Topic .

Atmosphere and Structure Composition

Introduction.

Atmosphere, composition and structure. Earth's atmosphere is composed of about 78% nitrogen, 21% oxygen, and 0.93% argon. The remainder, less than 0.1%, contains such trace gases as water vapor, carbon dioxide, and ozone.

The troposphere.

The troposphere contains over 80% of the mass of the atmosphere, along with nearly all of the water vapor. This layer contains the air we breathe, the winds we observe and the clouds that bring our rain. In fact, all of what we know as "weather" occurs in the troposphere, whose name means "changing sphere." All of the cold fronts, warm fronts, high and low pressure systems, storm systems, and other features seen on a weather map occur in this lowest layer. Severe thunderstorms may penetrate the tropopause.

Within the troposphere the temperature drops with increasing height at an average rate of about 11.7°F per every 3,281 ft (6.5°C per every 1,000 meters). This quantity is known as the lapse rate. When air begins to rise, it will expand and cool at a faster rate determined by the laws of thermodynamics. This means that if a parcel of air begins to rise, it will soon find itself cooler and denser than its surroundings, and will sink back downward. This is an example of a stable atmosphere—vertical air motion is prevented. Due to the fact that air masses move around in the troposphere, a cold air mass may move into an area and have a higher lapse rate. That is, its temperature drops off more quickly with height. Under these weather conditions, air that begins rising and cooling will become warmer than its surroundings. It then is like a hot-air balloon, it is less dense than the surrounding air and is buoyant, so it will continue to rise and cool in a process called convection. If this is sustained, the atmosphere is said to be unstable and the rising parcel of air will cool to the point where its water vapor condenses to form cloud droplets. The air parcel is now a convective cloud. If the buoyancy is vigorous enough, a storm cloud will develop as the cloud droplets grow to the size of raindrops and begin to fall out of the cloud as rain. Thus under certain conditions, the temperature profile of the troposphere makes possible storm clouds and precipitation.

During a strong thunderstorm, cumulonimbus clouds (the type that produce heavy rain, high winds, and hail) may grow tall enough to reach or extend into the tropopause. Here they run into strong stratospheric winds, which may shear off the top of the clouds and stop their growth. One can see this effect in the "anvil" clouds associated with strong summer thunderstorms.

The stratosphere.

The beginning of the stratosphere is defined as that point where the temperature reaches a minimum and the lapse rate abruptly drops to **zero**. This temperature structure has one important consequence: it inhibits rising air. Any air that begins to rise will become cooler and denser than the surrounding air. The stratosphere, then, is very stable.

Although the stratosphere has very little water, clouds of ice crystals may form at times in the lower stratosphere over the polar regions. Early Arctic explorers named these clouds nacreous or mother-of-pearl clouds because of their iridescent appearance. More recently, very thin, widespread clouds have been found to form in the polar stratosphere under extremely cold conditions. These clouds, called polar stratospheric clouds, or PSCs, appear to be small crystals of ice or frozen mixtures of ice and **nitric acid**. PSCs play a key role in the development of the ozone hole, which is described below.

The stratosphere contains most of the ozone found in the earth's atmosphere. In fact, the presence of ozone is the reason for the temperature profile found in the stratosphere. As described previously, ozone and oxygen gas both absorb short wave solar radiation. In the series of reactions that follow, heat is released. This heat warms the atmosphere in the layer at about 12–27 mi (20–45 km) and gives the stratosphere its characteristic temperature increase with height.

The ozone layer has been the subject of some concern. In 1985, scientists from the British Antarctic Survey noticed that the amount of stratospheric ozone over the South Pole was dropping sharply during the spring months, recovering somewhat as spring turned to summer. An examination of the historical records revealed that the springtime ozone losses had begun around the late 1960s and had grown much more severe by the late 1970s. By the mid-1980s virtually all the ozone was disappearing from parts of the polar stratosphere during the late winter and early spring. These ozone losses, dubbed the ozone hole, were the subject of intense research both in the field and in the laboratory. The picture that has emerged implicates **chlorine** as the chemical responsible for ozone destruction in the ozone hole. Chlorine apparently gets into the stratosphere from chlorofluorocarbons, or CFCs—industrial chemicals widely used as refrigerants, aerosol propellants, and solvents. Laboratory experiments show that after destroying an ozone molecule, chlorine is tied up in a form unable to react with any more ozone. However, it can chemically react with other chlorine compounds on the surfaces of polar stratospheric cloud particles, which frees the chlorine to attack more ozone. In other words, each chlorine molecule is recycled many times so that it can destroy thousands of ozone molecules. The realization of chlorine's role in ozone depletion brought about an international agreement in 1987, the Montreal Protocol, which committed the participating industrialized countries to begin phasing out CFCs.

