UNIT 7 METEOROLOGY

Structure

7.0 INTRODUCTION

Meteorology is the study of the atmosphere and its phenomena. It can also be defined as the science of the air. The term meteorology comes from a Greek word "*meteoros*" which means "high in the air". This term got its origin from the time of Aristotle, a Greek Philosopher around 340 B.C. who wrote the book on natural philosophy entitled "Meterologica". The book represented the submission on knowledge of weather, climate, astronomy, geography and chemistry. In his book, Aristotle made an attempt to explain atmospheric phenomena in a philosophical way. After several years Aristotle's student Theophrastus published a book entitled *Book of Signs* which was based on weather forecasting. The origin of Meteorology did not have its meaning until the invention of weather instruments. With the development of better instruments, the science of meteorology developed. Meteorology received a major boost in 1843 with the discovery of Telegraph. In 1950s another milestone was crossed by Meteorology with the development of high-speed computers which solved the mathematical equations that easily described the behaviour of atmosphere. After World War II, abundant military radars were available which were further transformed into precipitation measuring tools. First weather satellite Trios I was launched in 1960 opening the way for space-age meteorology. Throughout 1990s, several attempts were made to develop more sophisticated satellites which could do accurate forecasting.

"Atmospheric Science involves the movement of air masses in the atmosphere, Atmospheric heat balance, atmospheric chemical composition and reactions". Atmosphere plays a major protective role. It absorbs major part of cosmic rays from outer space and protects organisms from their deleterious effects. It also absorbs electromagnetic radiations from the sun, allowing transmission of radiation in the region of 300-2500 nm (near-ultraviolet, visible and near-infrared radiation) and 0.01-40 m (radio waves). The atmosphere screens out harmful ultraviolet rays by absorbing electromagnetic radiations that would otherwise be very harmful for living beings. Mention what will be dealt in this unit

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7.1 OBJECTIVES

After studying this unit, you will be able to

- Describe the composition, stratification and significance of atmosphere;
- Explain physical factors governing the atmosphere like pressure, temperature, wind, humidity, moisture and temperature;
- Describe Earth's radiation budget;
- Analyse thermodynamic diagrams, Tephigram and mixing heights;
- Explain Enthalpy and Entropy.

7.2 COMPOSITION OF ATMOSPHERE

Now let us learn about the composition of atmosphere. Dry air near the surface of ground level up to several kilometres mainly comprises of 78.08% Nitrogen and 20.95% of Oxygen and in small amounts i.e. 0.934% Argon and 0.035% carbon dioxide is present. Other constituents of air consist of noble gases like Xenon, Neon, Krypton and Helium are also present along with other trace gases (CH_4, CO, N_2O, HNO_3, NH_3 etc). The air present in the atmosphere may also contain 0.1 to 5% water by volume with normal range of 1 to 3%.

7.3 STRATIFICATION OF ATMOSPHERE

"Atmosphere is stratified on the basis of temperature/density relationships which are based on the interrelationship between physical and photochemical phenomena in the air". Atmosphere may be divided into following strata:

Troposphere: It is the lowest layer of the atmosphere which extends from sea level to an altitude of 10-16 km. It is characterised by homogeneous composition of major gases (due to constant mixing by circular air masses) apart from water. The content of water vapour is variable due to cloud formation, precipitation and evaporation from terrestrial water bodies. It is marked by decreasing temperature with increasing altitude from the heat radiating surface of the atmosphere.

Stratosphere: Stratosphere is the second lowest layer of earth's surface atmosphere. This layer ranges from 10-50 km. stratopause is the upper boundary of stratosphere while tropopause is the lower boundary. Stratosphere is abundant in ozone molecules which forms ozone layer that is helpful in protection of earth's surface from ultra violet radiations. Stratosphere contains less amount of water vapours hence it is dry.

Mesosphere: Mesosphere lies in between stratosphere and thermosphere. It ranges from 50-85 km. there is decreases in temperature in mesosphere. The upper boundary of mesosphere is known as mesopause. Meteors vaporize on entering in mesosphere. "Very strange, high altitude clouds called "noctilucent clouds" or "polar mesospheric clouds" sometime form in the mesosphere near the poles".

Thermosphere: It is the thickest layer in the atmosphere which extends from 80km and above. Thermosphere is divided into two regions, i.e. ionosphere and exosphere. In ionosphere radiations of sun tends to charge particles. This layer also exhibits light shows known as “Aurora borealis or Northern lights”. Exosphere extends above 550km where satellite freely orbits around the earth.

Check your progress 1

Note: a) Write your answer in about 50 words.

b) Check your progress with possible answers given at the end of the unit.

1. Give an account of atmospheric stratification?

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Pressure

You have learnt about atmosphere, now let us read about pressure. To study the fluid behaviour, it is more convenient to use the term pressure inspite of force. Pressure can be defined as the force applied per unit of an area. Pascal or Newton per square meter is the standard unit for describing pressure. For example, for an object which is sitting on the surface, it is the weight of the object which creates force while pressing on the surface therefore, different pressure is exerted on the surface (Figure 7.1).

$$Pressure = \frac{\text{Force}}{\text{Area}} = \frac{F}{A}$$

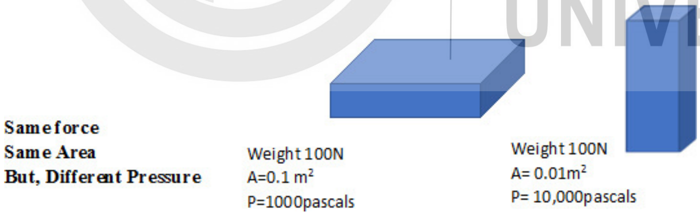

Figure 7.1: Different pressure exerted by same force and area

In our daily life we encounter various situations in which pressure plays important role. Suppose when we peel an apple, pressure is the main parameter working in but if the knife is sharp hence area of contact becomes minor and force exerted on the blade while peeling is less.

The medium is in continuous distribution of matter while dealing with a pressure of liquid at rest. But for pressure of gas, it is an average pressure generated from the molecular collision with walls.

Temperature

Measure of heat is known as temperature. In general terms heat means energy, so when more energy is there, the hotter things get. From daily experiences we observe that when you exercise hard, you become sweaty and hot. The reason behind is that we have used a lot of energy while exercising which increases heat of the body.

