Thermodynamics I

Lecture 14

The Ideal Gas Equation (Ch-3)

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THE IDEAL-GAS EQUATION OF STATE

Temp. °C T	Sat. press. kPa P_{sat}	Specific volume m³/kg: Sat. liquid v_f	Sat. vapor v_g
85	57.868	0.001032	2.8261
90	70.183	0.001036	2.3593
95	84.609	0.001040	1.9808

Temperature

Corresponding saturation pressure

Specific volume of saturated liquid

Specific volume of saturated vapor

T,°C	v m³/kg	u kJ/kg	h kJ/kg
	$P = 0.1$ MPa (99.61°C)		
Sat.	1.6941	2505.6	2675.0
100	1.6959	2506.2	2675.8
150	1.9367	2582.9	2776.6
⋮	⋮	⋮	⋮
1300	7.2605	4687.2	5413.3
	$P = 0.5$ MPa (151.83°C)		
Sat.	0.37483	2560.7	2748.1
200	0.42503	2643.3	2855.8
250	0.47443	2723.8	2961.0

Property tables provide very accurate information about the properties, but they are bulky and vulnerable to typographical errors.

A more practical and desirable approach would be to have some simple relations among the properties that are sufficiently general and accurate.

THE IDEAL-GAS EQUATION OF STATE

- **Equation of state**: Any equation that relates the pressure, temperature, and specific volume of a substance.
- The simplest and best-known equation of state for substances in the gas phase is the ideal-gas equation of state. This equation predicts the *P*-*v*-*T* behavior of a gas quite accurately within some properly selected region.

1662: Robert Boyle

1802: J. Charles and J. Gay-Lussac

$$P = R\left(\frac{T}{v}\right)$$

Ideal-gas equation of state

$$Pv = RT$$

THE IDEAL-GAS EQUATION OF STATE

- The **gas constant R** is different for each gas and is determined from

$$R = \frac{R_u}{M} \qquad (\text{kJ/kg}\cdot\text{K or kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})$$

***R*: gas constant**
***M*: molar mass (kg/kmol)**
***R_u*: universal gas constant**

Substance	R, kJ/kg·K
Air	0.2870
Helium	2.0769
Argon	0.2081
Nitrogen	0.2968

$$R_u = \begin{cases} 8.31447 \text{ kJ/kmol}\cdot\text{K} \\ 8.31447 \text{ kPa}\cdot\text{m}^3/\text{kmol}\cdot\text{K} \\ 0.0831447 \text{ bar}\cdot\text{m}^3/\text{kmol}\cdot\text{K} \\ 1.98588 \text{ Btu/lbmol}\cdot\text{R} \\ 10.7316 \text{ psia}\cdot\text{ft}^3/\text{lbmol}\cdot\text{R} \\ 1545.37 \text{ ft}\cdot\text{lbf/lbmol}\cdot\text{R} \end{cases}$$

Different substances have different gas constants.

THE IDEAL-GAS EQUATION OF STATE

- The **molar mass M** can simply be defined as the mass of one mole (also called a gram-mole, abbreviated gmol) of a substance in grams, or the mass of one kmol (also called a kilogram-mole, abbreviated kgmol) in kilograms.
- The **mass of a system** is equal to the product of its molar mass M and the mole number N:

$$m = MN \qquad (\text{kg})$$

$$\boxed{P\upsilon = RT}$$

$$V = m\upsilon \longrightarrow \boxed{PV = mRT}$$

$$mR = (MN)R = NR_u \longrightarrow \boxed{PV = NR_uT}$$

$$V = N\bar{\upsilon} \longrightarrow \boxed{P\bar{\upsilon} = R_uT}$$

Per unit mass	Per unit mole
v, m^3/kg	$\bar{v}$, $m^3/kmol$
u, kJ/kg	$\bar{u}$, kJ/kmol
h, kJ/kg	$\bar{h}$, kJ/kmol

Where $\bar{v}$ is the molar specific volume, that is, the volume per unit mole (in $m^3/kmol$ or $ft^3/lbmol$). A bar above a property denotes values on a unit-mole basis throughout this text.

Properties per unit mole are denoted with a bar on the top.

Ideal gas equation at two states for a fixed mass

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

The ideal-gas relation often is not applicable to real gases; thus, care should be exercised when using it.

Real gases behave as an ideal gas at low densities (i.e., low pressure, high temperature).

Example 3-10

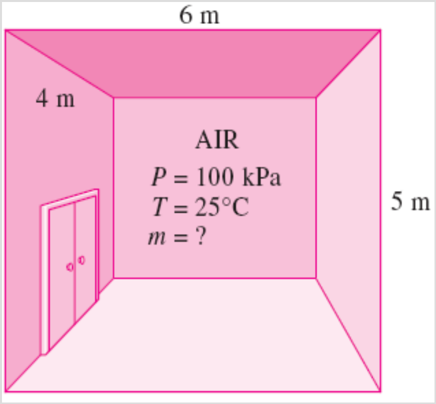
Determine the mass of the air in a room whose dimensions are 4 m × 5 m × 6 m at 100 kPa and 25°C.

