LECTURE 7

CE 433

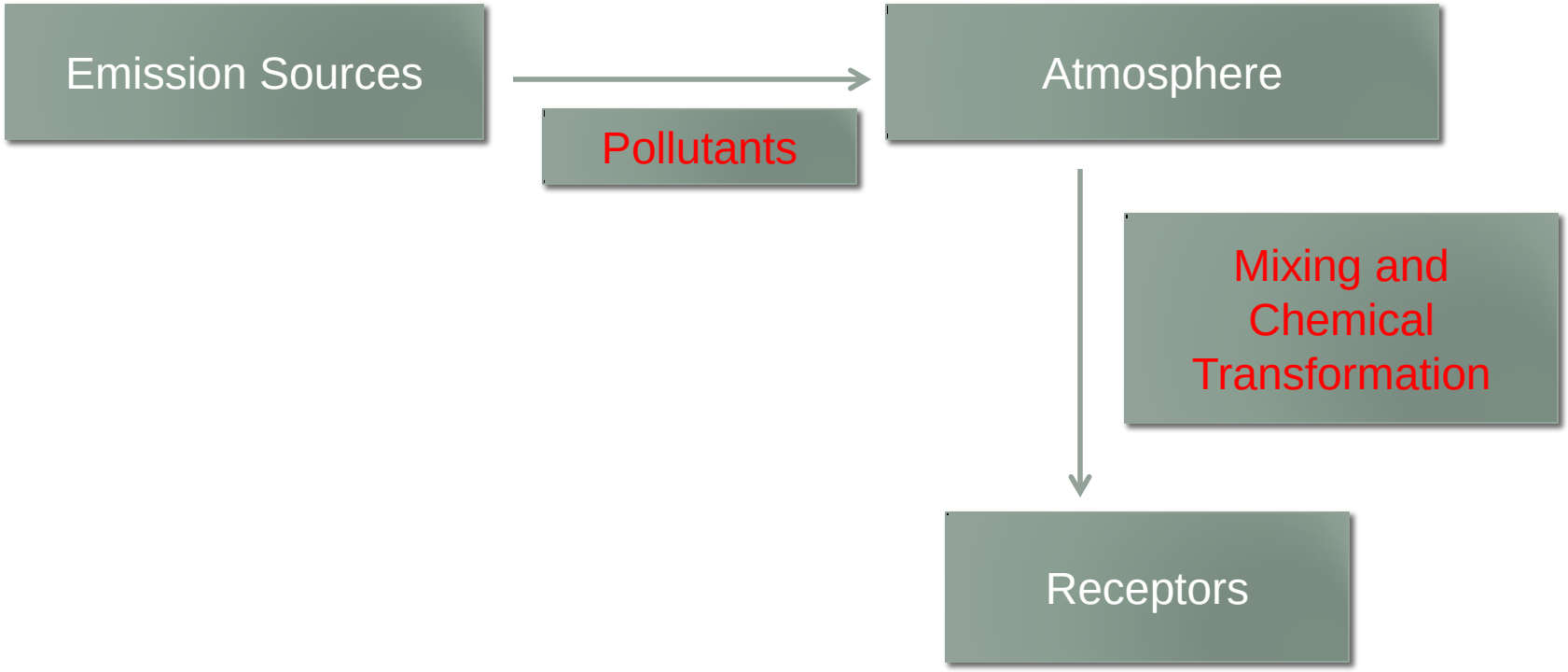
Excerpts from Lecture notes of Professor M. Ashraf Ali, BUET.

AIR POLLUTION

- Air Pollution may be defined as any atmospheric condition in which substances are present at concentrations, above their normal ambient levels, to produce measurable adverse effect on man, animal, vegetation or materials.

