

COMPOSITION & STRUCTURE OF THE ATMOSPHERE

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COMPOSITION & STRUCTURE OF THE ATMOSPHERE

- Earth is surrounded by a gaseous envelop known as atmosphere. In other words we can say- **“Earth’s atmosphere is a multi-layered gaseous envelope surrounding the earth from all sides and is attached to the earth’s surface by its gravitational force”**. It comprises of various gases and minute suspended solid and liquid particles. These elements are creating conditions suitable for life on the Earth. Research indicates that 97% of the total atmospheric mass is concentrated within the first 25 km of altitude. So, atmospheric density diminishes as the altitude increases. Atmosphere is composed of three major constituents, that is, gases, water vapour and aerosols. Regarding gases, the composition can be studied under two heads e.g. (a) Constant gases and (b) Variable gases.

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- **Constant Gases:**
- Nitrogen and oxygen are the predominant constant gases, constituting approximately 99% of the earth's atmosphere. Notably, the concentrations of nitrogen and oxygen remain constant up to an altitude of 80 km. Oxygen which is vital for living organisms is produced by vegetation and removed through diverse organic and inorganic processes. Nitrogen is comparatively an inert gas. So it acts as a diluent and enters the air through the processes like decay or combustion of organic substances, volcanic activity etc. It is removed by specific biological processes. Other gases, including carbon dioxide, argon, traces of inert gases, water vapour, and ozone, make up the remaining 1% which are called minor gases and their concentration varies.

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- The concentration of gases like carbon dioxide, water vapour; ozone etc. exhibits spatio-temporal variations. Carbon dioxide is crucial for photosynthesis and contributes to the greenhouse effect by trapping heat in the lower atmosphere. Human activities, particularly fossil fuels usage, have elevated its concentration to approximately 0.04% by volume of dry air. Ozone, found around 30 km above earth, shields against harmful ultraviolet radiation of the sun. However, human interventions, such as CFCs and HFCs usage, have led to the formation of ozone hole, notably above Antarctica, posing a threat to life. Water vapour is another variable gas, the concentration of which ranges from 0.02 to 4 per cent by volume in dry and humid climates, respectively. It is a very important constituent of atmosphere and plays a role in the cloud formation, which yields rain and contributes to the greenhouse effect.

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- Apart from gases and water vapour, atmosphere also has suspended particulate matter (SPM) or aerosols which comprises of solid particles of varying sizes and liquid droplets collectively suspended in the atmosphere. Their size varies in size between 2.5μ to 10μ and originates from sources like dry soil, sea-salts, pollen, volcanic ash, industrial effluents and even meteoric particles. The concentration of particulate matter is higher in arid regions compared to humid ones, impacting the air quality and causing respiratory issues.

Percentage of Gases (Approx.) by Volume of Dry Air

SL.NO.	Gases	Symbol	% occurrence
1.	Nitrogen	N ₂	78.08
1.	Oxygen	O ₂	20.95
1.	Argon	Ar	0.93
1.	Carbon dioxide	CO ₂	0.04
1.	Neon	Ne	0.0018
1.	Helium	He	0.0005
1.	Methane	CH ₄	0.0002
1.	Krypton (Kr)	Kr	0.0001
1.	Hydrogen	H ₂	0.00005
1.	Nitrous oxide	N ₂ O	0.00003
1.	Xenon	Xe	0.00001
1.	Ozone	O ₃	Trace to 0.00080

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- There are also trace amounts of water vapour, varying from almost 0% to around 4% depending on the location and weather conditions. Now try answering a self-assessment question to check your understanding.

VERTICAL STRUCTURE OF THE ATMOSPHERE

- The vertical structure of the earth's atmosphere has been the subject of significant interest for meteorologists and scientists throughout history. Critical aspects such as air navigation and the transmission of information through radio and TV signals rely on an understanding of the distinct regions within the atmosphere. To categorise these regions, meteorologists employ different criteria, with temperature being one of the most crucial factors. The atmosphere is characterised by a layered structure based on temperature differences. Imagine the atmosphere as a series of concentric shells or layers encircling the earth, each defined by specific temperature characteristics. This stratification is vital for comprehending the dynamic and complex nature of our atmosphere. The layered structure is not only a conceptual framework but also a practical tool for meteorologists to study and analyse atmospheric phenomena. The temperature-based classification of atmosphere results in distinct layers, each with unique thermal properties. Let us study the major layers of the atmosphere, from the earth's surface outward.