Solution The mass of air in a room is to be determined.
Analysis A sketch of the room is given in Fig. 3–48. Air at specified conditions can be treated as an ideal gas. From Table A–1, the gas constant of air is $R = 0.287$ kPa · m³/kg · K, and the absolute temperature is $T = 25°C + 273 = 298$ K. The volume of the room is

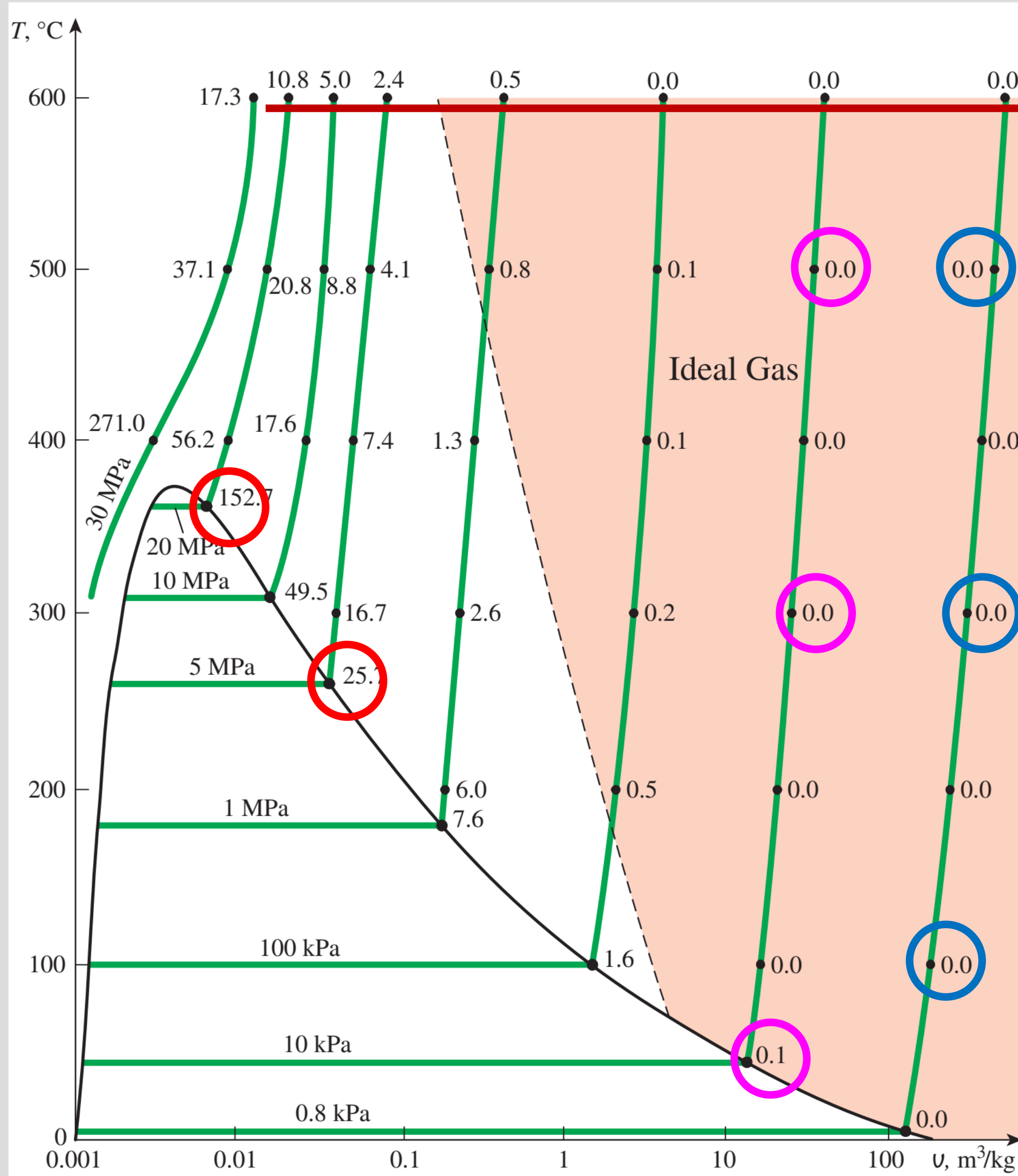
$$V = (4\ \text{m})(5\ \text{m})(6\ \text{m}) = 120\ \text{m}^3$$

$$\boxed{PV = mRT}$$

$$m = \frac{PV}{RT} = \frac{(100\ \text{kPa})(120\ \text{m}^3)}{(0.287\ \text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(298\ \text{K})} = \mathbf{140.3\ kg}$$