- Key Points:
  - Type of pollutant
  - Concentration in air
  - Time of exposure

Components of air pollution problem



Composition of atmospheric gases in clean, dry air at ground level (TABLE)

composition of dry clean air

http://www.dep.state.pa.us/earthdaycentral97/air_teachers/TAB1.htm

component	content		component	content	
	% by Vol.	ppm		% by Vol.	ppm
Nitrogen	78.09	780,900	Hydrogen	.00005	0.5
Oxygen	20.94	209,400	Methane	.00015	1.5
Argon	.93	9,300	Nitrogen dioxide	.0000001	0.001
Carbon dioxide	.0318	318	Ozone	.000002	0.02
Neon	.0018	18	Sulfur dioxide	.00000002	0.0002
Helium	.00052	5.2	Carbon monoxide	.00001	0.1
Krypton	.0001	1	Ammonia	.000001	0.01
Xeon	.000008	0.08			
Nitrous oxide	.000025				

Source: http://www.slideshare.net/armindaortiz/e1-environmental-chemistry-air-pollution

Composition of atmospheric gases in clean, dry air at ground level (TABLE)

- The trace gases comprising less than 1% of the atmosphere play a crucial role in the earth's radio active balance and in the chemical properties of the atmosphere. The trace gas concentrations have changed rapidly and remarkably over the last two centuries

Global Causes of Deaths

- Acute lower respiratory Infections: 7%
- Diseases of the respiratory system: 6%
- Tuberculosis: 6%
- Diarrhoea: 5%
- HIV/AIDs: 5%
- Malaria: 3%
- Other infectious/parasitic diseases: 6%
- Cancers: 12%
- Other unknown causes: 21%
- Disease of the circulatory system: 29%
- Percentage of Air Pollution Related Mortality: 4-8% (WHO estimate)

Indoor Air Pollution

- Apart from outdoor air pollution, indoor air pollution (IAP), resulting primarily from combustion of biomass (e.g. firewood, animal dung, crop residue) and fossil fuels (e.g. kerosene) in traditional cooking stoves in rural areas and urban slums, is a major concern in Bangladesh as well as many developing countries

Sources of Indoor Air Pollution

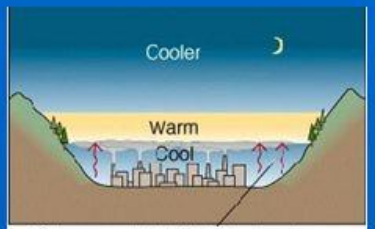
- Cooking (especially using biomass fuel in traditional cooking stoves in developing countries)
- Tobacco smoking
- Heating appliances
- Vapors from building materials, paints, furniture, etc.
- Radon (natural radioactive gas released from earth)

Pollution exposure at home and workplace is often greater than outdoors

"….modest improvements in indoor air quality can improve public health as much as major reductions in traditional outdoor sources….."

