ chemistry.

Acidic gases such as HCl and HNO₃ are highly corrosive to materials and biological tissues. The main sources of HCl include outdoor-to-indoor transport and thermal decomposition of polyvinyl chloride (PVC). During a fire event, high exposure to HCl from PVC burning can be a real health concern. Major sources of indoor HNO₃ include penetration of outdoor HNO₃ formed in photochemical smog episodes and HNO₃ formed indoors via reactions involving O₃, NO₂ and water vapour. Normally, indoor HCl and HNO₃ concentrations are lower than their outdoor levels due to their high reactivity (loss to walls). Compared to HCl and HNO₃, HNO₂ is less corrosive. However, indoor levels of HNO₂ can be substantially higher than outdoor levels and indoor concentrations of the other two acidic gases, due to the presence of a strong indoor source of HNO₂ resulting from heterogeneous reactions involving NO₂ and water films on indoor surfaces⁴⁰. Hence, combustion appliances are sources for both NO₂ exposure and HNO₂ exposure. Epidemiological studies of NO₂ health effects should consequently consider the potential confounding effects of HNO₂ and vice versa. **Radon-222**, an odourless, colourless, and tasteless noble gas, is an isotope produced as a result of the decay of **radium-226**, which is found in the Earth's crust as a decay product of uranium. Radon has a half-life of 3.8 days and its decay produces a series of short-lived solid-phase daughter products over a few days until **lead-210** is produced. These products tend to become associated with airborne particles. The effect of radon decay indoors, therefore, is to make fine particles slightly radioactive and thus expose lung tissue when they deposit during breathing. During the decay process, three types of radiation (α , β , γ) are emitted, all capable of ionizing atoms in living cells, leading to cell damage. However, most of the dose is to the respiratory tract and most of this dose comes from the α radiation. Primary sources of radon in buildings are the soil beneath and adjacent to buildings, domestic water

supplies (e.g. well water) and building materials. In soil, radon moves through air spaces between soil particles. The fraction of radon that enters soil pores depends on :

- 1.the soil type,**
- 2. pore volume**
- 3. water content.**

This is why buildings on sandy or gravelly soils typically have higher radon levels than those on clay soils. Movement of soil radon into buildings is primarily through convection—i.e. driven by pressures due to indoor–outdoor temperature differences and pressures associated with winds. Hence, substantial seasonal and diurnal variations are typical in indoor radon concentrations. (Concentrations based on short-term measurements should thus be reported carefully because the measurements may not be representative of long-term cumulative exposure.) Highest radon concentrations in water have been found in drilled wells, particularly in areas with granitic bedrock containing uranium. Radon in groundwater is released when temperature is increased, pressure is increased, and/or water is aerated. (Showering provides optimum conditions for radon release from water.) The primary concern about radon exposure is its potential to cause lung cancer, which has been shown in uranium miners and others. It has been reported that lung cancer risk is dependent on cumulative dose in a linear dose–response fashion. Although some ecologic studies have suggested links between radon exposure and other types of cancers, these have not been confirmed by data obtained from underground miners. The US Environmental Protection Agency (EPA) has set a guideline value for indoor radon level of 4 pCi/l measured as an annual average. It has been estimated that this guideline value is exceeded in approximately 6% of US residences and in approximately 30% of residences in Midwestern states. Estimated to cause 7–30 thousand deaths annually in the USA, **radon exposure is the second leading cause of lung cancer, following smoking.** Much of its damage actually occurs in smokers, however, because of a synergistic relationship between the two risk factors. Because radon contamination is naturally derived and imperceptible to

human senses, its risk typically causes less alarm than other cancer-causing substances that may pose a significantly smaller risk.