The mesosphere and thermosphere.

The upper mesosphere and the lower thermosphere contain charged atoms and molecules (ions in a region known as the ionosphere. The atmospheric constituents at this level include nitrogen gas, atomic oxygen and nitrogen (O and N), and nitric oxide (NO). All of these are exposed to strong solar emission of ultraviolet and x ray radiation, which can result in ionization, knocking off an electron to form an atom or molecule with a positive charge. The ionosphere is a region enriched in free electrons and positive ions. This charged particle region affects the propagation of radio waves, reflecting them as a mirror reflects light. The ionosphere makes it possible to tune in radio stations very far from the transmitter; even if the radio waves coming directly from the transmitter are blocked by mountains or the curvature of the earth, one can still receive the waves bounced off the ionosphere. After the sun sets, the numbers of electrons and ions in the lower layers drop drastically, since the sun's radiation is no longer available to keep them ionized. Even at night, however, the higher layers retain some ions. The result is that the ionosphere is higher at night, which allows radio waves to bounce for longer distances. This is the reason that one can frequently tune in more distant radio stations at night than during the day.

The upper thermosphere is also where the bright nighttime displays of colors and flashes known as the aurora occur. The aurora are caused by energetic particles emitted by the sun. These particles become trapped by Earth's magnetic field and collide with the relatively few gas atoms present above about 60 mi (100 km), mostly atomic oxygen (O) and nitrogen gas ($N2$). These collisions cause the atoms and molecules to emit light, resulting in spectacular displays.

Composition.

Earth's atmosphere is composed of about 78% **nitrogen**, 21% **oxygen**, and 0.93% argon. The remainder, less than 0.1%, contains many small but important trace gases, including **water** vapor, **carbon dioxide**, and **ozone**. All of these trace gases have important effects on the earth's climate. The atmosphere can be divided into vertical layers determined by the way **temperature** changes with height. The layer closest to the surface is the troposphere, which contains over 80% of the atmospheric **mass** and nearly all the water vapor. The next layer, the stratosphere, contains most of the atmosphere's ozone, which absorbs high **energy radiation** from the **sun** and makes life on the surface possible. Above the stratosphere are the mesosphere and thermosphere. These two layers include regions of charged **atoms** and molecules, or ions. Called the ionosphere, this region is important to **radio** communications, since **radio waves** can bounce off the layer and travel great distances. It is thought that the present atmosphere developed from gases ejected by volcanoes. Oxygen, upon which all **animal** life depends, probably built up as excess emissions from plants that produce it as a waste product during **photosynthesis**. Human activities may be affecting the levels of some important atmospheric components, particularly **carbon** dioxide and ozone.

Major gases.

The most common atmospheric gas, nitrogen (chemical symbol N2) accounts for about 78% of the atmosphere. Nitrogen gas is largely inert, meaning that it does not readily react with other substances to form new chemical compounds. The next most common gas, oxygen (O2), makes up about 21% of the atmosphere. Oxygen is required for the respiration (breathing) of all animal life on Earth, from humans to bacteria. In contrast to nitrogen, oxygen is extremely reactive. It participates in oxidation, a type of chemical reaction that can be observed everywhere. Some common examples of oxidation are apples turning from white to brown after being sliced, the rusting of iron, and the very rapid oxidation reaction we call fire. Just under 1% of the atmosphere is made up of argon (Ar), which is a very inert noble gas, meaning that it does not take part in any chemical reactions under normal circumstances.

Together, these three gases account for 99.96% of the atmosphere. The remaining 0.04% contains a wide variety of trace gases, several of which are crucial to life on Earth.

Important trace gases.

Carbon dioxide (CO2) affects the earth's climate and plays a large support role in the biosphere, the collection of living things that populate the earth's surface. Only about 0.0325% of the atmosphere is CO2. Carbon dioxide is required by plant life for photosynthesis, the process of using sunlight to store energy as simple sugars, upon which all life on Earth depends. Carbon dioxide is also one of a class of compounds called greenhouse gases. These gases are made up of molecules that absorb and emit infrared radiation, which we feel as heat. The solar energy radiated from the sun is mostly in the visible range, within a narrow band of wavelengths. This radiation is absorbed by the earth's surface, then reradiated back out to space not as visible light, but as longer wavelength infrared radiation. Greenhouse gas molecules absorb some of this radiation before it escapes to space, and re-emit some of it back toward the surface. In this way, these gases trap some of the escaping heat and increase the overall temperature of the atmosphere. If the atmosphere had no greenhouse gases, it is estimated that the earth's surface would be 90°F (32°C) cooler.