Historical Perspective

Air Pollution Episodes

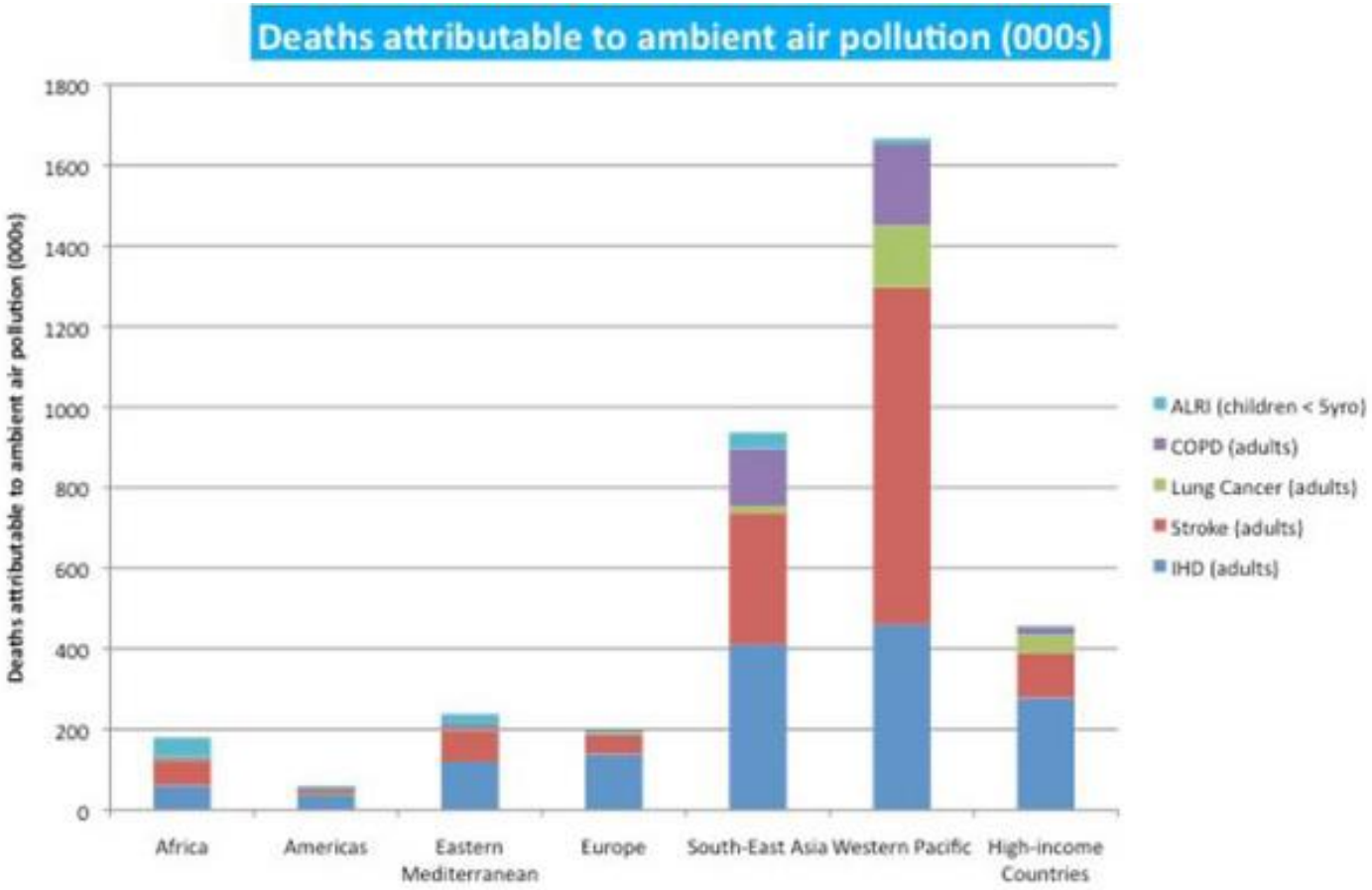


Rising warm air is inhibited by inversions

- 1930, Muese River Valley, Belgium - 63 deaths
- 1948, Donora, Pennsylvania - 23 deaths, 7,000 people affected
- 1950, Poza Rica, Mexico - 22 deaths, 320 hospitalized
- 1952, London - 4,000 deaths
- 1953, New York City - 200 deaths
- 1962, London – 700 deaths
- 1984, Bhopal, India - 4,000 immediate deaths, 15,000 deaths later