In addition to gases and airborne particles, **airborne fibres** present indoors may pose health risks. Due to the known health effects of asbestos fibres, the use of asbestos in US buildings was banned nearly three decades ago. Avoiding asbestos fibres in old buildings is a top priority in indoor air quality management for those buildings. Although newer buildings do not contain asbestos, synthetic vitreous fibres (also referred to as man-made mineral fibres, glass fibres) can be found in spray-applied fireproofing, ceiling tiles, thermal insulation, sound insulation, fabrics, filtration components, plasters and acoustic surface treatments. Health concerns relating to synthetic vitreous fibres arise when erosion of fibres occurs from the parent material into the air stream of buildings. Vitreous fibres have been suspected as possible causes of certain SBS symptoms and may cause irritation to the eye, skin, mucous membranes and respiratory tract. It is believed that cancer risks associated with typical building levels of vitreous fibres are low. Marked as a 'healthier' and greener alternative of vitreous fibres, the cellulose fibre is a recycled product made from newsprint. It contains boric acid for fire retardation. However, little information is available on the health effects of cellulose fibre exposure, although concerns have been raised about their potential to cause irritation to the mucous membranes and the upper respiratory tract. Concerns also arise when comparing cellulose fibres with sawdust that is composed mainly of cellulose, polyoses and lignin, as sawdust is classified as a known human carcinogen by IARC.

Lecture 9

Indoor organic contaminants

Indoor organic contaminants are conventionally classified by volatility. VOCs have boiling points from 38°C. Indoor organic compounds are released from a variety of building materials such as vinyl tile and coving: compounds include phthalate esters, 2-ethyl-1-hexanol), carpets (4-PCH, 4-VCH, styrene), linoleum (C5–C11 aldehydes and acids), particleboard (formaldehyde, other aldehydes, ketones) and power cables (acetophenone, dimethylbenzyl alcohol). A large variety of consumer products can contribute to indoor levels of VOCs and SVOCs, including paints (texanols, ethylene glycol, pinene, butoxyethoxyethanol), paint thinners (C7–C12 alkanes), paint strippers (methylene chloride), adhesives (benzene, alkyl benzenes), caulks (ketones, esters, glycols) and cleaners (2-butoxyethanol, limonene, 2-butanone). Other indoor sources of VOCs and SVOCs include frying foods (1,3-butadiene, acrolein, PAHs), smoking (nicotine, aldehydes, benzene, PAHs), dry cleaned clothing (tetrachloroethylene), deodorizers (p-dichlorobenzene), showering (chloroform), moulds (sesquiterpenes) and pesticides (chlorpyrifos, diazinon, dichlorvos). Due to the presence of these numerous indoor sources, many organic compounds are present indoors at concentrations substantially higher than outdoors. High indoor concentrations, coupled with the fact that people spend a larger fraction of time indoors, often make the outdoor contribution to total personal VOC exposure insignificant or negligible^{46,47}. Some VOCs and SVOCs are mutagenic and/or carcinogenic—for example, benzene, styrene, tetrachloroethylene, 1,1,1-trichloroethane, trichloroethylene, dichlorobenzene, methylene chloride and chloroform. Long-term exposure to these compounds is thus a concern in terms of cancer risks. Many VOCs and SVOCs found indoors have the potential to cause sensory irritation (e.g. aldehydes) and central nervous system symptoms (e.g. pesticides). Available studies also suggest that paternal exposure to VOCs (e.g. in chlorinated solvents, spray paints, dyes/pigments, cutting oils) during work, and maternal VOC exposures during pregnancy, are responsible for increased risk of childhood leukaemia⁴⁸. There was a conventional misconception that residential and office buildings have

VOC concentrations typically two or more orders of magnitude lower than occupational standards or guidelines, in which case exposure to VOCs in residential and office settings would not be likely to be responsible for acute symptoms. However, there are several significant differences between workplace (industrial) exposure and residential/office exposure:

- 1 .Personal protection (e.g. respirators, safety goggles) is normally used in workplace settings, but not in residences or offices. People usually spend longer time in residences (and offices) than in workplaces where VOC levels are high for a certain period of time. Therefore people may receive higher cumulative VOC doses in residences and offices.
2. Residential/office exposure affects a much larger population, including those individuals more susceptible to chemical exposure (e.g. asthmatics, children and the elderly).
3. Workplace exposure involves one or more known chemicals. However, residential/office exposure usually involves a complex mixture. For measurement convenience, indoor VOC mixture is often characterized as total volatile organic compounds (TVOC).

