AIR POLLUTION:

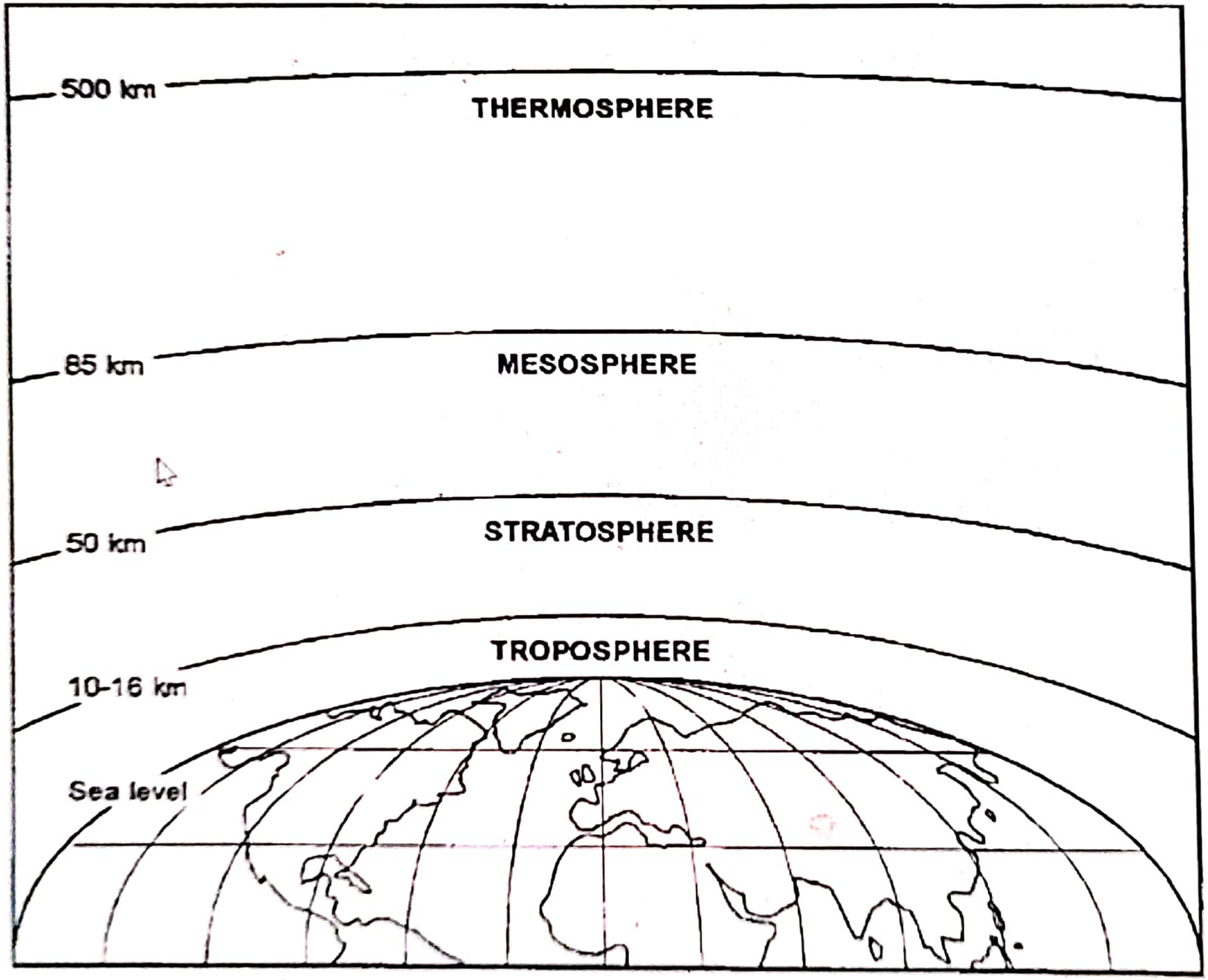
Introduction

- <u>BIOSPHERE</u>:

The layer around the earth where air (atmosphere), water (hydrosphere) and minerals-solids (lithosphere) interact with living beings is called the biosphere.

- Functions of the <u>**atmosphere**</u> include:
  - Protection from harmful radiation.
  - Moderating the surface temperature.
  - Providing a medium (air) that allows organisms to exchange gases in order to survive (breathing).

The Atmosphere



Definitions of Air pollution

- **As given by IS-4167**

  "Air pollution is the presence in ambient atmosphere of substances, generally resulting from the activities of man, in sufficient concentration, present for a sufficient time and under circumstances which interfere significantly with the comfort, health or welfare of persons or with the full use or enjoyment of property"

- **As given by American Medical Association**

  "Air pollution is the excessive concentration of foreign matter in the air which adversely affects the well being of the individual or causes damage to property"

- As given by Engineers Joint Council, USA

"Air pollution means the presence in the outdoor atmosphere of one or more contaminants, such as dust, fumes, gas, mist, odour, smoke or vapour, in quantities, with characteristics, and of durations such as to be injurious to human, plant or animal life or property, or which unreasonably interferes with the comfortable enjoyment of life and property"

Importance / significance of Air pollution

- Air pollution is a major threat of the 21st century.
- Air pollution is woven throughout the fabric of modern life.
- Man has polluted air so much that clean air has become more than a luxury for him today.
- Since air pollution has been mainly caused by rapid industrialization in some western countries, some critics comment on air pollution as the "PRIZE OF INDUSTRIALIZATION".
- Air pollution caused by automobiles has been described as the "DISEASE OF WEALTH".

Why is Air Pollution an issue ??