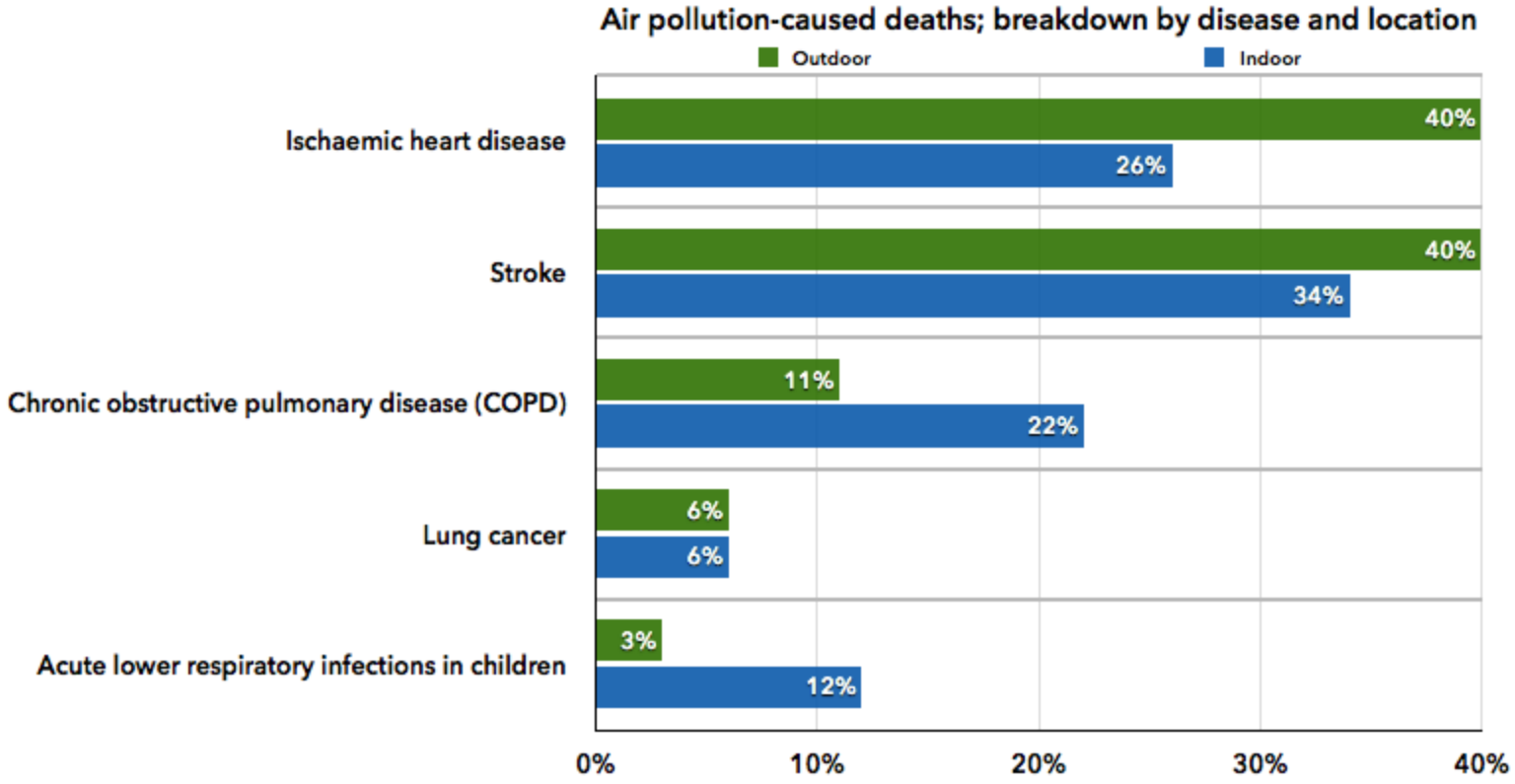
Source: http://slideplayer.com/slide/5713975/

Deaths Attributable to Air Pollution (2012)



