TOPIC II - GAS PROPERTIES

Perfect/Ideal gases (Lecture 1/2)

Establish laws for p, V, T, U relationships

Contents:

1. Definition of a Property
2. Perfect (Ideal) Gas Law
3. Internal Energy

Recall **state postulate** – two independent properties determine equilibrium state.

E.g. p, T allow us to find ρ, u, h, s

equilibrium - all driving forces acting on system are balanced

TOPIC II - GAS PROPERTIES

Perfect/Ideal gases (Lecture 1/2)

1) Definition of a Property

Describes a state of equilibrium – independent of path

independent properties can be combined

$$\rho = m/V \qquad (1)$$

$$v = V/m = 1/\rho \qquad (2)$$

extensive properties (V, m, …) – depend on system size

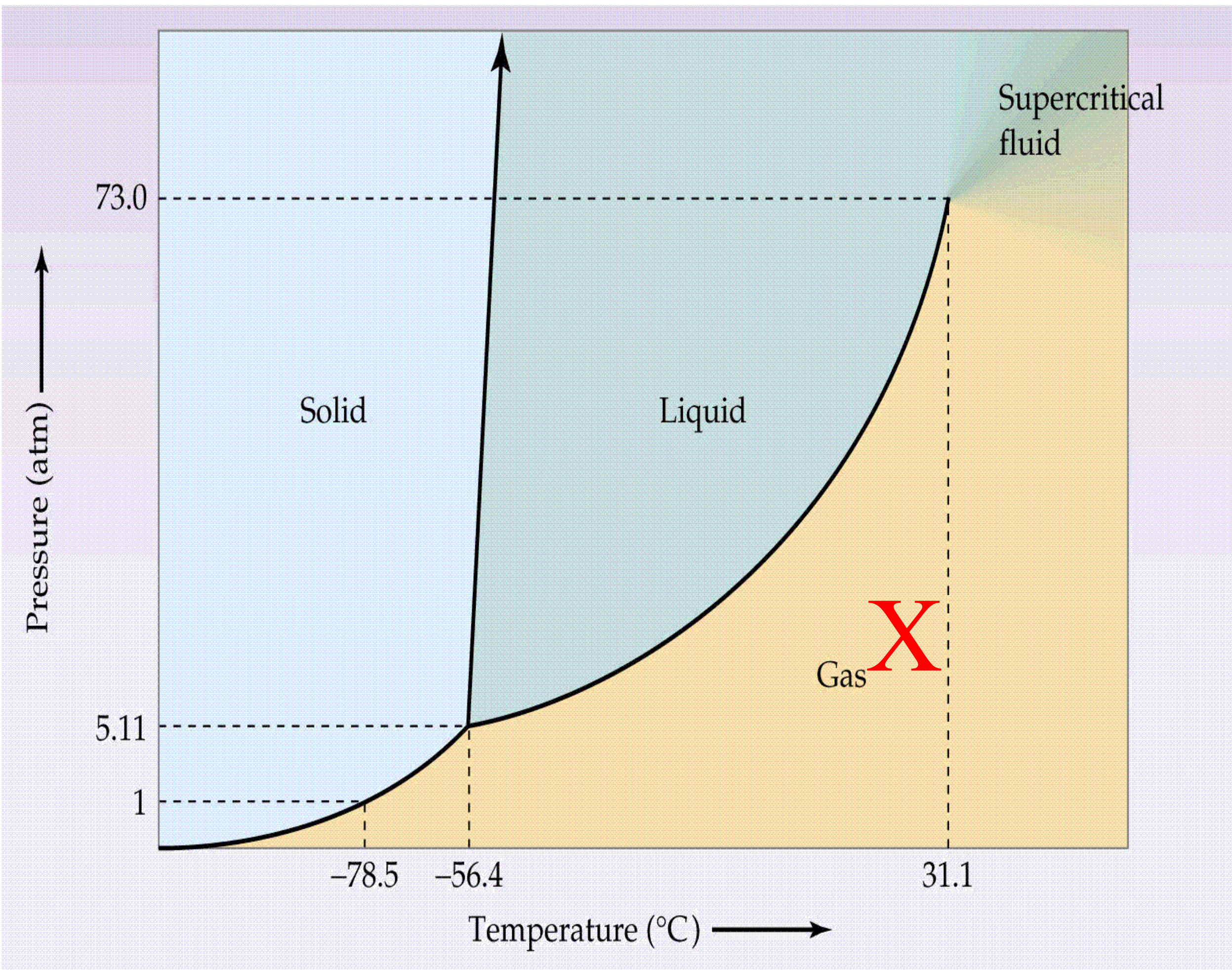
intensive properties (T, p, v, …) do not. Specific properties refer to a unit mass. Three other intensive properties:-

