Advanced Natural Gas Technology (PGE 516)

Gas Properties Overview

BY
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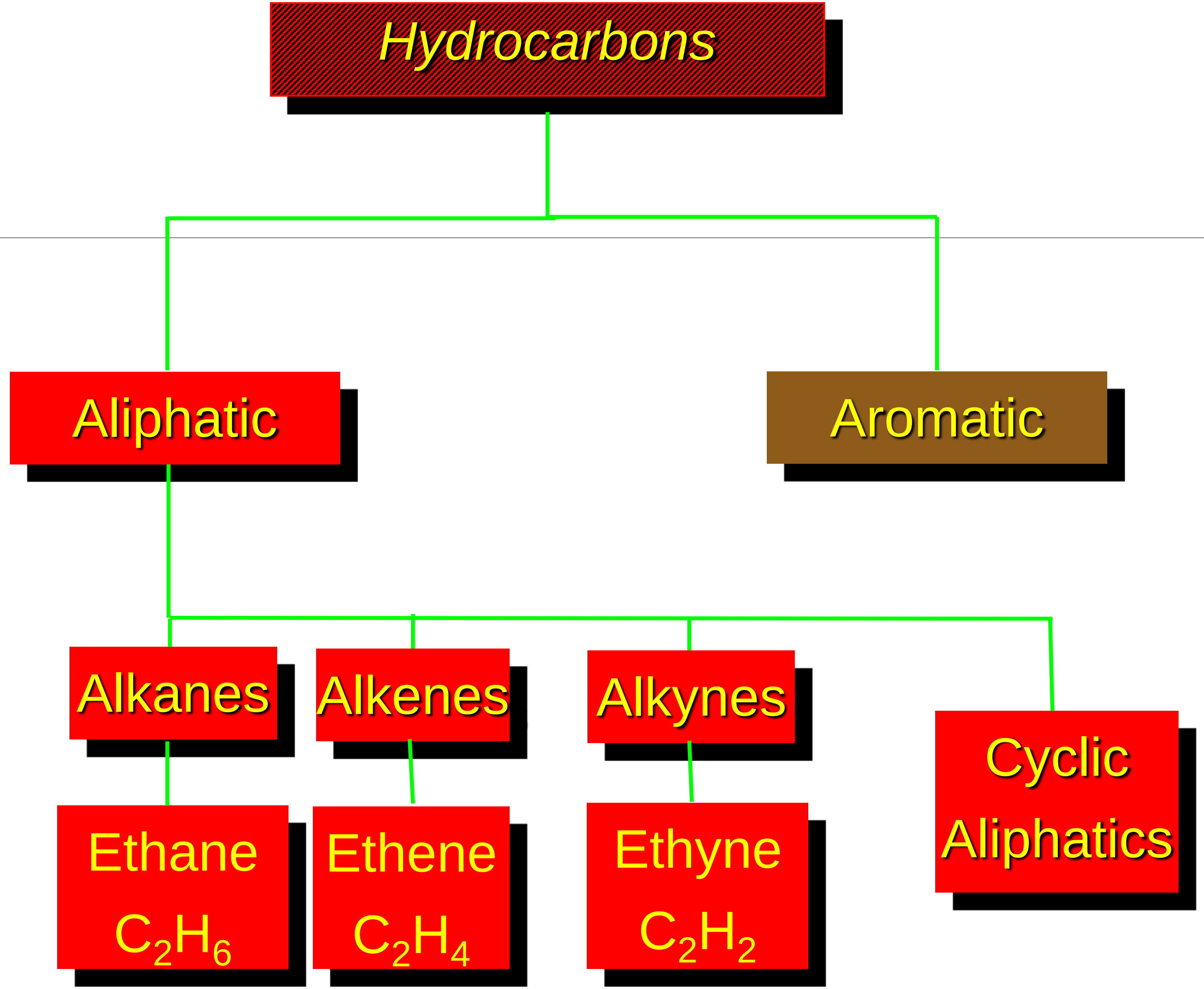
Natural gas	
Hydrocarbon	
Methane	70–98%
Ethane	1–10%
Propane	trace–5%
Butanes	trace–2%
Pentanes	trace–1%
Hexanes	trace–½%
Heptanes +	trace–½%
Nonhydrocarbon	
Nitrogen	trace–15%
Carbon dioxide*	trace–5%
Hydrogen sulfide*	trace–3%
Helium	up to 5%, usually trace or none

*Occasionally natural gases are found which are predominately carbon dioxide or hydrogen sulfide.

Gas from a well which also is producing petroleum liquid	
Hydrocarbon	
Methane	45–92%
Ethane	4–21%
Propane	1–15%
Butanes	½–7%
Pentanes	trace–3%
Hexanes	trace–2%
Heptanes +	none–1½%
Nonhydrocarbon	
Nitrogen	trace–up to 10%
Carbon dioxide	trace–4%
Hydrogen sulfide	none–trace–6%
Helium	none

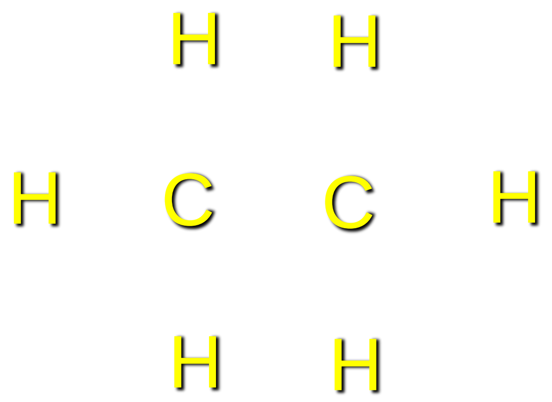

Hydrocarbons
Aliphatic
Aromatic
Alkanes
Alkenes
Alkynes
Cyclic Aliphatics
Ethane C_2H_6
Ethene C_2H_4
Ethyne C_2H_2

Hydrocarbons

Aliphatic

Alkanes

Alkanes are hydrocarbons in which all of the bonds are *single* bonds.



Hydrocarbons

Aliphatic

Alkenes

Alkenes are hydrocarbons that contain a carbon-carbon *double* bond.

H H

C C

H H

Hydrocarbons

Aliphatic

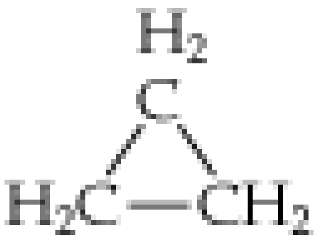
Alkynes are hydrocarbons that contain a carbon-carbon *triple* bond.

Alkynes

HC CH

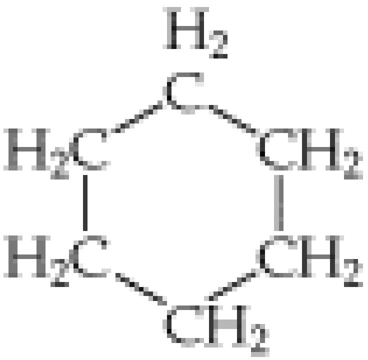
Cycloalkanes

Carbon atoms that are joined in a ring or circle



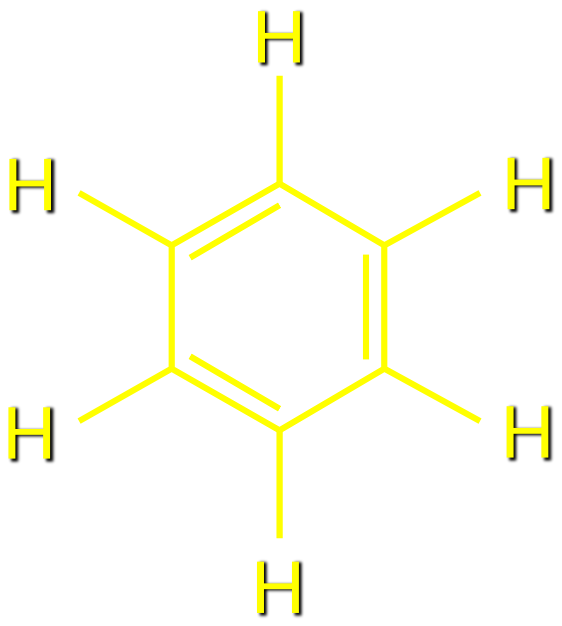
Simplest: Cyclopropane

Another: Cyclohexane

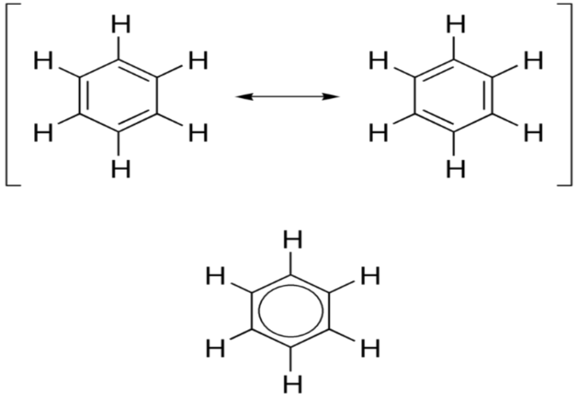


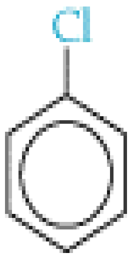
Hydrocarbons

Aromatic

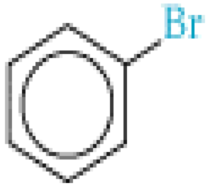


Aromatic

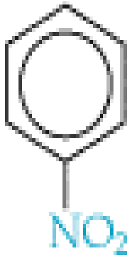




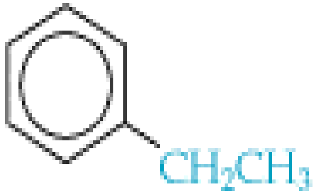
Chlorobenzene



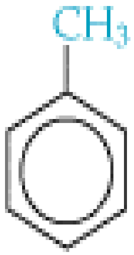
Bromobenzene



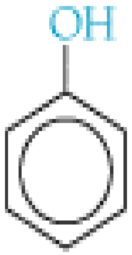
Nitrobenzene



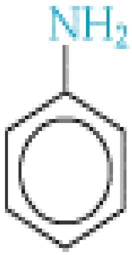
Ethylbenzene



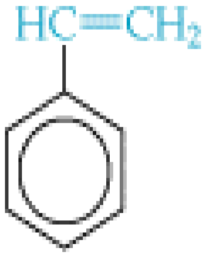
Toluene
(Methylbenzene)



Phenol
(Hydroxybenzene)



Aniline
(Aminobenzene)



Styrene
(Vinylbenzene)

Definition

Three phases of matter

- Solid: Definite shape and volume
- Liquid: Definite volume, shape of container
- Gas: Shape and volume of container

- A gas is a collection of molecules that are very far apart on average.
  - In air, gas molecules occupy only 0.1% of the total volume.
  - In liquids, molecules occupy ~ 70% of the total space

Definition

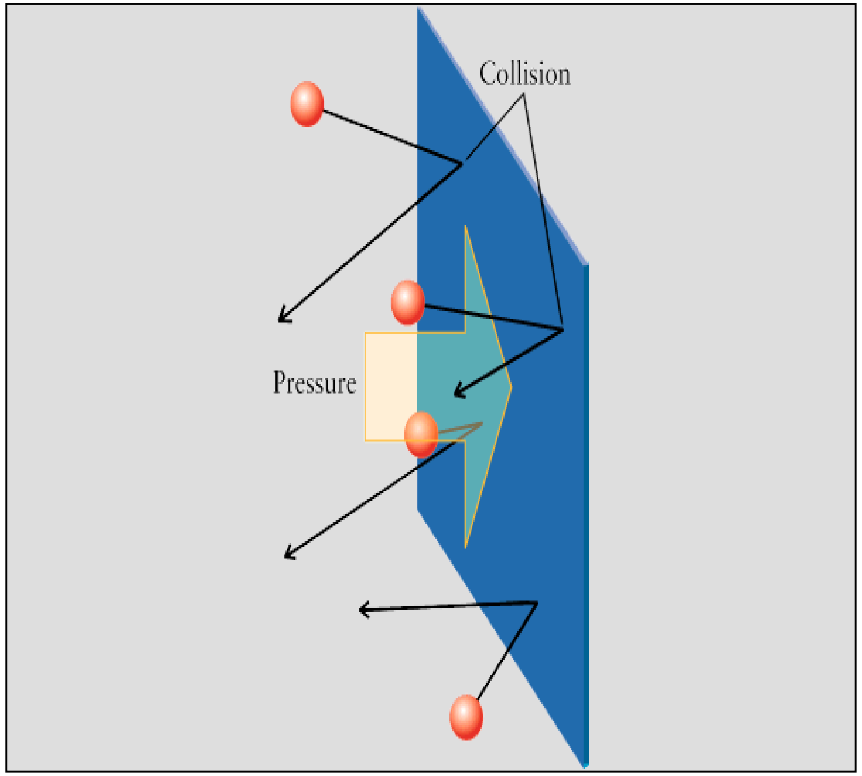
- Gases are highly compressible.
  - Volume decreases when pressure is applied.
- Gases form homogeneous mixtures with each other regardless of the identities or relative proportions of the different gases.
  - Water and gasoline
    - Heterogeneous mixture.
  - Water vapor and gasoline vapor
    - Homogeneous mixture.

Definition

- Four quantities are commonly needed to describe a gas:
  - Amount of gas (n)
  - Temperature (T)
  - Volume (V)
  - Pressure (P)

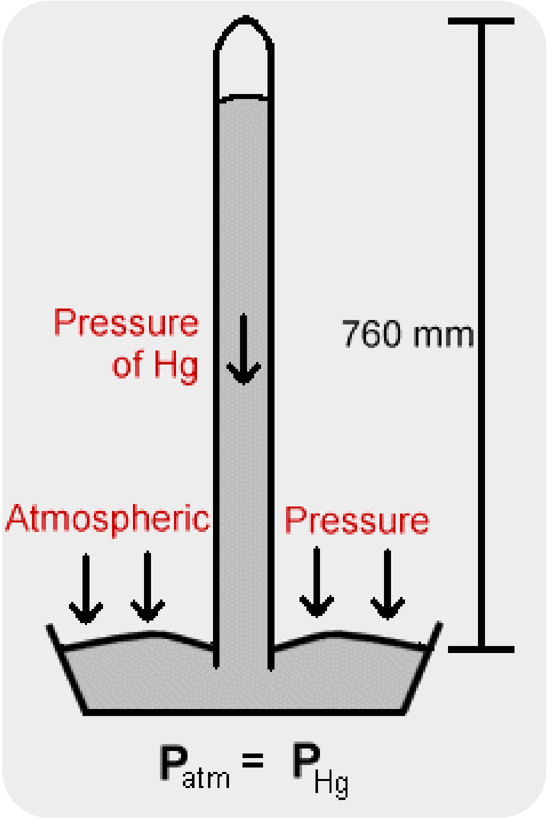
Gas Pressure

- Gases exerted pressure on the objects in their surroundings
- Pressure is caused by collisions between the gas molecules and objects with which they are in contact.
- Pressure: the force exerted on a unit area
  - $P = \frac{F}{A}$



Gas Pressure

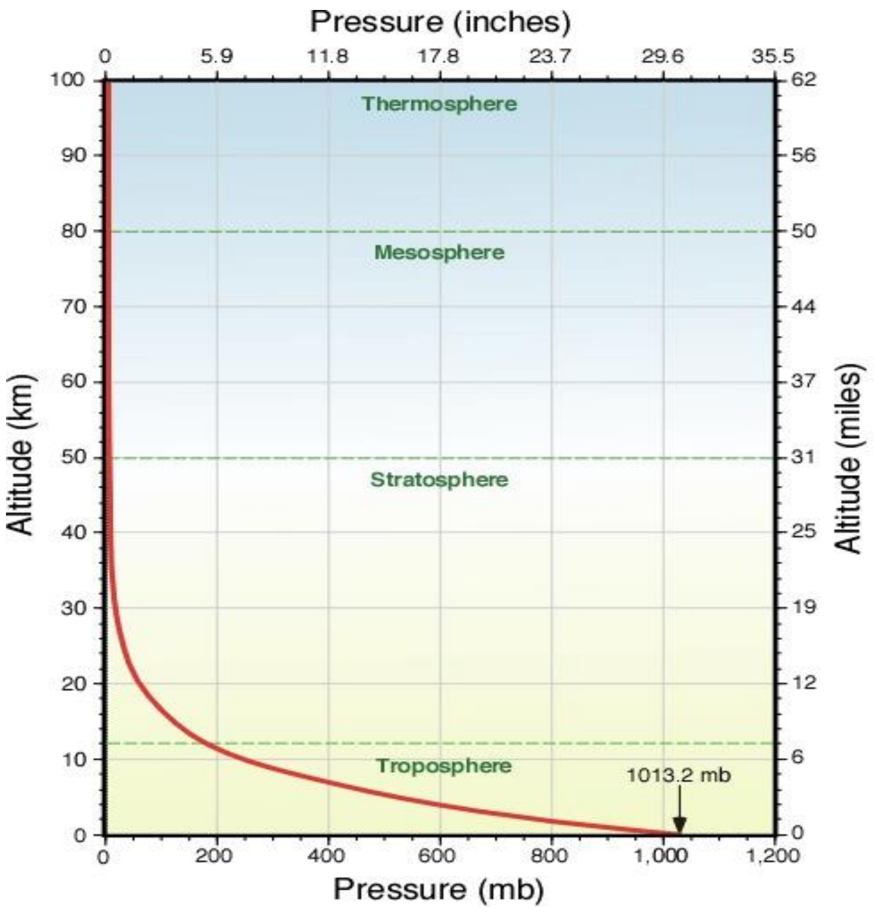
- Gas pressure units
  - mm Hg (1 atm = 760 mm Hg)
  - in. Hg (= 29.92 in. Hg)
  - psi (= 14.7 psi)
  - atm
  - torr (= 760 torr)
  - pa (SI unit) (= 1.01325×10^5 Pa)
  - kPa (= 101.325 kPa)