Depending on the country, the temperature can be measured in two different units. The US uses the Fahrenheit scale while rest of the world measures temperature on Celsius scale. Both the scales give different number for same temperature measurement. For instance, the "Celsius scale has 0 degrees for freezing of water and 100 degrees for boiling of water whereas Fahrenheit scale is based on the water freezing temperature at 32 degrees and boiling at 212 degrees". Kelvin is another standard scientific scale for temperature measurement. Absolute zero or 0 Kelvin could be the minimum possible temperature at which the particle can generate heat or could be able to move. On Fahrenheit scale, absolute zero is -459-degree Fahrenheit. Thermometer is the device used to measure temperature of objects, air or liquids.

Wind

Climate and weather changes frequently therefore to determine and control weather, wind plays important role. Wind is "the movement of air relative to the surface of the earth". Wind blows due to the difference in horizontal and vertical gradient of atmospheric pressure. Pressure can be the reason behind distribution of winds. On the surface of earth, wind blows around low pressure that is cyclones or high-pressure anticyclones region. Winds generally have clockwise rotation in and around southern hemisphere while flows counter clockwise in northern hemisphere.

Humidity

Humidity is the amount of atmospheric water vapor. Humidity can be measured as Relative humidity or Dew point temperature. Water vapor is the vapored form of water. Water vapours are transparent as gases. Naked eyes are not able to see humidity but can see it while condensing back to droplets of water. "Relative humidity is a measure of how close to saturation the air is with water vapor". At a given conditions of temperature and pressure, the maximum amount of water held by the air before the vapor begins to form droplets of fog or clouds. When relative humidity is 100%, then the air is totally saturated. When it is 0% it means that no water vapor is present in air. At 0-degree F which is very cold temperature, the dewpoint is also 0 degree then there is 100% relative humidity means the air cannot hold more water vapours without condensing back to liquid droplets. But in absolute terms, the amount of water vapor is less as absolute humidity is very low.

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Check Your Progress 2

Note: a) Write your answer in about 50 words.

b) Check your progress with possible answers given at the end of the unit.

2. What is relative humidity?

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7.4 MOISTURE VARIABLES

In order to specify the humidity or amount of moisture in air, there are various variables. These can be described as follows:

- Dewpoint temperature
- Saturation vapor pressure
- Relative humidity
- Specific humidity
- Mixing ratio
- Wet bulb temperature
- Vapor pressure
- Saturation mixing point

Virtual Temperature

At a given conditions of pressure, moist air density is same as dry air density. The density of warm air is least than cold air and water vapours are least dense than dry air, therefore the virtual temperature remains increased or equivalent to actual temperature. It is noted that saturation mixing ratio increases tremendously with temperature or approximately doubles with successive rise of 10^{0}C, for higher dewpoint it is important to consider initial temperature correction (Fig 7.2).

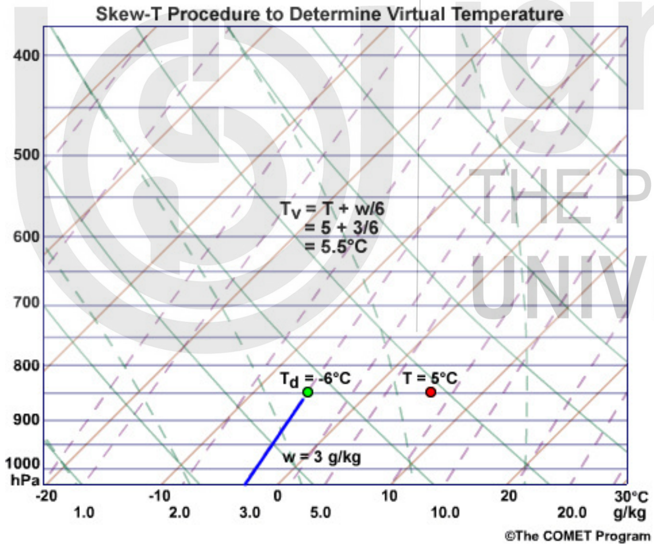

Figure 7.2: Skew-T Procedure to determine virtual temperature
(http://tornado.sfsu.edu/geosciences/classes/m201/buoyancy/SkewTMastery/mesoprim/skewt/tv2.htm)

1. Firstly, mixing ratio is determined
2. Virtual temperature is then calculated by following calculation:

   $T_v \sim T + w/6$

In this example:

$T = 5°C$ and $T_d = -6°C$.

Thus, w = 3.0 g/kg.

$T_v = T + w/6$

$= 5 + 3/6$

$= 5.5°C$

Radiation from Sunlight

Sunlight or radiations of Sun comprises of mixture of IR and UV radiations. UV rays comes in between infrared and ultraviolet radiations in electromagnetic spectrum. The "speed of electromagnetic waves in vacuum is 3.0×10^8 m/s". 1 AU is the average distance between sun and earth in one earth orbit. Therefore, these electromagnetic radiations from the sun takes 8 minutes to reach the earth. The energy radiated from the core of Sun is due to the fusion reaction occur which eliminates high energy gamma radiations. As the gamma ray photons reaches to the surface of sun, they get absorbed by solar plasma and makes gamma radiations to re-emit at lower frequencies.

Electromagnetic radiations of sun strike atmosphere of earth, some part of these radiations get adsorbed by the atmosphere while rest moves to the earth's surface. Accordingly, the UV radiations of sun are absorbed. The ozone layer absorbs the UV radiations and re-emit as heat to warm up the stratosphere. While rest of the radiations are radiated back to the outer space. Parallelly, the radiations which are not absorbed by the atmosphere strikes the surface of earth to heat it up. Moreover, greenhouse gases (GHGs) present in the atmosphere are also responsible for absorption and heating up of atmosphere.

Solar Constant

The solar constant, "a measure of flux, is the amount of incoming solar electromagnetic radiation per unit area that would be incident on a plane perpendicular to the rays, at a distance of one astronomical unit (AU)(roughly the mean distance from the Sun to the Earth)". Visible light and all solar radiations constitute to solar constant. The value of solar constant is approximately 1.366 kilowatts per square meter (kW/m^2) measured by the satellite.

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Note: a) Write your answer in about 50 words.

b) Check your progress with possible answers given at the end of the unit.

3. Define Solar constant?

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Surface and Planetary Albedo

Planetary albedo is the "division in atmospheric reflection and surface reflection components by shortwave fluxes at the top and surface of the atmosphere in association with simple radiation model". Atmospheric reflection contributes to about 88% of the global planetary albedo while small contribution is due to surface reflection.

The planetary albedo is a "function of the optical properties of objects within the atmosphere (e.g., clouds, water vapor, and aerosols) and objects that constitute the planet's surface (e.g., ice, ocean, and trees)" (Wielicki et al. 1995; Hall 2004). Atmospheric contribution towards planetary albedo can be categorised in 3 bulk processes:

1) incident solar radiations are radiated back to the space by aerosols and clouds.