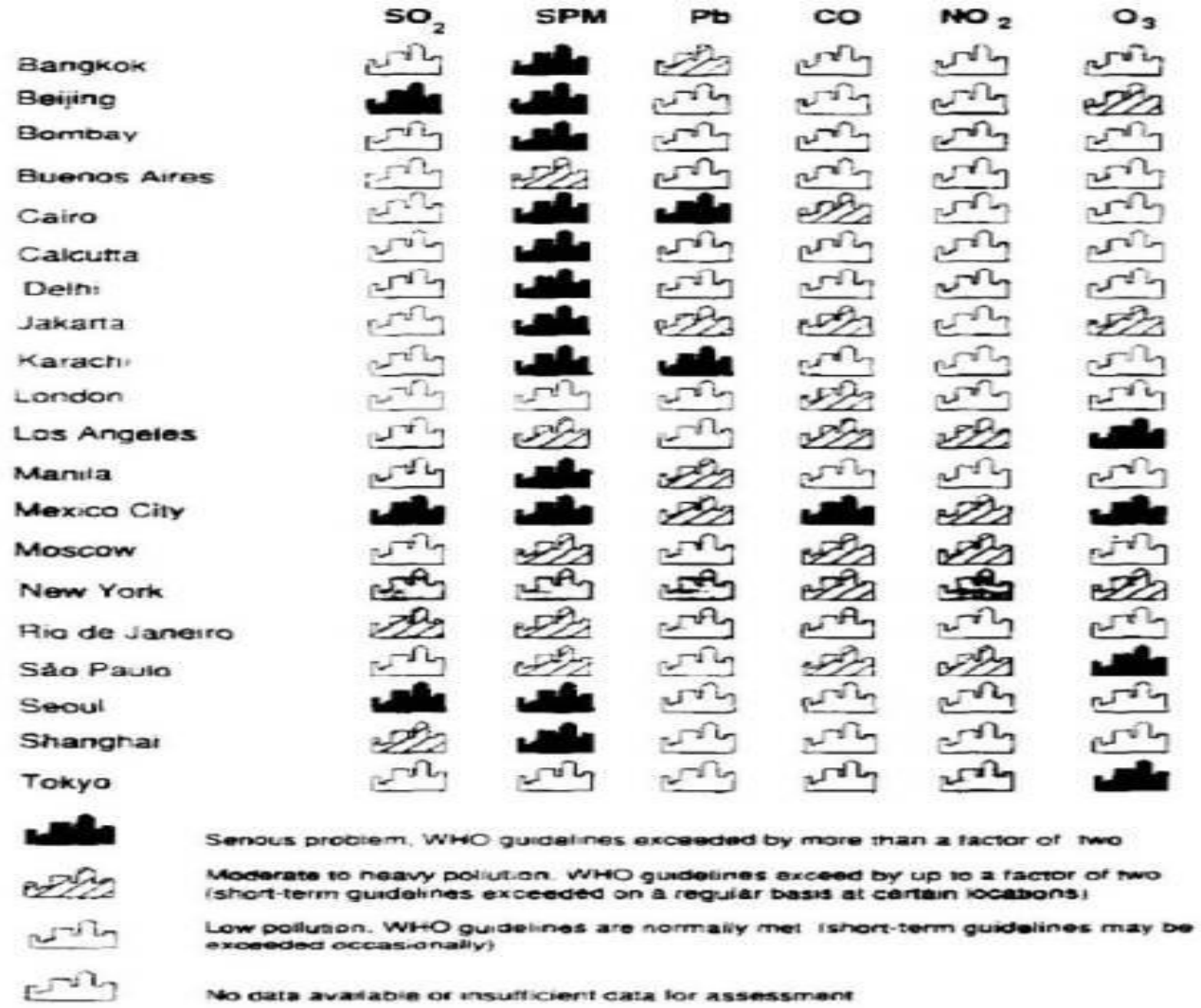
Source: http://public.wmo.int/en/resources/bulletin/air-quality-and-human-health-priority-joint-action

Premature Deaths Estimated due to Air Pollution (WHO, 2012)



Source: http://www.greencarcongress.com/2014/03/20140325-who.html

Overview of Air Quality in Asian Megacities (WHO, 1996)



Source: https://pollutionfree.wordpress.com/2010/12/06/air-pollution-in-the-world%E2%80%99s-megacities/

Sources of Air Pollution

- Major sources are use of fossil fuel for heating and cooling for transportation, for industry and for energy conversion (responsible for majority of air pollution on a global scale)
- Incineration of various forms of industrial, municipal and private wastes
- Certain chemicals (e.g. perchloroethylene from dry cleaners, methylene chloride used as solvent and paint stripper) and materials (e.g. asbestos used as fire-proofing materials) used in different processes and purposes also contribute to air pollution.

