CHE 302
Thermodynamics I

QUIZZES

Oιδ
Molecular weights:

1. Find molecular weight of Carbon Dioxide CO2

2. Find molecular weight of table salt: NaCl
Molecular weights:

• 3. Find molecular weight of Aspirin: C₉H₈O₄

• 4. Find molecular weight of penicillin: C₁₆H₁₈N₂O₄S
Temperature conversion

• 1.. Today is 94°F, what is it in Rankine (°R)?
• In Kelvin (K), and in Celsius (°C)?

• 2.. -195°F (at night on Mars) is how many Kelvin? Degrees °C?
• 3.. In a Carnot engine, the high temperature is 975 °C, and low temperature is 20 °C; what is its thermal efficiency, η?
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Thermodynamics I

QUIZ
OJE
1. Calculate the electrical work

• 1.. Electrical work

• Formula: \[ W = \int V_e dQ_e \]

• What work (in J) is performed when delivering a charge \( Q_e \) of 0.35 Coulomb through a constant voltage \( V_e \) of 23 Volts?

• Note: units 1 Coulomb * 1 Volt = 1 Joule
2. Calculate the surface work

• 1. A surface tension, 
\[ \Gamma \left( \frac{\text{dyne}}{\text{cm}} \right) \], stretches a membrane of surface area by \( A \) \( \text{cm}^2 \)

• Formula: \( W = - \int \Gamma \, dA \)

• What work (in erg) is performed when the tension of 41 \text{dyne/cm} stretches the member surface by 101 \( \text{cm}^2 \)? Is this work positive or negative?
3. Converting lb$_m$ to lb$_f$!

\[ W = \int f \, ds \]

Example: Crane lifts 2000 lb$_m$ over a vertical distance 53 ft.

Calculate the work in ft-lb$_f$!
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Thermodynamics I

QUIZ

OJG
4. Do the same calculation as 3.

- Mass of block is now \( 909.1 \text{ kg} \)
- Distance moved \( 16.16 \text{ m} \)
- Find the work in Joule.
- Convert the Joules to \( \text{ft-lb}_f \).
QUIZ:

• Calculate the volume (in liter) of air (assuming ideal gas, i.e. \( PV = nRT \)) at \( T = 70^\circ F \), and \( P = 1 \) atm for one lbmol.

• Calculate the temperature of nitrogen (ideal gas) at 20 psia and 102 cuft/lbmol.

• Calculate the specific volume (m\(^3\)/kmol) of CO2 (ideal gas) at 0.012 bar and -195\(^\circ\)F.
QUIZ

• Air is contained in a vertical piston–cylinder assembly by a piston of mass 50 kg and having a face area of 0.01 m². The mass of the air is 5 g, and initially the air occupies a volume of 5 liters. The atmosphere exerts a pressure of 100 kPa on the top of the piston. The volume of the air slowly decreases to 0.002 m³ as the specific internal energy of the air decreases by 260 kJ/kg. Neglecting friction between the piston and the cylinder wall, determine the heat transfer to the air, in kJ.
QUIZ

(1) Read the steam tables:
• For steam at
• $T = 520 \, ^\circ C$
• $P = 200 \, \text{bar}$
• Find its specific volume, $v \, (m^3/kg)$,
• Enthalpy $h \, (kJ/kg)$, and internal energy $(kJ/kg)$.

(2) Read the Mollier chart for steam at
• $T = 950 \, ^\circ F$
• $P = 3000 \, \text{psia}$
• Find its enthalpy $h = \text{Btu/lbm}$

(3) Convert the $h$ from (2) to units $kJ/kg$
QUIZ:

• Evaluate the heat capacity $C_p$ (cal/(gmol.K)) of nitrogen

• At $T = 298$ K

• (a) using Book formula, (Table A.21, p.852) &

• (b) using new formula!
New Heat Capacity expression:
(used by API*)

\[C_p^* = B + C\left[\frac{(D/T)}{\sinh(D/T)}\right]^2 + E\left[\frac{(F/T)}{\cosh(F/T)}\right]^2\]

For N2: [ C_p* in cal/(gmol.K)]
B=6.95808,  C=2.03952,  D= 1681.60,  E=0.506863,  F=6535.68

