

# PETE 310

Lectures # 9 & 10  
Ideal and Real Gases

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## Equations of State The Ideal Gas

- Ideal gas properties
  - Volume of gas molecules is negligible compared with gas volume
  - Forces of attraction or repulsion between molecules or walls of container are zero
  - No loss of internal energy due to collisions

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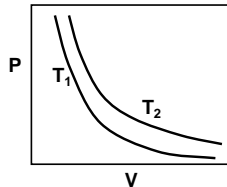
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### Boyle's Law

$$V \propto \frac{1}{P}$$

At fixed T



### Gay Lussac's Law

$$V \propto T$$

At fixed P

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## Avogadro's Law

At the same P and T equal Volumes of gas contain the same # of molecules

$N_A = 2.73 \times 10^{26}$  molecules/lb mole

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## Internet Lesson on Ideal Gas Behavior

- Experimental instructions

<http://jersey.uoregon.edu/vlab/Piston/>

- Problems with solutions

<http://dbhs.wvusd.k12.ca.us/GasLaw/WS-Ideal.html>



Hi, I am Boyle

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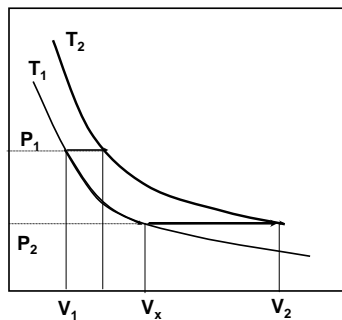
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## Ideal Equation of State Construction



Step 1

$$P_1 V_1 = P_2 V^x$$

Step 2

$$\frac{V^x}{T_1} = \frac{V_2}{T_2}$$

Combining

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

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## Boyle & Charles laws

Boyle



Charles



a cool website with lots of info..

<http://dbhs.wvusd.k12.ca.us/GasLaw/KMT-Gas-Laws.html>

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## Boyle & Charles laws

$$\left( V \propto \frac{1}{P} \right)_T$$

$$(V \propto T)_P$$

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

$$\frac{P V_M}{T} = R$$

$$(V_M = V / n)$$

R = gas constant, depends upon units used  
See page 95 McCain book

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## Ideal Gas Mixture

- The pressure in a vessel containing an ideal gas mixture ( $n$ ) or a single gas component ( $n_k$ ) is

$$P = \frac{nRT}{V_t}$$

<http://home.a-city.de/walter.fendt/phe/gaslaw.htm>

$$P_k = \frac{n_k RT}{V_t}$$

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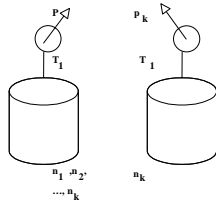
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## Partial Pressure

$$\frac{P_k}{P} = \frac{n_k}{n} = y_k$$

- $P_k$  is the partial pressure of component  $k$ , and by definition

$$\sum_{i=1}^{N_c} P_k = P$$



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## Density of ideal gas

$$P = \frac{nRT}{V_t} \Rightarrow \frac{m}{M_w V_t} = \rho = \frac{P}{RT}$$

Watch out the units!

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## Mixtures of Ideal Gases

- Dalton's law of partial pressures
- Amagat's law of partial volumes
- Specific gravity of a gas

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## Apparent Molecular Weight of a Gas Mixture

- Determine the  $M_{wa}$  and density of a mixture of 30% $C_1$ , 40% $C_2$ , and 30% $C_3$  at  $T=200^\circ\text{F}$  and  $P=4000$  psia

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## Behavior of Real Gases

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## Equations of State for Gases

- Ideal gas  $\frac{PV_M}{RT} = 1$

- Real gas  $\frac{PV_M}{RT} = Z$

Z is the ratio of the "real molar volume" over the "ideal molar volume" of a substance measured at the same  $\left(\frac{PV_M}{RT}\right)\left(\frac{RT}{PV_M^i}\right) = \frac{Z}{1} = Z$  pressure and temperature.

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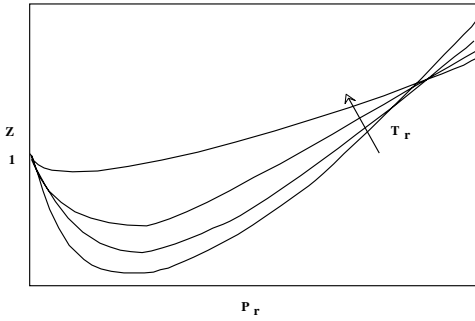
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## Compressibility Factor Charts



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## The Principle of Corresponding States



*“All fluids when compared at the same reduced temperature and reduced pressure, have approximately the same compressibility factor, and all deviate from ideal gas behavior to about the same degree”*

The Principle of Corresponding states (POC) originated with single component fluids.