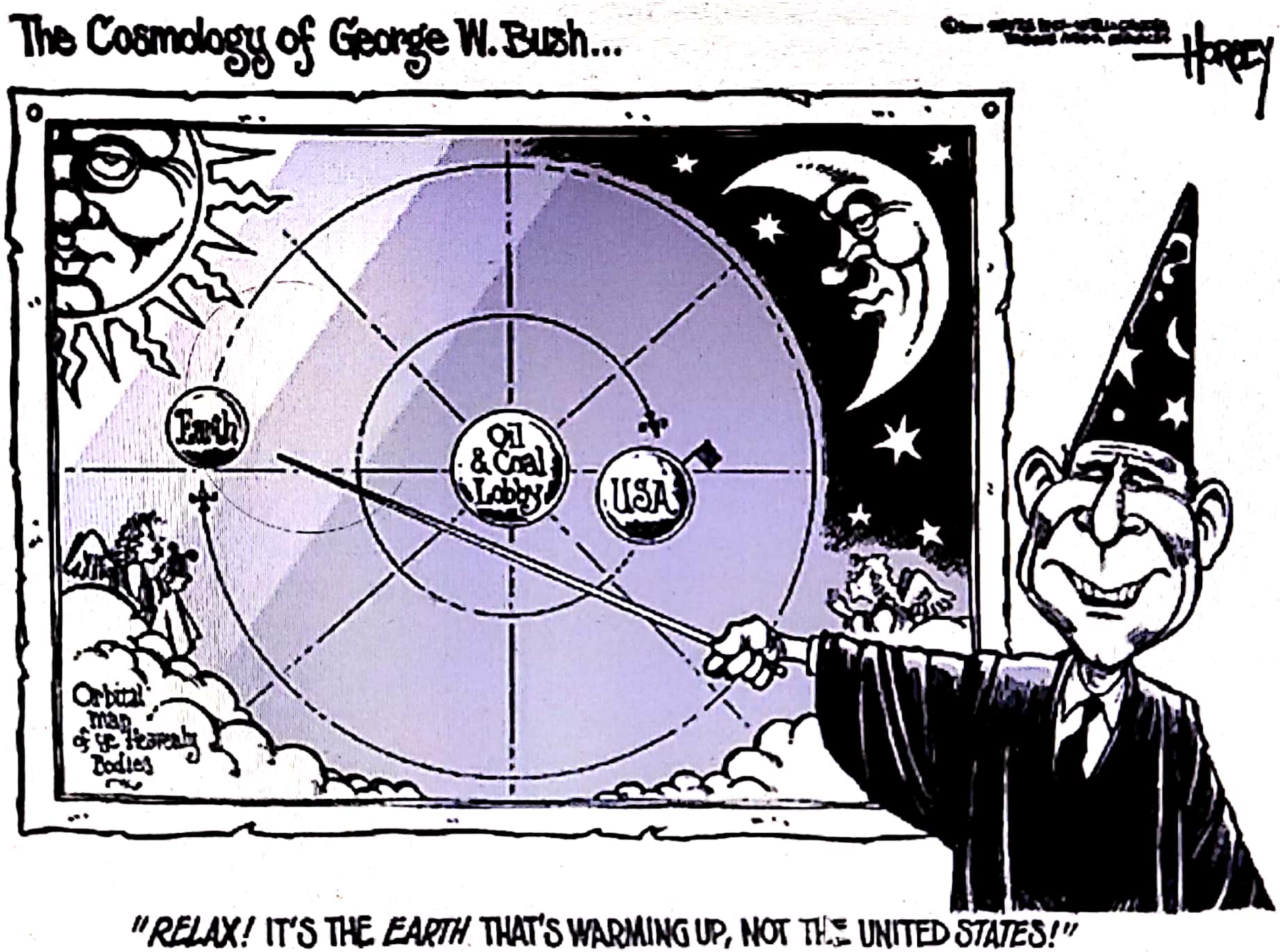
- Involuntary exposure.
- Affects large numbers of people.
- No threshold effect.
- The health costs are enormous.
- Affects the health of flora and fauna.
- Other health effects of air pollution: road trauma ↑, physical activity ↓

Contribution of air pollution (above WHO guidelines) to the global burden of disease

(adapted from Murray and Lopez 1997)

% disability life years attributable.

Risk factor	Developed	Developing
Malnutrition	0	18
Hygiene	0.1	7.6
Tobacco	12.1	1.4
Alcohol	9.6	2.7
Air pollution	1.5	0.4


The Cosmology of George W. Bush...
Horsey
Earth
Oil & Coal Lobby
USA
Orbital map of ye Heavenly Bodies
"RELAX! IT'S THE EARTH THAT'S WARMING UP, NOT THE UNITED STATES!"


Chris Madden

Sources of air pollution

Emission (air pollution) may be classified by source as stationary or mobile sources. The detailed classification is given as below:

- **Stationary sources**

  Again sub-classified as

  - Point sources
    - ✓ Industrial processing
    - ✓ Power plants
    - ✓ Industrial fuel combustion (coal, oil, gas)
    - ✓ Solid waste disposal incinerators
    - ✓ Open burning

Industrial processing

- Chemical Processing

- Mineral Processing

- Petroleum Refining

- Solvent Evaporation

- ## Area sources
  - ✓ Residential heating (coal, gas, oil)
  - ✓ Institutional and commercial heating
  - ✓ On site incineration
  - ✓ Open burning
  - ✓ Evaporative losses

- <u>Mobile sources</u>

  Again sub-classified as

  - <u>Line sources</u>
    - ✓ Highway vehicles
    - ✓ Rail-road locomotives
    - ✓ Channel vessels
  - <u>Area sources</u>
    - ✓ Motor vehicles (light, medium, heavy)
    - ✓ Rail yard locomotives
    - ✓ Port vessels
    - ✓ Aircrafts (airports)

Classification of air pollutants:

Air pollutants can be classified as follows:

- **Primary pollutants:**

Primary air pollutants are those emitted directly from identifiable sources. e.g.