*American Petroleum Institute
\[ \ln y = c x + y + \text{constant} \]

\[ \frac{\partial x}{\partial y} = 0 + x + 0 \]

\[ C_p = C^\text{ideal}_p + C^\text{non-ideal}_p \]

\[ H_2 - H_1 = \int_{T_1}^{T_2} C_p \, dT, \quad U_2 - U_1 = \int_{T_1}^{T_2} C_v \, dT \]

**Table A.21 (p.852)**

<table>
<thead>
<tr>
<th>Gas</th>
<th>( \frac{C_p}{R} )</th>
<th>( \eta )</th>
<th>( \beta )</th>
<th>( \gamma )</th>
<th>( \varepsilon )</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2</td>
<td>3.6375</td>
<td>1.234</td>
<td>0.632</td>
<td>0.226</td>
<td></td>
</tr>
<tr>
<td>N2</td>
<td>6.8375</td>
<td>1.208</td>
<td>0.632</td>
<td>0.226</td>
<td>0.678</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\( R \): gas constant

T: Kelvin
QUIZ

• For ethane at $T=922K$, and volume $v=0.188m^3/kmol$, find its pressure $P$ (bar).
• Use
  (1) ideal gas,
• (2) van der Waals,
• (3) Redlich-kwong equations. Also
• (4) the compressibility chart!

$T_c = 305K$
$P_c = 48.8$ bar
QUIZ

• For 2.77 kmol of $\text{CO}_2$ at 102 atm, volume is 1 m$^3$, find its T in Kelvin.

• Use
  (1) ideal gas,
  (2) van der Waals,
  (3) Redlich-Kwong equations. Also
  (4) the compressibility chart!

Winnick: p.97-98 eg.4.4
487K.
• Use

• $v'_{R} = \overline{v} \left( \frac{P_c}{RT_c} \right)$

• And Figure A-1
Fig. A1. Generalized Z-Chart
<table>
<thead>
<tr>
<th>Substance</th>
<th>( a )</th>
<th>( b )</th>
<th>( a )</th>
<th>( b )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>1.368</td>
<td>0.0367</td>
<td>15.989</td>
<td>0.02541</td>
</tr>
<tr>
<td>Butane ((C_4H_{10}))</td>
<td>13.86</td>
<td>0.1162</td>
<td>289.55</td>
<td>0.08060</td>
</tr>
<tr>
<td>Carbon dioxide ((CO_2))</td>
<td>3.647</td>
<td>0.0428</td>
<td>64.43</td>
<td>0.02963</td>
</tr>
<tr>
<td>Carbon monoxide ((CO))</td>
<td>1.474</td>
<td>0.0395</td>
<td>17.22</td>
<td>0.02737</td>
</tr>
<tr>
<td>Methane ((CH_4))</td>
<td>2.293</td>
<td>0.0428</td>
<td>32.11</td>
<td>0.02965</td>
</tr>
<tr>
<td>Nitrogen ((N_2))</td>
<td>1.366</td>
<td>0.0386</td>
<td>15.53</td>
<td>0.02677</td>
</tr>
<tr>
<td>Oxygen ((O_2))</td>
<td>1.369</td>
<td>0.0317</td>
<td>17.22</td>
<td>0.02197</td>
</tr>
<tr>
<td>Propane ((C_3H_8))</td>
<td>9.349</td>
<td>0.0901</td>
<td>182.23</td>
<td>0.06242</td>
</tr>
<tr>
<td>Refrigerant 12</td>
<td>10.49</td>
<td>0.0971</td>
<td>208.59</td>
<td>0.06731</td>
</tr>
<tr>
<td>Sulfur dioxide ((SO_2))</td>
<td>6.883</td>
<td>0.0569</td>
<td>144.80</td>
<td>0.03945</td>
</tr>
<tr>
<td>Water ((H_2O))</td>
<td>5.531</td>
<td>0.0305</td>
<td>142.59</td>
<td>0.02111</td>
</tr>
</tbody>
</table>

*Source: Calculated from critical data.*
## Table A-24E

### Constants for the van der Waals, Redlich–Kwong, and Benedict–Webb–Rubin Equations of State

1. **van der Waals and Redlich–Kwong**: Constants for pressure in atm, specific volume in ft\(^3\)/lbmol, and temperature in °R.