Indoor TVOC has been used as an indicator of building healthiness because the prevalence rate of SBS symptoms or complaints was suggested to correlate with TVOC concentration. The effectiveness of using TVOC as an indicator of indoor air quality, however, has been increasingly questioned recently, given that large differences in health effects exist among different individual VOCs and that different indoor environments may comprise distinct VOC mixtures. Despite efforts made over the past two decades, the aetiology of SBS is still poorly understood. Other terminologies, such as medically unexplained symptoms and non-specific-building-related illness, have appeared in the literature, describing SBS symptoms or similar symptoms and illnesses⁴⁹. Non-specific-building-related illness (NSBRI) is characterized by the following symptoms: mucous membrane irritation (ocular, nasal), headache, fatigue, shortness of breath, rash and odour complaints. Recent studies suggest that indoor pollutant mixtures, along with psychophysiological factors, may play an important role in causing NSBRI. Epidemiological investigations of building-related health complaints document multiple

factors including VOCs, characteristics of the ventilation system, work-related stressors and gender as contributory to symptoms. Laboratory animal studies suggest that formation of irritating particles from reactions between ozone and terpenes could contribute to the health effects of NSBRI41. Controlled human exposure studies have consistently shown that several hours exposure to a VOC mixture representative of typical problem buildings, compared to clean air, increased symptoms and complaints about the odour. Objective effects of this VOC exposure have been demonstrated for neurobehavioural performance, lung function and nasal inflammation, in some but not all studies. Exposure to SVOCs can occur not only via inhalation but, because they may be present in settled dust, also via ingestion. Ingestion of house dust is an important exposure route for small children who usually have frequent hand-to-mouth activities. It is suggested that exposure to plasticizer chemicals (e.g. diethylhexyl phthalate) may be partly responsible for the significant increase in asthma prevalence in the last two decades because the hydrolysis products of diethylhexyl phthalate cause bronchial hyper-reactivity in rats. It is also known that prostaglandin can mediate inflammatory responses such as those that cause asthmatic attacks, yet diethylhexyl phthalate and other phthalic acid esters have a similar chemical structure to prostaglandin. In addition, Finnish scientists reported an association between plastic interior surfaces and bronchial obstruction in young children. Another group of SVOCs commonly found indoors are pesticides. It has been demonstrated that furniture, stuffed toys and carpeting can serve as reservoirs of pesticides for weeks after application and that ingestion exposure can be the most important exposure route in children. It has been suggested that the extensive use of indoor pesticides may contribute to acute symptoms, cancer, immunological effects and reproductive effects. The magnitude of risk is not well known, however, due to the lack of data.

A global health concern in the future?

Given the wide range of indoor chemical contaminants highlighted above, it is clear that concern about indoor air pollution is nearly ubiquitous, although the pollutants of concern in modern buildings are different from those in solid-fuel-burning households. Nevertheless, indoor air pollution fits within the risk transition framework, in which

the traditional risks of household fuel combustion subside and modern risks from building materials emerge. the absolute risk declines dramatically as traditional solid fuels are replaced, but the trend of relative risk (percent of total risk) is less clear because overall health risk declines as well.

However, total risk is likely to peak in cities in developing countries where there is an overlap between the traditional and modern risks. Whether indoor air pollution is a future health concern, therefore, would depend on the future trends of the two curves. Globally the traditional risk curve will approach zero as the use of solid fuels for household energy continues to decline. The modern risk curve, however, is more difficult to predict, but may be a cause for pessimism at least for the near future given that the consumption of tobacco and use of synthetic chemicals and materials do not seem likely to fall. Although society routinely substitutes new materials and chemicals for existing ones, the health effects of most of these are not fully understood before they have been put on the market. Chronic effects of cumulative exposure to low-level multiple chemicals have been recognized recently to be an important area of research. It is vital to understand whether this type of exposure has contributed to the increase in the prevalence of asthma, autism, childhood cancer and medically unexplained symptoms and to the apparent decline in human reproductive function (e.g. sperm counts) in some populations. Unfortunately, health risks associated with indoor air pollution have not, in general, received adequate attention from the regulatory sector, building designers or even health professionals. Although the health and other benefits brought by switching the use of solid fuels to that of liquid or gas fuels, or just introducing improved stoves with chimneys, are tremendous and can well offset their cost, only one large-scale implementation effort has been made—the improved stove programme in China, which has introduced nearly 200 million stoves since the early 1980s. Just as clean water and sanitation at the household level have come to have high priority as primary health measures in all poor parts of the world, however, so should clean household fuels and ventilation.