Coarser particles
(greater than 10 μ in dia - SPM)
Finer particles
(less than 10 μ in diameter-PM_{10} and $PM_{2.5}$)
Sulphur compounds
Oxides of nitrogen
Carbon monoxide
Halogen compounds
Organic compounds
Radioactive compounds

Secondary pollutants (2° air pollutants):

Secondary pollutants are those which are formed in the air due to interaction of primary pollutants among themselves or by reaction with normal atmospheric constituents like sunlight, water vapour etc. e.g.

Ozone

Formaldehyde

PAN (peroxy acetyl nitrate)

Photochemical smog (SMOKE + FOG)

Formation of acid mists

Air pollutants can also be classified as follows:

- **Natural air pollutants:**

Air borne natural pollutants are significant because of the allergic responses produced in sensitive individuals. Many people suffer from asthma, hay fever, bronchitis, dermatitis e.g.

Natural fog
Pollen grains
Bacteria
Products of volcanic eruptions
Forest fires

Aerosols (particulates):

***An aerosol can be defined as a colloidal system in which the dispersion medium is a gas and the dispersed phase is solid or liquid*.**

The term "aerosol" is used during the time it is suspended in the air. After it has settled, either by virtue of its self weight, by agglomeration or by impact on a solid or liquid surface, the term no longer implies.

However, it is a nuisance both as an aerosol (visibility reduction) and as settled or deposited matter (soiling of surfaces, corrosion etc.)

e.g.

☺ The particulates consist of fine solids or liquid droplets suspended in air. These different types of particulates have definitive meanings, as follows:

- † Grit – solid particles suspended in air with a diameter over 500 µm;
- † Dust – solid particles suspended in air with a diameter between 0.25 and 500µm;
- † Smoke – gas borne solids with particles usually less than 2µm in diameter.
- † Fumes – suspended solids in air less than 1µm in diameter, normally released from chemical or metallurgical processes;
- † Mist – liquid droplets suspended in air with a diameter of less than 2 µm;
- † Aerosol – solid or liquid particles in suspension in air or some other gas, with a diameter of less than 1 µm.

Gases:

Sulphur compounds	SO_2, SO_3, H_2S, mercaptans
Nitrogen compounds	NO, NO_2, NH_3
Oxygen compounds	O_3, CO, CO_2
Halogen compounds	HF, HCl
Organic compounds	Aldehydes, hydrocarbons
Radioactive compounds	Radioactive gases

How are we affected?

Three main routes by which pollutants enter the body:

- absorption through the skin
- ingestion
- inhalation

Impact of air pollutants on human body system:

- Vision (Eye)
  - Reduction in sharpness of vision
  - Irritation
  - Excessive rubbing, leading to physical damage of the eye.
- Respiratory system
  - Upper respiratory tract (> 10 μ), leads to acute bronchitis
  - Lower respiratory tract (< 10 μ), leads to chronic bronchitis, chronic asthma.
- Skin (dermal)
  - Dermatitis, allergic rashes.

SMALLER AIRWAYS

Diagram of the Effect of Edema on the Cross-Sectional Airway Diameter

(R = radius)

Adult Airway

Area = $\pi R^2 = \pi\, 10^2 = 100\,\pi\ mm^2$ (Normal)

If have 1 mm Edema Area = $\pi\, 9^2 = 81\,\pi\ mm^2$

or 81% of normal

Full Term Newborn

Area = $\pi R^2 = \pi\, 3^2 = 9\,\pi\ mm^2$ (Normal)

If have 1 mm Edema Area = $\pi\, 2^2 = 4\,\pi\ mm^2$

or 44% of normal

DEPOSITION OF POLLUTANTS IN RESPIRATORY TRACT

Water Solubility	Initial Level of Impact	Compounds
High	Eyes Nose Pharynx Larynx	Aldehydes Ammonia Chlorine Sulfur dioxide
Medium	Trachea Bronchi	Ozone
Low	Bronchioles Alveoli	Nitrogen dioxide Phosgene

SIZE MATTERS

- Coarse particles
  - (10 micrometres)