2) the opacity of atmosphere to downwelling the shortwave radiation limits them to reach the surface.

3) the shortwave radiations upwelling due to atmospheric opacity limits the reflected shortwave radiations escaping to the space (Qu and Hall 2005).

Thus, "the atmosphere influences the planetary albedo by way of direct reflection back to space (process 1) and by attenuating the effect of surface albedo on planetary albedo (processes 2 and 3). Both the atmospheric and surface contributions to planetary albedo are functions of the climate state".

Emission and Absorption of Terrestrial Radiation

It is well known that **"**Every object with temperature greater than absolute zero emits radiation at the intensity proportional to the fourth power of its absolute temperature". So, it can be can be concluded that external or outer space is approximately near or on the absolute zero. The terrestrial temperature of the atmosphere ranges from very cold to 50^{0}C. Hence, the long wave radiations of the atmosphere tend to move towards earth and also back to space. The long wave radiations emitted from the earth's surface are found in the infra-red range of 4-100μ with maximum at 10μ. Moreover, maximum radiations absorbed by the atmosphere is reverted back to the surface of the earth as "counter radiations". These radiations are helpful in prevention of excessive cooling during nights. All atmospheric layers contribute in radiations absorption and emission but lower layers are efficient absorbers due to presence of water vapours, methane, carbon dioxide etc.

7.5 GREENHOUSE EFFECT

A natural process which makes the earth's surface warm is known as greenhouse effect. When radiations from sun strike the atmosphere of earth, greenhouse gases absorb and re radiates some of the radiations while rest are redirected back to space. The energy absorbed by the atmosphere and surface of earth maintains temperature of 33 degrees C warmer at earth which makes life possible on earth.

Step 1: solar energy strike earth's surface, some radiations get reflected back to the space.

Step 2: the remaining solar radiations are absorbed by oceans and land to heat up the earth.

Step 3: heat radiates towards space from earth.

Step 4: GHGs trap some of the radiations in the earth's atmosphere to sustain life.

Step 5: anthropogenic activities like land clearing, fossil fuel burning and agriculture results in increment of GHGs in atmosphere.

Step 6: due to extreme heat trapping by GHGs results in rise in earth temperature.

Greenhouse gases

There are various greenhouse gases present in the atmosphere. The main gases are "nitrous oxide, carbon dioxide, methane and water vapor". All these gases are made up of three or more atoms and these atoms are loosely bounded to one another hence on absorption of heat get vibrated. These vibrating molecules tend to release radiations which further get absorbed by another greenhouse gas molecule. This is the reason behind the heat near the surface of earth.

Some of the common greenhouse gases are enlisted below:

Carbon dioxide (CO_2): It is made up one carbon atom joined by two oxygen atoms. Carbon dioxide makes small contribution to the atmospheric constitution of gases but found to have large effect on the climate. The amount of CO_2 is 270 parts per million volume in atmosphere in the mid-90s but fast-growing industrial revolution leads to the increase in carbon dioxide amount in atmosphere. It is now reaching to 400 parts per million volume.

Methane (CH_4): It is a far more powerful gas than carbon dioxide. The structure of methane comprises of one carbon and four hydrogen atoms. This gas also contributes in warming inspite of its less quantity in atmosphere. Methane releases carbon dioxide which is also a GHG in the atmosphere when burned, so it is also used as fuel.

Even though small amount of greenhouse gases is present in the atmosphere but they contribute more in increasing greenhouse effect. These greenhouse gases are increasing due to various activities such as burning of fossil fuels releases gases and pollutants in the atmospheric air. There are other sources also for instance, farm animals release methane while digesting their food, cement formation from limestone also releases carbon dioxide gas in ambient air.

7.6 EARTH'S RADIATION BUDGET

You must be aware of financial budget that includes balancing of incoming and outgoing money. Similarly, if energy from sun is earth's income while the energy that escapes from earth to space is earth's spending. If incoming radiations of sun will be increased then the earth would heat up. Due to extra heat, the earth can emit longwave radiations. Alternatively, if incoming solar radiations decreased, the earth is likely to cool. Hence all the solar radiations are not re radiated back to the space. Some of these radiations get trapped by the greenhouse gases while some are stored in oceans and ground.

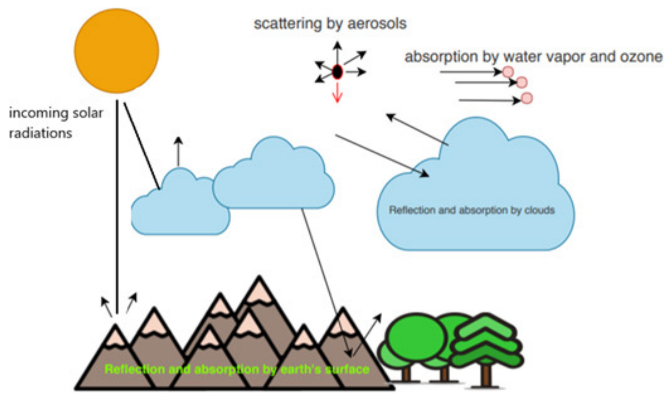

Figure 7.3: Earth's net radiation

The "balance maintained in the incoming and outgoing energy at the apex of atmosphere is known as **Earth's net radiation** or **net flux**" (Figure 7.3). It is the total energy of the system. Energy of the sun enters into the system or atmosphere. This energy goes out by means of two ways i.e. reflection of radiations or energy by earth's surface,

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aerosols and clouds. Another way is thermal radiation i.e. heat emitted by clouds in the atmosphere or by surface of earth. "The global average net radiation must be close to zero over the span of a year or else the average temperature will rise or fall".

7.7 ATMOSPHERIC STABILITY

Atmospheric stability governs that whether the air will increase or not. Moreover, it causes clear skies, storms or sinks or may do nothing. Stability depends on "Dry Saturated Adiabatic Lapse Rates and the Environmental Lapse Rates." Thereof to determine the atmospheric stability conditions we can compare ELR with DALR and SALR.

Stability forms

There are three essential types of stability. These are illustrated using a diagram (Figure 7.4).