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## Typical Reduced Parameters

● Material properties are usually expressed in terms of reduced parameters such as:

• Reduced Temperature:

$$T_r = (T / T_c)$$

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## Typical Reduced Parameters

- Reduced Pressure:

$$P_r = (P / P_c)$$

- Reduced Molar Volume:

$$V_r = (V_M / V_{M_c})$$

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## Reduced Parameters

- Usually  $T_r$  and  $P_r \rightarrow V_r$  obtained as a function of  $T_r$  and  $P_r$
- These are called two-parameter Corresponding States models
- Three-parameter corresponding states models improve predictions but third parameter is not  $V_r$  (not independent variable)

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## Generalized Corresponding States Three-Parameter

- This third parameter is called the acentric factor.
- It takes into account the non-spherical nature of molecules
- Peng Robinson and the Soave Redlich Kwong equations of state (EOS) are examples of three parameter corresponding states models.

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## Compressibility Factor Charts

- Following the POC only one compressibility factor chart can be used to determine volumetric properties of any pure fluid by using its reduced properties. The shape of this chart is in general.

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## Corresponding States Correlations & Models

- The objective is then to find a model (models) to predict the Z factor.
- Ideal gas behavior is described from the ideal gas Equation of State (EOS) with a compressibility factor of 1.

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## Extension of Corresponding States to Mixtures

- Z factor charts (all built from EOS) are also used for multicomponent systems in this case the coordinates used are “pseudo-reduced properties”
- For a mixture you can use the same charts as for a pure component.

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## Pseudoreduced Properties

- For mixtures the same type of charts apply but using "pseudoreduced properties" which are defined similarly as the ratio of pressure (or temperature) with "pseudoreduced critical pressure" (or temperature). These pseudocritical properties are an average of the critical properties of the components in the mixture. Charts for mixtures can also be used for single component fluids.

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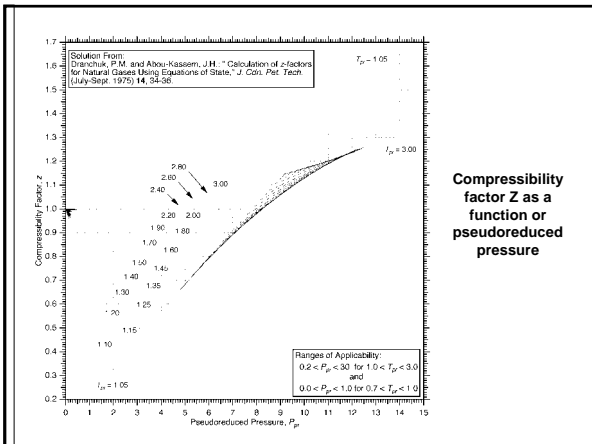
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## Pseudocritical Properties of Natural Gases

- Pseudoreduced Pressure

$$P_{pr} = \frac{P}{P_{pc}}$$

- Pseudoreduced Temperature

$$T_{pr} = \frac{T}{T_{pc}}$$

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### Pseudocritical Properties of Natural Gases

- If only the specific gravity and Mw of the gases is known then charts are available to estimate these pseudocritical properties (McCain figure 3-10 ).

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### Pseudocritical Properties of Natural Gases

- Naturally the degree of accuracy is reduced substantially. We will see methods when compositional information is available, in this case:

$$P_{pc} = \sum_{i=1}^{N_c} (y_i P_{ci}) \quad T_{pc} = \sum_{i=1}^{N_c} (y_i T_{ci})$$

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### Pseudocritical Properties of Natural Gases

- Once Z is evaluated you can find the gas density as

$$\rho_g = \frac{M}{V} (\text{lbm} / \text{ft}^3)$$

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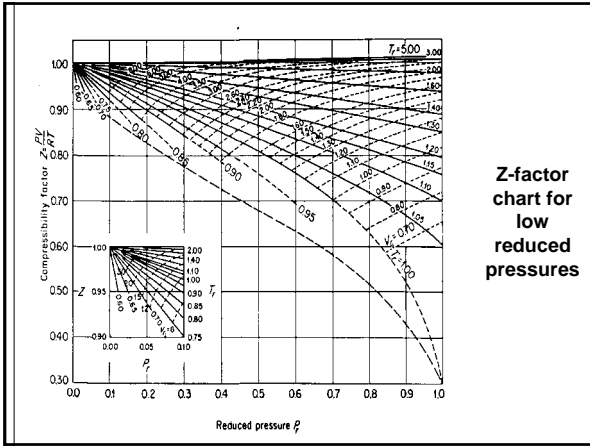
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**Z-factor  
chart for  
low  
reduced  
pressures**

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