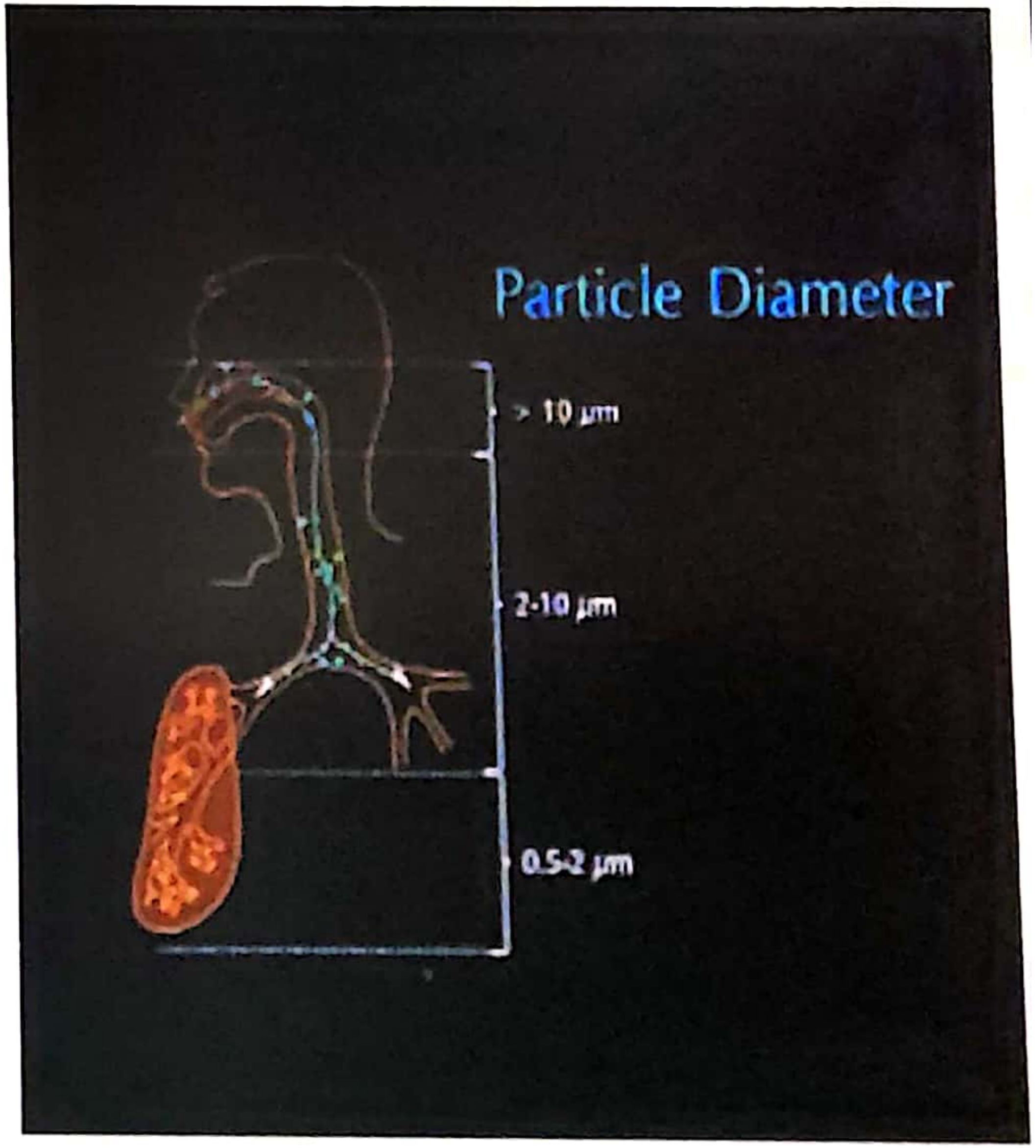
Gets removed by natural human mechanism like coughing and sneezing.

  - (2.5–10 micrometres)

Deposited in the upper respiratory tract and large airways.

- Fine particles
  - (< 2.5 micrometres)

May reach terminal bronchioles and alveoli.



Methods of identifying air pollution

- There are three methods of identifying air pollution. They are:

1) Sensory recognition
   - ✓ Strong or unusual odours
   - ✓ Reduced visibility
   - ✓ Eye irritation
   - ✓ Typical / acid taste in the mouth
   - ✓ Feel of grit / dust under foot

2) Physical measurement

It is often not possible to detect trace quantities of many air-borne toxic substances or the presence of radioactive matter through the senses.

Their identification requires physical measurement by standard methods of sampling and analysis.

- Measurements of air quality generally fall into three classes:
  - **Measurements of Emissions** - also called **source sampling (monitoring)** - when a particular emission source is measured, generally by on the spot tests.
  - **Ambient Air Quality** - also called **area sampling (monitoring)**. Measures the quality of all the air in a particular place. Almost all the evidence of health effects is based on these measurements.

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  - **Meteorological Measurement** - Measures meteorological factors that show how pollutants are transferred from source to recipient

3) <u>Effects on plants, animals and buildings</u>

The plants, animals and buildings act to some extent as indicators of certain atmospheric pollutants / impurities.

AIR POLLUTION DILUTION & DISPERSION

What is Advection ???

- Most obvious effect of atmosphere on emission
- Advection: implies transport of pollutant downwind of source

What is Dilution ???

- It is also termed as “mixing”.
- It is accomplished through “turbulence”
- Mainly atmospheric turbulence is active
- Mechanical + Thermal turbulence

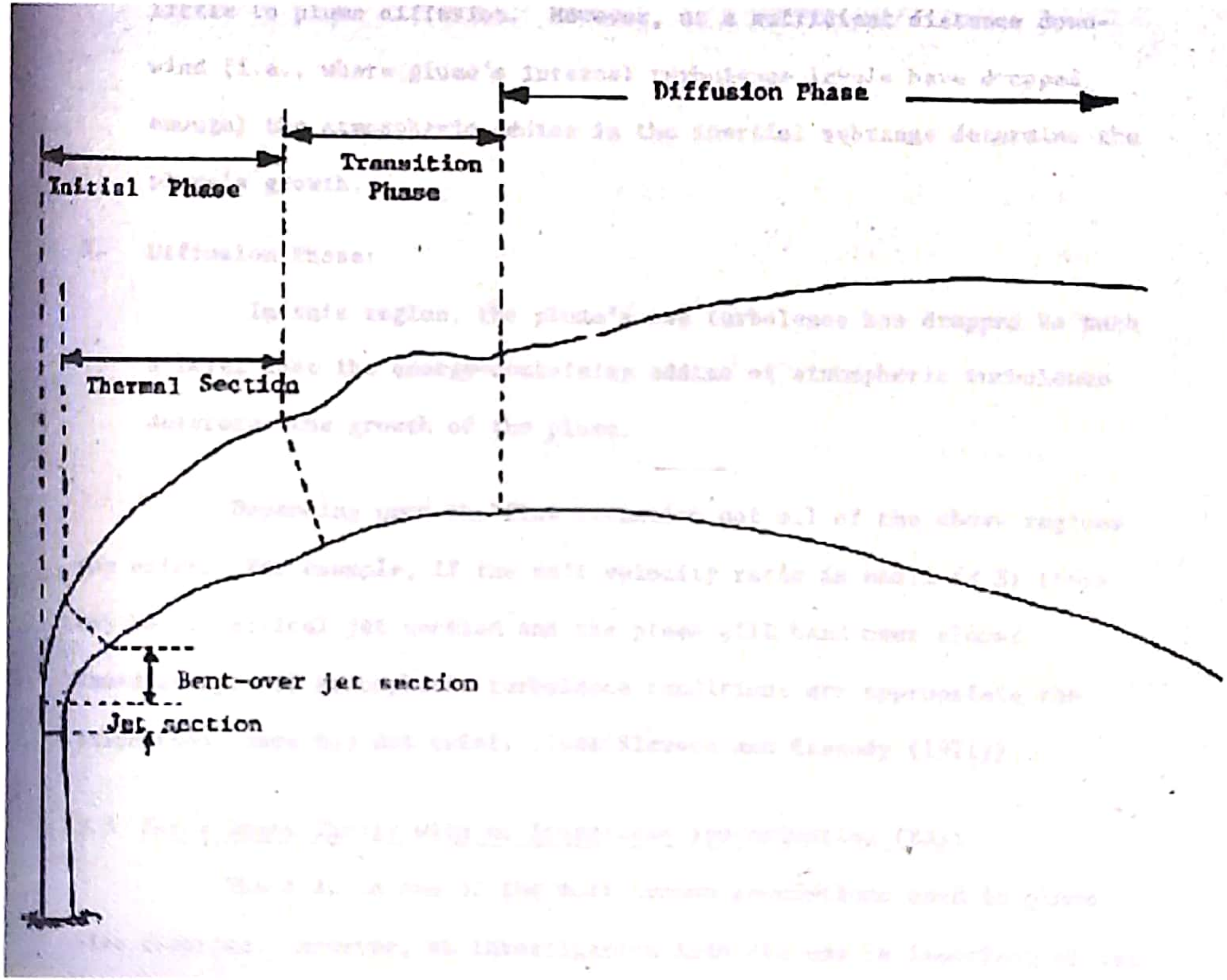
What is Dispersion ???