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- Vertical Layers of the Atmosphere Based on Thermal Properties
Earth's atmosphere is said to have the five layers based on the thermal characteristics. These are: Troposphere, Stratosphere, Mesosphere, Thermosphere and Exosphere. Most of the climatologists study ozonosphere as a part of stratosphere. Also ionosphere is taken under the layer thermosphere. Let us learn about these layers in detail. Troposphere The troposphere is positioned as the lowermost layer of the earth's atmosphere and constitutes three-fourths of the total gaseous mass enveloping our planet. This layer is dynamic and crucial for various atmospheric processes, hosting almost all water vapour and dust particles. This nomenclature 'troposphere' was first suggested by Tiessence de Bort.

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- It is derived from two Greek words, i.e., 'tropos' which means mixing and 'sphere' which means zone. So the term troposphere means the zone where mixing of gases occurs most readily. The troposphere serves as the arena for most convective air currents, giving rise to weather phenomena such as clouds, lightning, thunderstorms, and snowfall. A distinctive characteristic of the troposphere is the uniform decrease in temperature with altitude. This decrease occurs at a rate of 6.5°C per 1000 meters of ascent and is known as the normal lapse rate. This information helps explain why higher-altitude locations like Manali, Gangtok, Kodaikanal etc. exhibit cooler temperatures compared to plains. Interestingly, the height or extent of the troposphere is not constant either in time or space. At the poles, the troposphere's height is approximately 8 km, while at the equator; it extends to about 16 km. This non-uniformity is attributed to the higher surface temperatures at the equator, resulting in more vigorous convective air currents which push the extent of troposphere at equator than at the poles. Additionally, the height of the troposphere varies with the seasons, increasing during summer and decreasing during winter. The lower part of the troposphere, extending to about 3 km from the earth's surface, is often referred to as the friction layer due to it experiencing maximum friction between the earth's surface and the atmosphere. This layer also exhibits the phenomenon of temperature inversions. A temperature inversion exists when the temperature increases instead of decreasing with altitude. You will study about this in a forthcoming unit on temperature in this course.

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- At the upper boundary of the troposphere, a transitional zone known as the 'tropopause' separates it from the next layer, the stratosphere. The word 'tropopause' was coined by Sir Napier Shaw from two Greek words, i.e., 'tropos' and 'pause' which means the zone where mixing stops. Similar to the troposphere, the height of the tropopause is greater near the equator when compared to the poles. This variation contributes to the fact that the lowest temperature in the tropopause occurs over the equator rather than over the poles. The tropopause marks the end of the decrease in temperature due to the normal lapse rate, reaching a minimum of -50°C to -60°C . This temperature trend becomes reverse and is a crucial point of discussion in the subsequent section, highlighting the distinctive characteristics of the stratosphere.

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- **Stratosphere** The stratosphere is situated approximately between 12 km and 50 km above the earth's surface, making it the second major layer of the earth's atmosphere. Unlike the troposphere beneath it, the stratosphere is characterised by unique features that distinguishes it from the layers above and below. One prominent characteristic of the stratosphere is its relative stability and lack of turbulence. Unlike the dynamic troposphere, the stratosphere experiences minimal vertical movement of air. It happens in the lower part of the stratosphere up to a maximum of about 25 km from the earth's surface where this isothermal behaviour is seen. This stability contributes to its suitability for aviation, as airplanes preferentially fly in the stratosphere to minimise fuel consumption and to avoid turbulence and air resistance. Cirrus clouds, a type of high-altitude cloud, are observed in the lower stratosphere. These clouds are composed of ice crystals and form under specific conditions in this stable layer. Above 25 km in altitude, a distinct temperature trend emerges in the stratosphere. There is a steep increase in temperature with height, reaching approximately 0°C at an altitude of 50 km. This temperature rise is primarily attributed to the presence of ozone in this part of the stratosphere. As it absorbs the ultraviolet radiation of the sun, it leads to the warming of the stratosphere in this upper region. Ozone concentration is a characteristic feature of the stratosphere. It is found in the lower portion of the stratosphere, approximately between 15 km and 35 km above the earth. The average concentration is about 0.3 parts per million. Its thickness varies seasonally and geographically. This layer absorbs most of the sun's ultraviolet radiation which is harmful to the earth living beings. It causes increase in the incidents of skin cancer, cataract, damage to the immune system, change in the genetic structure of life forms, retarded plant growth and reduction in phytoplankton growth in the oceans.

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- The upper boundary of the stratosphere is defined as the stratopause, marking the transition to the next layer of the atmosphere, the mesosphere. The stratopause extends to an average altitude of 50 km. The stability, dryness, and unique temperature characteristics of the stratosphere make it a critical component of earth's atmosphere, influencing both atmospheric dynamics and human activities such as air travel.