u – internal energy (today)
h – enthalpy (next lecture)
s – entropy (much later)

TOPIC II - GAS PROPERTIES

Perfect/Ideal gases (Lecture 1/2)

Conditions that interest us:



Perfect gases where molecule-to-molecule forces are very small. (See location X).

Air is usually far from triple and critical point.

TOPIC II - GAS PROPERTIES

Perfect/Ideal gases (Lecture 1/2)

2. Perfect (Ideal) Gas Law

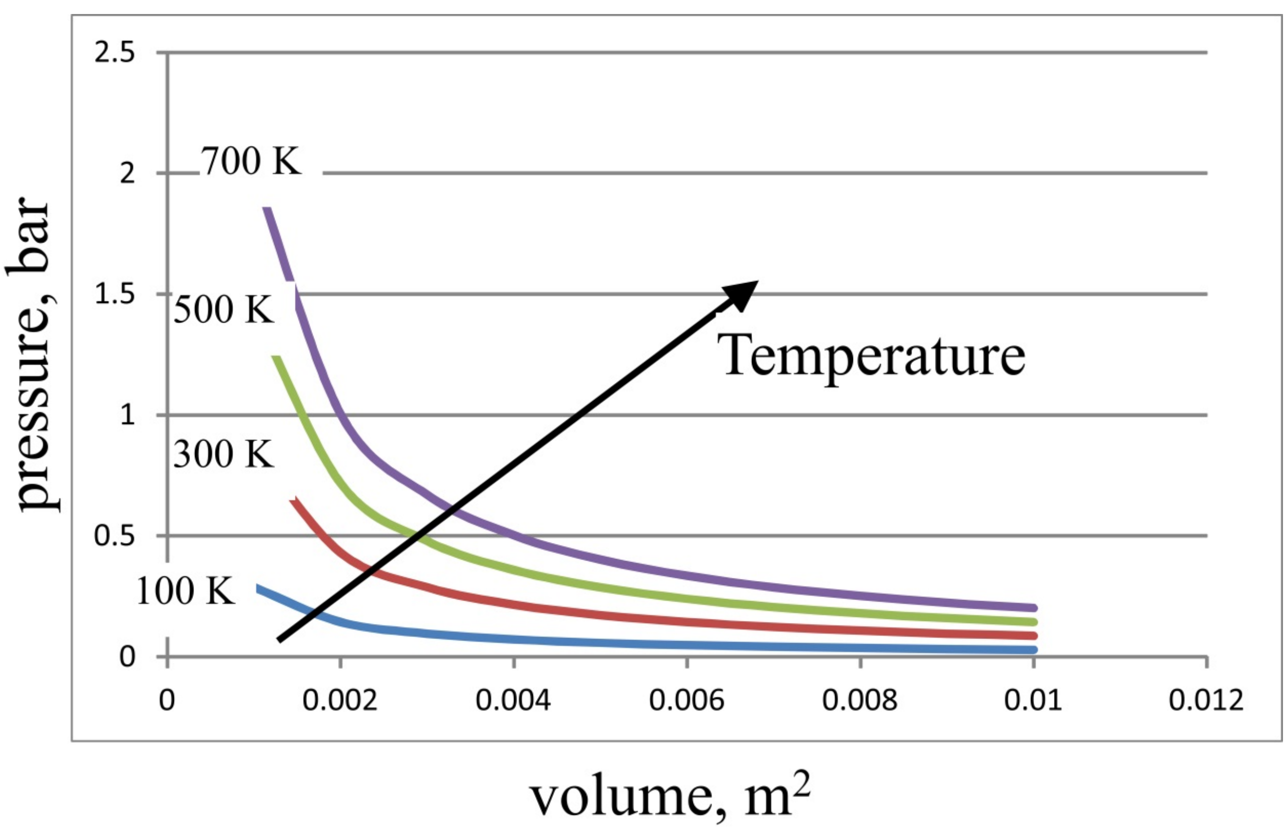
Gives ideal (or perfect) gas law.