Gas Pressure

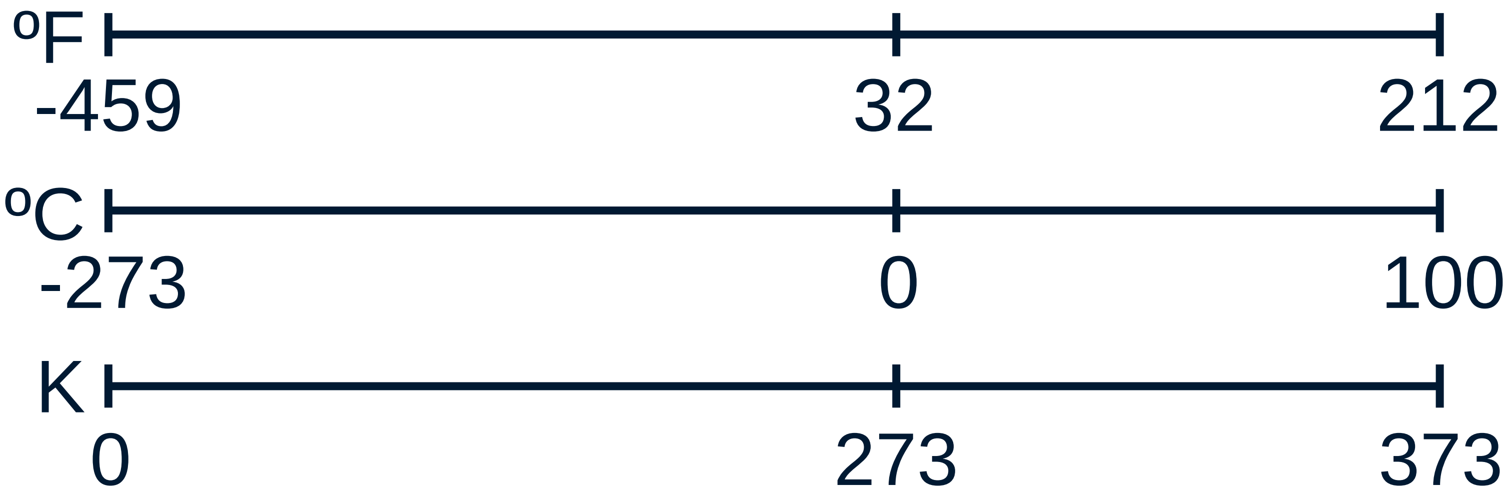
- **Atmospheric pressure:** the pressure exerted by gas molecules in the air on all objects exposed to the atmosphere
- Atmospheric pressure varies with altitude.

Altitude (ft) (above sea level)	Atmospheric Pressure		
	in. Hg	Torr	psi
0	29.92	760	14.65
5000	24.90	632.5	12.23
10,000	20.58	522.7	10.10



Gas Temperature

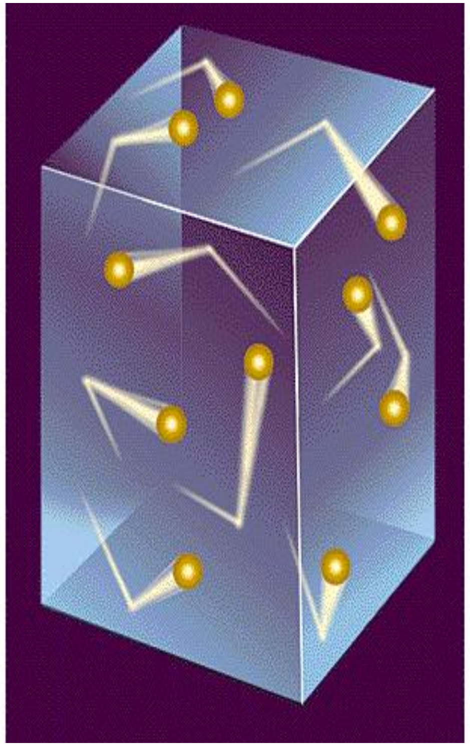
- Always use **absolute temperature** (Kelvin) when working with gases.



$$°C = \frac{5}{9}(°F - 32) \qquad K = °C + 273$$

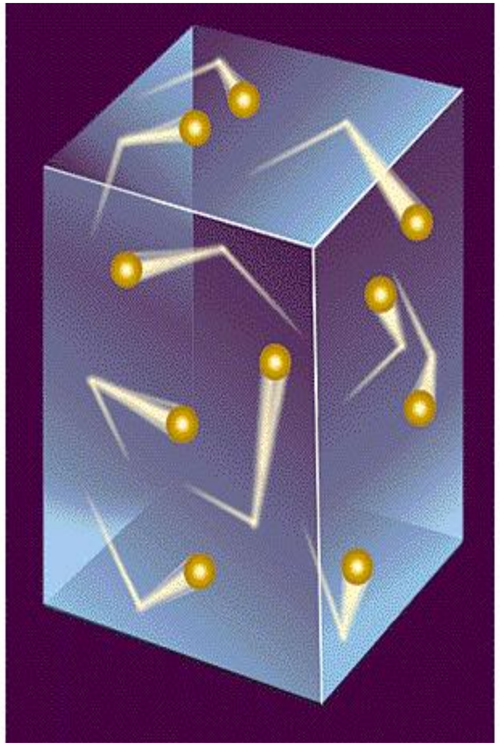
Kinetic Molecular Theory

- The behavior of gases can be described using Kinetic Molecular Theory
  - "Theory of Moving Molecules"
- Molecules Gases consist of large numbers of that are in continuous, random motion.
- The combined volume of all the molecules of the gas is negligible compared to the total volume in which the gas is contained.
  - *i.e.* the molecules are very far apart on average

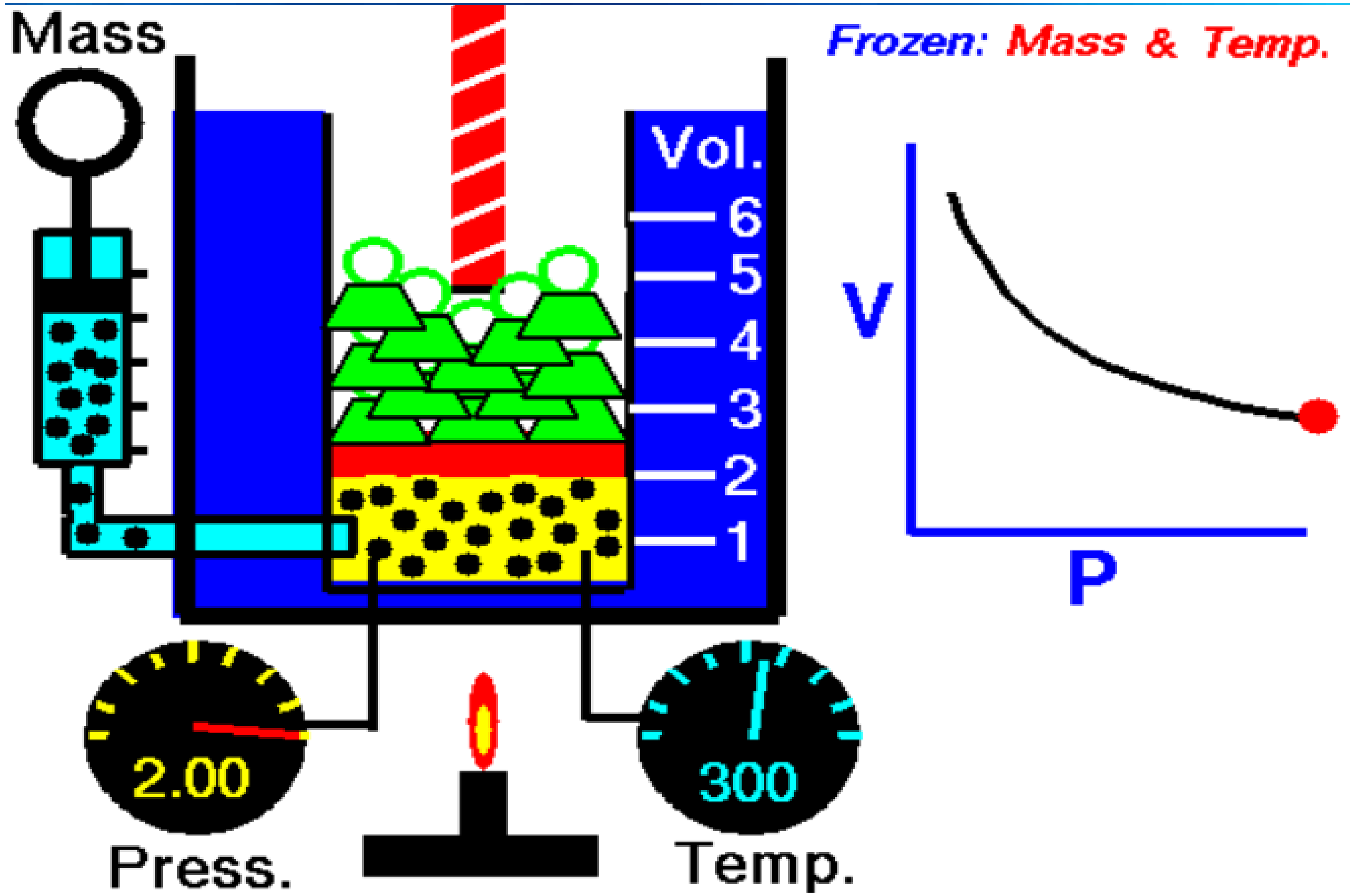


Kinetic Molecular Theory

- Particles in an ideal gas…
  - have no volume.
  - have elastic collisions.
  - are in constant, random, straight-line motion.
  - don't attract or repel each other.
  - have an avg. KE directly related to Kelvin temperature.
    - At any given temperature all molecules of a gas have the same average kinetic energy.
    - As T (in K) increases, KE increases.



Gas Laws



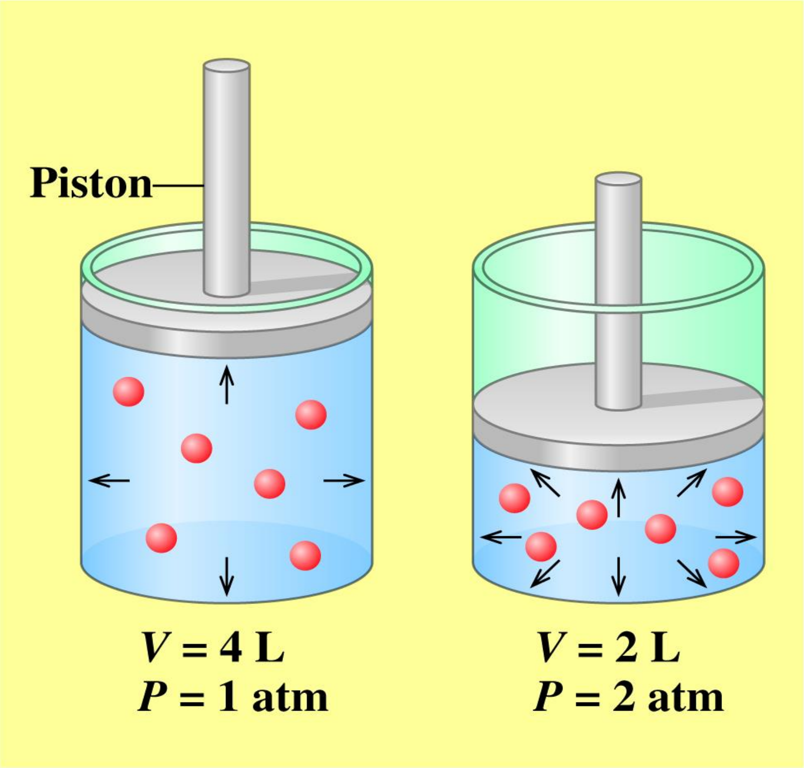
Boyle's Law

The product of pressure and volume for a gas is constant for a fixed amount of gas at fixed temperature.

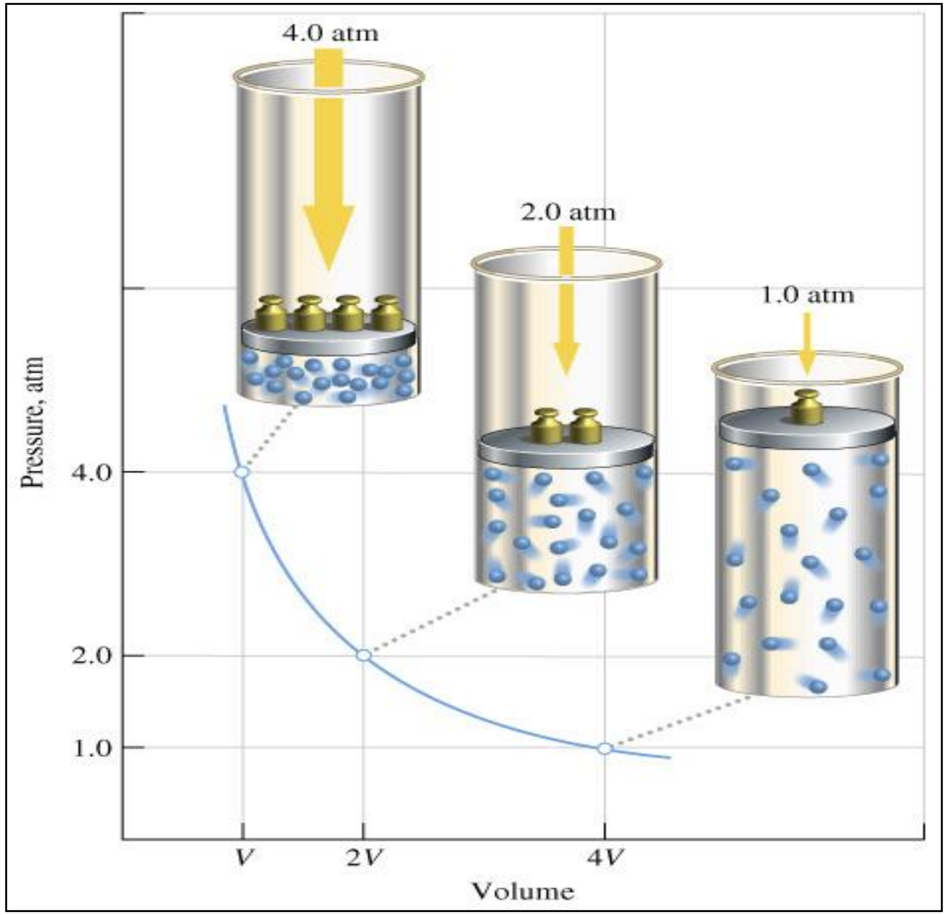
$$P \propto \frac{1}{V}$$

$$PV = constant$$

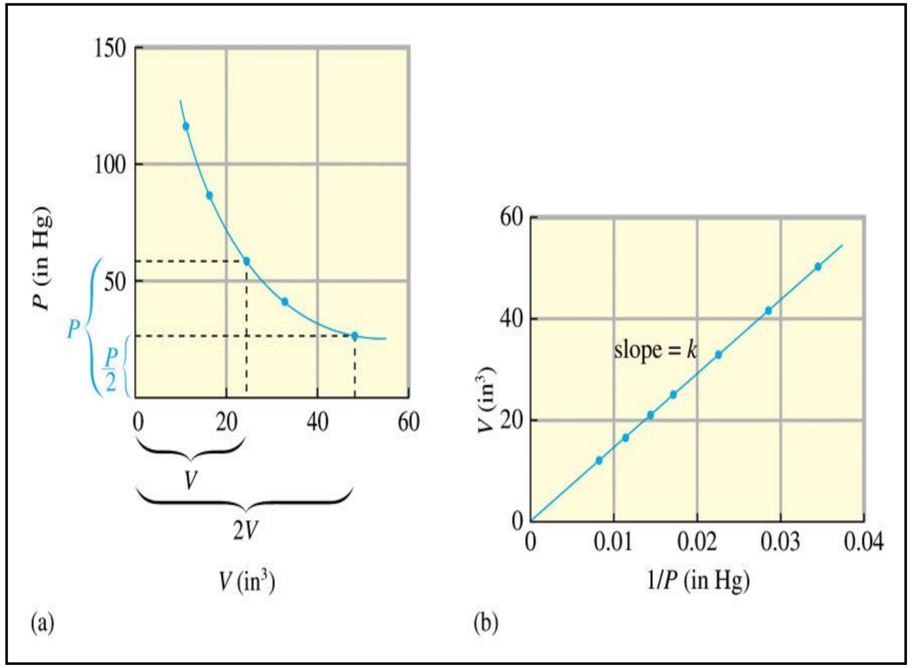
$$P_i V_i = P_f V_f$$ (T, n are constant)



Boyle's Law



4.0 atm
2.0 atm
1.0 atm
Pressure, atm
4.0
2.0
1.0
V
2V
4V
Volume



150
100
50
P (in Hg)
P
P/2
0
20
40
60
V
2V
V (in³)
(a)
60
40
20
0
slope = k
V (in³)
0
0.01
0.02
0.03
0.04
1/P (in Hg)
(b)

Charles Law

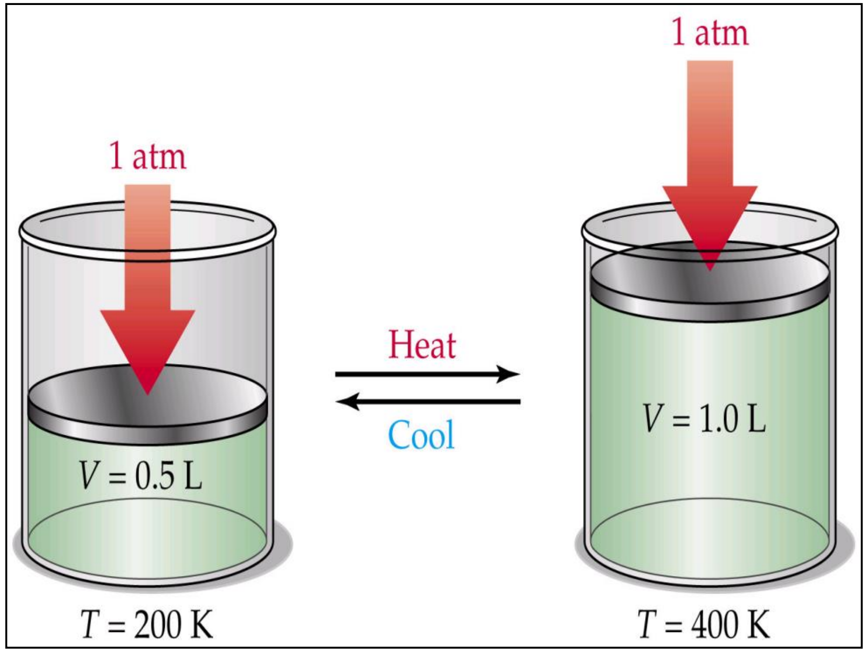
Volume of a gas varies directly with the absolute temperature at constant pressure.