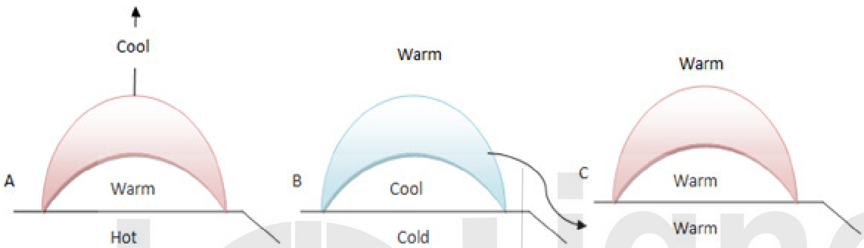

Figure 7.4: Atmospheric stability forms

In the given example, a parcel is in the interaction with a surface. Basically, "Air takes on the characteristics of the surface beneath it." Therefore, each parcel formed is having same features as the surface beneath it. The following rule is followed to determine the stability condition.

A) If the parcel of the air is warmer than the surroundings then it will rise and less dense. This air is unstable and can cause storms.

B) If the parcel of air is cooler than the surroundings then it will be denser and sink towards the surface. This type of air is stable and results in clear skies.

C) If the parcel of air is of same temperatures as surroundings then the parcel will not move and the air is neutral.

To determine the atmospheric stability, adiabatic lapse rates have been plotted on a diagram (Figure 7.5). Here are some of the stability diagrams and their illustrations:

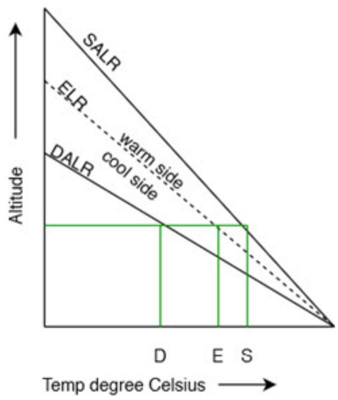

Figure 7.5: Stability diagram

SALR is the saturated adiabatic rate

ELR is the Environmental lapse rate

DALR is the Dry and saturated adiabatic lapse rates.

"DALR and SALR are fixed and will always plot" as shown in diagram. While ELR is variable and can be plot in various positions giving different stability conditions.

Diagram illustration: ELR shows warm and cold side's means temperature increases towards right along X-axis. The region towards right along X-axis and it is warm while towards it is cold. The "dry air 'D' is on the left of the ELR 'E' while the saturated air 'S' is on the right of E". At a given level, dry air cools rapidly than the environment. Hence dry air is stable. On the other hand, saturated air cools slowly as compared to the surroundings and warm the ambient environment. Therefore, this diagram shows the unstable situation.

"A parcel line plotting to the right of the ELR indicates unstable conditions for that parcel type. A parcel line plotting to the left of the ELR indicates stable conditions for that parcel type". **Specific stability conditions**: the diagrams shown below depict the stability forms

Absolute stability:

A condition is said to be absolute stability when both parcel plots are on the same ELR side i.e. on left or cool side (figure 7.6a). It means that they are stable. The air will not rise as it is of relative humidity and cools faster than surroundings. This type of air tends to create clear skies and sink.

Absolute instability

The absolute instability condition reveals that both parcel lines are on the ELR right side or the warmer side (figure 7.6b). Hence, air with relative humidity cools slower than surroundings and will always be warmer than ambient environment.

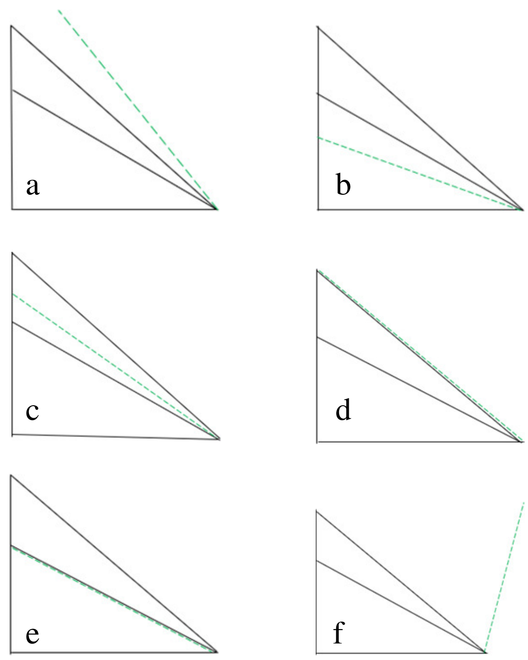

Figure 7.6: Diagrammatic illustration of (a) absolute stability (b) absolute instability (c) conditional stability (d) wet neutral (e) dry neutral (f) external stability

Conditional stability

During conditional stability, ELR falls in between the SALR and DALR (figure 7.6c). The DALR is on the left side i.e. cooler side while the SALR is on the right side i.e. the warmer side. Hence, it can be concluded that the saturated parcel of air is unstable and dry parcels are stable.

Wet neutral

In wet neutral conditions, the ELR matches the SALR (figure 7.6d). Hence, the saturated parcels of air will be neutral. The dry air parcels will be stable as they are on the cool or left side of the ELR.

Dry neutral

When ELR matches the DALR, the dry parcels of air are neutral (figure 7.6e). The saturated parcels are unstable as they on the warmer side.

Extreme stability

Negative ELR shows that warm air moves on the top of cold air. This is known as **Temperature inversion**. Both parcels are on the left side i.e. cooler side therefore none of the parcel will rise (figure 7.6f).

Check Your Progress 4

Note: a) Write your answer in about 50 words.

b) Check your progress with possible answers given at the end of the unit.

4. Explain various stability conditions?

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Turbulence

"Any irregular or disturbed flow in the atmosphere. In aviation, it refers to bumpiness in flight".

Types and Causes: Turbulence is based on its intensity classification light to extreme.

- LLT is abbreviated as Low-level turbulence
- TNT means Turbulence in and near thunderstorms
- CAT is Clear air turbulence
- While MWT is Mountain wave turbulence

Low-level turbulence- LLT occurs with the boundary of atmosphere where friction and surface heating play important role. It is further divided in sub categories:

- ***Mechanical turbulence* –** LLT resulting from hinderance of airflow from any obstruction or friction. It causes speed of wind to slows down in the lower layer of atmosphere which results in turning of air over turbulent eddies. Fluctuations in winds and vertical velocities is due to mechanical turbulence.

- ***Thermal turbulence*** – Dry convection results in thermal turbulence. It occurs in good weather conditions during daytime.
- ***Turbulence in fronts*** – "LLT produced when moving frontal boundaries are combine with convection and strong winds".
- ***Wake Turbulence*** – wake turbulence is the turbulence of solid body at the rear end which is in motion with respect to fluid.