Lecture 10

Glossary in Air pollution

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z

Abatement of pollutants - the reduction in degree or intensity, or elimination, of pollution; this includes emission reductions by developing clean systems as well as reduction through altered source sector activity.

Acid deposition - Atmospheric input to ecosystems of pollutants which may acidify soils and freshwaters; this includes species derived from SO₂, NO_x and NH₃ emissions, as well as a number of other minor pollutants (e.g. HCl, HF). Acid deposition is more general than "**acid rain**", since it includes both wet deposition and dry deposition.

Acid Neutralising Capacity (ANC) - Measure of ability of water or soil to resist changes in pH. An important chemical parameter used in **critical load** calculations.

Acid rain - Precipitation which has been rendered (made) acidic by airborne pollutants; Also see **Acid deposition**.

Acidification - a decrease in pH of surface waters and soils. As soils naturally become acidified over time; acidification generally refers to the enhanced changes due to anthropogenic deposition of sulphur and nitrogen species.

Acidification Strategy - 1997 EU strategy that aims to significantly reduce the areas under threat from critical loads exceedance of acidity in the European Union by 2010. This includes the establishment of national emission ceilings for acid rain pollutants (**sulphur dioxide, nitrogen oxides, ammonia** and **Volatile Organic Compounds**) to reduce emissions beyond existing commitments, a directive limiting the sulphur content of heavy fuel oils, and an amendment of the large combustion plant directive (more information about the **Acidification Strategy**).

Aerosol - a suspension of small size (generally under one micron) liquid or solid particles in air gas.

Air monitoring - sampling for and measuring of pollutants present in the atmosphere; monitoring systems range from continuous and hourly sampling to weekly or monthly sampling.

Air pollution episode - A period of abnormally high concentration of air pollutants, often due to low winds and temperature inversion, that can cause illness and death. Also see: **episode pollution**.

Air quality standards - The level of pollutants prescribed by regulations that may not be exceeded during a given time in a defined area.

Ammonia (NH₃) - a pungent, colourless, gaseous pollutants formed mainly from volatilisation of decomposing excreta or fertilisers. NH₃ is alkaline, but may be acidifying if oxidised to nitrate in soils.

AOT - unit to estimate **critical levels** for effects of phytotoxic pollutants, such as ozone: **Accumulated exposure Over a Threshold** of e.g. 40 ppb ("AOT40")

Area Source - Any small source of non-natural air pollution that is released over a relatively small area but which cannot be classified as a point source. Such sources may include vehicles and other small engines, small businesses and household activities.

Background Level - In air pollution control, the concentration of air pollutants in a definite area during a fixed period of time prior to the starting up or on the stoppage of a source of emission under control; also the average level of pollutants present in ambient air, originally referring to natural sources.

BAT - Best Available Techniques

BATNEEC - Best Available Techniques Not Entailing Excessive Cost.

Bioaccumulants - Substances that increase in concentration in living organisms as they take in contaminated air, water, or food because the substances are very slowly metabolised or excreted.

Biodiversity - the variability among living organisms from all sources including, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.

Biodiversity Action Plan (BAP) - The **UK Biodiversity Action Plan** (published in 1994) sets out a 20 year strategy, a vital part of which includes schemes to conserve certain endangered wildlife habitats and plant/animal species. The overall aim is to preserve, and where possible enhance, the range and biodiversity of naturally occurring wildlife in the UK. The **Habitats Directive** is part of this strategy.

Biodiversity Convention - The Convention on Biological Diversity agreed at the Earth Summit in Rio de Janeiro in 1992 is a framework for maintaining and enhancing global biodiversity.

Bog - A type of wetland that accumulates appreciable peat deposits. Bogs depend primarily on precipitation for their water and nutrient source (i.e. they are **ombrotrophic**) and are usually acidic and rich in plant residue with a conspicuous mat of living green moss.