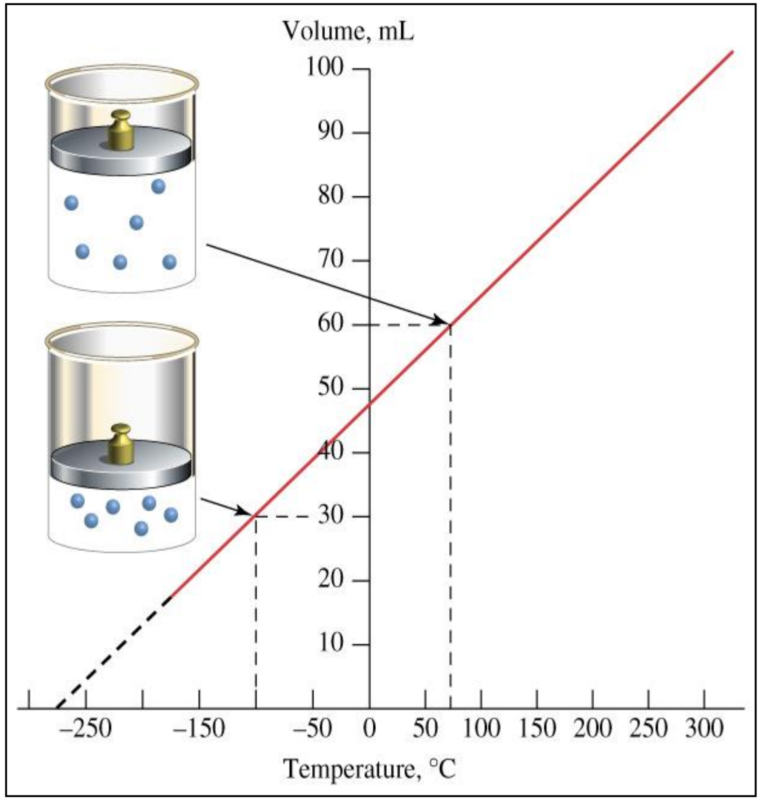
$V \propto T$

$\frac{V}{T} = constant$

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

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





Avogadro's Law

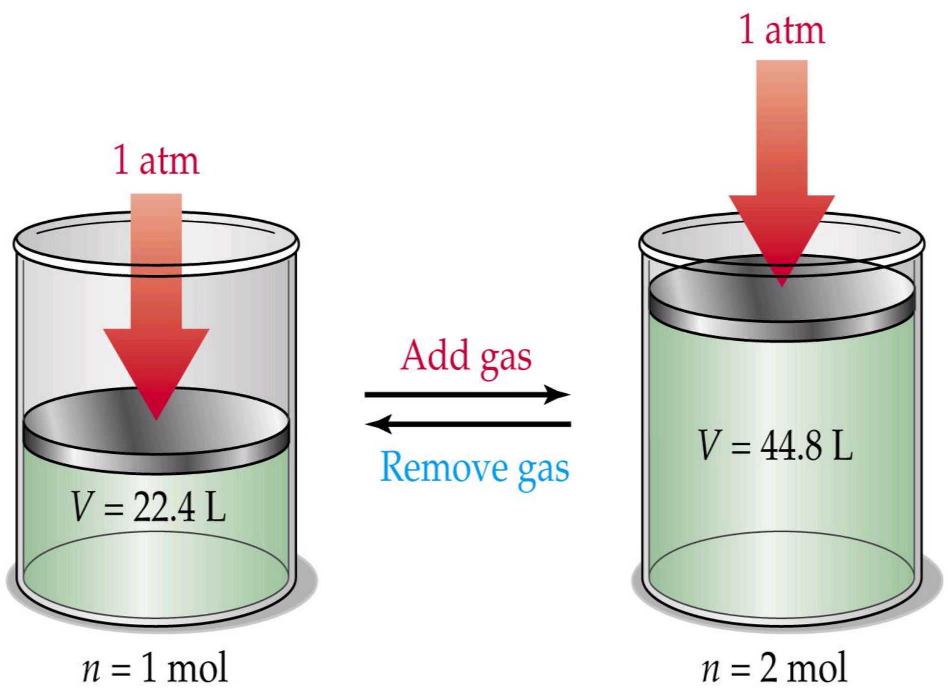
At constant temperature and pressure, the volume of a gas is directly related to the number of moles.

$$V \propto n$$

$$\frac{V}{n} = constant$$

$$\frac{V_1}{n_1} = \frac{V_2}{n_2}$$

$$\frac{V_1}{V_2} = \frac{n_1}{n_2}$$



Gay-Lussac's Law

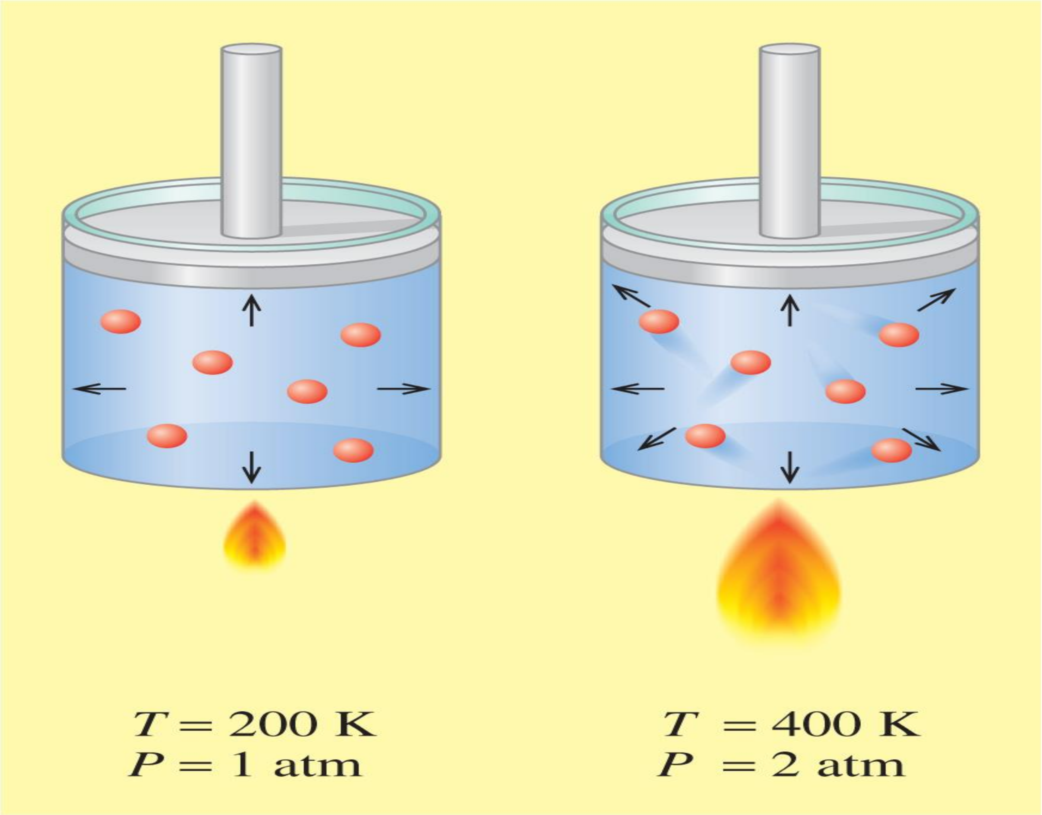
At constant volume, pressure and absolute temperature of a gas are directly related.

$$P \propto T$$

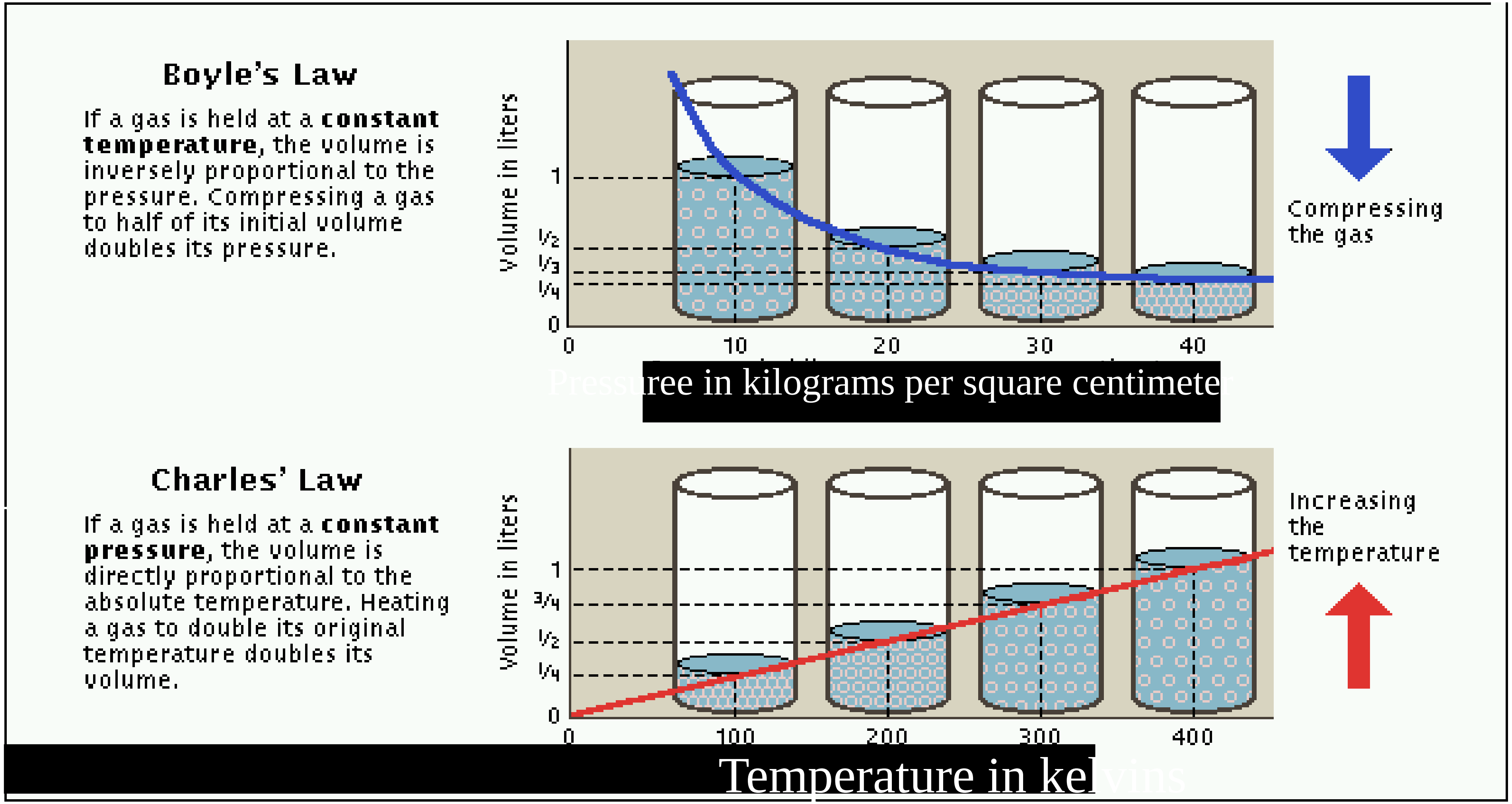
$$\frac{P}{T} = constant$$

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

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



Combined Law



Combined Law

Boyle's Law	$V = kP^{-1}$	$P_1V_1 = P_2V_2$ (at a fixed temperature)
Charles' Law	$V = bT$	$V_1 / V_2 = T_1 / T_2$ (at a fixed pressure)
Avogadro	$V = an$ n = number of moles	(at a fixed pressure and temperature)

$V = nRTP^{-1}$	**$PV = nRT$** **ideal gas law**	an empirical law

Partial Pressure

- Pressure exerted by each individual gas within a mixed gas.
- **Dalton's Law:** The total pressure of a gas mixture is the sum of the partial pressures of the component gases.

$$P_t = P_1 + P_2 + P_3 + P_4 + \ldots\ldots..$$

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

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

Partial Pressure

$$PV = nRT$$

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

$$P_k = \frac{n_k\, RT}{V}$$

$\frac{P_k}{P} = \frac{n_k}{\sum n_k} = y_k$ or

$$P_k = y_k\, P$$

Mole % and Volume %

- Based on Avogadro's Law, **volume%** and **mole%** are equivalent.
- $V_i \propto n_i$ or $V_i = k\, n_i$
- $volume\% = \frac{V_i}{\sum V_i} = \frac{k\, n_i}{\sum k\, n_i} \times 100 = \frac{n_i}{\sum n_i} \times 100 = mole\%$

Component	Mole fraction, y_i
C_1	0.850
C_2	0.090
C_3	0.040
n-C_4	0.020
	1.000

Ideal vs. Real Gas

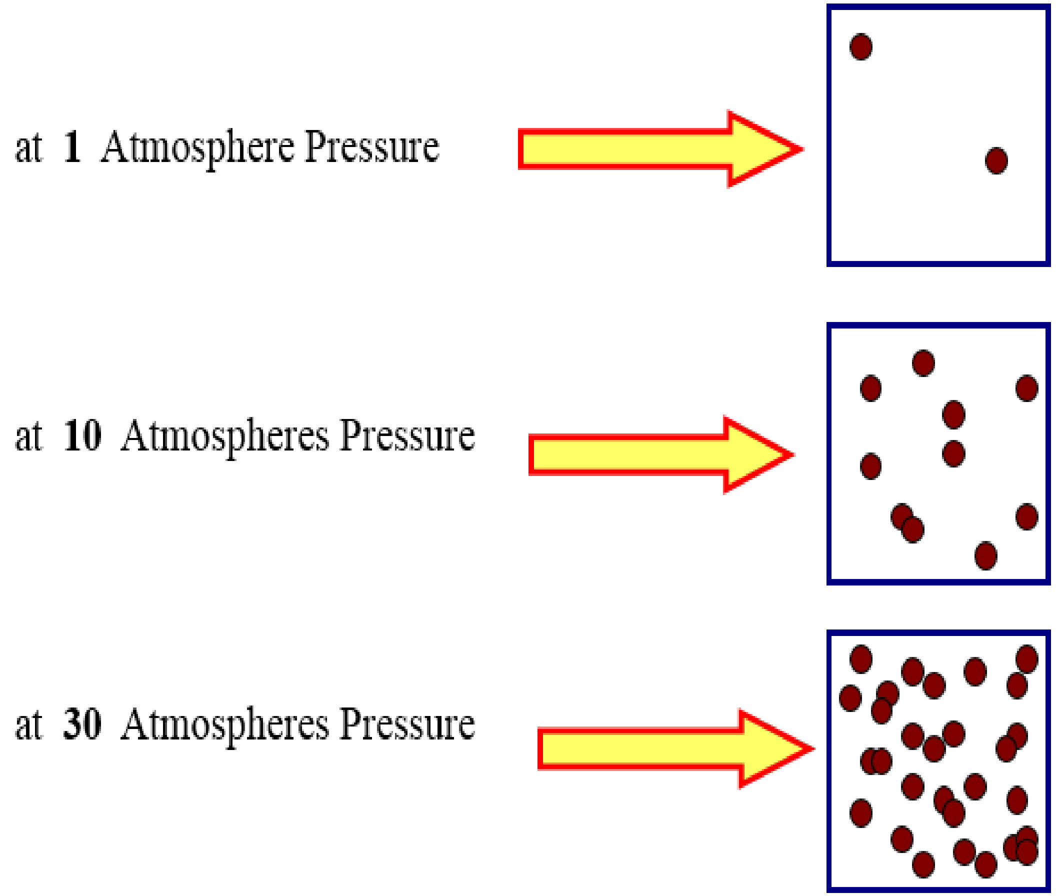
	Ideal Gas	Real Gas
Obey PV=nRT	Always	Only at very low P and high T
Molecular volume	Zero	Small but nonzero
Molecular attractions	Zero	Small
Molecular repulsions	Zero	Small

Real Gas

- Real molecules do take up space and do interact with each other (especially polar molecules).