- Dispersion =
  Advection (Transport) + Dilution (Diffusion)

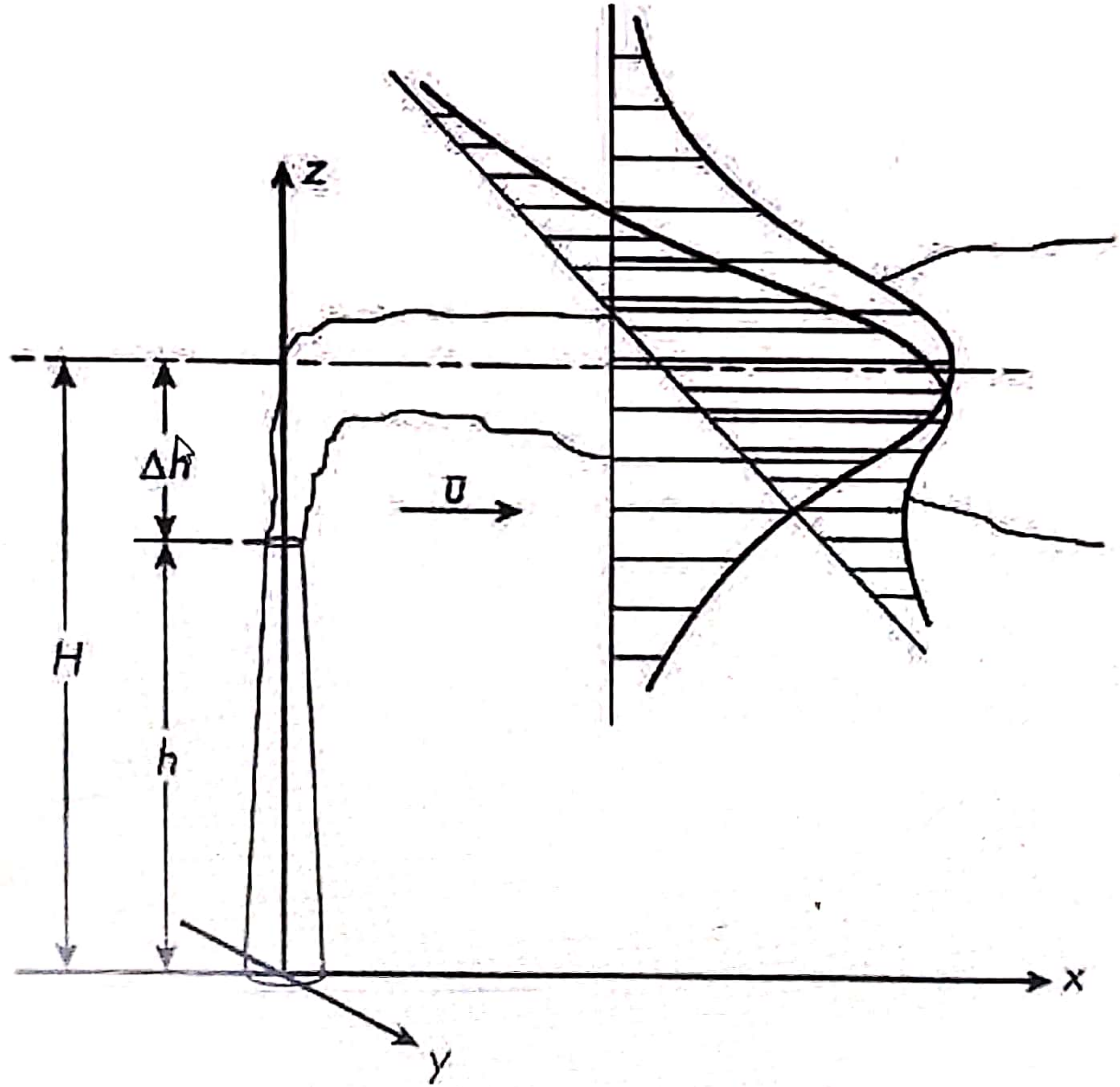
Factors that determine dispersion

- Physical nature of effluents
- Chemical nature of effluents
- Meteorology
- Location of the stack
- Nature of terrain downwind from the stack