Calcicolous - growing or living in soil rich in lime

Calcifuge - plant growing or living in acid soil

Carbon sequestration - The removal of carbon dioxide from the atmosphere; generally through photosynthesis to fix it as organic compounds in plants and soils; increasing the potential for carbon sequestration is a goal of the [Kyoto Protocol](#).

Catalytic Converter - an air pollution abatement device used primarily on motor vehicles; removes organic contaminants by oxidising them into carbon dioxide and water through chemical reaction. May convert NO_x to nitrogen and oxygen, or promote other similar reactions. Inefficiencies in catalytic converters lead to increased emissions of N₂O and NH₃.

CBED (Concentration Based Estimated Deposition) - a model, used in APIS, which calculates the concentration and deposition of pollutants in the UK. For detailed information see <http://www.pollutantdeposition.ceh.ac.uk/content/cbed-concentration-based-estimated-deposition>

Chlorinated hydrocarbons - a class of persistent, broad-spectrum insecticides, that linger in the environment and accumulate in the food chain. Examples are DDT, aldrin, dieldrin, heptachlor, chlordane, lindane, endrin, mirex, benzene, hexachloride, and toxaphene.

Chlorofluorocarbons (CFCs) - A family of inert, nontoxic, and easily liquefied chemicals used in refrigeration, air conditioning, packaging, insulation, or as solvents and aerosol propellants. Because CFCs are not destroyed in the lower atmosphere they drift into the upper atmosphere where their chlorine components destroy ozone.

Chlorosis - deficiency of chlorophyll in a normally green part of a plant so that it appears yellow-green yellow or white, as a result of mineral deficiency, inadequate light or infection.

Climate change - This term is commonly used interchangeably with "global warming" and "the greenhouse effect," but is a more descriptive term. Climate change refers to the build-up of man-made gases in the atmosphere that trap the sun's heat ([radiative forcing](#)), causing changes in weather patterns on a global scale. The effects include changes in rainfall patterns, sea level rise, potential droughts, habitat loss, and heat stress. The greenhouse gases of most concern are carbon dioxide, methane, and nitrous oxides. If these gases double, the earth could warm up by 1.5° C to 4.5° C by the year 2050, with changes in global precipitation having the greatest consequences.

Critical Chemical Value - the highest value of a critical chemical parameter or combination of parameters (e.g. pH, Al/Ca ratio) that does not cause a significant harmful response in a biological indicator.

Critical level - threshold for direct effects of pollutant concentrations according to current knowledge (Also see [Critical load](#)). The exceedance of a critical level is defined as the atmospheric concentration of the pollutant above the critical level. (Also see [exceedance](#)).

Critical load - a quantitative estimate of exposure to deposition of one or more pollutants, below which significant harmful effects on sensitive elements of the environment do not occur, according to present knowledge (a detailed description is given [here](#); also see: [Critical level](#)).

The exceedance of a critical load is defined as the atmospheric deposition of the pollutant above the critical load. (Also see [exceedance](#)).

Concentration - includes high or low concentration of air pollution which may occur over short periods of time (< 24 h) or continuously over longer periods (> 24h).

Direct Impacts - occur through the toxic effects of air pollutants. These are normally scaled according to the exposure to air pollution concentrations in the air. A critical level represents the threshold for direct toxicity of air pollutants. Direct impacts and critical levels are particularly relevant to short term pollutant exposure events of several hours or days. (see also [indirect impacts](#)).

Dry deposition - direct input of atmospheric pollutants onto surfaces or uptake by plants upon contact with the ground; this pathway is important for uptake of gases and particles; for other deposition pathways, also see: [wet deposition](#) and [Occult deposition](#).

Dystrophic - used to describe unproductive waterbodies, which are deficient in calcium, very poor in plants nutrients, especially nitrates (typical for acid peat areas).

Ecological Indicator - A characteristic of the environment that, when measured, quantifies magnitude of stress, habitat characteristics, degree of exposure to a stressor, or ecological response to exposure. The term is a collective term for response, exposure, habitat and stressor indicators.