Turbulence in and near thunderstorms (TNT) – "Turbulence which occurs within developing convective clouds and thunderstorms, in the vicinity of thunderstorm tops and wakes, downbursts, and gust fronts".

- ***Turbulence within thunderstorms*** – These types of turbulence occurs more frequently and they are intense. They can cause strong updrafts and downdraft TNT which is the characteristic of clouds, it can be worse as they can cause icing, lightning, heavy rain and possibly hailstorms.
- ***Turbulence below thunderstorms*** – microbursts, down storms and downbursts are all the primary turbulence areas. Turbulence below thunderstorms can produce wind shear, high turbulence, low visibility and heavy rainfall.
- ***Turbulence around thunderstorms*** – "Turbulence is produced around the thunderstorm when the cell acts as a barrier to the large-scale airflow".

Clear air turbulence (CAT) – Clear air turbulence occurs in convective activity free atmosphere.

Mountain wave turbulence (MWT) – "Turbulence produced in conjunction with lee waves, which are gravity waves that occur when stable air flows over a mountain barrier". Mountain wave turbulence intensity depends upon the wind speed in the adjacent mountains.

- ***Lee wave region*** – the upper layer of lee wave region lies within 5000 ft. in tropopause where low level turbulence occurs occasionally.
- ***Lower turbulent zone*** - The lowest region of lee wave system extends from ground to the top of mountains.

Check Your Progress 5

Note: a) Write your answer in about 50 words.

b) Check your progress with possible answers given at the end of the unit.

5. What is turbulence. List its various types?

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Diffusion

Diffusion is a "physical process that refers to the net movement of molecules from a region of high concentration to one of lower concentration". Diffusion material can be any gas. Solid or liquid and diffusion can occur from within these three states. The important "characteristic of diffusion is the movement along concentration gradient". Moreover, the diffusion rate depends on the material and medium interaction. For example, diffusion between gases occurs more frequently. Similarly, the smell of ammonia gas also diffuses quickly in the ambient air. Diffusion plays important role in chemical and biological processes. Biological phenomenon's in body facilitated by diffusion. However, various chemical processes are driven by diffusion which is the important principle behind many reactions.

a) Factors affecting diffusion

There are various factors which affects the rate of diffusion. Some of these factors are enlisted below:

Temperature- As the temperature increases, the kinetic energy of the system also increases. As the energy increases hence, the rate of solute and solvent movement also increases resulting in increased collisions. For instance, the ice evaporates at faster rate on warmer day as each molecule of ice moves with higher energy and quickly escapes the solid state of ice.

Area of interaction- The smaller surface area results in low diffusion rate. For example, iodine is sublimed on the stove, fumes of purple colour appear and mixed with atmospheric air however if sublimation occurs in narrow crucible, the fumes appear slowly and then readily disappears. It means they are confined to low surface area resulting in lesser diffusion.

Size of particle- The rate of diffusion of small molecules is higher than the larger molecules at a given temperature. It also depends on the surface area and mass of the particle.

Concentration gradient - concentration is defined as the number of solute molecules that can be found within a given volume. Generally, the greater the concentration gradient, the greater the rate of diffusion

b) Types of diffusion

Simple – "Simple diffusion is merely the movement of molecules along their concentration gradient without the direct involvement of any other molecules".

Facilitated - "it requires the presence of another molecule (the facilitator) in order for diffusion to occur".

Check Your Progress 6

Note: a) Write your answer in about 50 words.

b) Check your progress with possible answers given at the end of the unit.

6. What is diffusion. What are the factors which affect diffusion?

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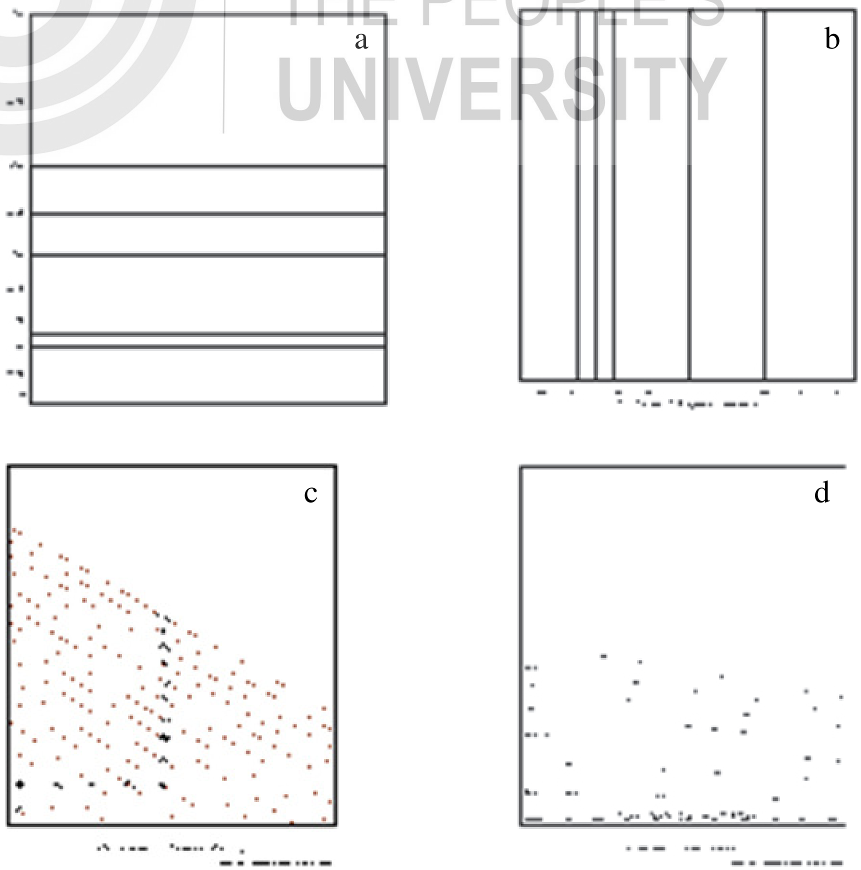
Adiabatic and Isentropic Process

Lapse rate is the atmospheric variation in temperature in lieu with height. For instance, there is a 6-degree C temperature drop down with every kilometre depending on the location. The concentration of atmospheric water vapours determines the value of lapse rate. Dry adiabatic lapse rate means that the air cools at 10-degree C at every kilometre distance. However, moist adiabatic lapse rate is the cooling of air at below 6-degree for every kilometre. **Adiabatic** means that no external energy is involved in air cooling or warming.