Water vapor (H2O) is found in the atmosphere in small and highly variable amounts. While it is nearly absent in most of the atmosphere, its concentration can range up to 4% in very warm, humid areas close to the surface. Despite its relative scarcity, atmospheric water probably has more of an impact on the earth than any of the major gases, aside from oxygen. Water vapor participates in the hydrologic cycle, the process that moves water between the oceans, the land surface waters, the atmosphere, and the polar ice caps. This water cycling drives erosion and rock weathering, determines the earth's weather, and sets up climate conditions that make land areas dry or wet, habitable or inhospitable. When cooled sufficiently, water vapor forms clouds by condensing to liquid water droplets, or at lower temperatures, solid ice crystals. Besides creating rain or snow, clouds affect Earth's climate by reflecting some of the energy coming from the sun, making the planet somewhat cooler. Water vapor is also an important greenhouse gas. It is concentrated near the surface and is much more prevalent near the tropics than in the polar regions.

Ozone (O3) is almost all found in a layer about 9–36 mi (15–60 km) in attitude. Ozone gas is irritating to peo ples' eyes and skin, and chemically attacks rubber and plant tissue. Nevertheless, it is vital to life on Earth because it absorbs most of the high energy radiation from the sun that is harmful to plants and animals. A portion of the energy radiated by the sun lies in the ultraviolet (UV) region. This shorter wavelength radiation is responsible for suntans, and is sufficiently powerful to harm cells, cause skin cancer, and burn tissue, as anyone who has had a painful sunburn knows. The ozone molecules, along with molecules of O_2, absorb nearly all the high energy UV rays, protecting the earth's surface from the most damaging radiation. The first step in this process occurs high in the atmosphere, where O_2 molecules absorb very high energy UV radiation. Upon doing so, each absorbing molecule breaks up into two oxygen atoms. The oxygen atoms eventually collide with another O_2molecule, forming a molecule of ozone, O_3 (a third molecule is required in the collision to carry away excess energy). Ozone in turn may absorb UV of slightly longer wavelength, which knocks off one of its oxygen atoms and leaves O_2. The free oxygen atom, being very reactive, will almost immediately recombine with another O_2, forming more ozone. The last two steps of this cycle keep repeating but do not create any new chemical compounds; they only act to absorb ultraviolet radiation. The amount of ozone in the stratosphere is minute. If it were all transported to the surface, the ozone gas would form a layer about 0.1–0.16 in (2.5–4.0 mm) thick. This layer, as thin as it is, is sufficient to shield the earth's occupants from harmful solar radiation.

Aerosols.

In addition to gases, the atmosphere has a wide variety of tiny particles suspended in the air, known collectively as aerosols. These particles may be liquid or solid, and are so small that they may require very long times to settle out of the atmosphere by gravity. Examples of aerosols include bits of suspended soil or desert sand, tiny smoke particles from a forest fire, salt particles left over after a droplet of ocean water has evaporated, plant pollen, volcanic dust plumes, and particles formed from the pollution created by a coal burning power plant. Aerosols significantly affect the atmospheric heat balance, cloud growth, and optical properties.

Aerosols cover a very wide size range. Raindrops suspended in a cloud are about 0.04–0.24 in (1–6 mm) in diameter. Fine desert sand and cloud droplets range in diameter down to about 0.0004 in (0.01 mm). Sea salt particles and smoke particles are 1/100th of this, about 0.0001 mm, or 0.1 micrometer, in diameter (1 micrometer = one thousandth of a millimeter). Smallest of all are the particles that form when certain gases condense; that is, when several gas molecules come together to form a stable cluster. These are the Aitkin nuclei, whose diameters can be measured down to a few nanometers (1 nanometer = one millionth of a millimeter).

Some aerosols are just the right size to efficiently scatter sunlight, making the atmosphere look hazy. Under the right conditions, aerosols act as collecting points for water vapor molecules, encouraging the growth of cloud droplets and speeding the formation of clouds. They may also play a role in Earth's climate; the aerosols are known to reflect a portion of incoming solar radiation back to space, which lowers the temperature of the earth's surface. Current research is focused on estimating how much cooling is provided by aerosols, as well as how and when aerosols form in the atmosphere.