Classification of Major Sources (Outdoor Pollution)

1) Mobile sources/transportation : include motor vehicle, rail, ship, aircraft
2) Stationary sources: include utility, industrial, institutional and commercial facilities. Examples are power plant, heating plant, paper-pulp industry, petroleum refineries, municipal waste combusters
3) Area sources: include many individually small activities, e.g. gasoline service stations, small paint shops, open burning associated with solid waste, agriculture and forest management, cooking in slum areas.
4) Incineration/burning of waste:
    1) Household and commercial waste
    2) Agricultural burning
    3) Industrial and hazardous waste incineration

Classification of Major Sources (Outdoor Pollution)

Miscellaneous:

1) Re suspension from road
2) Domestic fuel, wood burning
3) Forest fire, volcanic eruptions, pollen grains, certain bacteria, viruses (natural)
4) Chemicals and materials used in different processes (perchloroehtylene, methyl chloride)

Classification of Pollutants

- According to Origin:
  - 1) Primary Pollutants: Emitted directly into the atmosphere and are found in form in which they were emitted, e.g. So_x, NO_x, HC
  - 2) Secondary Pollutants: Derived from the primary pollutants by chemical or photo-chemical reactions in the atmosphere, e.g. ozone, peroxyacetyl nitrate
- According to Chemical Composition:
  - 1) Organic: e.g. Hydrocarbons (HC), Aldehydes and ketones (HCO), VOCs, PCBs, PAHs
  - 2) Inorganic: NO_x, SO_x, CO, HCl, H_2SO_4, H_2S, NH_3
- According to State of Matter
  - 1) Gaseous: CO, NO_x, So_x (Inorganic), Benzene, Methane (Organic)
  - 2) Particulates/Aerosols: Dust, smoke, fume, fly ash (solid), mist, spray (liquid), pollen, bacteria, virus (natural)

Criteria Air Pollutants and Toxins

- Six major air pollutants identified as causing health effects at concentrations above thresholds established at levels known to be safe. These are: CO, Pb, NO_2, O_3, SO_2, Particulate matter (PM).
- Air Toxins: Pollutants that are known or suspected to cause cancer or other serious health effects. Air toxins can come from natural sources (e.g. radon gas coming from the ground) or man-made sources, such as motor vehicles and industrial processes. Examples include benzene (from gasoline), perchloroehtylene (from dry cleaners), and methylene chloride (used as a solvent and paint stripper).

Units of Measurements

- Particulate matter (PM): mass/unit vol. of air

Example: mg/m^3 ; $\mu g/m^3$

- Gaseous pollutants:
  - Mass/unit vol.

  Example: mg/m^3 ; $\mu g/m^3$

  - ppm = ppmv = volume of pollutant per million volume of air mixture

$$1\text{ppm} = 1\ \text{ppmv} = \frac{1\ vol\ of\ gaseous\ pollutant}{10\ 6\ \ volume\ of\ air}$$

Relationship between two units for gaseous pollutants

Ideal gas law: PV = nRT

R = 0.082056 L atm mol^{-1} K^{-1}

So, Volume of 1 mole of an ideal gas at STP (P = 1 atm, T = 273.25 K)

$$V = \frac{nRT}{P} = 22.414 \text{ L}$$

Now, 1 ppm = $\frac{1\ cubic\ meter\ of\ pollutant}{10\ 6\ cubic\ meter\ of\ air}$

1 mg/m^3 = $\frac{1\ mg\ pollutant}{1\ cubic\ meter\ of\ air}$ = $\frac{10\ 6\ mg\ pollutant}{10\ 6\ cubic\ meter\ of\ air}$

Now at STP,

10^6 mg pollutant = 10^6 mg X 10^{-3} $\frac{g}{mg}$. $\frac{mol}{MW\ g}$ X $\frac{22.414\ L}{mol}$ X 10^{-3} $\frac{m3}{L}$ = ($\frac{22.414}{MW}$) m^3

So, at STP 1 mg/m^3 = ($\frac{22.414}{MW}$) m^3

Relationship between two units for gaseous pollutants Continued…

At any other temperature (T) and pressure (P)

10^6 mg pollutant = $\frac{22.414}{MW}$ x $\frac{T}{273.15\ P}$ [as $\frac{P1\ V1}{T1} = \frac{P2\ V2}{T2}$]

So, 1 mg/m^3 = ($\frac{22.414}{MW}$ x $\frac{T}{273.15\ P}$) ppm

In other words,

Conc. in mg/m^3 = Conc. In ppm x $\frac{MW}{22.414}$ x $\frac{273\ P}{T}$

Since 1 mol. Of all ideal gas occupies the same volume under same temp and pressure,