<table>
<thead>
<tr>
<th>Substance</th>
<th>van der Waals</th>
<th>Redlich–Kwong</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(a) atm ((\text{ft}^3)/lbmol)(^2)</td>
<td>(b) ft(^3)/lbmol</td>
</tr>
<tr>
<td>Air</td>
<td>345</td>
<td>0.586</td>
</tr>
<tr>
<td>Butane (C(<em>4)H(</em>{10}))</td>
<td>3,509</td>
<td>1.862</td>
</tr>
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<td>Carbon dioxide (CO(_2))</td>
<td>926</td>
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<td>Sulfur dioxide (SO(_2))</td>
<td>1,738</td>
<td>0.910</td>
</tr>
<tr>
<td>Water (H(_2)O)</td>
<td>1,400</td>
<td>0.488</td>
</tr>
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</table>

**Source**: Calculated from critical data.

2. **Benedict–Webb–Rubin**: Constants for pressure in atm, specific volume in ft\(^3\)/lbmol, and temperature in °R.
Three equations of State

- Ideal Gas

- Van der Waals (vdW)

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

- Redlich-Kwong (RK)

\[
P = \frac{RT}{V_m - b} - \frac{a}{\sqrt{T} V_m (V_m + b)},
\]
QUIZ

• For ammonia at $T = 60^\circ F$, and volume $v = 7.9134$ ft$^3$/lb$_m$, find its pressure in psia.

• Use (i) ideal gas, and

• (2) van der Waals, and

• (3) Redlich-Kwong

• $T_c = 730^\circ R$

• $P_c = 111.3$ atm

• 1 lbmol NH$_3$ = 17 lb$_m$, 1 atm = 14.7 psia

• $R = 0.7302$ atm*ft$^3$/lbmol.$^\circ R$
Equations of State (EoS)

(a) Virial EoS
\[ \frac{P_V}{RT} = 1 + \frac{B}{V} + \frac{C}{V^2} + \frac{D}{V^3} + \ldots \]

(b) Van der Waals
\[ P = \frac{RT}{V+b} - \frac{a}{V^2}, \]
Related to critical \( T_c, P_c \)
\[ a = \frac{27}{64} \frac{R^2 T_c^3}{P_c}, \]
\[ b = \frac{1}{8} \frac{R T_c}{P_c}, \]
\[ a' = 0.42748 \frac{R T_c^{1.5}}{P_c}, \]
\[ b' = 0.08664 \frac{R T_c}{P_c}, \]

(c) Redlich-Kwong
\[ P = \frac{RT}{V-b} - \frac{a'}{\sqrt{V(V+b)}} \]
Ammonia

- Expt. $P = 40$ psia (Table A-15E) p. 891
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2. Benedict–Webb–Rubin: Constants for pressure in atm, specific volume in ft³/lb mol, and temperature in °R
QUIZ: Calculate enthalpy

• Steam at $P = 5$ bar, $T = 360^\circ C$, $v = 0.5796 \text{ m}^3/\text{kg}$,
• and $u = 2898.7 \text{ kJ/kg}$.

• Use the formula
  • $H = U + PV$
  • $h = u + P v$

• To calculate $H$ (kJ/kg).
From steam table:

- \( h = 3188.4 \) (kJ/kg)
QUIZ

1. Find the partial derivatives of $\varphi$
   
   $$\varphi = x^2 y + 5x + \sin(xy)e^{-x^2y}$$

   $$\frac{\partial \varphi}{\partial x} \bigg|_y = ? \quad \frac{\partial \varphi}{\partial y} \bigg|_x = ?$$

2. Use the "RABBIT" rule to express

   $$\frac{\partial T}{\partial P} \bigg|_H = ? \quad \frac{\partial P}{\partial V} \bigg|_s = ?$$

3. Use partial differentiation to find the partial derivative $\frac{\partial V}{\partial T} \bigg|_P$ from the van der Waals eq.

   $$P = \frac{RT}{v-b} - \frac{a}{v^2}$$