- Need to add correction factors to the ideal gas law to account for these.

- Ideally, the volume of the molecules was neglected



Real Gas

But since real gases do have volume, we need:

<u>**Volume Correction**</u>

- The actual volume free to move in is less because of particle size.
- More molecules will have more effect.
- Corrected volume $V' = V - nb$
- "*b*" is a constant that differs for each gas.

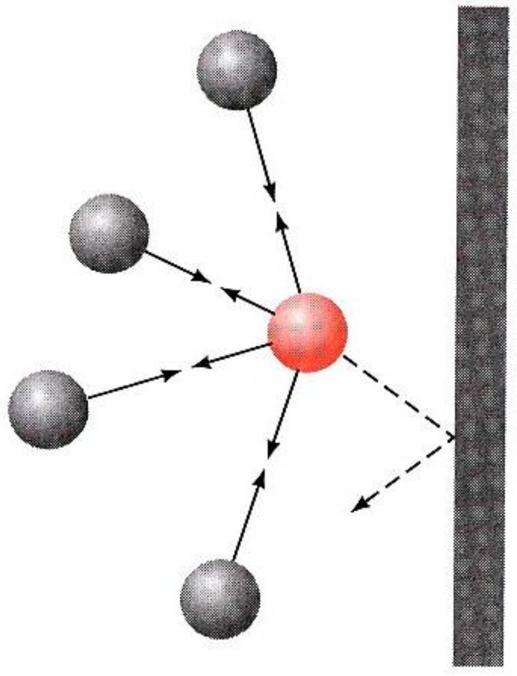
Real Gas

But since real gases do have volume, we need:

Pressure Correction

- Because the molecules are attracted to each other, the pressure on the container will be less than ideal.
- Pressure depends on the number of molecules per liter.
- Since two molecules interact, the effect must be squared

$$P_{observed} = P - a\left(\frac{n}{V}\right)^2$$



Van Der Waal's Equation

$$\left[P_{obs} + a\left(\frac{n}{V}\right)^2\right](V - nb) = nRT$$

Corrected Pressure — Corrected Volume

- "a" and "b" are determined by experiment
- "a" and "b" are different for each gas
- bigger molecules have larger "b"
- "a" depends on both size and polarity

Real Gas

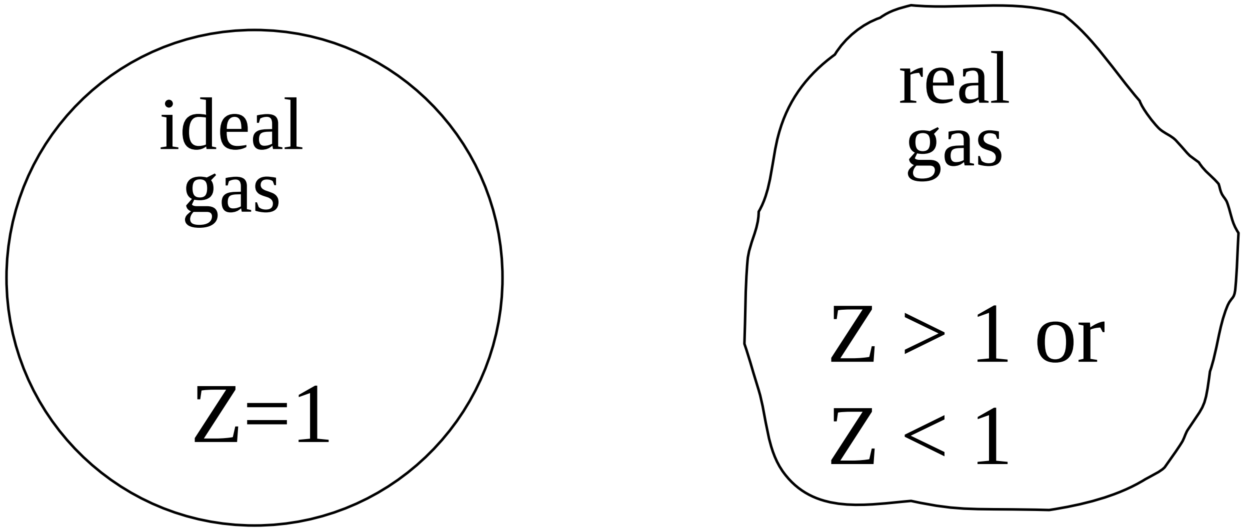
- $PV_M = RT$
- $\frac{PV_M}{RT}$ = 1 (ideal gas)
- $\frac{PV_M}{RT}$ = Z (real gas)
- What is V_M ?

- $PV_M = ZRT$
- $PV = ZnRT$

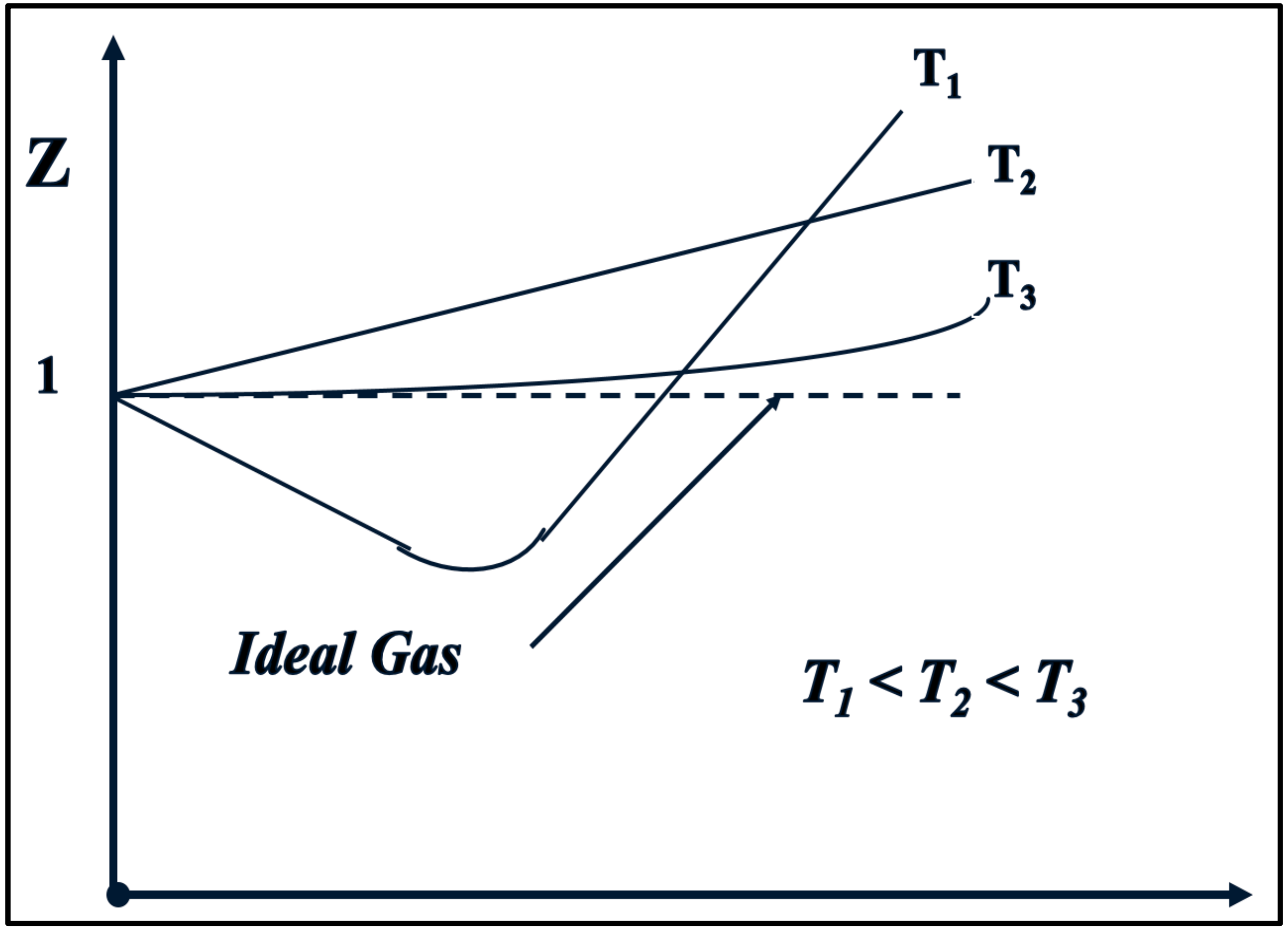
Compressibility Factor

The deviation from ideal-gas behavior can be properly accounted for by using the compressibility factor Z, defined as:

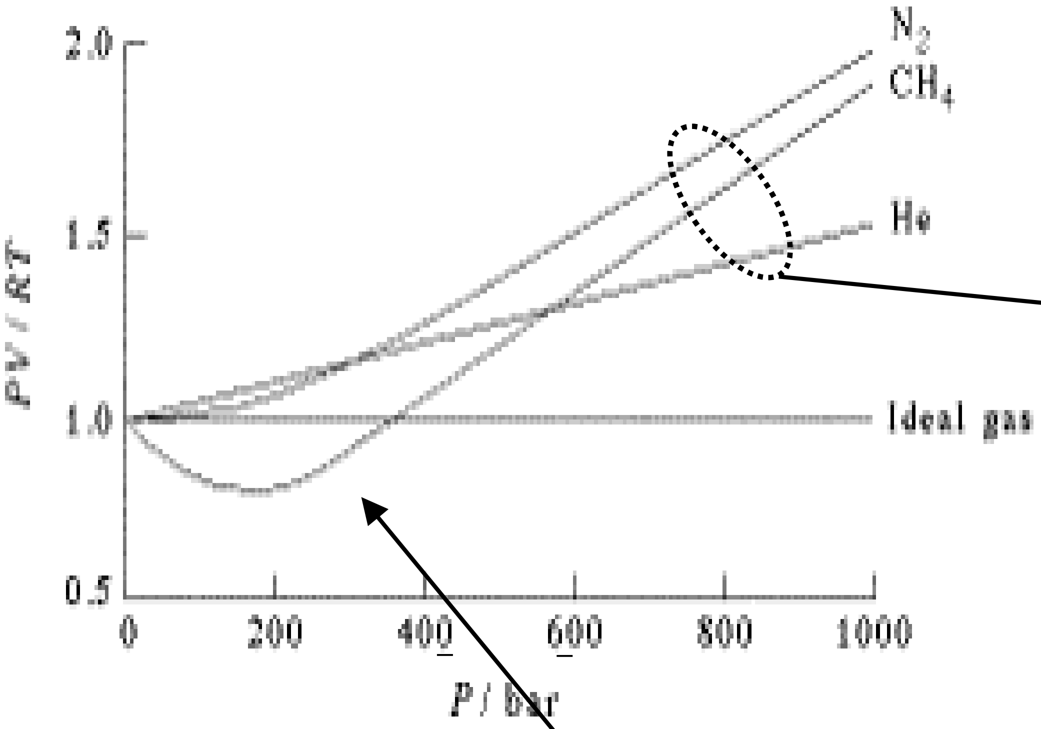
$$Z = \frac{V_{actual}}{V_{ideal}}$$



Compressibility Factor



Compressibility Factor



A high pressure, molecules are more influenced by repulsive forces.

$V_{real} > V_{ideal}$

$\therefore\ Z > 1$

The effect of molecular attraction causes:

$V_{real} < V_{ideal}$

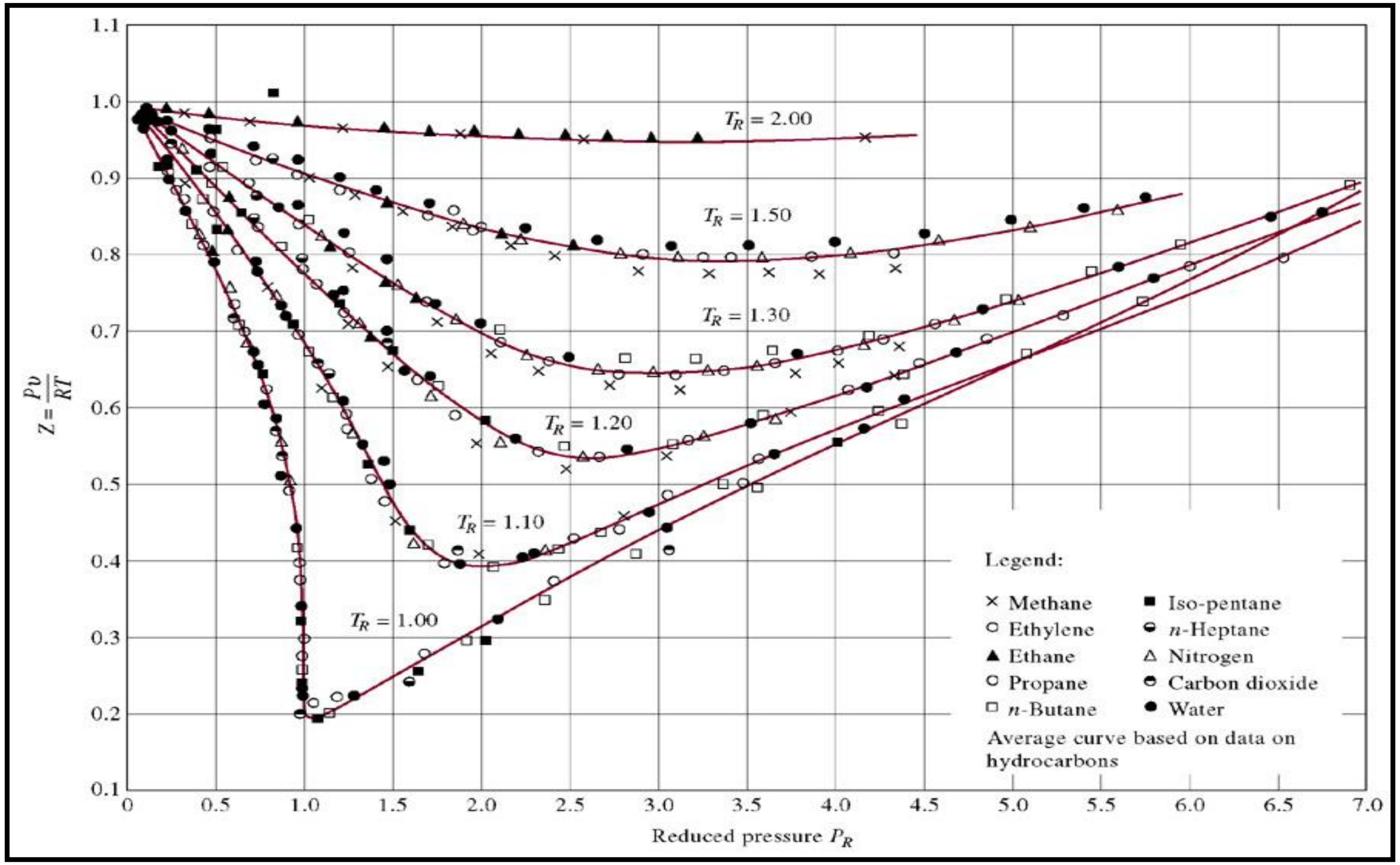
$\therefore\ Z < 1$

Compressibility Factor

- What is it really doing?
- It accounts mainly for two things
  - Molecular structure
  - intermolecular attractive forces
- Still we have a problem?
- Universal Z factor chart. (How?)
- The compressibility factor Z is approximately the same for all gases at the same reduced temperature and reduced pressure.

