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Lecture Title	**COMPOSITION AND STRUCTURE OF THE ATMOSPHERE**	
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Lecture 1 – COMPOSITION AND STRUCTURE OF THE ATMOSPHERE

1.1 GENERAL

- Earth system consists of four spheres:-
  - Lithosphere
  - Hydrosphere
  - Biosphere
  - Atmosphere
- Energy sources for the Earth system are
  - Sun – *Very important for atmosphere!*
  - Residual heat in the interior of the Earth – *Not important for the atmosphere!*

1.2 COMPOSITION OF THE ATMOSPHERE

- Atmosphere is the envelope of gases that surround a planet and are held to it by the planet's gravitational attraction
- Air is composed of fixed gases, variable gases and aerosols as shown in table (**1.1**)
- Fixed gases:-
  - Nitrogen (**N_2**) **78**%
  - Oxygen (**O_2**) **21**%
  - Argon (**Ar**) **0.9**%
  - Carbon dioxide (**CO_2**)
  - Neon (**Ne**)
  - Helium (**He**)
  - Methane (**CH_4**)
  - Krypton (**Kr**)
  - Hydrogen (**H_2**)
- Variable gases:-
  - Water vapor (**H_2O**)
  - Ozone (**O_3**)
    - **90**% of ozone is in the stratosphere
    - Has several important roles
    - Absorbs harmful ultra-violet (**UV**) radiation

- Aerosols are tiny suspended solid particles (dust, smoke, etc.) or liquid droplets that enter the atmosphere from either natural or human (anthropogenic) sources, such as the burning of fossil fuels
- Sulfur-containing fossil fuels, such as coal, produce *sulfate aerosols*

Table.(1.1) : Composition of the Atmosphere near the Earth's Surface

Permanent Gases			Variable Gases			
Gas	*Symbol*	*Percent (by Volume) Dry Air*	*Gas (and Particles)*	*Symbol*	*Percent (by Volume)*	*Parts per Million (ppm)**
Nitrogen	N_2	78.08	Water vapor	H_2O	0 to 4	
Oxygen	O_2	20.95	Carbon dioxide	CO_2	0.037	368*
Argon	Ar	0.93	Methane	CH_4	0.00017	1.7
Neon	Ne	0.0018	Nitrous oxide	N_2O	0.00003	0.3
Helium	He	0.0005	Ozone	O_3	0.000004	0.04†
Hydrogen	H_2	0.00006	Particles (dust, soot, etc.)		0.000001	0.01–0.15
Xenon	Xe	0.000009	Chlorofluorocarbons (CFCs)		0.00000002	0.0002

1.3 IDEAL GAS LAW

- Air behaves like an *ideal gas*
- In an ideal gas, volume depends only on pressure, temperature, and number of molecules
- The *ideal gas law* (also known as the *equation of state*) relates pressure, temperature, and density (or volume)

  - In chemistry the ideal gas law is

$$pV = nRT$$

Where:

P : is pressure.

V : is volume.

N : is the number of moles of gas.

R : is the universal gas constant.

T : is absolute temperature.

- In meteorology we use a different form, which is derived by first dividing both sides by volume, and then multiplying top and bottom of the right-hand side by molar mass (molecular weight), ***M***, to get

$$p = \frac{n}{V}RT = \frac{Mn}{V}\frac{R}{M}T$$

Recognizing that ***Mn*** is the mass of the gas, so that ***Mn/V*** is the density, we end up with

$$p = \rho\frac{R}{M}T$$

We then define ***R/M*** to be a new constant, ***R'*** , called the **specific gas constant**, so that the ideal gas law is now

$$p = \rho R' T$$

Where :

$$R' \equiv \frac{R}{M}$$

- For dry air, the specific gas constant is called $\boldsymbol{R_d}$, and has a value of **287.1** J kg^{-1} K^{-1}

$$\boxed{p = \rho R_d T}$$ ***Ideal Gas Law for Dry Air***

- The reason this form is more popular with meteorologists , is that in the atmosphere it makes more sense to think more in terms of air density, rather than in the volume and number of moles of the air

1.4 PRESSURE AND DENSITY

- Density is mass per volume
  - Density is greatest at the surface of the earth, and decreases as you go up as shown in figure (**1.1**)
- Pressure is force per area
  - There are two types of pressure
    - ***Hydrostatic pressure***, which is just due to the weight of the air above you
    - ***Dynamic pressure***, which is due to the motion of the air
- In meteorology, dynamic pressure is usually very small, and we will assume for now that atmospheric pressure is solely due to hydrostatic pressure

