Lecture 5

Ideal and Real Gases

Coverage

- Concept of ideal gas, enthalpy and specific heat capacities of an ideal gas, P – V – T surface of an ideal gas, triple point, real gases

5.1 Basic Concepts of Ideal Gases

- An ideal gas is a theoretical gas or imaginary gas composed of a set of randomly moving, non-interacting point like particles and they obeys the gas law always.
- Microscopic definition: There is no force between molecules, the molecules themselves do not occupy the volume of elastic particles.
- Macro definition: Gases that follow the Craberon equation
- Conditions of use: general gas, except steam such as: H_2, O_2, N_2, Air, etc. Water vapor, ammonia vapor can not

5.1 Basic Concepts of Ideal Gases cont…

2. Ideal Gas Equation of State

Ideal gas equation of state also known as Crabelon equation

1kg:	$pv=RT$	p--Absolute pressure Pa
mkg:	$pV=mRT$	T--absolute temperature scale K
1kmol:	$pV_m=R_mT$	R gaseous constant
nkmol:	$pV=nR_mT$	R_m General gaseous constant J/kmolK

5.1 Basic Concepts of Ideal Gases cont…

3. The Gas Body Constant R and the General Gas Body Constant R_m

- Avogadero's law states that the molar volume V_m of any given gas is the same at the same temperature and pressure.
- In the standard state: p=101325Pa, T=273.15K
  V m^3/kmol
- R=8314.3 J/kmolK independent of gas type
- $R=R_m/M=8314.3/M$ J/kmolK
- M-Molar Mass Varies with Gas Type

5.1 Basic Concepts of Ideal Gases cont…

- Typical Example 5-1
- The volume of the rigid gas storage tank is 3 m^3, and the pressure meter installed on the tank reads 30 kPa and the temperature meter indicates 30 ^oC. If you fill the tank CO_2 gas 12kg, the temperature indicates 70^oC,how much is the pressure gauge reading of the gas tank? The local atmospheric pressure is 100kPa.
- Solution: M= 44kg /kmol

  $R=R_m/44 =188.96$

- Fff
- $m_1 = \frac{p_1 V}{RT_1} = \frac{(30+100)\times1000\times3}{188.96\times(30+273)} = 6.811kg$
- FFFF
- $p_2 = \frac{(m_1+12)RT_2}{V} = \frac{(6.811+12)\times188.96\times343}{3} = 0.406MPa$

5-2 Specific Heat Capacity of an Ideal Gas

- General Concept of Specific Heat Capacity
- Definition: An increase of 1 K per unit volume of substance
- The heat exchanged. Namely: $c = \frac{\delta q}{dT}$
- Classification:

  Units of Quantity
  - Mass specific heat capacity c [J/(kg.K)]
  - Molar specific heat capacity c_m [J/(mol.K)]
  - Volumetric specific heat capacity c' [J/(m³.K)]

  Process approach
  - Specific heat capacity at constant pressure c_p $= \left(\frac{\partial h}{\partial T}\right)_p$
  - Specific heat capacity at constant volume c_v $= \left(\frac{\partial u}{\partial T}\right)_v$

5-2 Specific Heat Capacity of an Ideal Gas cont…

1. General Concept of Specific Heat Capacity

- Influencing factors: the type of substance, the unit of quantity, the process path, the state (temperature), and humidity.
- Function: Heat calculation and calculation of derived parameter increment.
- Explanation: Specific heat capacity is related to the process path, and the thermal coefficient belongs to the process quantity. But the c_v, and the processes of c_p have been determined and can be regarded as state variables/quantities.

5-2 Specific Heat Capacity of an Ideal Gas cont…

2. Characteristics of Internal Energy and Enthalpy of Ideal Gases

Properties: The thermodynamic energy and enthalpy of an ideal gas are temperature-dependent

Single-valued functions, i.e.: u=f(T),h=f(T).

Specific heat capacity at constant pressure c_p $= \left(\frac{\partial h}{\partial T}\right)_p = \frac{dh}{dT} = f(T)$

Specific heat capacity at constant volume c_v $= \left(\frac{\partial u}{\partial T}\right)_v = \frac{du}{dT} = f(T)$

$$c_p = \frac{dh}{dT} = \frac{du}{dT} + \frac{d(pv)}{dT} = c_v + R$$

5-2 Specific Heat Capacity of an Ideal Gas cont…

3. Specific Heat Capacity of an Ideal Gas

- Meyer’s formula: $c_p = c_v + R$
- Discussion:1. $c_p > c_v$

  2. $R = c_p - c_v$ another physical meaning of R

  3. $c_p(T) - c_v(T) = Constant$ independent of *T*

- Heat ratio:$k = \frac{c_p}{c_v} > 1$

$$c_v = \frac{R}{\kappa - 1}$$

$$c_p = \frac{\kappa R}{\kappa - 1}$$

5-2 Specific Heat Capacity of an Ideal Gas cont...