Episode (pollution) - An air pollution incident in a given area caused by a concentration of atmospheric pollutants under meteorological conditions that may result in a significant increase in effects on people and ecosystems.

ETS - The **Effective Temperature Sum** is the annual sum of daily temperatures exceeding a threshold temperature, expressed as degree days per year. A threshold of ETS > 5 °C of 1000 degree days is used in the setting of the SO₂ critical level.

Exceedance - violation of environmental protection standards by exceeding allowable limits or concentration levels.

Exposure - means deposition experienced on an area basis e.g. m⁻² yr⁻¹; kg ha⁻¹ yr⁻¹.

Fluorocarbons (FCs) - organic compounds analogous to hydrocarbons in which one or more hydrogen atoms are replaced by fluorine; was used as a propellant for domestic aerosols, now found mainly in coolants and some industrial processes. FCs containing chlorine are called chlorofluorocarbons (CFCs). They are believed to be modifying the ozone layer in the stratosphere, thereby allowing more harmful solar radiation to reach the Earth's surface.

Habitat - place where an organism (e.g. human, animal, plant, micro-organism) or population of organisms live, characterised by its surroundings, both living and non-living.

Hydrogen Sulphide (H₂S)- a gas characterised by a "rotten egg" smell that is emitted during organic decomposition; often produced by and found in the vicinity of oil refineries, chemical plants and sewage treatment plants; can cause illness or kill at high concentrations.

Indirect impacts - occur as a consequence of the deposition of air pollutants. In situations where pollutant concentrations may be less than the thresholds for direct impacts, effects on species and habitats may still occur as a result of the long term input of pollutants from the atmosphere. A critical load represent the threshold for indirect effects of air pollutants though long term atmospheric deposition. Indirect effects normally occur as a result of accumulated pollutant deposition over several years (see also [direct impacts](#)).

Inversion - an atmospheric condition caused by a layer of warm air preventing the rise of cool air trapped beneath it. This traps pollutants that might otherwise be dispersed and diluted, and can cause an air pollution episode.

Methane - a colourless, non-poisonous, flammable gas emitted by marshes and dumps undergoing anaerobic decomposition.

Mineralisation - decomposition or oxidization of the chemical compounds in organic matter into plant-accessible forms

NAQS - National Air Quality Strategy 1997

Nitric Oxide (NO) - precursor of ozone, nitrogen dioxide (NO₂), and nitrate; usually emitted from combustion processes. Converted to NO₂ in the atmosphere, it then becomes involved in the photochemical process and/or particulate formation.

Nitrification - is the biological oxidation of ammonia with oxygen into nitrite, often followed by oxidation of nitrites into nitrates.

Nitrogen oxide (NO_x) - product of combustion of fossil fuels (transport, stationary sources); a major contributor to the formation of ozone in the troposphere and acid deposition.

Nitrophilous - plants favouring conditions with high available nitrogen supply.

Occult deposition - deposition of acid compounds and other pollutants onto vegetation, buildings etc. by direct contact with mist or cloud containing droplets of contaminated water. The mass of pollutants deposited in this way is much less than in [wet deposition](#) from precipitation, but concentrations in cloud/mist droplets can be very high, leading to direct impacts. Also see: [Dry deposition](#) and [deposition](#).

Oligotrophic - used to describe unproductive ecosystems, which are poor in plant nutrients; such waterbodies are clear water due to lack of plankton.

Ombrotrophic - An ombrotrophic bog/mire receives its water supply and all nutrients from the atmosphere alone, i.e. precipitation and [deposition](#) from the atmosphere (from Greek: ombros =

rainstorm, trophos = feeder). Other peatlands, e.g. fens, receive at least some of their water supply and nutrients from the groundwater ("geotrophic" (=earth-fed)). Ombrotrophic bogs/mires (e.g. raised bogs and blanket bogs) are some of the most nutrient-poor and acidic habitats in the UK, and are therefore very sensitive to air pollutant deposition.

Ozone - a pungent, colourless, toxic gas. Close to the earth's surface ("tropospheric ozone") it is produced photochemically from hydrocarbons, NO_x and sunlight, and is a major component of smog. In the stratosphere, it protects the earth from harmful ultraviolet radiation.