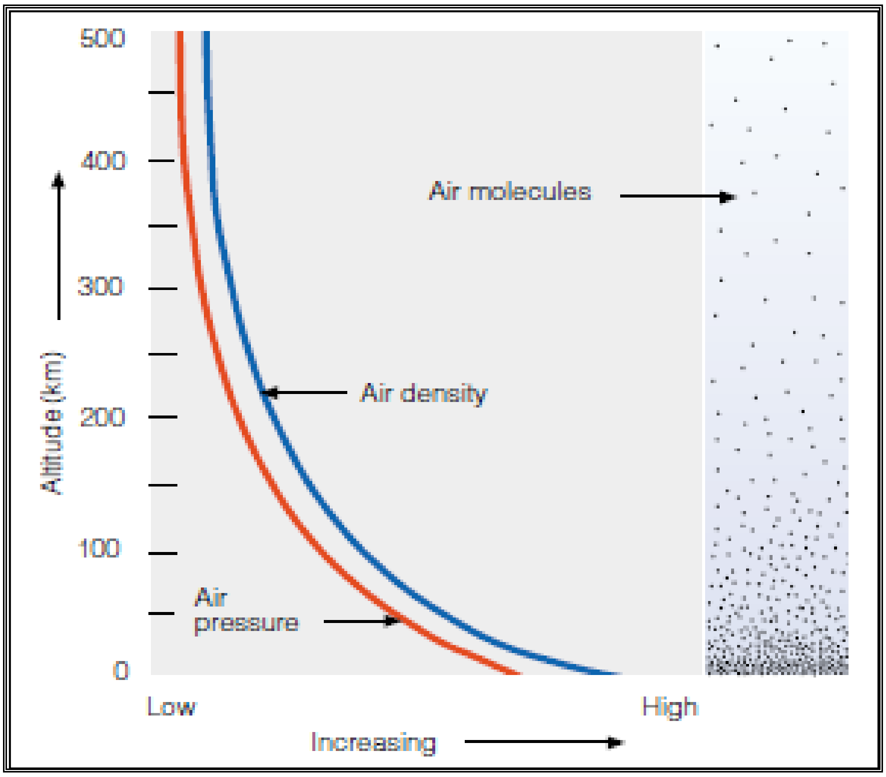
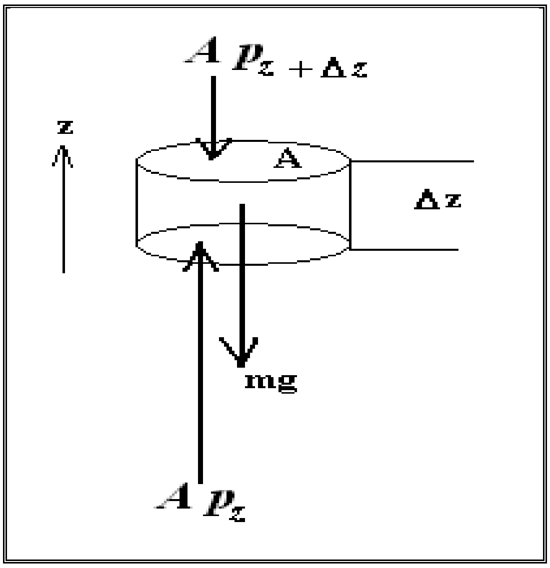


Fig.(1.1) : Both air pressure and air density decrease with increasing altitude

1.5 HYDROSTATIC BALANCE

- In an atmosphere at rest, there are three forces acting on an air parcel
  - Gravity acting downward
  - Pressure force acting upward
  - Pressure force acting downward
- The picture below shows a cylindrical air parcel of mass ***m*** and with top and bottom surface area ***A***, with these forces acting on it
- $p_z + \Delta z$ is the pressure at the **top** of the air parcel, and p_z is the pressure at the **bottom**