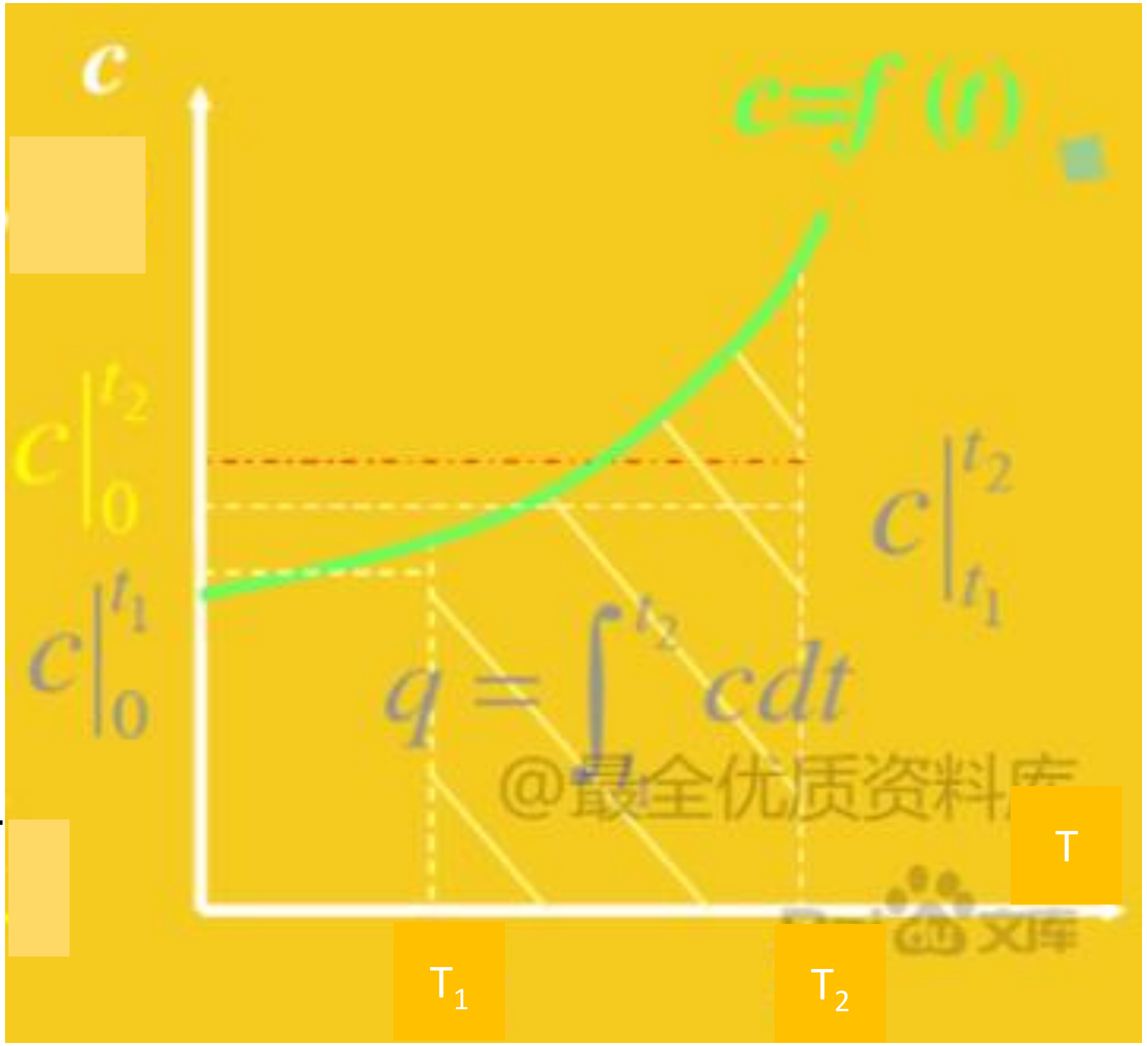
3. Specific Heat Capacity of an Ideal Gas

- The c_p and c_v of the gas can be divided into:

- Real specific heat $c = \frac{\delta q}{dT}(c_p, c_v)$

- Mean specific heat $c|_{T_1}^{T_2} = \frac{\int_{T_1}^{T_2} c\,dT}{t_2 - t_1}$

- Definite specific heat $c|_{T_1}^{T_2} = \frac{c|_0^{T_2} T_2 - c|_0^{T_1} T_1}{T_2 - T_1}$



5-2 Specific Heat Capacity of an Ideal Gas cont...