1 ppmv = $\frac{1\ mol\ pollutant}{10\ 6\ mol\ air}$

Similarly, since each mole contains the same number of molecules (6.02 x 10^{23} molecule/mol),

1 ppmv = $\frac{1\ molecule\ of\ \ pollutant}{10\ 6\ molecules\ of\ \ air}$

Problem

- Bangladesh national ambient air quality standard for CO is 10 mg/m^3 (8-hr avg). Express the standard in ppm

Regulations/Standards

- Two types of standards:
  1) Emission standard
  2) Air Quality standard

Emission Standard: Source cannot emit more than a specified mass of pollutant (over a period of time).

This is based on technology, economics, relation to airborne concentration.

The objective is to control pollutant sources so that ambient pollutant concentrations are reduced to levels considered safe from public health point of view.

Regulations/Standards

- Bangladesh Environmental Conservation Rules (ECR) 1997 has set emission standards for motor vehicle, industries etc. The motor vehicle standard has been revised in July 2005.
- Example: Petrol/gas driven motor vehicle (6-8 seater):

Standards at the time of registration

CO : 2.2 gm/km

HC + NOx : 0.5 gm//km

- Example: Gas fired power plant: gaseous discharge NO_x-

i) >= 500 MW : 50 ppm

ii) 200-500 MW: 40 ppm

iii) <200 MW : 30 ppm

Regulations/Standards

(2) Air Quality Standards:

- Airborne concentration of a pollutant cannon exceed a specified value over a certain “averaging period”.
- Air quality standards are based only on effects

Why averaging period ?

- Because higher the concentration, shorter the exposure time required for undesirable effects
- A pollutant at a certain concentration may be harmful over longer exposure time, but relatively harmless over shorter exposure time

Example: Bangladesh standard for CO:

10 mg/m^3 (averaging period: 8 hr)

40 mg/m^3 (averaging period: 1 hr)

- Measurement and reporting of a particular air pollutant should be consistent with the “averaging period” of that particular air pollutant

Bangladesh Air Quality Standard

- Environmental Conservation Rules (ECR) 1997
- Air Quality Standard contained in ECR 1997 revised in July 2005 (in micrograms/m^3)

Table 8. Bangladesh National Ambient Air Quality Standards

Pollutant	Objective	Averaging time
Carbon Monoxide (CO)	10 mg/m^3 (9 ppm)	8-hour
	40 mg/m^3 (35 ppm)	1-hour
Nitrogen Dioxide (NO_2)	100 $\mu g/m^3$ (0.053 ppm)	Annual
Ozone (O_3)	157 $\mu g/m^3$ (0.08 ppm)	8-hour
	235 $\mu g/m^3$ (0.12 ppm)	1-hour
Sulfur Dioxide (SO_2)	365 $\mu g/m^3$ (0.14 ppm)	24-hour
	80 $\mu g/m^3$ (0.03 ppm)	Annual
PM_{10}	150 $\mu g/m^3$	24-hour
	50 $\mu g/m^3$	Annual
$PM_{2.5}$	65 $\mu g/m^3$	24-hour
	15 $\mu g/m^3$	Annual
Lead (Pb)	0.5 $\mu g/m^3$	Annual

Air Quality Index (AQI)

- The AQI is a tool that simplifies reporting air quality to the general public. It has been adopted by the USEPA and is used by many cities to report to the public an overall assessment of a given day's air quality.
- The AQI converts concentration of 5 criteria pollutants (PM, O_3, CO, SO_2, NO_2) into a single index (number) between 0 and 500 and assigns a descriptive term (e.g. good, moderate) to that value.

Air Quality Index (AQI) Categories (USEPA)

Level	AQI	Meaning	Activities
Good	0 to 50	Air quality is considered satisfactory.	All activities OK.
Moderate	51 to 100	Air quality is acceptable; however some pollutants may affect unusually sensitive groups.	Sensitive groups should reduce exertion outside.
Unhealthy for Sensitive Groups	101 to 150	Sensitive groups may experience health effects. The general public is not likely to be affected.	All groups should reduce prolonged exertion outside.
Unhealthy	151 to 200	Everyone may begin to experience health effects; sensitive groups may experience more serious effects.	Avoid prolonged exertion outside.
Very Unhealthy	201 to 300	Health warnings of emergency conditions. The entire population is more likely to be affected.	Avoid all outdoor activities.
Hazardous	301 to 500	Health alert: everyone may experience more serious effects.	Remain indoors.