Isentropic processes are processes in which no change in entropy occurs i.e. ds=0 while adiabatic processes show no transfer in heat i.e. dQ=0. Adiabatic process may be reversible/irreversible. Suppose, the energy gained by the system via heating is given by ÎQ where system temperature is denoted by T and entropy is given by dS. Hence, in case of irreversible process, ÎQ=0 but ÎQ‘‘TdS. Alternatively, all variables are equivalent in case of reversible process. Therefore, it can be represented as ÎQ=0=TdS. So, this process can also be called as **isentropic**.

7.8 THERMODYNAMIC DIAGRAMS

The atmospheric features such as wind, temperature, pressure and moisture can be analysed by thermodynamic diagrams. A weather balloon fitted with an instrument having a radio transmitter. This radio transmitter transmits data on the surface of earth which is then received by a receiver for soundings or vertical measurements and it is known as rawinsonde. Rawinsonde have additional features of direction as well as wind speed determination.



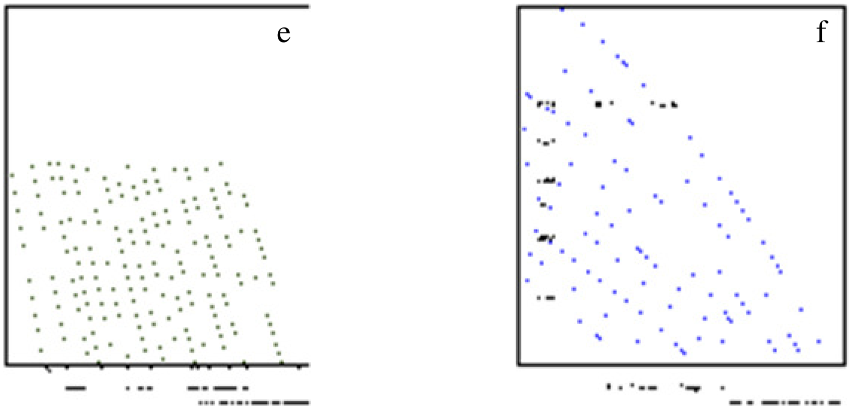


Figure 3.7: Diagram showing (a) vertical axis (b) horizontal axis (c) sloping solid lines (d) horizontal small angled dotted lines (e) saturation mixing ratio (f) pseudo or wet adiabatic

The **vertical axis** denotes the level of pressure (figure 3.7a). The initial level for vertical axis is 1050mb and on moving upwards along the axis, it decreases. The isobars run parallelly straight along horizontal axis. Exponential decrease in pressure with increasing height is reflected by the spacings.

The **Horizontal Axis** denotes increase in temperature in degree C towards right (figure 3.7b). "These isotherms run straight up and down".

At approximately 45°, **sloping solid lines** represents "constant potential temperature (è) or isentropes". These can also be called as dry adiabats (figure 3.7c). The labelling is done on every 10°K ranging from 273K at 1000mb. if air is lifted adiabatically, air will cool for every kilometre at 10°C.

Lines which denotes above sea level height in km having a standard pressure of 1013.25mb. these are horizontal small angle dotted lines (figure 3.7d).

Inclined Solid Lines at a Minor Angle from the Vertical: "These lines indicate lines of constant **saturation mixing ratio, w_s**, indicating the maximum amount of water vapor the air can hold, given in grams of vapor per kilogram of dry air" (figure 3.7e).

Sloping Dashed Lines: "These lines are *pseudo*, or *wet adiabats*, also known as lines of **equivalent potential temperature, θ_e.** Following these lines is identical to lifting a parcel wet adiabatically. At lower temperatures, less vapor is condensing releasing less latent heat; hence the line's slope approaches that of the dry adiabat" (figure 3.7f).

7.9 T-PHIGRAM AND MIXING HEIGHT

Tephigram

One among various features of thermodynamic diagrams is the Tephigram which is useful in plotting radiosonde soundings in order to analyse the atmospheric temperature and humidity (Figure 3.8). Tephigram can be used initially for local weather forecasting of clear skies, rain or thunderstorms. On the basis of area between rise in air parcel along moist or dry adiabatic and the Tephigram is used in local forecasting.

The principle characteristics of Tephigram to analyse radiosonde sounding are as follows:

The temperature in Tephigram is marked at the bottom ranging from -90^{0}C to 50^{0}C and can increase up to 10^{0}C while at the absolute temperature is demarcated. It means that vertical lines are equivalent temperature lines or can be considered as isothermals.

While along the vertical lines or on the right, the scale of potential temperature ranges from 260 K to 370 K and increases up to 10 K. Moreover, on the left entropy ranges from 960 to 1310 $Jkg^{-10\cdot}C^{-1}$.

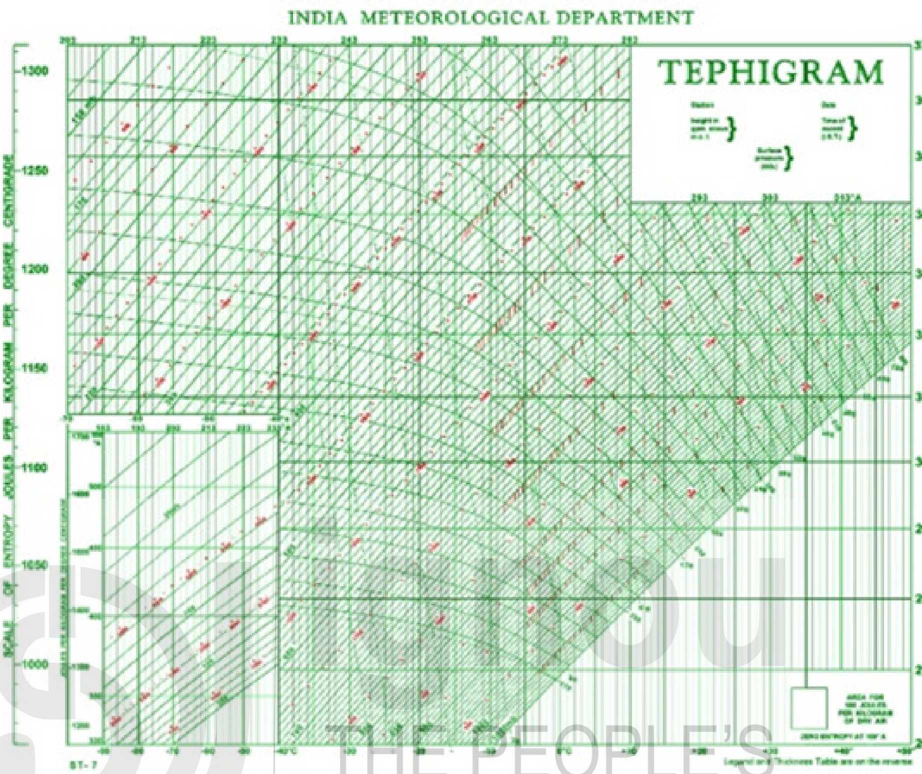


Figure 7.8: Tephigram

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Mixing height

The height of air vertical mixing and suspended particles is known as mixing height. The profile of atmospheric temperature determines the height. At a given rate, the parcel of air uplifts from earth is called dry adiabatic lapse rate. The parcel of air continues to rise till it is warmer than surroundings. It will stop by slowing down on getting colder than ambient temperature. It is the point where air parcel temperature exceeds the curve which denotes vertical profile of temperature and measures mixing height.