Basic Segments of an Elevated Plume



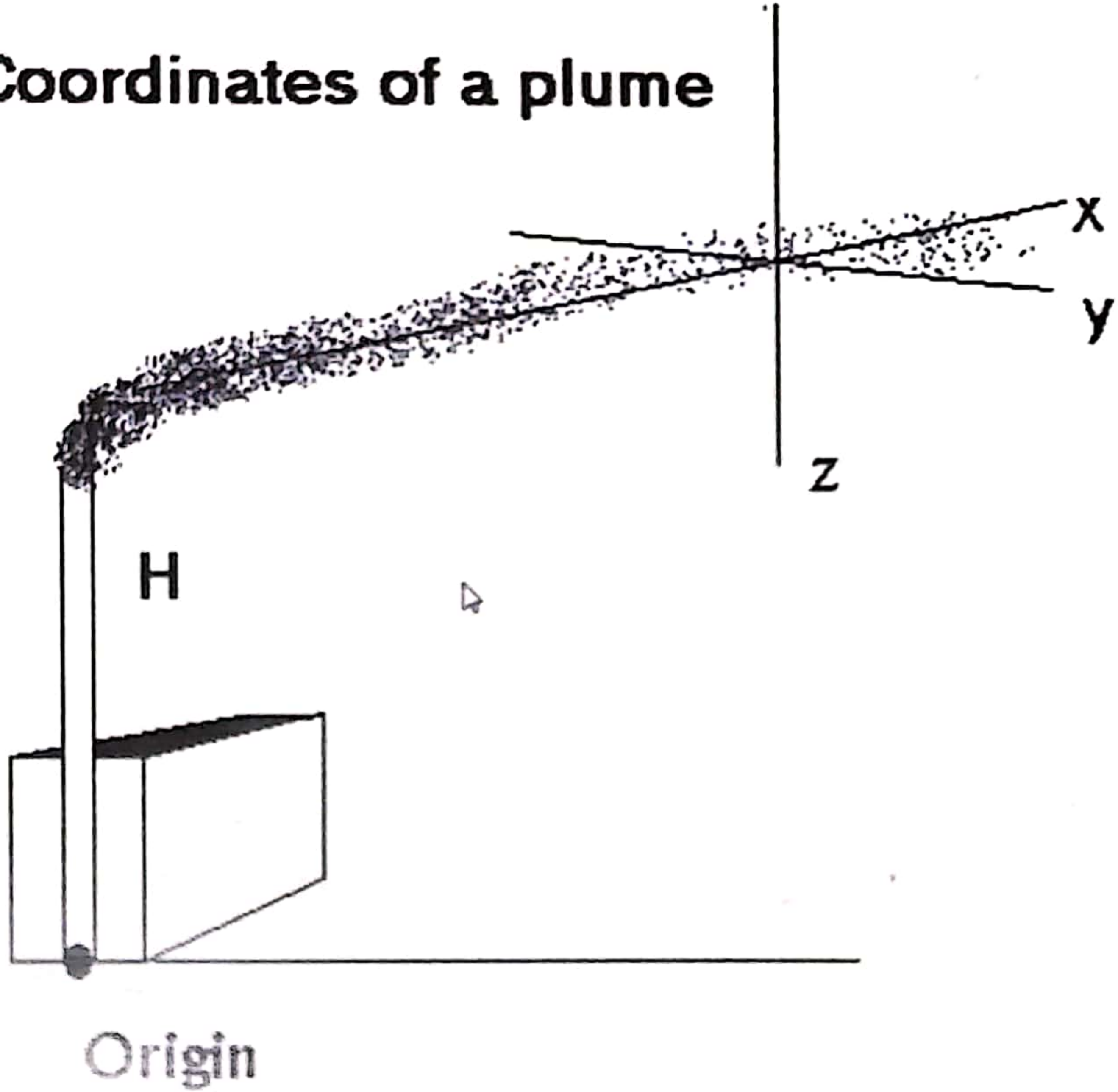
Flow regimes of a plume


z
Δh
ū
H
h
x
y

Basic Segments of An Elevated Plume

- **Initial phase**
  - Vertical Jet : Effluents are not deflected immediately upon entering the cross flow if ($Vs / U > 4$)
  - Bent-Over Jet Section : Entrainment of the cross flow is rapid because by this time appreciable growth of vortices has taken place.
  - Thermal Section : Self generated turbulence causes mixing and determines the growth of plume.
- **Transition phase (Thermal phase + Break up phase)**
  - Plume's internal turbulence levels have dropped enough so that the atmospheric eddies in the inertial sub range determines the plume's growth.
- **Diffusion phase**
  - The plume's own turbulence has dropped and energy containing eddies of atmospheric turbulence determine the growth of plume.

Coordinates of a plume



Plume rise depends upon;

Stack characteristics (Geometrical Height & Internal Diameter)

Meteorological conditions

Physical and chemical nature of effluent

Exit velocity

Stack gas temperature

Ambient temperature

Wind speed

Atmospheric stability

Wind shear

Calculation of EFFECTIVE Stack Height

- $H = h + \Delta h$

  where h = physical stack height

  Δh = plume rise

- Plume rise (Δh) depends on internal parameters :

Buoyancy Effect: Rise due to the temperature difference between stack plume and ambient air.

Momentum Effect: Rise due to exit velocity of the effluents (emissions).

Thus, $\Delta h = \Delta h_{buoyancy} + \Delta h_{momentum}$

Here, Δh is known as plume rise.

Carson and Moses formula

- For super-adiabatic conditions

$$\Delta h = 3.47\frac{V_s d}{u} + 5.15\frac{Q_h^{0.5}}{u};$$

Where

- V_s = stack gas exit speed (in m/s),
- u = wind speed (in m/s),
- d = stack diameter (in m),
- Q_h = heat emission rate from the stack (in kJ/s)
- The heat emission rate is measured in kilojoules per second.