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- **Mesosphere** Up to this point, you've gained knowledge about the troposphere and stratosphere. Now, let's delve into the mesosphere, the layer beyond the stratopause. Positioned between 50 km and 80 km from the earth's surface, the mesosphere exhibits distinct characteristics. The mesosphere is marked by a temperature decrease with height, primarily due to the absence of the ozone layer in this region. The ozone layer, which absorbs harmful ultraviolet rays from the sun, contributes to the warming of the stratosphere. As you ascend through the mesosphere, temperatures drop, reaching a minimum of -100°C at an altitude of 80 km. The upper segment of the mesosphere is referred to as the mesopause. Notably, the mesosphere hosts the thin noctilucent clouds, particularly visible over high latitudes during summer. These clouds exhibit luminescence during twilight or shine brightly during the night. Composed of extremely small ice crystals, measuring up to 200 nm in diameter, these mesospheric clouds exist at an altitude ranging from 75 to 85 km. They are considered the highest altitude clouds.

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- Additionally, the mesosphere is a zone where meteorites disintegrate due to substantial friction. A meteor is the flash of light that we see in the sky during night, when a small chunk of interplanetary debris burns due to friction while passing through our atmosphere. The debris of the interplanetary matter is called meteoroid and a few which make their passage to the earth's surface are called meteorites. This disintegration occurs here because the layers of the atmosphere above the mesosphere, namely the thermosphere and exosphere, have an extremely low density of air. Consequently, the mesosphere becomes the key location for the friction which meteorites encounter upon entering the earth's atmosphere.

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- **Ionosphere or Thermosphere** Revisiting the region beyond the mesopause, you'll observe the presence of a high-temperature zone known as the thermosphere. The lower part of the thermosphere is referred to as the ionosphere, spanning altitudes between 100 and 400 km. The discovery of the ionosphere is credited to Kennelly and Heaviside. This layer earns its name because the gaseous atoms or molecules within it become ionised due to solar radiations. Ionisation is the process by which an atom or a molecule acquires a negative or positive charge by gaining or losing electrons often in conjunction with other chemical changes. The ionosphere plays a crucial role in reflecting electromagnetic waves back to the earth, facilitating radio and TV communication. An intriguing aspect of the ionosphere is the occurrence of Auroras, which typically manifest between 80 and 160 km in altitude. These natural displays of lights, especially near the magnetic poles, are caused by the excitation of the ionosphere by streams of high-energy particles from the sun. In the northern hemisphere, they are known as Aurora Borealis or northern lights, while in the southern hemisphere, they are termed as Aurora Australis or southern lights. The ionosphere is further categorised into several ionised layers, namely the D, E, F1, F2, and G layers. Let us explore the characteristics of each of these layers.

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- **D-Layer:** It is present between 60-99 km from the earth's surface during the day time. It absorbs medium and high-frequency waves and reflects low frequency waves. It disappears after sunset. **E-Layer:** Positioned at a height of 90-130 km from the earth's surface, the E-Layer reflects medium and high-frequency radio waves, also known as the Kennelly-Heaviside layer. This layer also vanishes after sunset. **Sporadic E-Layer:** Occurring under special circumstances, just like meteors or auroras, the sporadic E-layer is associated with high-velocity winds. It reflects very high-frequency radio waves and is found at an altitude of about 110 km. **E2 Layer:** Above the sporadic E-layer, the E2 layer is formed by the action of ultraviolet photons on oxygen molecules during the day, disappearing at sunset and appearing at a height of about 150 km from earth's surface. **F1 Layer and F2 Layer:** Together known as the Appleton Layer, these layers are found at a height of about 150-380 km from earth's surface. They play a crucial role in reflecting medium and high-frequency radio waves, contributing to the long-distance radio communication. crucial role in reflecting medium and high-frequency radio waves, contributing to the long-distance radio communication.

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- **G Layer:** Positioned above the F2 layer, the G layer is a reflecting layer that cannot be detected as it reflects all the waves reflected by the F1 layer. Found at a height of about 400 km above the earth's surface, it is characterised by the presence of free electrons resulting from the reaction of ultraviolet photons with nitrogen atoms. The thermosphere extends to several hundred km, with temperatures rising to about 2000°C at around 500 km in altitude. These high temperatures represent internal or kinetic energy of the molecules, but due to the sparse air density in this region, they cannot be recorded by a thermometer nor be felt, as is the case in the denser troposphere.

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- **Exosphere** The outermost layer of earth's atmosphere begins roughly at 500 km from the surface and stretches up to an altitude of approximately 1000 km. Known as the exosphere; it serves as a transitional region between earth's atmosphere and interplanetary space. At such heights, air density is exceedingly low, explaining why despite temperatures soaring to above 5000°C, it remains unfelt. Hydrogen and helium are the primary components within this region.
- In addition to temperature-based classifications of atmospheric layers, another criterion for categorisation revolves around chemical composition. This leads to a broad division of atmosphere into two main spheres: the homosphere and the heterosphere. The subsequent section discusses these spheres.

• Courtesy-IGNOU, EGYANKOSH

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- THANK YOU