Check Your Progress 7

Note: a) Write your answer in about 50 words.

b) Check your progress with possible answers given at the end of the unit.

7. What is mixing height?

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....

....

Specific Gas Constant

Specific gas constant of a given material is required in calculations which involves gas dynamic network. It is calculated using following equation:

$$\boldsymbol{R} = \frac{R}{\mathrm{M}}$$

Where $R = 8.314\ \mathrm{Jmol^{-1}K^{-1}}$ represents universal gas constant

M = molecular weight of material

The specific gas constant is temperature independent

Characteristics of specific gas constant (R)

- Non-Universal
- The value of the gas constant is considered by a specific gas which is used.
- This can be defined as a ratio of universal gas constant by molecules weight of the substance.

$$R = \frac{\mathrm{Ru}}{\mathrm{M}}$$

- In terms of R, a ideal gas law is,

$$\mathrm{PV} = \mathrm{mRT}$$

Where, P = absolute pressure of gas

V = volume occupied by the gas

m = mass of the gas

T = absolute temperature of the gas

Enthalpy and Entropy

Enthalpy

The study of relationship between heat/energy and work is defined as thermodynamics. One of the main parameters in thermodynamics is enthalpy. Enthalpy is the content of heat in a system and enthalpy is change is the heat which enters and leaves the system during a reaction. The occurrence of any given reaction depends upon if there is an increase in the enthalpy of the system means when energy released it is being added or decrease.

The phrases "internal enthalpy" and "enthalpy of the system" are two phrases with similar meaning. Likewise, the phrases "external enthalpy" or "enthalpy of the surroundings" refers to the energy of those molecules which are not involved in the reaction.

To summarize:

- Enthalpy is referred to as the heat content of the system.

- In a reaction, change in enthalpy is approximately equal to the heat evolved and generated while a reaction is occurring.
- During a reaction, when a system release energy, its energy content decreases and it has less energy with it.

Let's see why the energy of molecules changes during a reaction:

During a reaction, chemical bonding changes. Some bonds present in reactants are broken down while in products few new bonds are being formed. To break the bonds amount of energy is needed to breaking the bonds when new bonds are forming, with release of energy. Whether reaction proceeds in forward or backward direction among this bond making and bond-breaking steps:

- Exothermic reactions are the reactions which involves more heat evolution during new bond formation than old bond breaking.
- An exothermic reaction targets over stronger bonds than the weaker bonds.
- Extra energy is required during exothermic reactions in order to break bonds than to make bonds.

Entropy

"Entropy is the measure of thermal energy per unit of temperature of a system which is not available for any useful work". Entropy is also considered as the randomness of the system. Changes in the spontaneous direction can be measured by entropy.

Characteristics of the entropy

- Entropy of universe in spontaneous processes increases.
- As mass increases, entropy also increases.
- When liquids and solids dissolve in water, entropy of the system increases.
- Gas dissolution in water leads to decrease in entropy.
- Brittle and hard substances have low entropy.
- Chemical complexity increases entropy.

Check Your Progress 8

Note: a) Write your answer in about 50 words.

b) Check your progress with possible answers given at the end of the unit.

8. Give the formula to calculate specific gas constant. Give various characteristics of specific gas constant

....

....

....

9. What is Entropy. Give its characteristics?

....

....

....

7.10 LET US SUM UP

Meteorological studies make us to understand the phenomenon occurring in the atmosphere. All these phenomena are very important in our day to day life. In this chapter, we have studied about different processes related to temperature, moisture, wind, pressure, radiations etc. Phenomenon such as greenhouse effect is the fundamental process responsible for the warming of earth surface and makes life possible on earth. Also, various thermodynamic processes have been discussed in the chapter for understanding the atmospheric chemistry between all these variables.

7.11 KEYWORDS

Thermodynamic	:	It is the study of relationship between heat and other energy forms.
Stability	:	Lowest energy state of a system or chemical equilibria with its environment.
Radiation	:	Radiation is the energy that travels in the wave or particle form.
Isotherms	:	Isotherms are the lines of constant or equal temperature.
Convection	:	When a matter (air or liquid) travels away from the source on heating and carries thermal energy along. This kind of heat transfer is convection.
Photochemical	:	Chemical action of radiant energy or especially light.

S.C. Solomon, R.G. Roble, in Encyclopaedia of Atmospheric Sciences (Second Edition), 2015

Terminal Questions

1. What is Meteorology?

2. Explain the composition of atmosphere?

3. What is Planetary albedo?

4. Describe the phenomenon of Green House Effect?

7.12 REFERENCES AND SUGGESTED FURTHER READINGS

S.C. Solomon, R.G. Roble, in Encyclopaedia of Atmospheric Sciences (Second Edition), 2015

Dr. James G. Speight, in Environmental Organic Chemistry for Engineers, 2017

Wielicki, B. A., R. D. Cess, M. D. King, D. A. Randall, and E. F. Harrison, 1995: Mission to planet Earth—Role of clouds and radiation in climate. Bull. Amer. Meteor. Soc., 76, 2125–2153.

Hall, A., 2004: The role of surface albedo feedback in climate. J. Climate, 17, 1550–1568.

Qu, X., and A. Hall, 2005: Surface contribution to planetary albedo variability in the cryosphere regions. J. Climate, 18, 5239–5252

https://scied.ucar.edu/shortcontent/stratosphere-overview

https://web.mit.edu/16.unified/www/FALL/thermodynamics/notes/node42.html

7.13 ANSWERS TO CHECK YOUR PROGRESS

Answers to Check Your Progress 1

Your answers should include the following points

1. With altitude, air pressure and density decrease in the atmosphere. The pattern of temperature profile is constant hence it provides a useful metric to distinguish atmospheric layers. So, we can divide Earth's atmosphere into five layers:

   Exosphere (700- 10,000 Km)

   Thermosphere (80- 100 Km)

   Mesosphere (50- 80 Km)

   Stratosphere (12- 50 Km)

   Troposphere (0- 12 Km)

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Answers to Check Your Progress 2

Your answers should include the following points

2. Relative humidity is "the amount of water vapour present in air expressed as a percentage of the amount needed for saturation at the same temperature".