Ozone depletion - Destruction of the stratospheric ozone layer which shields the earth from ultraviolet radiation. This destruction of ozone is caused by certain chlorine and/or-bromine containing compounds ([chlorofluorocarbons](#) or halons), which break down when they reach the stratosphere and then catalytically destroy ozone molecules.

Parts Per Billion (ppb)/Parts Per Million (ppm) - Units commonly used to express contamination ratios, as in establishing the maximum permissible amount of a contaminant in water, land or air; the number of parts of a given pollutant in a million/billion parts of air.

pH - a unit for measuring hydrogen ion concentrations. A pH of 7 indicates a "neutral" water or solution. At pH lower than 7, a solution is acidic. At pH higher than 7, a solution is alkaline.

Photochemical Oxidants - air pollutants formed by the action of sunlight on oxides of nitrogen and hydrocarbons. The primary photochemical oxidant pollutant of concern is tropospheric ozone. Another photochemical oxidant is peroxyacetyl nitrate (PAN).

Photochemical Process - the process by which sunlight acts upon various compounds, causing a chemical reaction to occur.

Photochemical Smog - produced when hydrocarbons and NO_x combine in the presence of sunlight to form ozone.

Phytotoxic - harmful to plants.

PM₁₀ - **Particulate Matter** less than **10** microns, tiny solid or liquid particles of soot, dust, smoke, fumes, and aerosols. The size of the particles (10 microns or smaller, about 0.0004 inches or less) allows them to easily enter the air sacs in the lungs where they may be deposited, resulting in adverse health effects. PM₁₀ also reduces visibility.

PM_{2.5} - **Particulate Matter** less than **2.5** microns, tiny solid or liquid particles, generally soot and aerosols. The size of the particles (2.5 microns or smaller, about 0.0001 inches or less) allows them to easily enter the air sacs deep in the lungs where they may cause adverse health effects; PM_{2.5} also causes visibility reduction.

Pollutants (Air) - substances which, when present in the atmosphere under certain conditions, may become injurious to human, animal, plant or microbial life, or to property, or which may interfere with the use and enjoyment of life or property.

Primary Pollutants - pollutants emitted directly from identifiable sources. Also see: [Secondary pollutants](#).

Radiative forcing - Global-mean radiative forcing is a valuable concept for giving at least a first-order estimate of the potential climatic importance of various forcing mechanisms. It is a change imposed on the planetary energy balance that has the potential to alter global temperature. Greenhouse gases, for example, intercept some of the outgoing radiation and thereby act to force the Earth's surface to come to a higher equilibrium temperature. In contrast to greenhouse gases, which act only on outgoing infrared radiation, aerosol particles can influence both sides of the energy balance.

Receptors - refers to living organisms or materials which are affected and include interrelated collections of living organisms - i.e. ecosystems. A receptor may or may not be the most sensitive component in a given region.

Saturation - The condition of a liquid (water) or air when it has taken the maximum possible quantity of a given substance at a given temperature and pressure.

Secondary Pollutants - pollutants produced in the air by interaction between two or more primary pollutants, or by reaction with normal atmospheric constituents. Also see: [Primary pollutants](#).

Significant harmful effects - could be the consequences of a short or long term deposition. Several types of harmful effects may be defined including:

- chemical changes in soils and water which might cause direct or indirect effects on organisms
- changes in individual organisms, in populations and ecosystems.

Sink - Place in the environment where a compound or material collects.

Sulphur Dioxide (SO₂) - a pungent, colourless, gaseous pollutant formed primarily by the combustion of fossil fuels, especially coal and oil.

Transboundary Pollutants - air pollution that travels from one jurisdiction to another, often crossing international boundaries.

VOC - Volatile Organic Compounds; family of highly evaporative organic materials used in a variety of industrial applications, such as paints and solvents; VOCs emissions are major precursors of ground-level ozone and smog.

Wetdeposition - removal of airborne pollutants from the atmosphere to the earth's surface (plants, soil, materials) through precipitation, e.g. "[acid rain](#)". For other deposition pathways Also see: [deposition](#), [dry deposition](#) and [occult deposition](#).