

Gases and Vapors

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Section A

Introduction and Definitions

Gases and Vapors

Definition of Gas

- ◆ *Gas*—Normal formless state of matter which at room temperature and pressure has low density/viscosity and readily and uniformly distributes itself throughout any container
- ◆ Can be organic or inorganic
- ◆ Examples: O₂, SO₂, O₃, NO₂, formaldehyde (HCOH), methane (CH₄)

Gases and Vapors

Definition of Vapor

- ◆ *Vapor*—Gaseous form of a substance which coexists as a solid or liquid at normal temperature and pressure
- ◆ Can be organic or inorganic
- ◆ Examples: Hg, H₂O, benzene (C₆H₆), acetone (C₃H₆O), ethanol (C₂H₆O)

Gases and Vapors

Conditions

- ◆ STP (standard temperature and pressure)
 - 0°C and 760 mmHg (32° F and 29.92 inHg; 1 mole of any gas occupies 22.4 liters @ STP)
- ◆ NTP (normal temperature and pressure)
 - 25° C & 760 mmHg; 77° F and 29.92 inHg; 1 mole of any gas occupies 24.45 liters @ NTP

Vapor Pressure

- ◆ *Vapor pressure* is the pressure exerted when a solid or liquid is at equilibrium with its own vapor; the higher the vapor pressure, the more volatile the chemical
- ◆ Vapor pressure is measured in mmHg and is temperature dependent; the higher the temperature, the higher the vapor pressure (and equilibrium concentration)

Vapor Pressure

- ◆ Given two substances of the same volume, which one has more potential hazard?
 - Example: Motor oil vs. ether?
- ◆ Ether has more potential hazard than motor oil due to its high vapor pressure and volatility

Health Effects

- ◆ Gases and vapors are molecules, and as such, behavior is governed in large part by diffusion
- ◆ Exposure (absorption) in respiratory system is largely dependent on gas solubility in mucous membranes
- ◆ Gases and vapors can be local irritants or systemic toxins distributed in solution via blood and lymph

Examples of Health Effects

- ◆ **Asphyxiants:** Carbon dioxide, carbon monoxide
- ◆ **Irritants:** Chlorine, formaldehyde
- ◆ **Anesthetics:** Toluene, benzene
- ◆ **Hepatotoxins:** Carbon tetrachloride, chlorobenzene
- ◆ **Nephrotoxins:** Toluene, xylene

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Examples of Health Effects

- ◆ **Neurotoxins:** Carbon disulfide
- ◆ **Hematopoietic toxins:** Benzene, carbon monoxide
- ◆ **Pulmonary toxins:** Nitrogen dioxide, phosgene
- ◆ **Carcinogens:** Benzene, vinyl chloride monomer

Section B

Gas Laws

Boyle's Law

- ◆ At constant temperature, the volume (V) occupied by a gas is inversely proportional to the pressure (P); as the pressure goes up, the volume of the gas goes down and vice versa

$$P_1V_1 = P_2V_2 \quad \& \quad \frac{V_1}{V_2} = \frac{P_2}{P_1}; \text{ where :}$$

P_1 & V_1 are initial pressure and volume

P_2 & V_2 are final pressure and volume

Continued

Boyle's Law

- ◆ Example: If 400 ml of O₂ is collected at 780 mmHg, what volume will the gas occupy if the pressure is changed to 740 mmHg?

$$(780\text{mmHg})(400\text{ml}) = (740\text{mmHg})(X\text{ml})$$

$$X\text{ml} = \frac{(780\text{mmHg})(400\text{ml})}{(740\text{mmHg})}$$

$$X = 422\text{ml}$$

Charles' Law

- ◆ At constant pressure, the volume of a gas is directly proportional to its absolute temperature (Kelvin):

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

- ◆ Where: T_1 and V_1 = initial temperature and volume, and T_2 and V_2 = final temperature and volume

Continued

Charles' Law

- ◆ Example: At a constant pressure, what is the volume of a gas at -20°C if the gas occupied 50 ml @ 0°C ?

$$\frac{273\text{K}}{253\text{K}} = \frac{50\text{ ml}}{X\text{ ml}}$$

$$X\text{ml} = \frac{(50\text{ml} \times 253\text{K})}{273\text{K}} = 46.3\text{ml}$$

Boyle's and Charles' Laws Combined

- ◆ The density of a gas is related to the volume, temperature, and pressure
- ◆ As volume increases, density decreases proportionally; density varies inversely with volume, directly with pressure, and inversely with absolute temperature

Continued

Boyle's and Charles' Laws Combined

- ◆ Equations:

$$\frac{P_1 \times V_1}{T_1} = \frac{P_2 \times V_2}{T_2}$$

$$\frac{V_1}{V_2} = \frac{T_1}{T_2} = \frac{P_2}{P_1}$$

Boyle's and Charles' Laws Combined

- ◆ Example: If a gas occupies 100 ml at 760 mmHg and 27° C, what volume will it occupy at 800 mmHg and 50° C?

$$\frac{(760\text{mmHg})(100\text{ml})}{300\text{K}} = \frac{(800\text{mmHg})(X\text{ml})}{323\text{K}}$$

$$X\text{ml} = \frac{760\text{mmHg} \times 100\text{ml} \times 323\text{K}}{300\text{K} \times 800\text{mmHg}} = 102\text{ml}$$