$$Z = Z(P_R, T_R) \text{ for all gases}$$

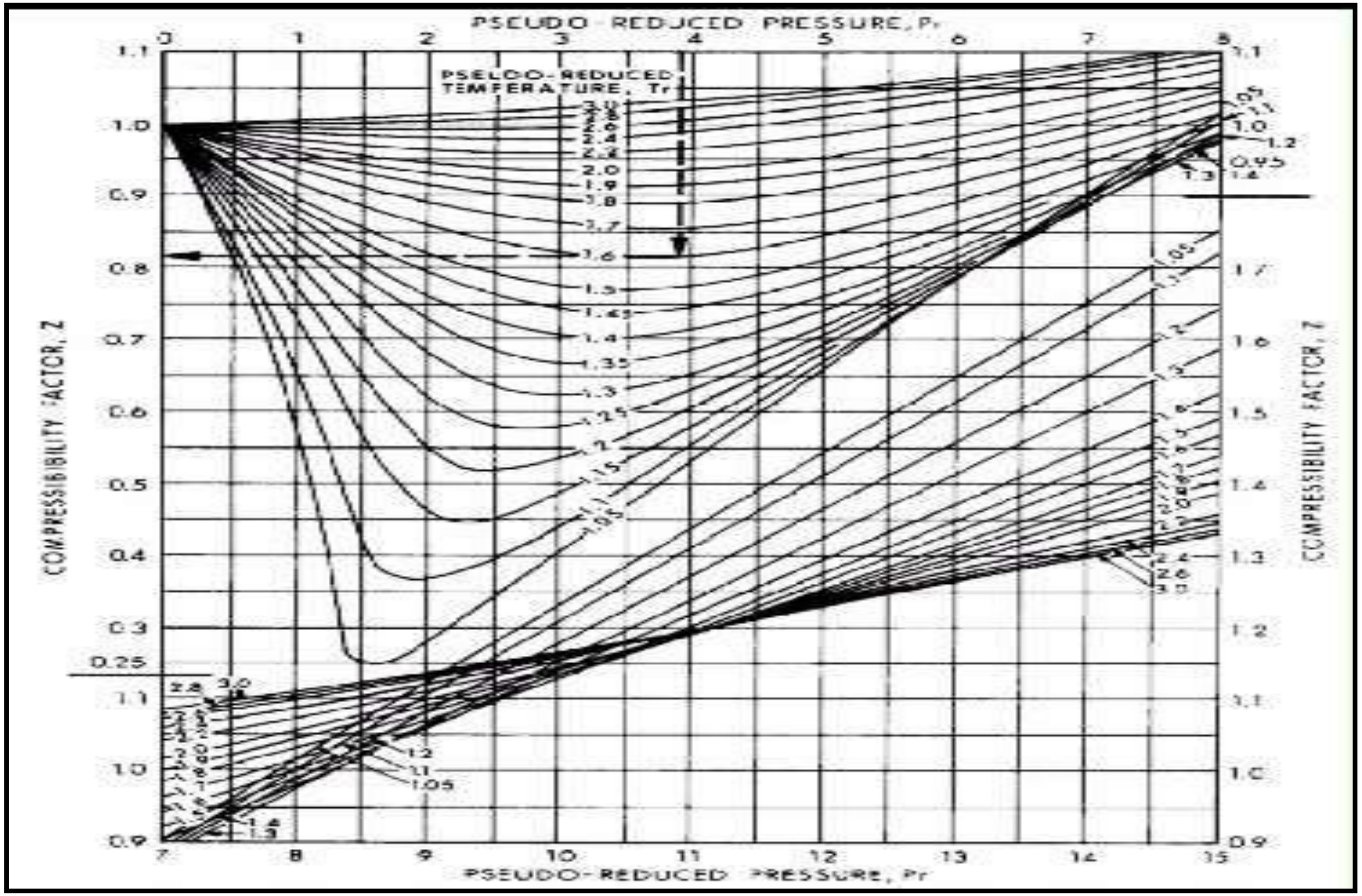
Compressibility Factor



Compressibility Factor

- $P_R = (reduced\ pressure)$
- $T_R = (reduced\ temperature)$
- $P_R = \frac{P}{P_c}$
- $T_R = \frac{T}{T_c}$
- What about gas mixture?
- Pseudo-critical pressure (P_{pc})
- Pseudo-critical temperature (T_{pc})
- $P_{pc} = \sum_{i=1}^{n} y_i\, P_{ci}$ $\qquad P_{pr} = \frac{P}{P_{pc}}$
- $T_{pc} = \sum_{i=1}^{n} y_i\, T_{ci}$ $\qquad T_{pr} = \frac{T}{T_{pc}}$

Compressibility Factor



Compressibility Factor

➢ <u>Example:</u>

A gas reservoir has the following gas composition: the initial reservoir pressure and temperature are 3000 psia and 180°F, respectively.

Component	y_i
CO_2	0.02
N_2	0.01
C_1	0.85
C_2	0.04
C_3	0.03
$i - C_4$	0.03
$n - C_4$	0.02

Calculate the gas compressibility factor under initial reservoir conditions.

Compressibility Factor

Solution:

Component	y_i	T_{ci}, °R	y_iT_{ci}	p_{ci}	$y_i\ p_{ci}$
CO_2	0.02	547.91	10.96	1071	21.42
N_2	0.01	227.49	2.27	493.1	4.93
C_1	0.85	343.33	291.83	666.4	566.44
C_2	0.04	549.92	22.00	706.5	28.26
C_3	0.03	666.06	19.98	616.4	18.48
i - C_4	0.03	734.46	22.03	527.9	15.84
n - C_4	0.02	765.62	15.31	550.6	11.01
			$T_{pc} = 383.38$		$p_{pc} = 666.38$

- $P_{pr} = \frac{3000}{666.38} = 4.5$
- $T_{pr} = \frac{(180+460)}{383.38} = 1.67$
- $Z = 0.85$

Gas Density

- $PV = ZnRT$
- $\rho = \frac{W}{V}$
- $n = \frac{W}{M_W}$
- $PV = \frac{W}{M_W} ZRT$
- $P\, M_W = \frac{W}{V} ZRT = \rho\, ZRT$
- $\rho = \frac{PM_W}{ZRT}$
- What about mixture?
- $\rho_g = \frac{PM_a}{ZRT}$
- $M_a = \sum_{i=1}^{n} y_i\, M_i$

Gas Density

Example:

Use the data given in the previous example to estimate the gas mixture density.

Solution:

Input: *P* = 3000 psia, *T*= 180 °F, *Z* = 0.85 (estimated from the z-factor chart)

- $\rho_g = \frac{PM_a}{ZRT}$
- $M_a = \sum_{i=1}^{n} y_i \, M_i$
- $M_a = 20.23$
- $\rho_a = \frac{(3000)(20.23)}{(0.85)(10.73)(180+460)} = 10.4 \, lb/ft^3$

Critical Properties Correlation

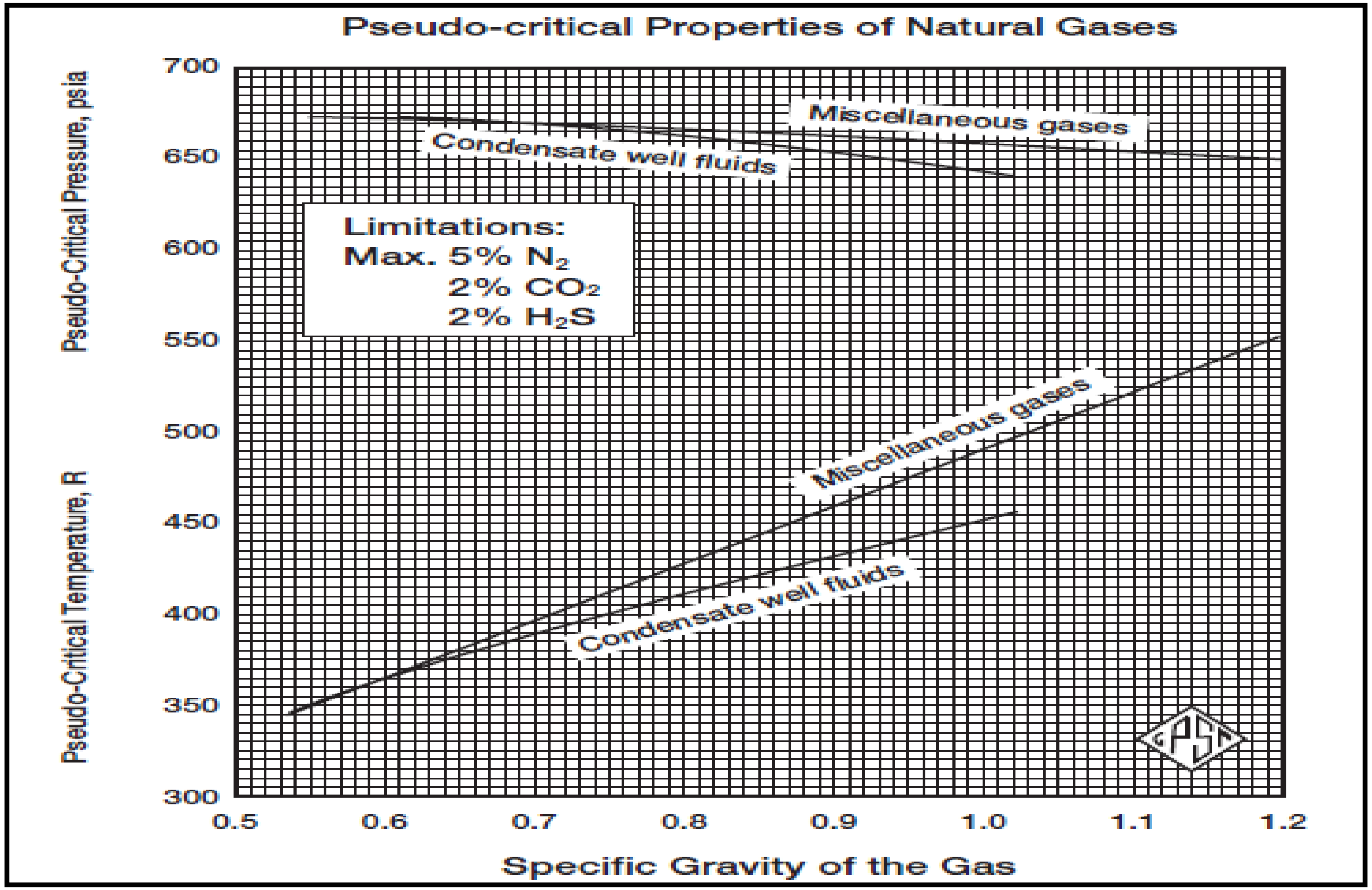
- Natural gas systems

$$T_{pc} = 168 + 325\,\gamma_g - 12.5\,{\gamma_g}^2$$
$$P_{pc} = 677 + 15.0\,\gamma_g - 37.5\,{\gamma_g}^2$$

- Condensate systems

$$T_{pc} = 187 + 330\,\gamma_g - 71.5\,{\gamma_g}^2$$
$$P_{pc} = 706 + 51.7\,\gamma_g - 11.1\,{\gamma_g}^2$$

Critical Properties Correlation



Non-HC Component effect on Z-factor

N_2, CO_2, and H_2S

HC

- Sour (1 gm of H_2S/100 ft^3)
- Sweet

Both sour and sweet gases contain CO_2, N_2 or both.

No significant effect for concentration < 5%

10% error for higher concentration.

Pseudo-critical properties need adjustment

- Wichert-Aziz correction method

Non-HC Component on Z-factor

Whichert-Aziz correction method

Why we need correction?

$T_{pc}' = T_{pc} - \varepsilon$

$P_{pc}' = \frac{P_{pc}T_{pc}'}{T_{pc}+B(1-B)\varepsilon}$

B = mole fraction of H_2S

ε = pseudo-critical temperature adjustment factor

$\varepsilon = 120 \times (A^{0.9} - A^{1.6}) + 15 \times (B^{0.5} - B^4)$

A = sum of CO_2 and H_2S mole fraction

Non-HC Component on Z-factor

Example:

A sour gas (sp. gr. 0.7) contains 5% CO_2 and 10% H_2S.

Calculate the density of the gas at (3500 psia and 160 °F)

Solution:

$T_{pc} = 168 + 325(0.7) - 12.5(0.7)^2$ = 389.38 °R

$P_{pc} = 677 + 15(0.7) - 37.5(0.7)^2$ = 669.1 psia

$\varepsilon = 120 \times (0.15^{0.9} - 0.15^{1.6}) + 15 \times (0.1^{0.5} - 0.1^{4})$ = 20.735 °R

$T_{pc}' = 389.38 - 20.735$ = 368.64 °R

$P_{pc}' = \frac{(669.1)(368.64)}{(389.38+0.1(1-0.1)(20.735)}$ = 630.44 psia

Non-HC Component on Z-factor

Example:

A sour gas (sp. gr. 0.7) contains 5% CO_2 and 10% H_2S.

Calculate the density of the gas at (3500 psia and 160 °F)

Solution cont.:

$P_{pr} = \frac{3500}{630.44}$ = 5.55

$T_{pr} = \frac{(160+460)}{368.64}$ = 1.68

Z = 0.89

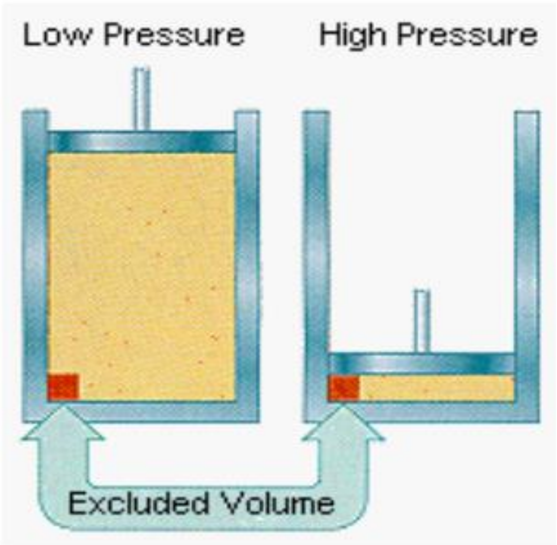
Ma = (28.96)(0.7) = 20.27

$\rho_g = \frac{(3500)(20.27)}{(0.89)(10.73)(620)}$ = 11.98 lb/ft^3

Van der Waals' equation

One mole of single pure gas (not applicable for gas mixture)

$$\left(P + \frac{a}{V^2}\right)(V - b) = RT$$



For n moles

$$\left(P + \frac{n^2 a}{V^2}\right)(V - nb) = nRT$$

a and b constant (different for each gas)

$\frac{a}{V^2}$ accounts for the attraction forces between molecules

b represents the volume of the molecules

At low pressure and high temperature the volume V is large and the above equation can be reduced to the general gas law (perfect gas behavior)

$$PV = nRT$$

Van der Waals' equation

For the units P (atm.), V (liters), T (°K), and R (0.08205) a and b are as follows:

Gas	**a** (atm liters2)	**b** (liters)
CH_4	2.253	0.04278
C_2H_6	5.489	0.0638
C_2H_4	4.471	0.05714
C_2H_2	4.39	0.05136
CO_2	3.592	0.04267

or, from critical data:

$$a = 3P_cV_c^{\ 2}$$

$$b = \frac{V_c}{3}$$

V_c : critical volume

P_c : critical pressure

Van der Waals' equation

Which gas has the lowest value of **a**? why?

Which gas has the largest value of **b**? why?

Substance	a	b	P_c	T_c
	($J \cdot m^3/mole^2$)	($m^3/mole$)	(MPa)	(K)
Air	0.1358	3.64×10^{-5}	3.77	133 K
Carbon Dioxide (CO_2)	0.3643	4.27×10^{-5}	7.39	304.2 K
Nitrogen (N_2)	0.1361	3.85×10^{-5}	3.39	126.2 K
Hydrogen (H_2)	0.0247	2.65×10^{-5}	1.3	33.2 K
Water (H_2O)	0.5507	3.04×10^{-5}	22.09	647.3 K
Ammonia (NH_3)	0.4233	3.73×10^{-5}	11.28	406 K
Helium (He)	0.00341	2.34×10^{-5}	0.23	5.2 K
Freon (CCl_2F_2)	1.078	9.98×10^{-5}	4.12	385 K

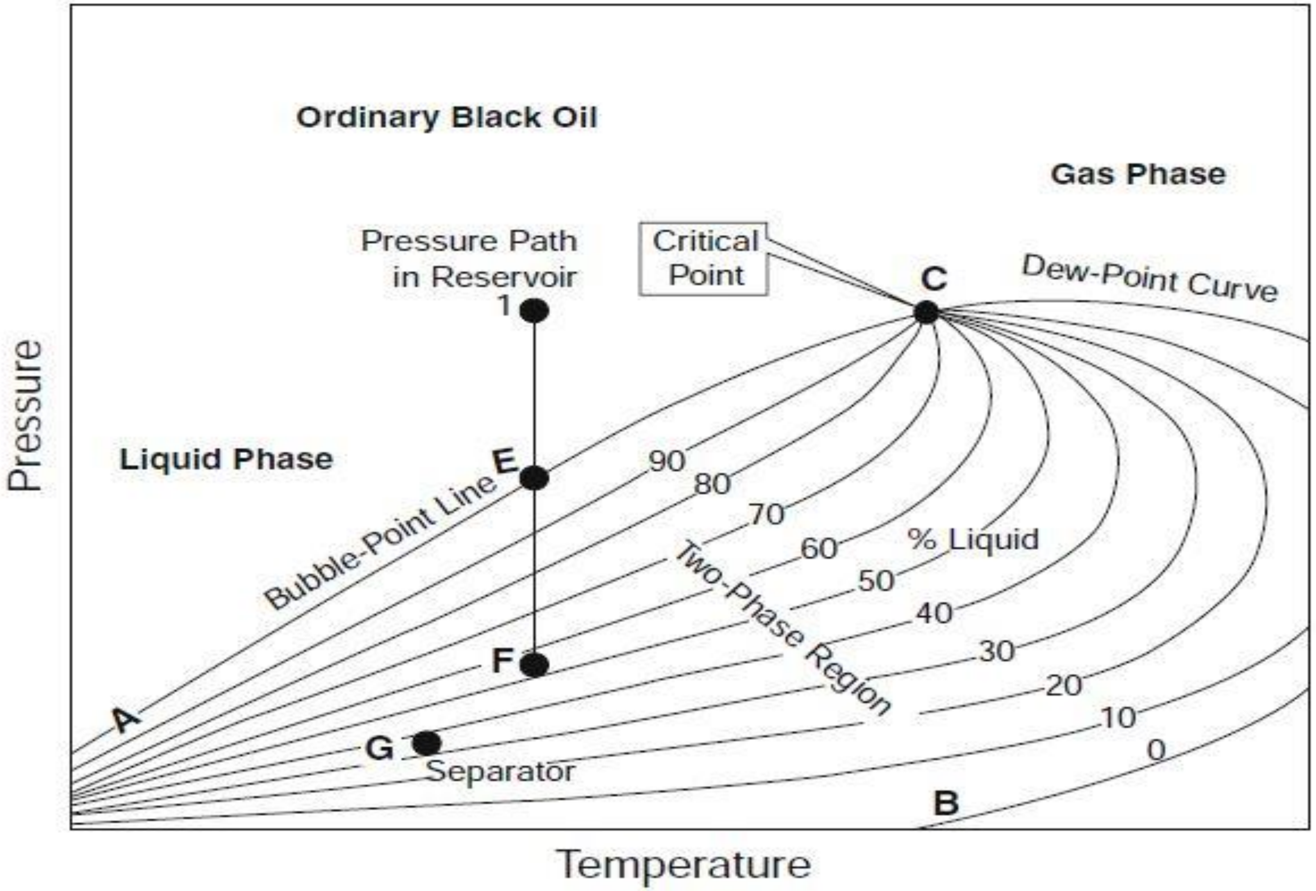
The Five Reservoir Fluids

Types of Reservoir Fluids:

- Black oil
- Volatile oil
- Retrograde gas condensate
- Wet gas
- Dry gas

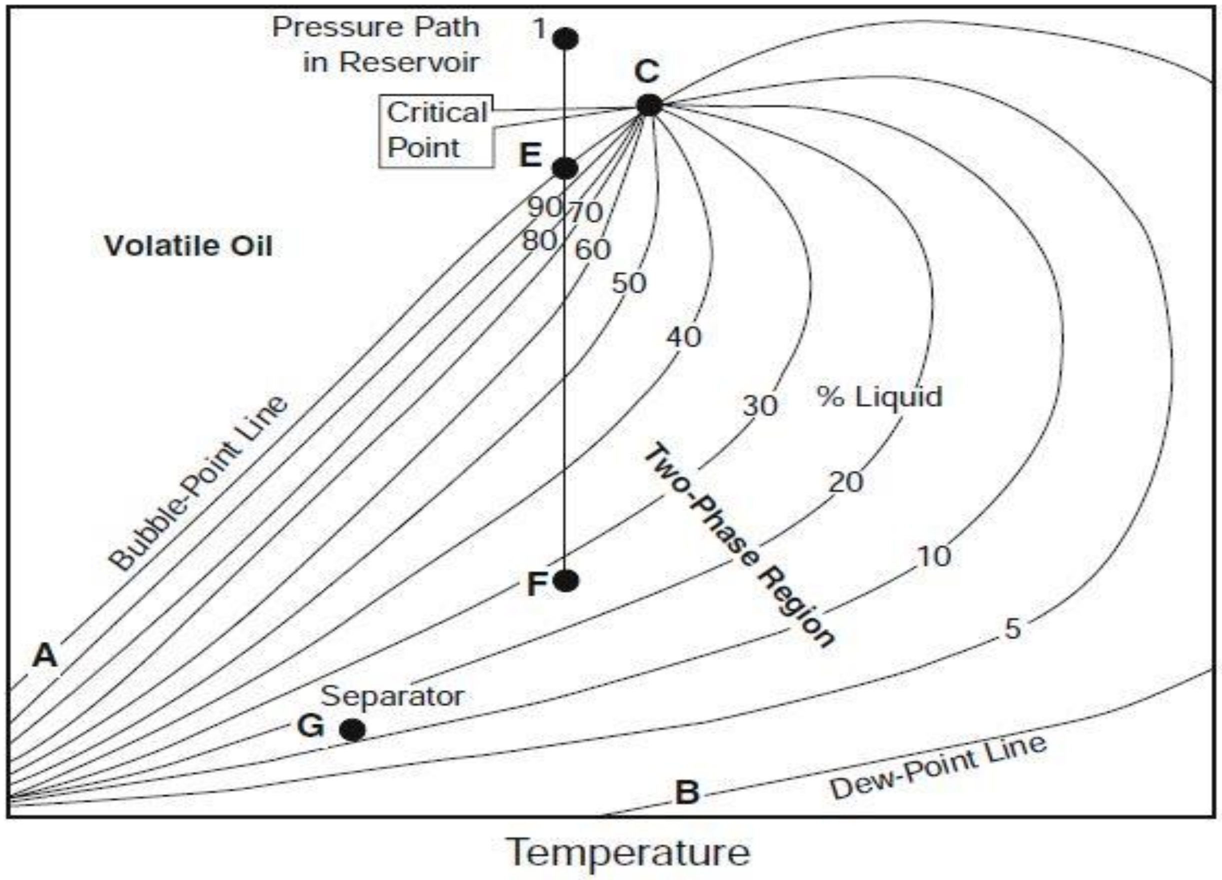
The Five Reservoir Fluids

Black Oil:



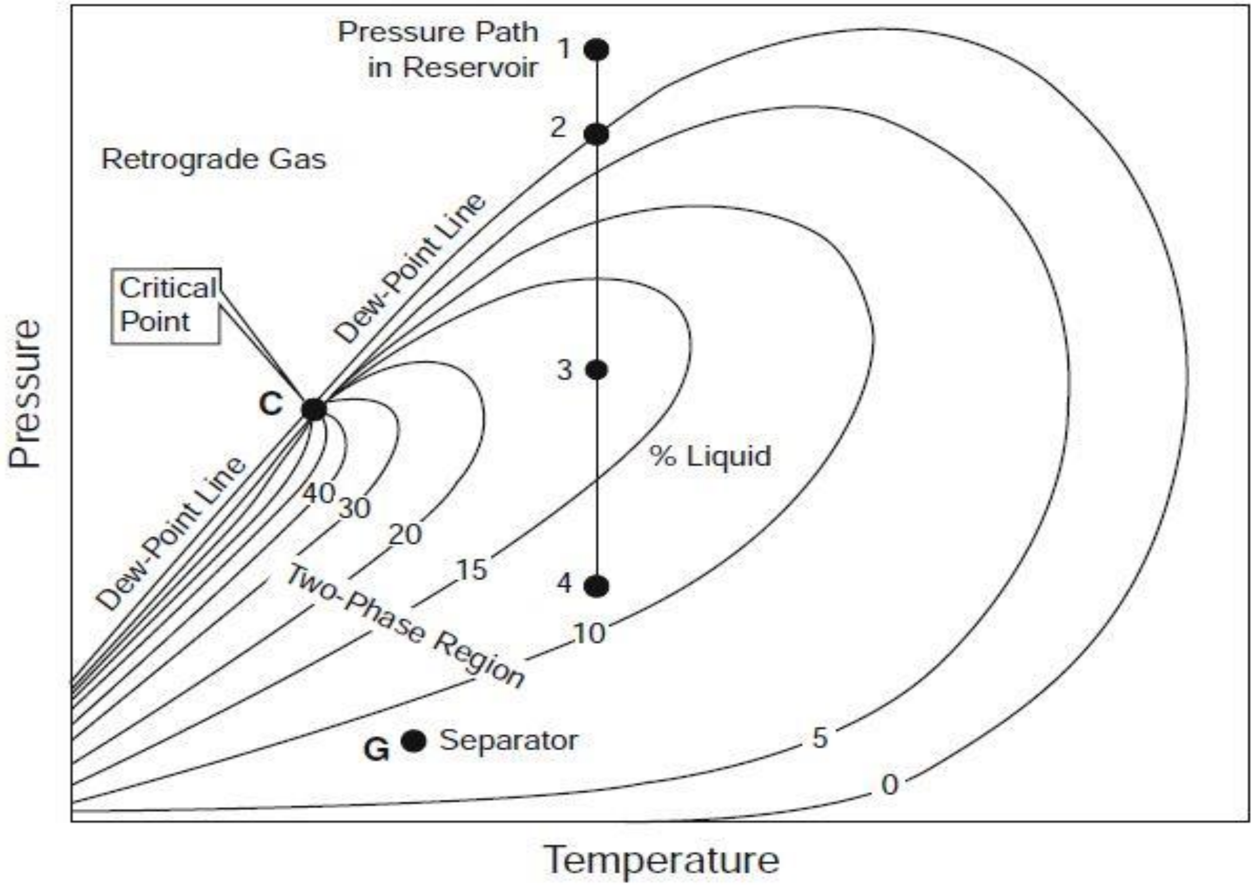
The Five Reservoir Fluids

Volatile Oil:



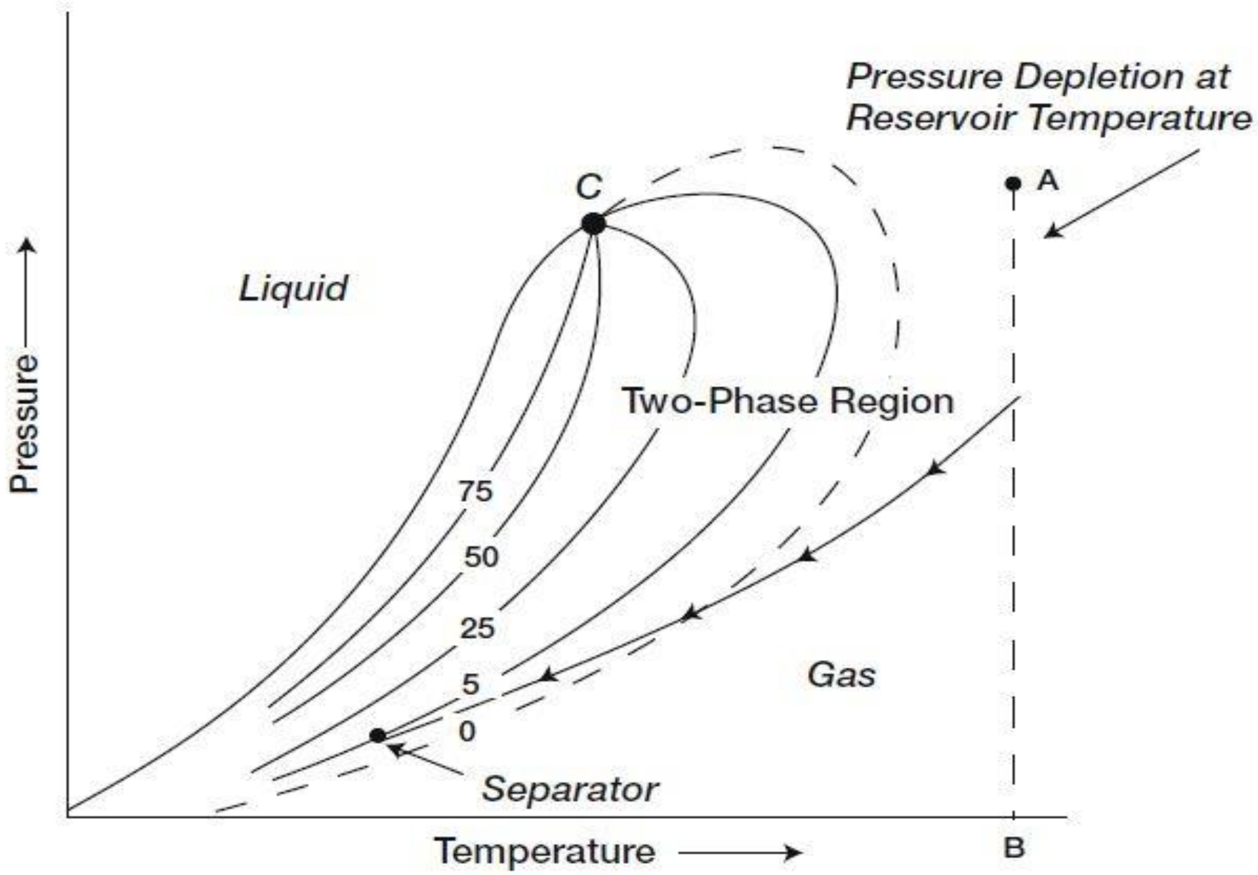
The Five Reservoir Fluids

Retrograde Gas Condensate:



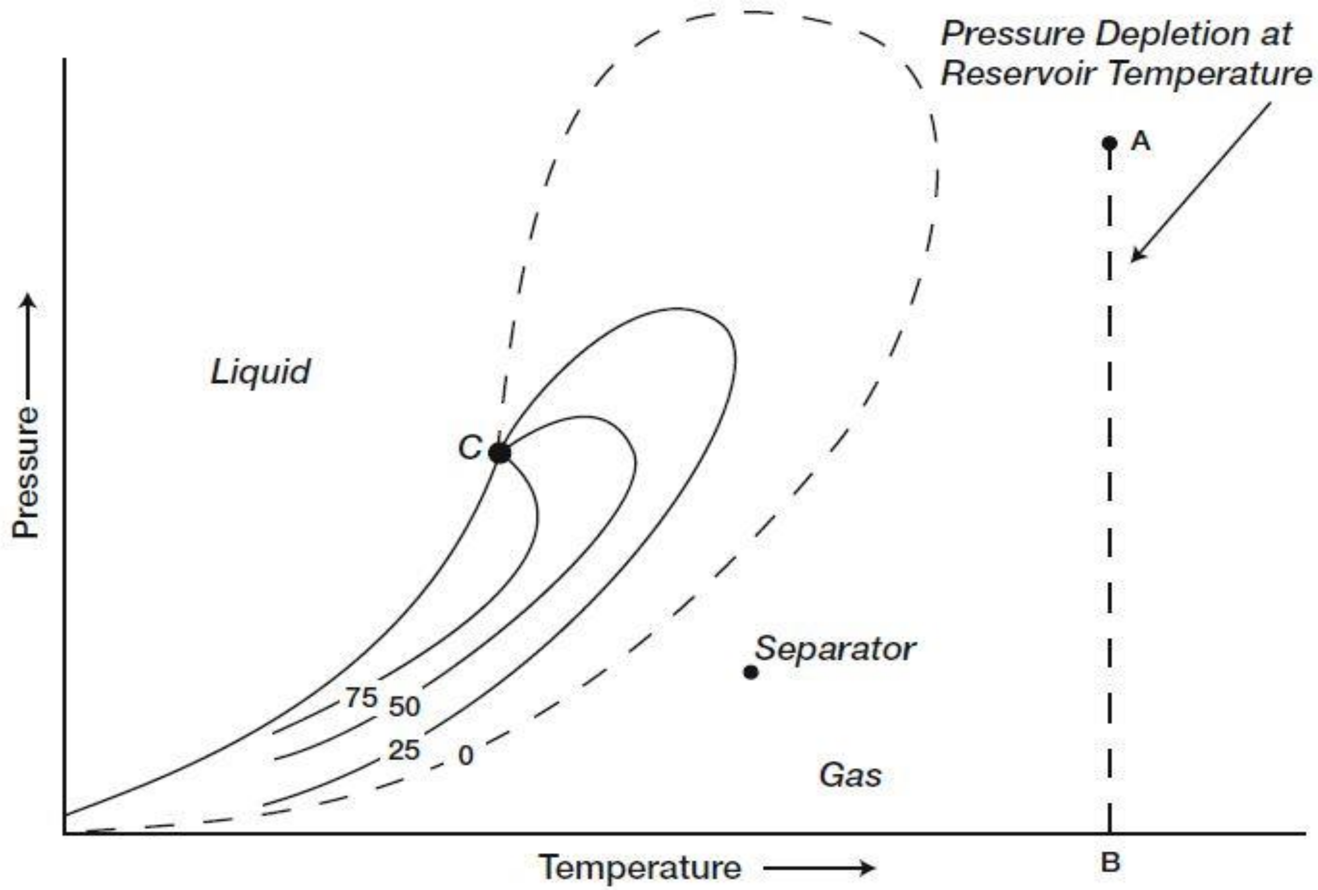
The Five Reservoir Fluids

Wet Gas:



The Five Reservoir Fluids

Dry Gas:



The Five Reservoir Fluids

Component	Black Oil	Volatile Oil	Gas Condensate	Wet Gas	Dry Gas
C_1	48.83	64.36	87.07	95.85	86.67
C_2	2.75	7.52	4.39	2.67	7.77
C_3	1.93	4.74	2.29	0.34	2.95
C_4	1.60	4.12	1.74	0.52	1.73
C_5	1.15	3.97	0.83	0.08	0.88
C_6	1.59	3.38	0.60	0.12	
C_7^+	42.15	11.91	3.80	0.42	
$M_wC_7^+$	225	181	112	157	
GOR	625	2000	18,200	105,000	-
Tank °API	34.3	50.1	60.8	54.7	-
Liquid Color	Greenish Black	Medium Orange	Light Straw	Water White	-

The Five Reservoir Fluids

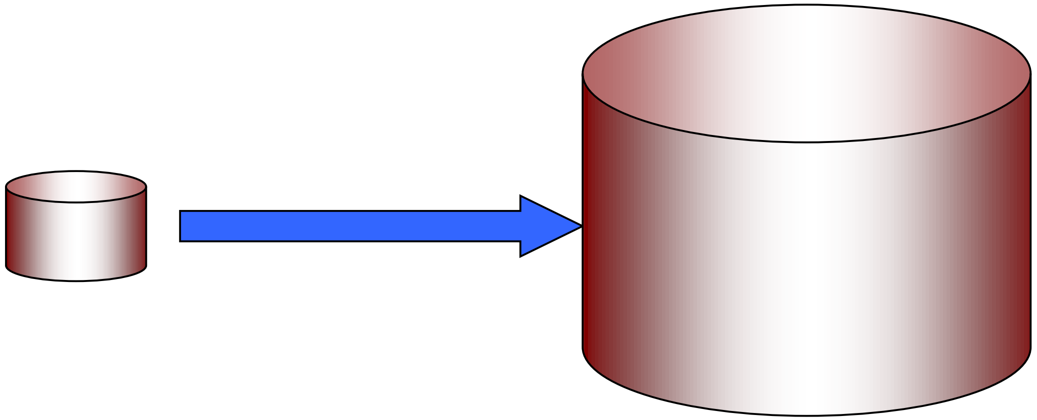
Differences between the three Gases:

- Retrograde gas condensate
  - Recombined surface gas and condensate represents the gas in the reservoir but not the total reservoir fluid (retrograde condensate stays in reservoir)
- Wet gas
  - Recombined surface gas and condensate represents gas in reservoir
- Dry gas
  - Gas at surface is same as gas in reservoir

Gas Properties

Gas Formation Volume Factor (Bg):

The volume of gas at reservoir conditions required to produce one standard volume of gas at the surface condition.