Air Quality Index

Table 10. Suggested AQI Scheme for Bangladesh			
AQI Value	Level of Health Concern (স্বাস্থ্যগত উদ্বেগের অবস্থান)		Colours
	English	উাংলা	
0 - 50	GOOD	ঋাল	GREEN
51-100	MODERATE	মধ্যম	YELLOW GREEN
101-150	CAUTION		YELLOW
151 – 200	UNHEALTHY	অস্বাস্থ্যকর	ORANGE
201 – 300	VERY UNHEALTHY	খুব অস্বাস্থ্যকর	RED
301 – 500	EXTREMELY UNHEALTHY	অত্যন্ত অস্বাস্থ্যকর	PURPLE

Air Quality Index

- AQI is calculated based on concentrations of 5 criteria pollutants :
  - O_3 (1-hr, 8-hr)
  - PM (PM_{10}. 24 hr ; $PM_{2.5}$ 24 hr)
  - CO (8-hr)
  - SO_2 (24-hr)
  - NO_2 (annual)
- Each pollutant concentration is converted into an AQI number using the method developed by USEPA. The highest AQI number is the AQI value of the day.
- For example: On a particular day, if a certain area has an AQI value of 120 for $PM_{2.5}$ and 88 for SO_2, then the AQI for that particular day is 120 and the critical pollutant is $PM_{2.5}$.

AQI Handout

- The AQI report
- Calculation of AQI
- Related tables and methods

Problem on AQI

- On Jan 10, 2009, the following air quality data have been recorded at the CAMs in Dhaka. Calculate and report AQI for 10/01/2010.
  - $PM_{2.5}$ = 190 µg/m^3 (24 hr)
  - PM_{10} = 280 µg/m^3 (24 hr)
  - O_3 = 0.095 ppm (8-hr)

Effects of Air Pollution

- Effects on atmospheric properties
- Effects on materials
- Effects on vegetation
- Effects on human health

Effects on atmospheric Properties

- Air pollutants affect atmospheric properties in the following ways:

1) Visibility reduction
2) Fog formation and precipitation
3) Solar radiation reduction
4) Temperature and wind direction alteration
5) Possible effect on global climate changes

Effects on Materials

- Air pollutants can affect materials by soiling or chemical deterioration. High smoke and particulate levels associated with soiling of clothing and structures. Acid or alkaline particles, especially those containing sulfur, corrode materials such as paint, masonry, electrical contacts and textiles
- Ozone is particularly effective in deteriorating rubber [residents of Los Angeles, USA with high O_3 levels must replace automobile fires and windshield wiper blades more frequently than residents in cities where O_3 concentrations are low.]

Effects on Vegetation

- Pollutants that are known phytotoxins (substances harmful to vegetation) are SO_2, peroxyacetyl nitrate, ethane, ozone. Of somewhat lesser severity are chlorine, hydrogen chloride, ammonia and mercury.
- Gaseous pollutants enter plant through stomata in the course of normal respiration of plant. Once in the leaf, pollutants destroy chlorophyll and disrupt photosynthesis.
- Damage can range from a reduction in growth rate to complete death of plant.
- Symptoms of damage are usually manifested in the leaf.

Effects on Human health

- Extremely high concentrations of air pollutants (for several hours/days) have resulted in serious “air pollution episodes”, causing significant deaths in injuries
- Disease of respiratory system are generally correlated with air pollution. Effects are particularly severe on vulnerable population, e.g. older people, infants, people suffering from other diseases
- In general, two types of reaction of respiratory system to air pollution:
  - Acute (e.g. irritative bronchitis)
  - Chronic (e.g. chronic bronchitis, pulmonary emphysema)