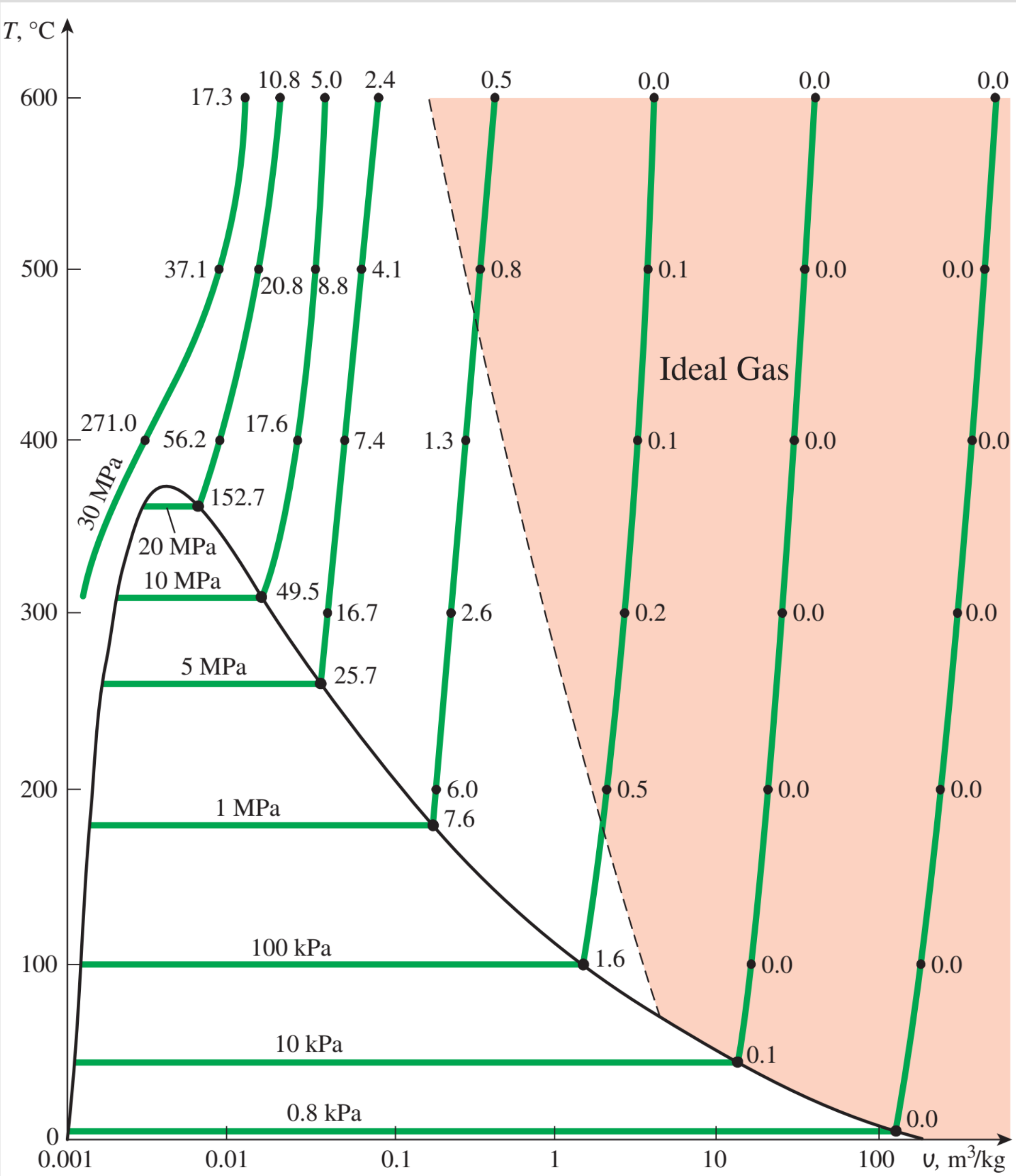


Is Water Vapor an Ideal Gas?



Percentage of error ($[|\upsilon_{table} - \upsilon_{ideal}|/\upsilon_{table}] \times 100$) involved in assuming steam to be an ideal gas, and the region where steam can be treated as an ideal gas with less than 1 percent error.

Is Water Vapor an Ideal Gas?



- At pressures below 10 kPa, water vapor can be treated as an ideal gas, regardless of its temperature, with negligible error (less than 0.1 percent).
- At higher pressures, however, the ideal gas assumption yields unacceptable errors, particularly in the vicinity of the critical point and the saturated vapor line.
- In air-conditioning applications, the water vapor in the air can be treated as an ideal gas. Why?
- In steam power plant applications, however, the pressures involved are usually very high; therefore, ideal-gas relations should not be used.