Gas Properties

Gas Formation Volume Factor (Bg):

$$B_g = \frac{V_R}{V_{SC}} = \frac{\frac{znRT}{P}}{\frac{nRT_{SC}}{P_{SC}}}$$

SC: P =14.65 psia, T = 520 °R, z = 1.0

$$B_g = \frac{P_{SC}}{T_{SC}}\frac{zT}{P} = \frac{14.65}{(520)}\frac{zT}{P} = 0.0282\,\frac{zT}{P}\,\frac{res\ cu\ ft}{scf}$$

$$B_g = 0.00502\,\frac{zT}{P}\,\frac{res\ bbl}{scf}$$

$$B_g = 5.02\,\frac{zT}{P}\,\frac{res\ bbl}{Mscf}$$

Volume of an arbitrary amount
of gas at reservoir T & P

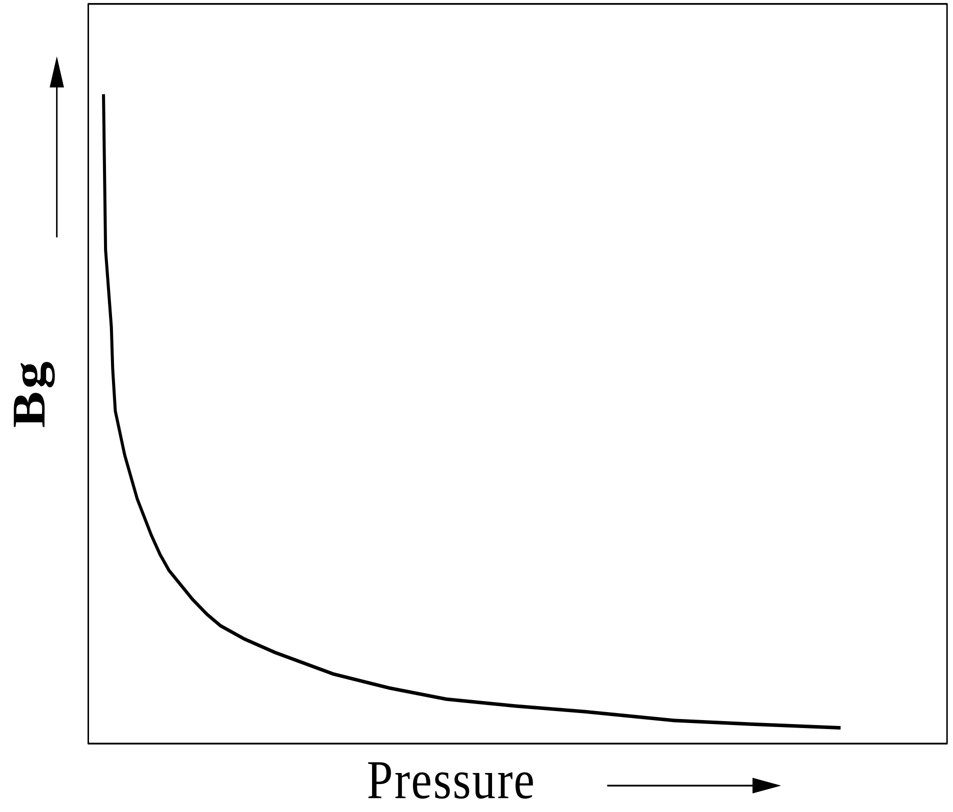
Volume at SAME amount
At standard T & P

$$B_g = \frac{V_R}{V_{SC}}$$

Gas Properties

Gas Formation Volume Factor (Bg):

Typical shape of Bg



Gas Properties

Gas Formation Volume Factor (Bg):

Example:

A gas has a specific gravity of 0.74. Calculate its formation volume factor at 210° F and 2300 psia.

Solution:

Tc = 396° R, *Pc* = 665 psia

$$T_r = \frac{460+210}{396} = 1.69, \; P_r = \frac{2300}{665} = 3.46 \text{ , } z = 0.86$$

$$B_g = 0.00502 \, \frac{(0.86)(670)}{(2300)} = 0.00126 \, \frac{res\ bbl}{scf} = 1.26 \frac{res\ bbl}{Mscf}$$

Gas Properties

Gas Viscosity (μ_g):

Viscosity is a measure of the resistance to flow exerted by a fluid.

Units:

Dynamic (μ): Poise (p) = g mas/(sec cm)

or centipoise (cp) = g mas/(100 sec cm)

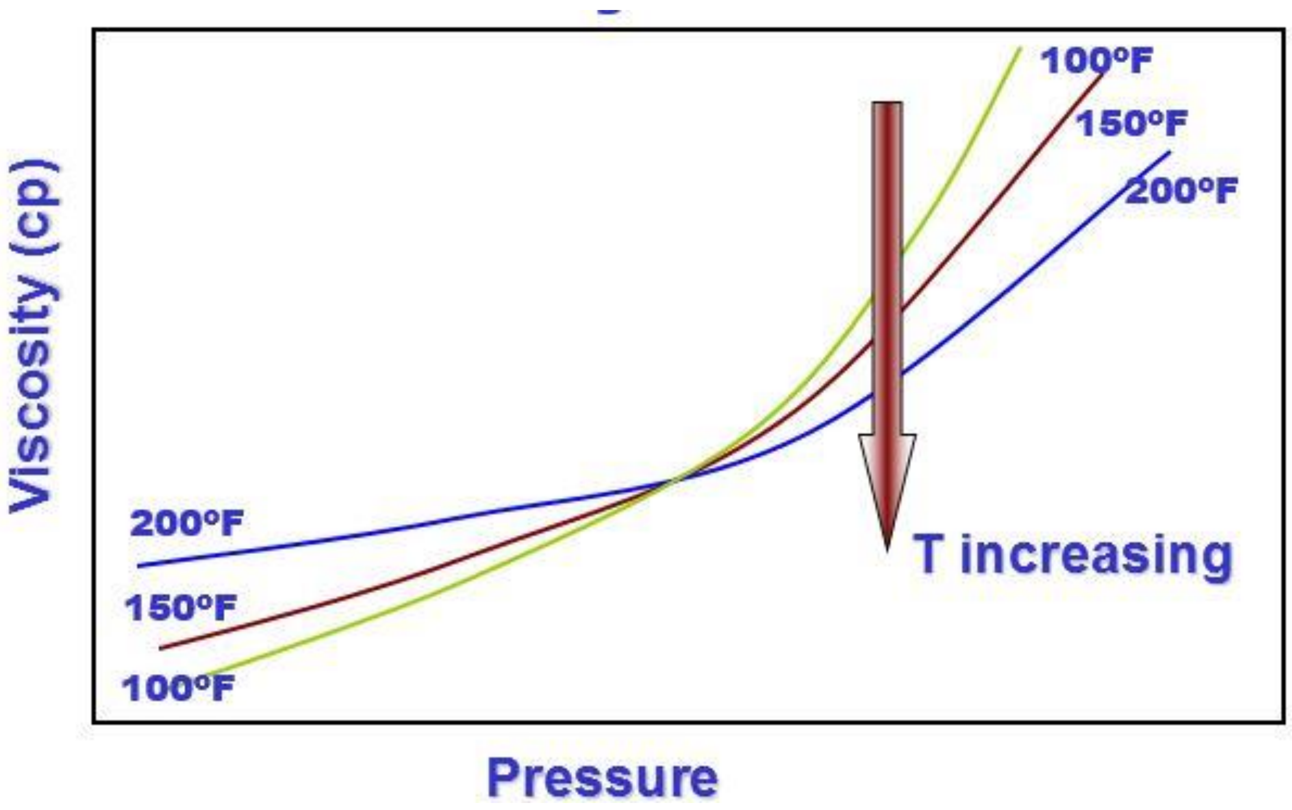
SI unit : Pascal second (Pa s) = 1 kg/(m s) = 10 p

Kinematic (*v*): viscosity/density : centipoise/gm/cc (cp/g/cc)

Gas Properties

Gas Viscosity (μ_g):

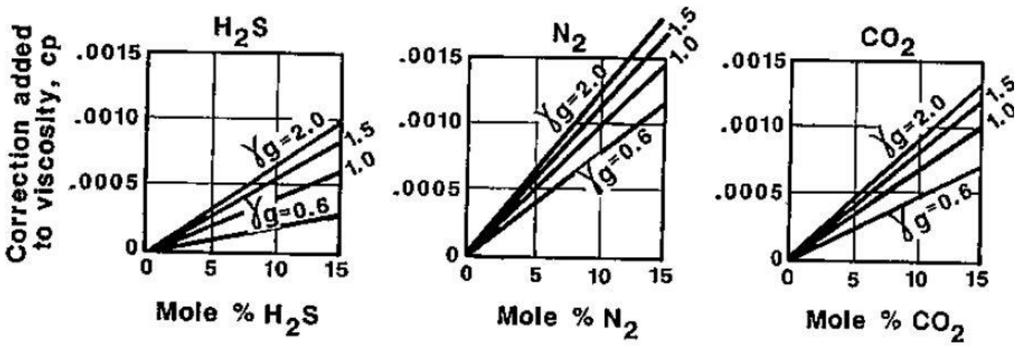
Typical shape:

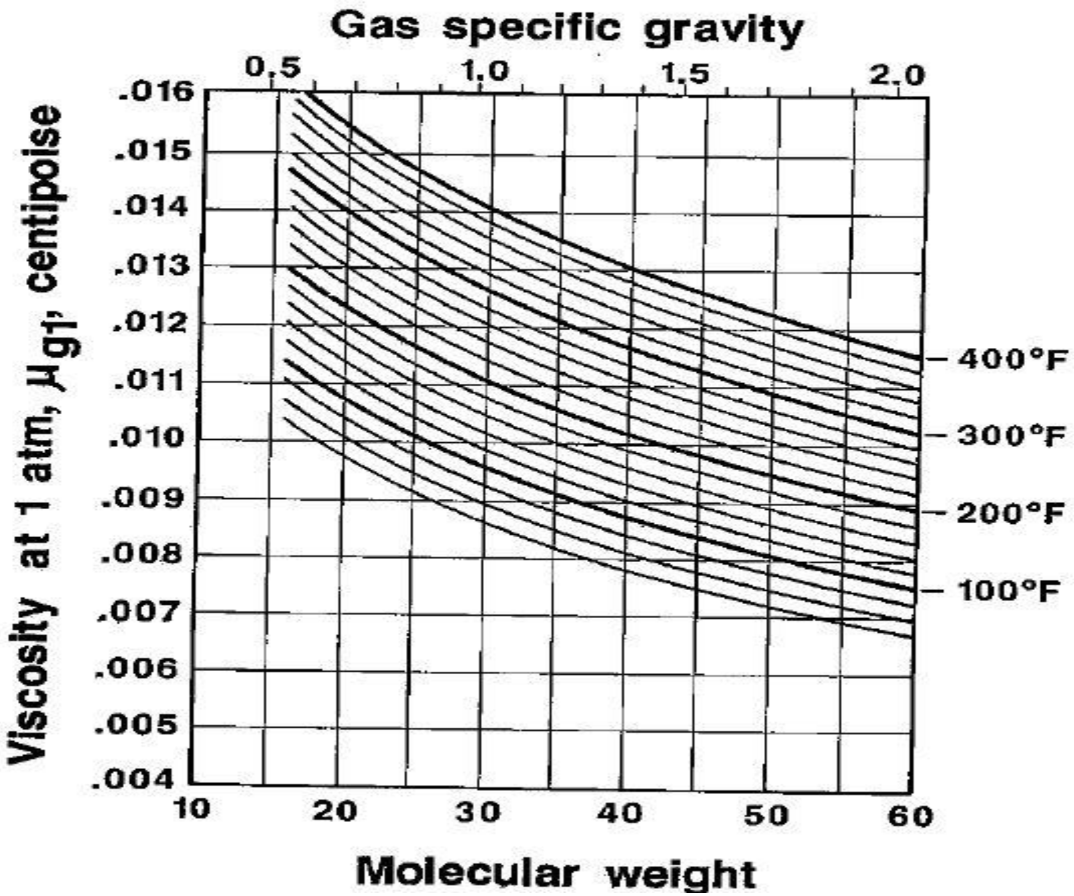


Gas Properties

Gas Viscosity (μ_g):

Correlation:

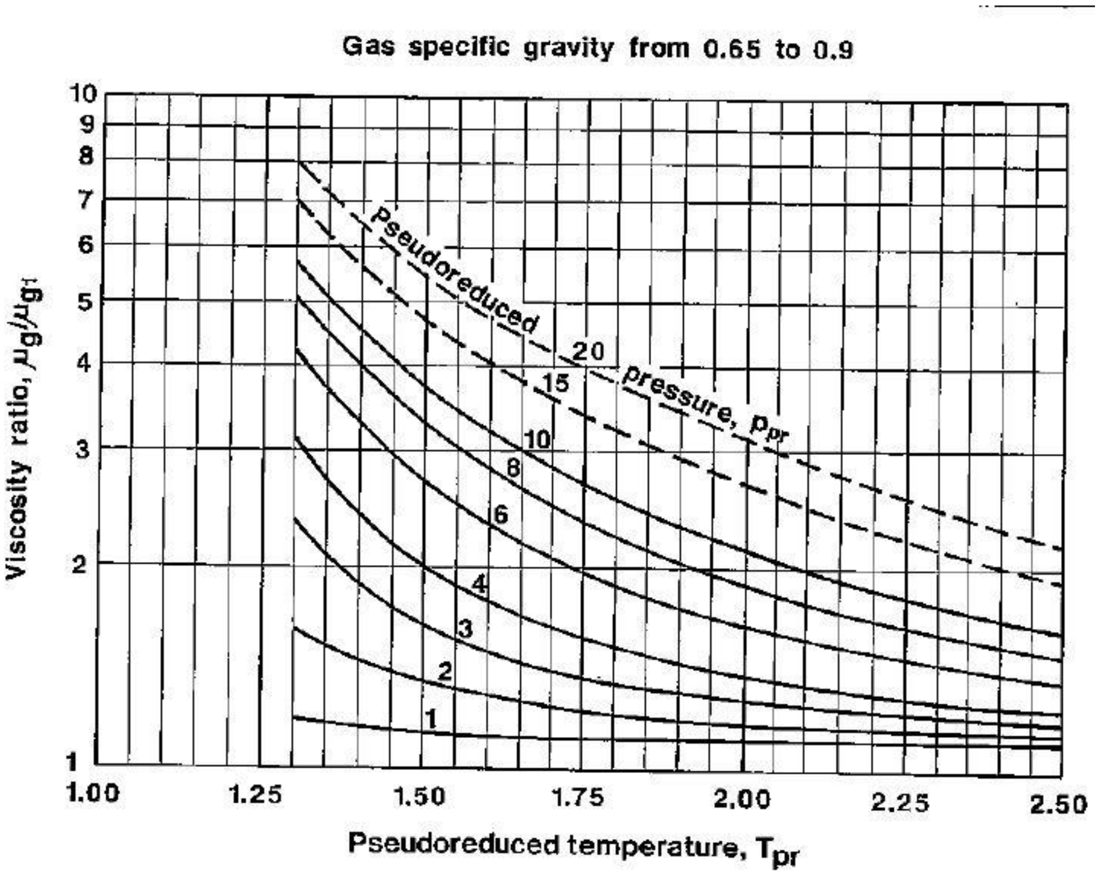




Gas Properties

Gas Viscosity (μ_g):