- If the air parcel is at rest, then from Newton's 2nd law of motion the forces must sum to zero,

$$Ap_z - Ap_{z+\Delta z} - mg = 0 \ldots(1)$$

- The **mass** of the air parcel is given by its **density** multiplied by the **volume**, or

$$m = \rho A \Delta_z$$

- If we put this into Equation (**1**) and rearrange, we get

$$\frac{(p_{z+\Delta z} - p_z)}{\Delta_z} = -\rho g$$

- So, for an atmosphere at rest be now have

$$\boxed{\frac{dp}{dz} = -\rho g} \quad \textit{\textbf{Hydrostatic Equation}}$$

- This is known as the *hydrostatic equation*
- The difference between the upward and downward pressure gradient forces is known as the ***pressure gradient force***
- In hydrostatic balance, the vertical pressure gradient force is exactly balanced by gravity
- Notice that in a hydrostatic atmosphere, ***dp/dz*** is negative
- This makes sense, since pressure decreases as you go upward (increasing ***z***)

1.6 HOW PRESSURE CHANGES WITH HEIGHT

- We can integrate the hydrostatic equation to find out how pressure changes with height

$$p(z) = p_{\circ} \exp(-\int_{0}^{z} \frac{g}{R_d} \frac{dz}{T})$$

- For an isothermal atmosphere (***T*** constant with height), however, this becomes

$$p(z) = p_{\circ} \exp(-\frac{g}{R_d T} z)$$

where $\boldsymbol{p_o}$ is the pressure at the surface

○ Defining the *scale height* as

$$H = \frac{R_d T}{g}$$

we get an equation for pressure versus height in an isothermal atmosphere as

$$\boxed{p(z) = p_{\circ} \exp(-z/H)}$$ ***Pressure Change in an Isothermal Atmosphere***

- The typical scale height used is $H \approx$ **8.1 km** (which corresponds to an average temperature of about **277 K**)
- Since density is related to pressure via the ideal gas law, we find that density in an isothermal atmosphere also decreases exponentially with height according to

$$\boxed{\rho(z) = \rho_{\circ} \exp(-z/H)}$$ ***Density Change in an Isothermal Atmosphere***

1.7 LAPSE RATE

- The lapse rate indicates how rapidly the temperature decreases with height
- Mathematically, it is defined as

$$\boxed{\gamma = -\frac{dT}{dz}} \quad \textbf{\textit{Definition of Lapse Rate}}$$

- Lapse rate is defined with a negative sign
- Thus, *if temperature decreases with height the lapse rate is positive*

1.8 THERMAL STRUCTURE OF THE ATMOSPHERE

- The atmosphere can be divided into different layers based on its thermal (temperature) structure as shown in figure (**1.2**)
- These layers are differentiated by whether the lapse rate is positive or negative
- The layers, from bottom to top, are shown in table (**1.2**)

Table (1.2) : Atmosphere Layers

Layer	Lapse rate	Mean Altitude	Remarks
Troposphere	+	0 – 11 km	- Contains majority of atmosphere. - Where most “weather” occurs. - Temperature decreases with height because heat source is at bottom (due to Sun’s rays striking earth). - Thickness (height) varies with season and location. -Higher in summer and in Tropics.
Stratosphere	–	11 – 47 km	- Contains ozone layer. - Temperature increases with height due to absorption of UV rays by ozone.
Mesosphere	+	47 – 85 km	-Temperature again decrease with height.
Thermosphere	–	> 85 km	- Temperature increases because heat source is at top (due to absorption of Sun’s rays by molecular nitrogen and oxygen).

- The levels separating the layers are named by taking the prefix of the layer below and putting the suffix –*pause* with it
   - Example – The top of the troposphere is the *tropopause*