Ideal Gas Law

$$PV = nRT$$

- ◆ P = Pressure (atmospheres)
- ◆ V = Volume (liters)
- ◆ n = Number of moles of gas
(mass in g/molecular weight)
- ◆ R = Molar gas constant
(0.0821 liter atm/mol K)
- ◆ T = Temperature (Kelvin)

Continued

Ideal Gas Law

- ◆ Example: What is the volume of 32 g of O₂ at 760 mmHg and 25° C?

$$(1\text{atm})(X) = (1\text{mole}) * \frac{0.0821\text{latm}}{\text{moleK}} * 298\text{K}$$

$$X = (1\text{mole}) * \frac{0.0821\text{latm}}{\text{moleK}} * \frac{298\text{K}}{1\text{atm}}$$

$$X = 24.45 \text{ liters}$$

Section C

Concentration Units

Gas and Vapor Concentrations

- ◆ Concentration equations:

$$C = \frac{\text{mass}_{\text{contaminant}}}{\text{volume}_{\text{air}}} = \frac{\text{volume}_{\text{contaminant}}}{\text{volume}_{\text{air}}} \times 10^6$$

- ◆ Concentration units:
mg/m³ ppm

Parts Per Million, PPM

- ◆
$$\text{ppm} = \frac{\text{parts of contaminant}}{\text{million parts of air}}$$

- L / 10⁶L or ml / m₃

- ◆ Similar to percent

$$\% = \frac{\text{parts}}{100 \text{ parts}}$$

Conversion of Units

- ◆ General form of conversion equation

$$X_{\text{ppm}} = \frac{Y_{\text{mg}}}{\text{m}^3} * \frac{\text{mmole}}{\text{MW}(\text{mg})} * \frac{24.45\text{ml}}{\text{mmole}}$$

- ◆ If X is given, solve for Y, and if Y is given, solve for X
 - Always do a *dimensional analysis* as a check

Conversion of Units

- ◆ Short-hand form of conversion equation:

$$X_{\text{ppm}} = \frac{Y_{\text{mg}} \cdot 24.45}{m^3 \cdot \text{MW}}$$

- ◆ If X is given, solve for Y, and if Y is given, solve for X

Conversion of Units

- ◆ Example: mg/m³ to ppm
- ◆ Express 50 mg/m³ benzene in ppm
molecular weight of benzene = 78
mg/mmol

$$X_{\text{ppm}} = \frac{50\text{mg}}{\text{m}^3} * \frac{\text{mmole}}{78\text{mg}} * \frac{24.45\text{ml}}{\text{mmol}}$$

$$X = 15.7\text{ppm}$$

Continued

Conversion of Units

- ◆ Example: ppm to mg/m³
- ◆ Express 50 ppm benzene in mg/m³

$$50\text{ppm} = \frac{Y\text{mg}}{\text{m}^3} * \frac{\text{mmol}}{78\text{mg}} * \frac{24.45\text{ml}}{\text{mmol}}$$

$$Y = \frac{159.5\text{mg}}{\text{m}^3}$$

Section D

General Considerations

Benzene Spill Scenario

- ◆ A 5 ml vial of benzene was spilled in a 400 m³ laboratory
- ◆ If this were reported to you, the industrial hygienist, how would you respond?
- ◆ Assumptions:
 - Room sealed
 - All of the benzene evaporates
 - Lab has well mixed air

Benzene Spill

- ◆ PEL for Benzene = 1 ppm (eight-hour TWA)
- ◆ Density of benzene = 0.8 g/ml
- ◆ MW of benzene = 78 mg/mmol
- ◆ Since *concentration = mass/(volume of air)*, we need to know what mass of benzene was spilled (i.e., 5 ml = ? g) in order to compare it to the PEL

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Benzene Spill

- ◆ Using the density of benzene, we can find the mass of benzene spilled:
 - $5 \text{ ml} * 0.8 \text{ g/ml} = 4 \text{ g}$ benzene spilled
- ◆ Now we can calculate the concentration of benzene using the volume of air in the lab:
 - $4 \text{ g benzene} / 400 \text{ m}^3 \text{ air} = 0.01 \text{ g/m}^3$

Benzene Spill

- ◆ We now have to convert this concentration to ppm, and we start by changing the units to mg/m³:

$$\left(\frac{0.01\text{g}}{\text{m}^3} \right) \left(\frac{1000\text{mg}}{1\text{g}} \right) = 10 \frac{\text{mg}}{\text{m}^3}$$

Continued

Benzene Spill

- ◆ Now using the molecular weight (78 mg/mmol), we convert to ppm:

$$\left(\frac{10\text{mg}}{\text{m}^3}\right)\left(\frac{\text{mmol}}{78\text{mg}}\right)\left(\frac{24.45\text{ml}}{\text{mmol}}\right) = \frac{3.13\text{ml}}{\text{m}^3}$$

$$3.13 \frac{\text{ml}}{\text{m}^3} = 3.13 \text{ ppm benzene}$$

Benzene Spill

- ◆ 3.13 ppm is 3 times the PEL, but remember that the PEL is a standard designed to protect workers for an eight-hour work day, five times a week, for many years—so don't panic!
- ◆ Some recommendations you could make would include closing the lab for a little while and opening a window or turning on or up the ventilation