Engineering forms:

$$p \mathcal{V} = R\,T \qquad (3)$$

$$pV = mRT \qquad (3b)$$

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2} \qquad (3c)$$



TOPIC II - GAS PROPERTIES

Perfect/Ideal gases (Lecture 1/2)

R is the specific gas constant (kJ kg^{-1} K^{-1}), following from universal gas constant
 (kJ kmol^{-1} K^{-1})

$$R = \frac{\tilde{R}}{\tilde{m}} \qquad (4)$$

If the amount of substance (in kmol) is

$$n = m / \tilde{m}$$

then

$$pV = n\,\tilde{R}\,T \qquad (5)$$

TOPIC II - GAS PROPERTIES

Perfect/Ideal gases (Lecture 1/2)

Example, air density at atmospheric pressure and 25^{o}C

$$R = \frac{\tilde{R}}{\tilde{m}} = \frac{8.314\, kJ\, kmol^{-1}\, K^{-1}}{29\, kg\, kmol^{-1}} = 0.287\, kJ\, kg^{-1}\, K^{-1}$$

$$\rho = \frac{1}{v} = \frac{p}{RT} = \frac{\left(1.013\, bar \times 100\, kN\, m^{-2}\, bar^{-1}\right)}{0.287\, kJ\, kg^{-1}\, K^{-1} \times (273+25)\, K} =$$

$$1.184 \frac{kN\, m^{-2}}{kJ\, kg^{-1}} = 1.184\, kg\, m^{-3}$$

Conversion factors yield engineering units (kN, kJ etc). E.g.

$$\boxed{\frac{100\,\mathrm{kN\,m^{-2}}}{1\,\mathrm{bar}} \equiv 1}$$

3. Internal Energy

Properties of steam (non-ideal) are tabulated against T, p. Air properties against T only.

Ideal gas => perfect gas **&** U = f (T) only

$$U = m\, c_v\, (T - T_o) \qquad (6)$$

$$u = U/m = c_v\, (T - T_o) \qquad (6b)$$

proportionality constant

T_o is a **datum temperature.**

If U is measured in a rigid vessel heat addition is

$$Q_v = U_2 - U_1 = m\, c_v\, (T_2 - T_1) \qquad (7)$$

provided V = constant and W = 0

TOPIC II - GAS PROPERTIES

Perfect/Ideal gases (Lecture 1/2)

***Definition**: The **specific heat capacity** is the quantity of energy required to raise the temperature of one unit mass by one degree of temperature. Term c_v refers to such energy addition <u>at constant volume</u>.*

It has units of $kJ\ kg^{-1}\ K^{-1}$.

air $c_v = 0.718\ kJ\ kg^{-1}\ K^{-1}$ or $c_v = 2.5\ R$

Because U is a property:

c_v can always be used to get U

Q, W then follow from NFEE

c_v only yields Q when W = 0

Note – energy can cross boundaries as:

…………………………………………………………

TOPIC II - GAS PROPERTIES

Perfect/Ideal gases (Lecture 1/2)

<u>Conclusions:</u>

This year – focus on pure substances with no change of phase.

Ideal– weak intermolecular forces and hence $pV = m R T$ and $U = m c_v (T – T_o)$

Engineers tend to prefer mass quantities to molar quantities (R vs $\tilde{R}$, m vs n)

Definition of specific heat capacity – depends on process (today we considered constant volume)

Think of c_v as an indicator of internal energy.