Carson and Moses formula

- For neutral stability

$$\Delta h = 0.35\frac{V_s d}{u} + 2.64\frac{Q_h^{0.5}}{u}$$

- For sub-adiabatic conditions

$$\Delta h = -1.04\frac{V_s d}{u} + 2.24\frac{Q_h^{0.5}}{u}$$

Where

- V, = stack gas exit speed (in m/s),
- u = wind speed (in m/s),
- d = stack diameter (in m),
- Q_h = heat emission rate from the stack (in kJ/s)
- The heat emission rate is measured in kilojoules per second.

Meteorological factors influencing air pollution:

The degree to which air pollution emitted from various sources concentrate in a particular area depends largely on meteorological conditions.

The applications of dispersion theory and a knowledge of local weather condition are necessary to determine the required stack height for an emission, and to evaluate the intensity of air pollution.

The important parameters that influence air pollution are: (1) Internal (2) External

The important **external** parameters that influence air pollution are meteorological parameters. They are:

- Primary parameters
- Secondary parameters

Temperature and atmospheric stability

In well mixed air, which is dry, for every 1000 m increase in altitude, the temperature decreases by about 9.8°C (≈10°C). This vertical temperature gradient is known as the '**Dry Adiabatic lapse rate**' (DALR) and the value given is the normal lapse rate.

When the reverse or negative lapse rate occurs, a dense cold stratum of air at ground level gets covered by lighter warmer air at higher level.

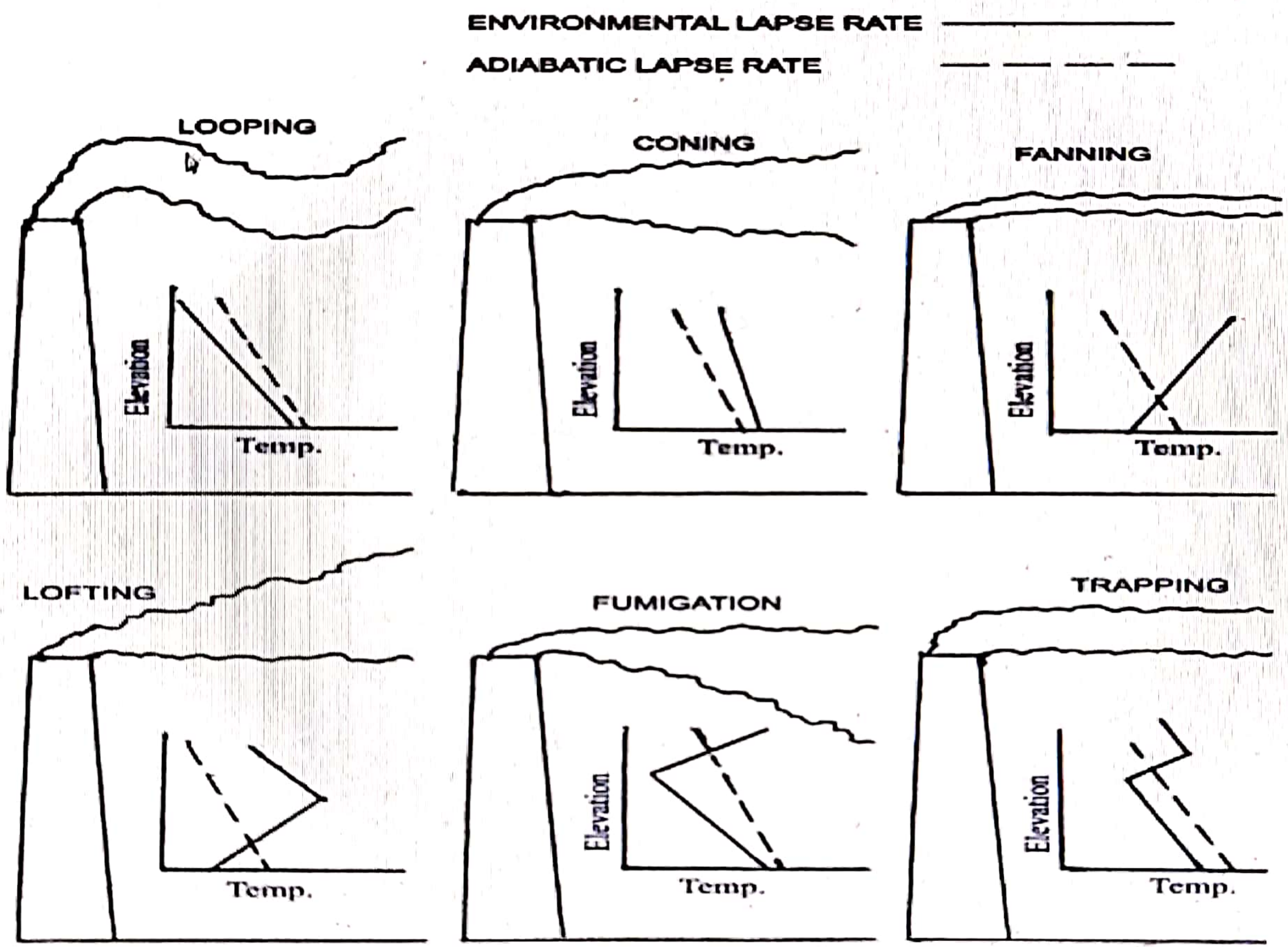
This phenomenon is known as **inversion**.

During temperature inversion, vertical air movement is stopped, the atmosphere becomes stable, very little turbulence or mixing takes place and hence pollutants in the air do not disperse.

In short –

- **STABLE Atmosphere - Little vertical mixing.**
- **UNSTABLE Atmosphere - Greater vertical mixing.**

Types of Plume



Note: Following Henry and Heincke (1996)

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- ❑ Secondary parameters

- **Primary parameters**

➢ Wind direction and speed

The direction and speed of surface winds govern the drift and diffusion of air pollutants discharged near the ground level.

