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Composition and Structure of Atmosphere

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Abstract

Air quality transcends all scales with in the atmosphere from the local to the global with handovers and feedbacks at each scale interaction. Air quality has manifold effects on health, ecosystems heritage and, climate. In this review the state of scientific understanding in relation to global and regional air quality is outlined. The review discusses air quality, in terms of emissions, processing and transport of trace gases and aerosols. New insights into the characterization of both natural and anthropogenic emissions are reviewed looking at both natural (e.g. dust and lightning) as well as plant emissions. Trends in anthropogenic emissions both by region and globally are discussed as well as biomass burning emissions. In terms of chemical processing the major air quality elements of ozone, non-methane hydrocarbons, nitrogen oxides and aerosols are covered. A number of topics are presented as a way of integrating the process view into the atmospheric context; these include the atmospheric oxidation efficiency, halogen and HOx chemistry, nighttime chemistry, tropical chemistry, heat waves, megacities, biomass burning and the regional hot spot of the Mediterranean. New findings with respect to the transport of pollutants across the scales are discussed, in particular the move to quantify the impact of long-range transport on regional air quality. Gaps and research questions that remain intractable are identified. The review concludes with a focus of research and policy questions for the coming decade. In particular, the policy challenges for concerted air quality and climate change policy (co-benefit) are discussed. (C) 2009 Elsevier Ltd. All rights reserved.

KEY TERMS:Infrared radiation ,Ionosphere ,Lapse rate ,Mesosphere ,Ozone hole ,Stratosphere ,Thermosphere ,Troposphere ,Ultraviolet radiation ,X-ray radiation

Introduction :

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. All of these trace gases have important effects on Earth's climate. The atmosphere can be divided into vertical layers determined by the way temperature changes with altitude. 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. The upper mesosphere and lower thermosphere are called the ionosphere, this region is important to radio communications, because 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 accumulated 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.

Composition of the atmosphere

Gases in Earth's Atmosphere

Nitrogen and oxygen are by far the most common; dry air is composed of about 78% nitrogen (N_2) and about 21% oxygen (O_2). Argon, carbon dioxide (CO_2), and many other gases are also present in much lower amounts; each makes up less than 1% of the atmosphere's mixture of gases. The atmosphere also includes water vapor. The amount of water vapor present varies a lot, but on average is around 1%. There are also many small particles - solids and liquids - "floating" in the atmosphere. These particles, which scientists call "aerosols", include dust, spores and pollen, salt from sea spray, volcanic ash, smoke, and more.

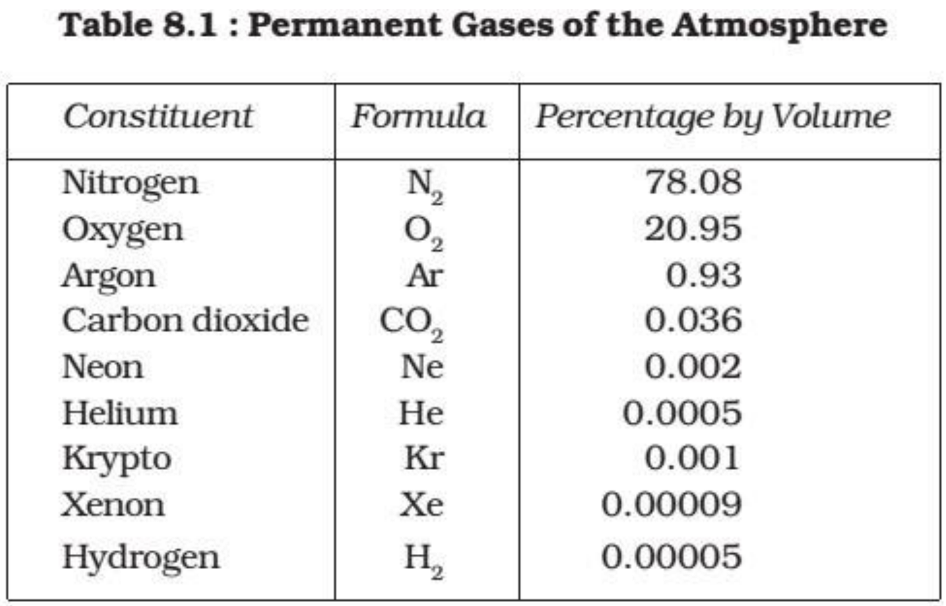


Table 8.1 : Permanent Gases of the Atmosphere

Constituent	*Formula*	*Percentage by Volume*
Nitrogen	N_2	78.08
Oxygen	O_2	20.95
Argon	Ar	0.93
Carbon dioxide	CO_2	0.036
Neon	Ne	0.002
Helium	He	0.0005
Krypto	Kr	0.001
Xenon	Xe	0.00009
Hydrogen	H_2	0.00005

Source: US Department of commerce, NOAA. 1976 Quoted in climatology, By Oliver and Hidore in 2003

Aerosol

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

The size of some aerosol particles allows them to efficiently scatter sunlight and create atmospheric haze. Under some 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. Aerosols are known to reflect a portion of incoming solar radiation back to space, which lowers the temperature of 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.