Answers to Check Your Progress 3

Your answers should include the following points

3. The **solar constant** is a flux density measuring mean solar electromagnetic radiation (solar irradiance) per unit area. It is measured on a surface perpendicular to the rays, one astronomical unit (AU) from the Sun (roughly the distance from the Sun to the Earth).

Answers to Check Your Progress 4

Your answers should include the following points

4. Stability (or atmospheric stability) refers to air's tendency to either rise and create storms (instability), or to resist vertical movement (stability). The simplest way to understand how stability works is to imagine a parcel of air having a thin, flexible cover that allows it to expand but prevents the air inside from mixing with the

surrounding air. Imagine that we take the balloon and force it up into the atmosphere. Since air pressure decreases with altitude, the balloon will relax and expand, and its temperature will therefore decrease.

- If the parcel of the air is warmer than the surroundings then it will rise and less dense. This air is **unstable** and can cause storms.
- If the parcel of air is cooler than the surroundings then it will be denser and sink towards the surface. This type of air is **stable** and results in clear skies.
- If the parcel of air is of same temperatures as surroundings then the parcel will not move and the air is **neutral**.

Answers to Check Your Progress 5

Your answers should include the following points

5. Turbulence can be defined as small-scale, short-term, random and frequent changes to the velocity of air. In other words, when there are rapid changes to either the air's speed or its direction of movement or both, conditions are said to be turbulent. Based on its intensity, turbulence can be classified from light to extreme as:

- LLT is abbreviated as Low-level turbulence
- TNT means Turbulence in and near thunderstorms
- CAT is Clear air turbulence
- While MWT is Mountain wave turbulence

Answers to Check Your Progress 6

Your answers should include the following points

6. Diffusion is the net movement of molecules or atoms from a region of high concentration to a region of low concentration. Factors affecting diffusion are:

- *Temperature*- As the temperature increases, the kinetic energy of the system also increases. As the energy increases hence, the rate of solute and solvent movement also increases resulting in increased collisions. For instance, the ice evaporates at faster rate on warmer day as each molecule of ice moves with higher energy and quickly escapes the solid state of ice.
- *Area of interaction*- The smaller surface area results in low diffusion rate. For example, iodine is sublimed on the stove, fumes of purple colour appear and mixed with atmospheric air however if sublimation occurs in narrow crucible, the fumes appear slowly and then readily disappears. It means they are confined to low surface area resulting in lesser diffusion.
- *Size of particle*- The rate of diffusion of small molecules is higher than the larger molecules at a given temperature. It also depends on the surface area and mass of the particle.
- *Concentration gradient* - concentration is defined as the number of solute molecules that can be found within a given volume. Generally, the greater the concentration gradient, the greater the rate of diffusion. The height of air vertical mixing and suspended particles is known as mixing height.

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Answers to Check Your Progress 7

Your answers should include the following points

7. The height of air vertical mixing and suspended particles is known as mixing height. The profile of atmospheric temperature determines the height. At a given rate, the parcel of air uplifts from earth is called dry adiabatic lapse rate. The parcel of air continues to rise till it is warmer than surroundings. It will stop by slowing down on getting colder than ambient temperature. It is the point where air parcel temperature exceeds the curve which denotes vertical profile of temperature and measures mixing height.

Answers to Check Your Progress 8

Your answers should include the following points

8. Specific gas constant of a given material is required in calculations which involves gas dynamic network. It is calculated using following equation:

$$\boldsymbol{R} = \frac{R}{\mathrm{M}}$$

Where $R = 8.314\ \mathrm{Jmol^{-1}K^{-1}}$ represents universal gas constant

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i) Non-Universal

ii) The value of the gas constant is considered by a specific gas which is used.

iii) This can be defined as a ratio of universal gas constant by molecules weight of the substance.

$$R = \frac{\mathrm{Ru}}{\mathrm{M}}$$

iv) In terms of R, a ideal gas law is,

$$\mathrm{PV} = \mathrm{mRT}$$

Where, P = absolute pressure of gas

V = volume occupied by the gas

m = mass of the gas

T = absolute temperature of the gas

9. "Entropy is the measure of thermal energy per unit of temperature of a system which is not available for any useful work". Entropy is also considered as the randomness of the system. Changes in the spontaneous direction can be measured by entropy. Characteristics of the entropy are:

- Entropy of universe in spontaneous processes increases.
- As mass increases, entropy also increases.

- When liquids and solids dissolve in water, entropy of the system increases.
- Gas dissolution in water leads to decrease in entropy.
- Brittle and hard substances have low entropy.
- Chemical complexity increases entropy.

Answers to Terminal Questions

1. Meteorology is a branch of the atmospheric sciences which includes atmospheric chemistry and atmospheric physics, with a major focus on weather forecasting.

2. Atmosphere mainly comprises of 78.08% Nitrogen, 20.95% of Oxygen, 0.934% Argon and 0.035% carbon dioxide. Other constituents of air consist of noble gases like Xenon, Neon, Krypton and Helium are also present along with other trace gases (CH_4, CO, N_2O, HNO_3, NH_3 etc). The air present in the atmosphere may also contain 0.1 to 5% water by volume with normal range of 1 to 3%.

3. Planetary albedo is the "division in atmospheric reflection and surface reflection components by shortwave fluxes at the top and surface of the atmosphere in association with simple radiation model".

4. A natural process which makes the earth's surface warm is known as greenhouse effect. When radiations from sun strike the atmosphere of earth, greenhouse gases absorb and re radiates some of the radiations while rest are redirected back to space. The energy absorbed by the atmosphere and surface of earth maintains temperature of 33 degrees C warmer at earth which makes life possible on earth.

Step 1: solar energy strike earth's surface, some radiations get reflected back to the space.

Step 2: the remaining solar radiations are absorbed by oceans and land to heat up the earth.

Step 3: heat radiates towards space from earth.

Step 4: GHGs trap some of the radiations in the earth's atmosphere to sustain life.

Step 5: anthropogenic activities like land clearing, fossil fuel burning and agriculture results in increment of GHGs in atmosphere.

Step 6: due to extreme heat trapping by GHGs results in rise in earth temperature.