- **High Winds = Greater dispersion.**
- **Low Winds = Less dispersion.**

➢ Mixing height

It can be defined as that height above the earth's surface to which related pollutants will extend.

It is usually related to one or more of the three factors: wind direction, wind speed and wind turbulence.

parameters

- ### Precipitation

Rainfall or precipitation exerts a two-fold cleansing action on the air pollutants discharged into the atmosphere.

Firstly, It accelerates the deposition of particulate matter on the ground and hence its removal from the atmosphere.

Secondly, it also helps to remove the concentration of gaseous pollutants which are soluble in water.

Nature is the best Wet Scrubber

- ### Humidity

The moisture content of the atmosphere influences the corrosive action of the air pollutants and indicates the potentiality for fog formation in relation to the degree of air pollution.

➢ Solar radiation

Depending on the location, solar radiation can have a pronounced effect on the type and rate of chemical reactions in the atmosphere.

The photochemical smog formation at Los Angeles is a typical example of the effect of solar radiation on air pollution.

- When NO_x, VOCs and sunlight come together, they can initiate a complex set of reactions that produce a number of secondary pollutants known as photochemical oxidants.
- Ozone (O_3) is the most abundant of the photochemical oxidants.
- Whereas stratospheric ozone protects our health by shielding us from UV radiation of sun, ground level ozone is harmful to our health.
- Combination of words SMOKE + FOG.
- Forms when heat and sunlight react gases.
- In the very simplest of terms, we can express the formation of photochemical smog as:

  VOCs + NO_x + Sunlight -----> Photochemical smog
- Occurs often with heavy traffic, high temperatures, and calm winds.

IDEAL CONDITIONS FOR SMOG FORMATION

- Near total dependence on automobiles for transportation.
- High NOx and hydrocarbon emissions.
- Long lasting atmospheric inversions restricting the vertical dispersion of pollutants.
- Area surrounded by mountains, reducing the horizontal dispersion.
- Abundance of sunshine.

- Limits visibility
- Decreases UV radiation
- Yellow / black color over cities
- Damage to tree foliage
- Reduce growth rates of certain sensitive tree species.
- Reduces crop yields for many important crops such as corn, wheat, soya beans and peanuts.
- Ozone part of SMOG cause;
    - chest / airway constriction
    - coughing.
    - irritation of the mucous membrane.
    - Permanent scarring of lung tissue, loss of lung function and reduced lung elasticity.
- Hydrocarbons part of SMOG cause;
    - eye irritation.

PROBLEM-3 (Carson Moses Formula)

Calculation of plume rise and effective stack height:

A chemical plant has a stack with a diameter of 2 m and emits gases with a stack exit velocity of 15 m/s and a heat emission rate of 4,800 kJ/S. The wind speed is 5 m/s. Stability is **neutral**. Estimate the plume rise. If the stack has a geometric height of 90 m, what is the effective stack height?

If the conditions improve from neutral to **super-adiabatic**, what will be the change in plume rise? Give your critical comments.

ANS:

$\Delta h = 38.68$ m $H = 128.68$ m

Holland Plume Rise Formula

- Simple
- More suitable for power plant
- For neutral conditions

$$\Delta h = \frac{d_s v_s}{u}\left[1.5 + 2.68\times 10^{-3} P\left(\frac{T_s - T_a}{T_s}\right) d_s\right]$$

Where

- v_s, = stack gas exit velocity (in m/s),
- u = wind speed (in m/s),
- d_s = stack diameter (in m),
- P = atmospheric pressure (kg/cm^2) at STP
- T_s = stack gas temperature (in °K)
- T_a = ambient air temperature (in °K)

PROBLEM-4 (Holland's Plume Rise)

Stack Height	-	50.00 m
Emission Rate	-	1.55 g/sec
Atmospheric pressure	-	10.8 m of water
Ambient Air Temperature	-	32 ° C
Stack Gas Exit Temperature	-	385 ° C
Stack Diameter	-	1.8 m
Stack Gas Exit Velocity	-	9.00 m/sec
Wind Speed at stack height	-	2.30 m/sec

Calculate the plume rise and effective stack height for neutral atmospheric conditions.

PROBLEM 2 **Calculation of wind speed at stack height:**

Sr. No.	Stability Class	Type of lapse rate	P-value
1)	A	Strong lapse rate	0.15
2)	B	Moderate lapse rate	0.15
3)	C	Small lapse rate	0.20
4)	D	Zero lapse rate	0.25
5)	E	Moderate inversion	0.30
6)	F	Strong inversion	0.30

$$u_H = u_a \times \{ H / z_a \}^{p}$$

Where,

u_H = wind speed at stack height ????

u_a = wind speed at **anemometer** height

H = Stack height

z_a = anemometer height (generally 10 m)

QUESTION:

- Suppose an anemometer at a height of 10 m above ground, measures the wind speed as 40 kmph, estimate the wind speed (m/s) at the top of a stack, 90 m tall, if the atmosphere is class E.

ANS: 21.477 m/sec

PROBLEM-1

Conversion from ppm to μg/m³ and vice versa

1 mol of an ideal gas at Standard Temperature & Pressure (STP i.e. 25°C and 1atm) occupies a volume of $24.465 \times 10^3\ m^3$

$$\text{Concentration in } g/m^3 = \frac{1}{24.465 \times 10^3\ (m^3/mol)} \times \text{Molecular weight } (g/mol) \times \text{concentration } (ppm)$$

QUESTION:

- Convert 0.415 ppm concentration of Ozone in air as μg/m³ at standard temperature and pressure. (Take atomic weight of oxygen as 16)

- **ANS**: 814.22 μg/m³