Atmospheric structure

The atmosphere can be divided into layers based on the atmospheric pressure and temperature profiles (the way these quantities change with height). Atmospheric temperature drops steadily from its value at the surface, about 290K (63°F; 17°C), until it reaches a minimum of around 220K (–64°F;–53°C) at 6 mi (10 km) above the surface. This first layer is called the troposphere and ranges in pressure from over 1,000 millibars at sea level to 100 millibars at the top of the layer, the tropopause. Above the tropopause, the temperature rises with increasing altitude up to about 27 mi (45 km). This region of increasing temperatures is the stratosphere, spanning a pressure range from 100 millibars at its base to about 10 millibars at the stratopause, the top of the layer. Above 30 mi (50 km), the temperature resumes its drop with altitude, reaching a very cold minimum of 180K (–135°F;–93°C) at around 48 mi (80 km). This layer is the mesosphere, which at its top (the mesopause) has an atmospheric pressure of only 0.01 millibars (that is, only 1/100,000th of the surface pressure). Above the mesosphere lies the thermosphere, extending hundreds of miles upward toward the vacuum of space. It is not possible to place an exact top of the atmosphere because air molecules become scarcer until the atmosphere blends with the material found in space.

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. All of what we know as weather occurs in the troposphere, the name of which 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, temperature decreases 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 in which vertical air movement is prevented. Because air masses move within the troposphere, a cold air mass may move into an area and have a higher lapse rate. That is, its temperature falls 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 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

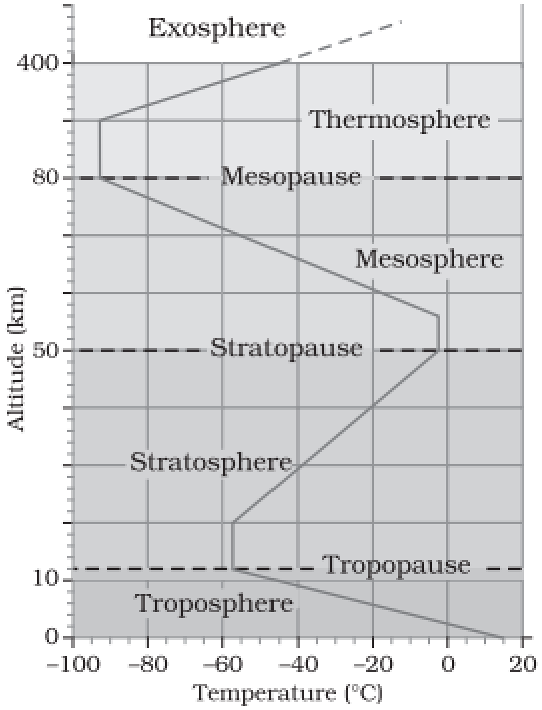
The beginning of the stratosphere is defined as that point where the temperature reaches a minimum and the lapse rate abruptly drops to zero. This temperature structure has one important consequence: it inhibits rising air. Any air that begins to rise will become cooler and denser than the surrounding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

The stratosphere contains most of the ozone found in Earth's atmosphere, and the presence of ozone is the reason for the temperature profile found in the stratosphere. 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 concern. In 1985, scientists from the British Antarctic Survey noticed that the amount of stratospheric ozone over the South Pole fell 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.

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 and 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.

The understanding 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.



Source: US Department of commerce, NOAA. 1976 Quoted in climatology, By Oliver and Hidore in 2003

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, 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 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, because 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 to more distant radio stations at night than during the day. The upper thermosphere is also where the bright night time displays of colors and flashes known as the aurora occur. The aurora is 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 (N_2). These collisions cause the atoms and molecules to emit light, resulting in spectacular displays.

The thermosphere is a layer of Earth's atmosphere. The thermosphere is directly above the mesosphere and below the exosphere. It extends from about 90 km (56 miles) to between 500 and 1,000 km (311 to 621 miles) above our planet.

Temperatures climb sharply in the lower thermosphere (below 200 to 300 km altitude), then level off and hold fairly steady with increasing altitude above that height. Solar activity strongly influences temperature in the thermosphere. The thermosphere is typically about 200° C (360° F) hotter in the daytime than at night, and roughly 500° C (900° F) hotter when the Sun is very active than at other times. Temperatures in the upper thermosphere can range from about 500° C (932° F) to 2,000° C (3,632° F) or higher.

The boundary between the thermosphere and the exosphere above it is called the thermopause. At the bottom of the thermosphere is the mesopause, the boundary between the thermosphere and the mesosphere below.

Although the thermosphere is considered part of Earth's atmosphere, the air density is so low in this layer that most of the thermosphere is what we normally think of as outer space. In fact, the most common definition says that space begins at an altitude of 100 km (62 miles), slightly above the mesopause at the bottom of the thermosphere. The space shuttle and the International Space Station both orbit Earth within the thermosphere.

Below the thermosphere, gases made of different types of atoms and molecules are thoroughly mixed together by turbulence in the atmosphere. Air in the lower atmosphere is mainly composed of the familiar blend of about 80% nitrogen molecules (N_2) and about 20% oxygen molecules (O_2). In the thermosphere and above, gas particles collide so infrequently that the gases become somewhat separated based on the types of chemical elements they contain. Energetic ultraviolet and X-ray photons from the Sun also break apart molecules in the thermosphere. In the upper thermosphere, atomic oxygen (O), atomic nitrogen (N), and helium (He) are the main components of air. Much of the X-ray and UV radiation from the Sun is absorbed in the thermosphere. When the Sun is very active and emitting more high energy radiation, the thermosphere gets hotter and expands or "puffs up". Because of this, the height of the top of the thermosphere (the thermopause) varies. The thermopause is found at an altitude between 500 km and 1,000 km or higher.

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