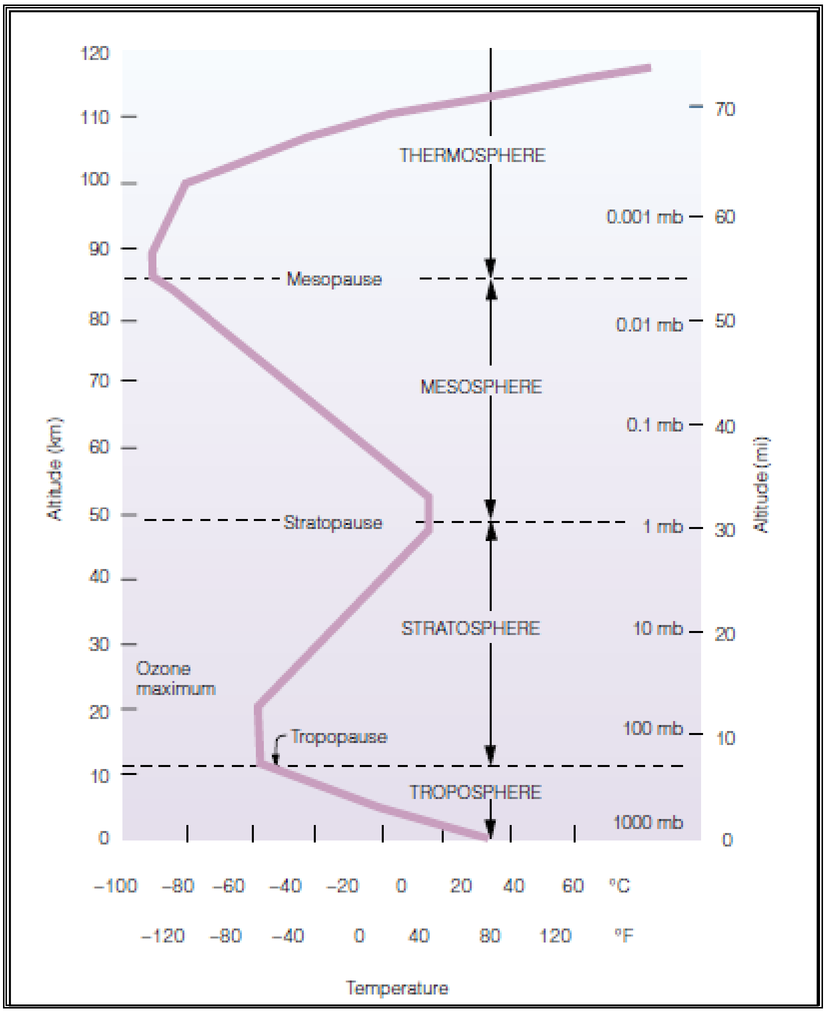


Fig.(1.2) : Layers of the Atmospheric as related to the average profile of air temperature above the earth's surface

1.9 HETEROSPHERE AND HOMOSPHERE

- Lower part of atmosphere (below about **80** km) is well mixed (fixed gases are found in constant proportions) as shown in figure (**1.3**)
  - The well-mixed layer is called the *homosphere*
  - Above the homosphere is found the *heterosphere*, which is not well mixed
  - Lighter molecules found at higher altitudes

1.10 IONOSPHERE

- The ionosphere is the region above about **60** km, where there are numerous ions and free electrons present
  - Affects propagation of radio waves

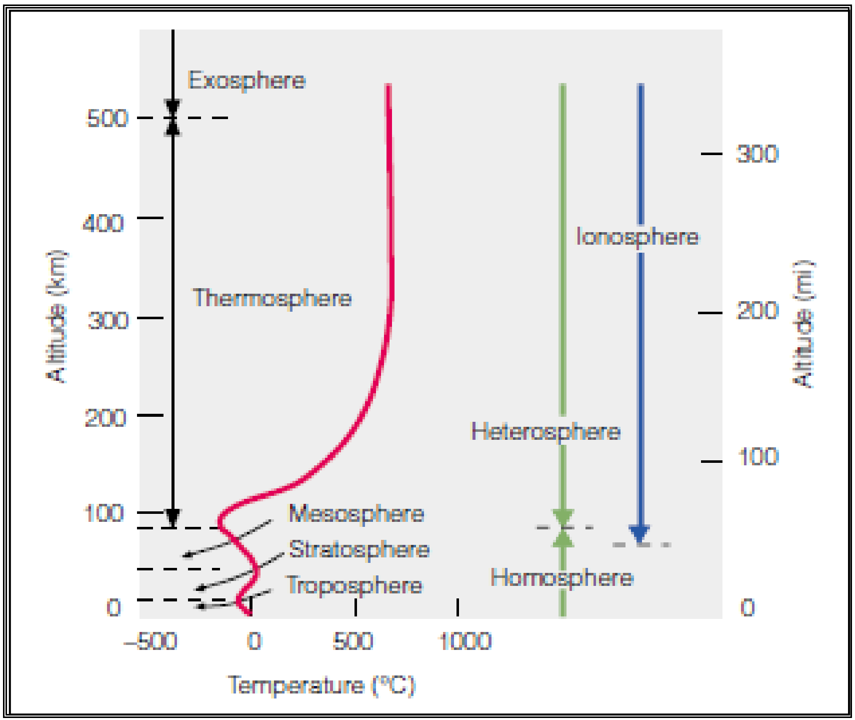


Fig. (1.3) : Layers of the Atmosphere based on temperature , composition and electrical properties