

# THERMODYNAMICS

## PROPERTIES OF SINGLE-COMPONENT SYSTEMS

### Nomenclature

1. Intensive properties are independent of mass.
2. Extensive properties are proportional to mass.
3. Specific properties are lowercase (extensive/mass).

### State Functions (properties)

Absolute Pressure, $P$	(lb/in <sup>2</sup> or Pa)
Absolute Temperature, $T$	(°R or K)
Volume, $V$	(ft <sup>3</sup> or m <sup>3</sup> )
Specific Volume, $v = V/m$	(ft <sup>3</sup> /lbm or m <sup>3</sup> /kg)
Internal Energy, $U$	(Btu or kJ)
Specific Internal Energy, $u = U/m$	(usually in Btu/lbm or kJ/kg)
Enthalpy, $H$	(Btu or kJ)
Specific Enthalpy, $h = u + Pv = H/m$	(usually in Btu/lbm or kJ/kg)
Entropy, $S$	(Btu/°R or kJ/K)
Specific Entropy, $s = S/m$	[Btu/(lbm·°R) or kJ/(kg·K)]
Gibbs Free Energy, $g = h - Ts$	(usually in Btu/lbm or kJ/kg)
Helmholtz Free Energy, $a = u - Ts$	(usually in Btu/lbm or kJ/kg)
Heat Capacity at Constant Pressure, $c_p = \left(\frac{\partial h}{\partial T}\right)_p$	
Heat Capacity at Constant Volume, $c_v = \left(\frac{\partial u}{\partial T}\right)_v$	

Quality  $x$  (applies to liquid-vapor systems at saturation) is defined as the mass fraction of the vapor phase:

$$x = m_v/(m_v + m_l), \text{ where}$$

$m_v$  = mass of vapor, and

$m_l$  = mass of liquid.

Specific volume of a two-phase system can be written:

$$v = xv_g + (1 - x)v_l \text{ or } v = v_g + xv_{g\ell}, \text{ where}$$

$v_g$  = specific volume of saturated liquid,

$v_l$  = specific volume of saturated vapor, and

$v_{g\ell}$  = specific volume change upon vaporization,

$$= v_g - v_l$$

Similar expressions exist for  $u$ ,  $h$ , and  $s$ :

$$u = xu_g + (1 - x)u_l \text{ or } u = u_g + xu_{g\ell}$$

$$h = xh_g + (1 - x)h_l \text{ or } h = h_g + xh_{g\ell}$$

$$s = xs_g + (1 - x)s_l \text{ or } s = s_g + xs_{g\ell}$$

For a simple substance, specification of any two intensive, independent properties is sufficient to fix all the rest.

For an ideal gas,  $Pv = RT$  or  $PV = mRT$ , and  $P_1v_1/T_1 = P_2v_2/T_2$ , where

$P$  = pressure,

$v$  = specific volume,

$m$  = mass of gas,

$R$  = gas constant, and

$T$  = absolute temperature.

$V$  = volume.

$R$  is specific to each gas but can be found from

$$R = \frac{R}{(mol \cdot wt)}, \text{ where}$$

$R$  = the universal gas constant

$$= 1,545 \text{ ft-lbD/(lbmol·°R)} = 8,314 \text{ J/(kmol·K)}.$$

For ideal gases,  $c_p - c_v = R$

Also, for ideal gases:

$$\left(\frac{\partial h}{\partial T}\right)_p = 0 \quad \left(\frac{\partial u}{\partial T}\right)_v = 0$$

For cold air standard, heat capacities are assumed to be constant at their room temperature values. In that case, the following are true:

$$\Delta u = c_p \Delta T, \quad \Delta h = c_p \Delta T$$

$$\Delta s = c_p \ln(T_2/T_1) - R \ln(P_2/P_1); \text{ and}$$

$$\Delta s = c_v \ln(T_2/T_1) + R \ln(v_2/v_1).$$

For heat capacities that are temperature dependent, the value to be used in the above equations for  $\Delta h$  is known as the mean heat capacity ( $\bar{c}_p$ ) and is given by

$$\bar{c}_p = \frac{\int_{T_1}^{T_2} c_p dT}{T_2 - T_1}$$

Also, for constant entropy processes:

$$\frac{P_2}{P_1} = \left(\frac{v_1}{v_2}\right)^k; \quad \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{1}{k-1}}$$

$$\frac{v_2}{v_1} = \left(\frac{v_1}{v_2}\right)^{k-1}, \text{ where } k = c_p/c_v$$

For real gases, several equations of state are available; one such equation is the van der Waals equation with constants based on the critical point:

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

$$\text{where } a = \left(\frac{27}{64}\right) \left(\frac{R^2 T_c^2}{P_c}\right), \quad b = \frac{RT_c}{8P_c}$$

where  $P_c$  and  $T_c$  are the pressure and temperature at the critical point, respectively, and  $V$  is the molar specific volume.

# Thermodynamics Chemistry Study Guide Answers

**Aftab S. Hassan,James L. Flowers**

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