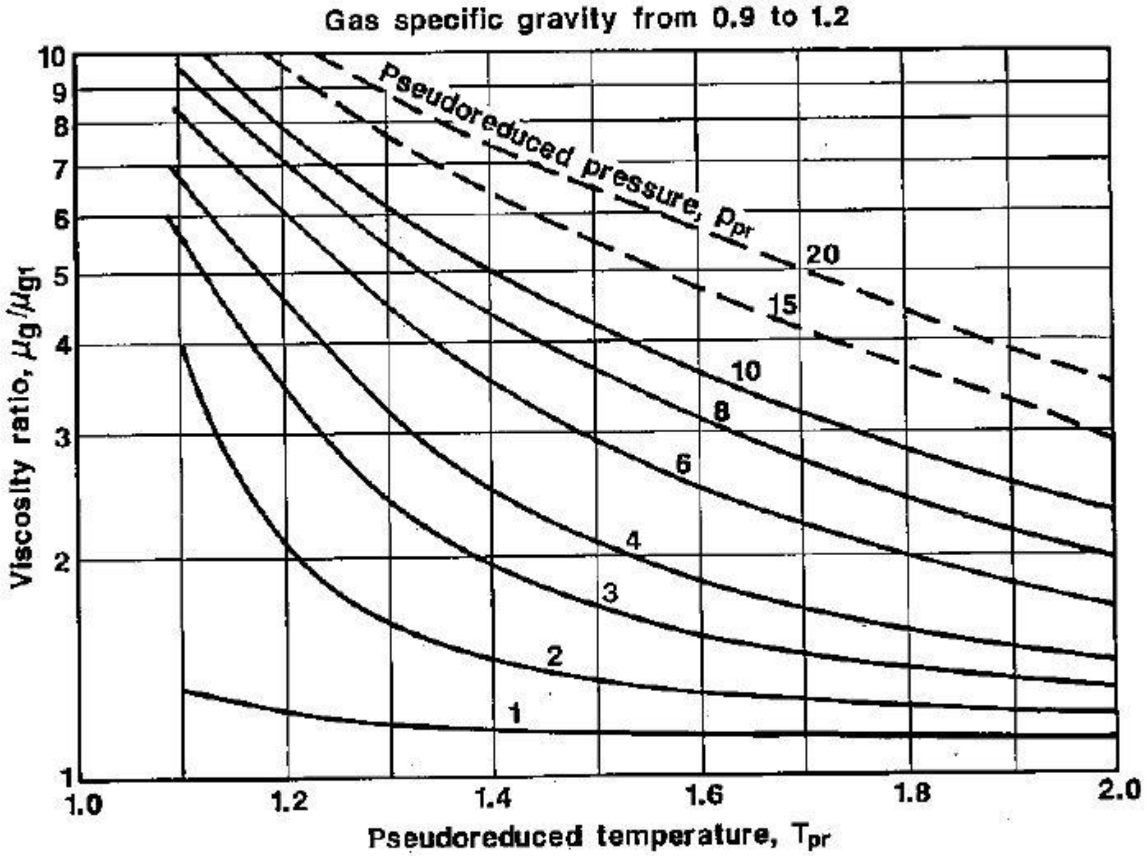
Correlation:



Gas Properties

Gas Viscosity (μ_g):

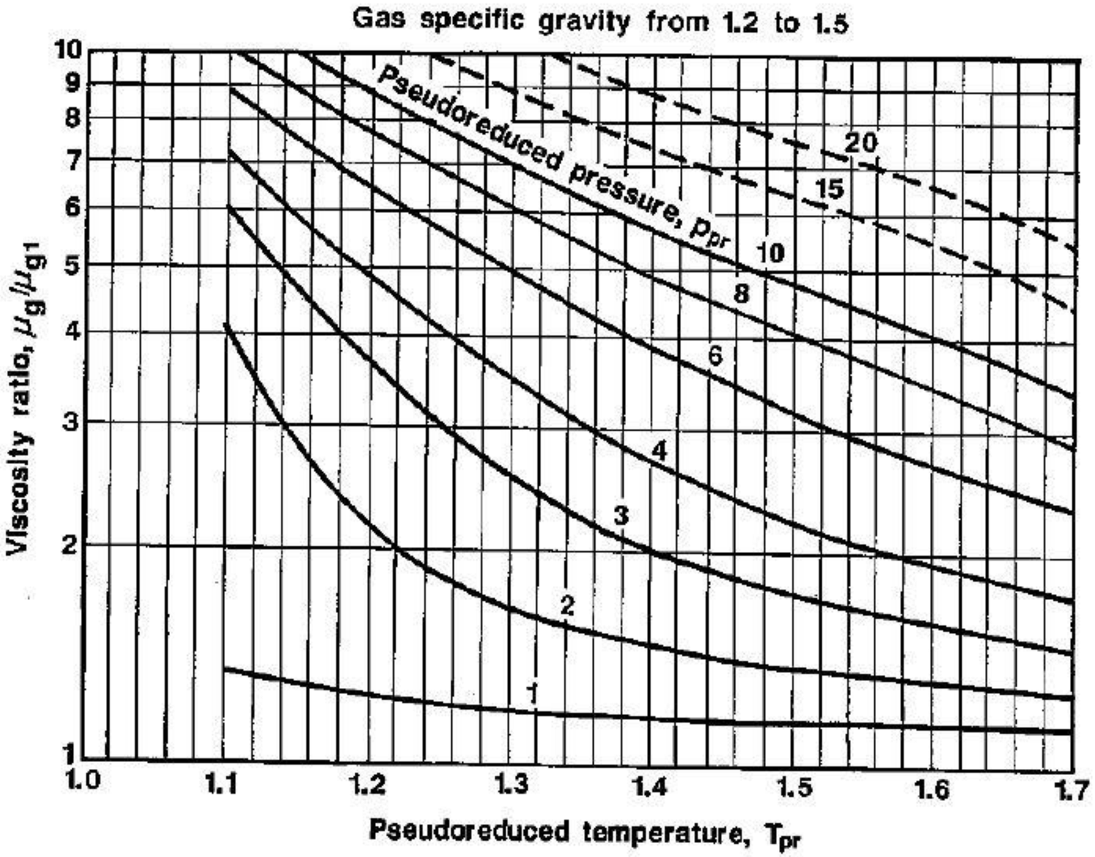
Correlation:



Gas Properties

Gas Viscosity (μ_g):

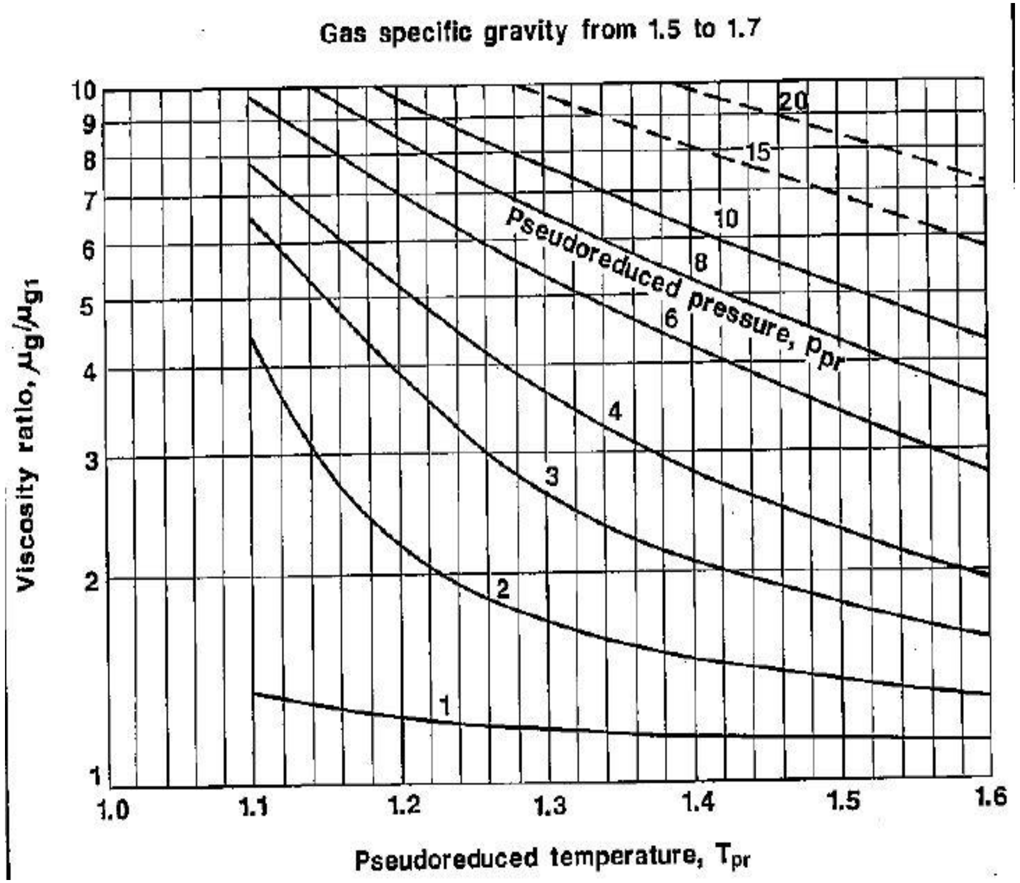
Correlation:



Gas Properties

Gas Viscosity (μ_g):

Correlation:



Gas Properties

Gas Viscosity (μ_g):

Correlation:

EXAMPLE 6–9: *Calculate the viscosity of the gas mixture given below at 200°F and a pressure of one atmosphere absolute.*

Component	Composition, mole fraction
Methane	0.850
Ethane	0.090
Propane	0.040
n-Butane	0.020
	1.000

Gas Properties

Gas Viscosity (μ_g):

Correlation:

Solution:

First, calculate the specific gravity of the gas.

$$M_a = \sum_j y_j M_j$$

Component M_j	y_j	M_j	y_j
C_1	0.85	16.04	13.63
C_2	0.09	30.07	2.71
C_3	0.04	44.10	1.76
$n-C_4$	0.02	58.12	1.16
	1.02	M_a	19.26

$$\gamma_g = \frac{M_a}{29}$$

$$\gamma_g = \frac{19.26}{29} = 0.664$$

Second, determine viscosity.

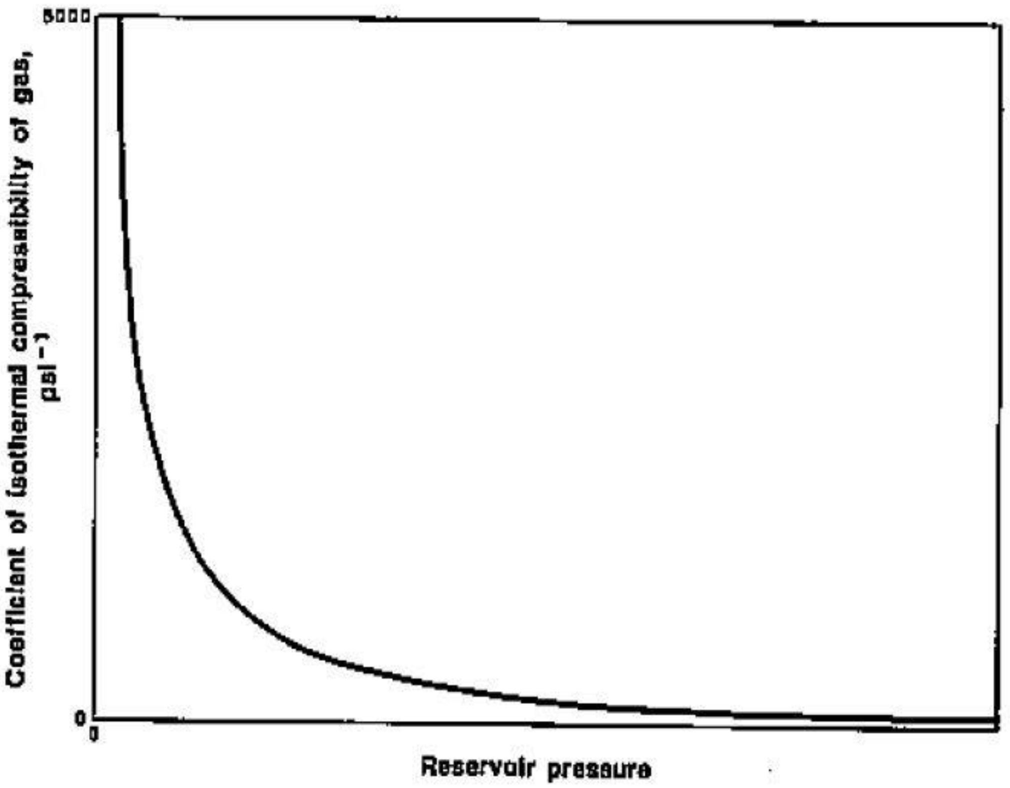
$$\mu_{g1} = 0.0125 \text{ cp at } 200°F, \text{ Figure 6–8}$$

Gas Properties

<u>Coefficient of Isothermal Compressibility of Gas (c_g):</u>

The change in gas volume per change in pressure at constant temperature.

$$c_g = -\frac{1}{V}\left(\frac{\partial V}{\partial P}\right)_T$$



Gas Properties

Coefficient of Isothermal Compressibility of Gas (c_g):

$$c_g = -\frac{1}{V}\left(\frac{\partial V}{\partial P}\right)_T$$

Ideal Gas: $V = \frac{nRT}{P} : \frac{\partial V}{\partial P} = -\frac{nRT}{P^2}$

$$c_g = -\left(\frac{P}{nRT}\right)\left(-\frac{nRT}{P^2}\right) = \frac{1}{P}$$

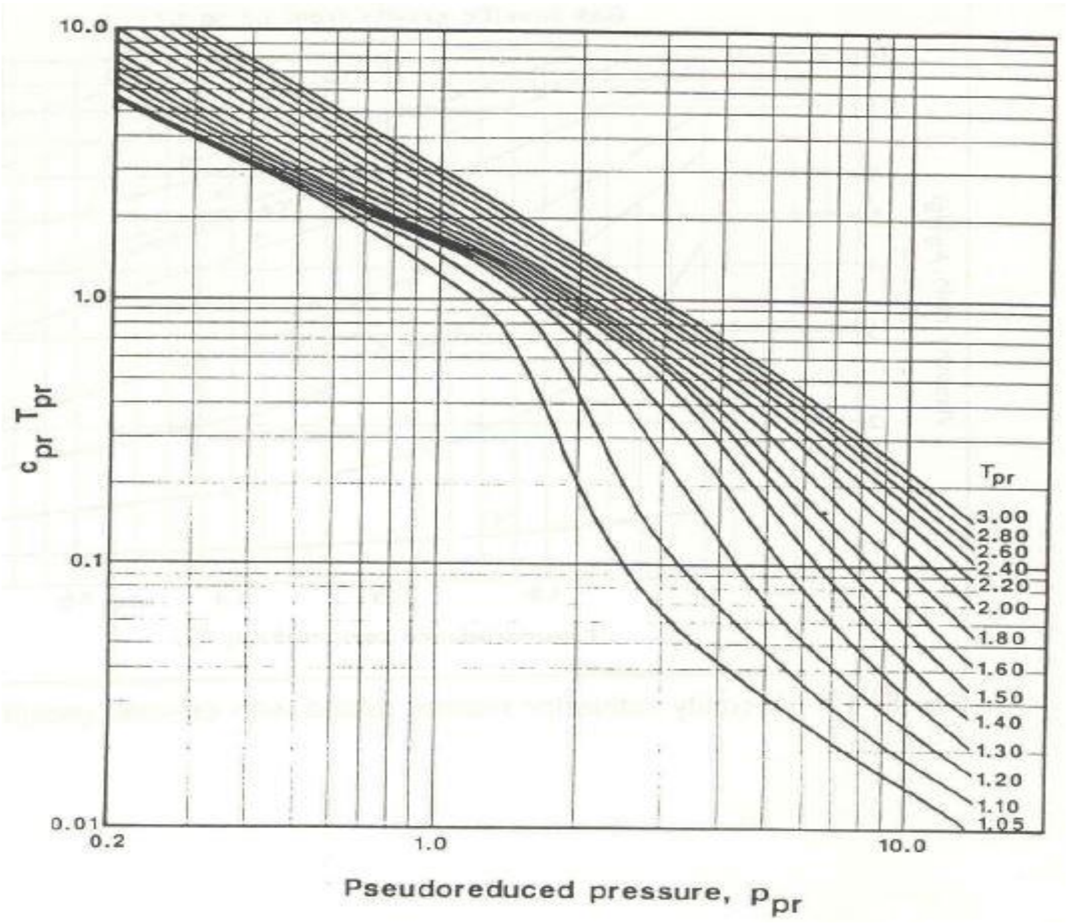
Real Gas: $V = \frac{znRT}{P} : \frac{\partial V}{\partial P} = nRT\,\frac{P\left(\frac{\partial z}{\partial P}\right)_T - z}{P^2}$

$$c_g = -\left(\frac{P}{znRT}\right)\left[nRT\,\frac{P\left(\frac{\partial z}{\partial P}\right)_T - z}{P^2}\right]$$

$$c_g = \frac{1}{P} - \frac{1}{z}\left(\frac{\partial z}{\partial P}\right)_T$$

Gas Properties

<u>Coefficient of Isothermal Compressibility of Gas (c_g):</u>



Gas Properties

Coefficient of Isothermal Compressibility of Gas (c_g):

Example:

Calculate the coefficient of isothermal compressibility of a dry gas with specific gravity of 0.818 at reservoir temperature of 220° F and 2100 psig.

Solution:

T_{pc} = 406° R

P_{pc} = 647 psig

$C_{pr} = c_g p_{pc}$

$$T_{pr} = 1.68 \text{ and } p_{pr} = 3.27$$

using appropriate $c_{pr}T_{pr}$ chart.

$$c_{pr}T_{pr} = 0.528$$

$$c_{pr} = \frac{0.528}{1.68} = 0.314$$

$$c_g = \frac{c_{pr}}{p_{pc}} = \frac{0.314}{647 \text{ psia}} = 486 \times 10^{-6} \text{ psi}^{-1}$$