3. Specific Heat Capacity of an Ideal Gas

- Definite specific heat capacity $c_v = \dfrac{R}{\kappa - 1}$ $\quad c_p = \dfrac{\kappa R}{\kappa - 1}$

$$k = \begin{cases} Monatomic\ gas \\ Diatomic\ gas \\ Polyatomic\ gas \end{cases}$$

- Such as: air R= 287 kJ/kgK, k,
- Then c_v=0.717 kJ/kgK, c_p= 1.004 kJ/kgK

5-2 Specific Heat Capacity of an Ideal Gas cont…

4. Enthalpy of idea gas

Enthalpy of idea gas is also a function of only temperature.

Consider a constant pressure process for ideal gas

$$\delta q = du + \delta w$$

$$c_p dT = dh - vdp$$

$$c_p dT = du + pdv + vdp - vdp$$

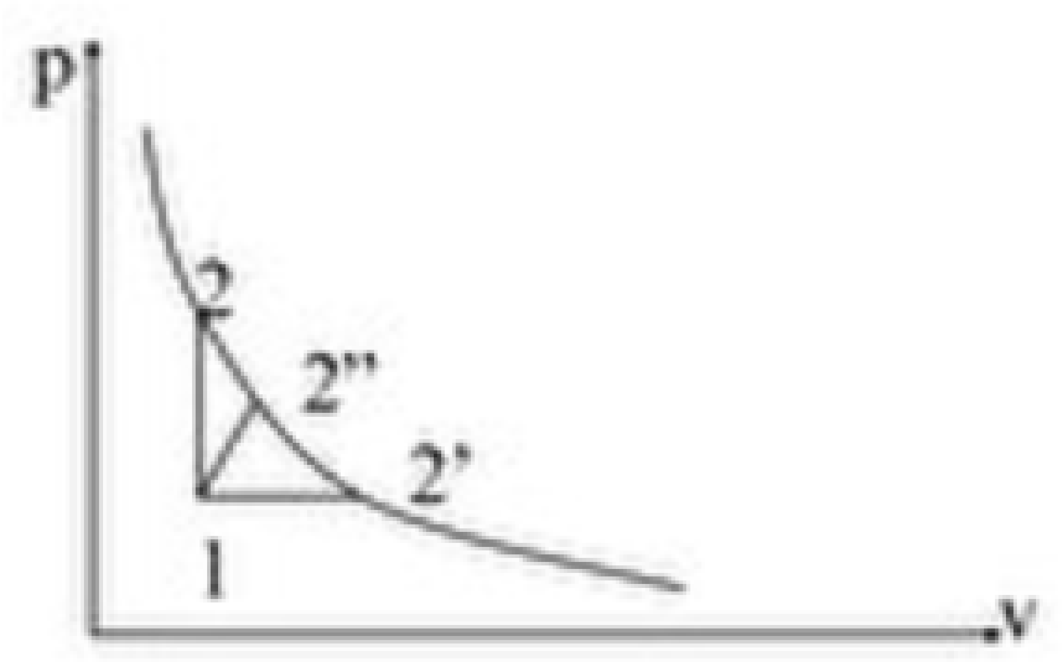
$$dh = c_p dT \qquad \Delta h = c_p \Delta T$$

5-2 Specific Heat Capacity of an Ideal Gas cont..

- Enthalpy is also a state property, its change is independent of process path.
- The change of enthalpy of ideal gas in any engineering is equal to the heat absorbed in the process of constant pressure in the same temperature range.
- If the specific heat is constant, $\Delta h = c_p \Delta T$

Example

- As shown in the figure, for ideal gas, if point 2, 2’, 2” are on the same isothermal line, 1-2 is constant volume process, 1-2’ is constant pressure and 1-2” is a random process. For reason that 2,2’, 2” is of the same temperature,
- $\Delta u_{1\text{-}2} = \Delta u_{1\text{-}2'} = \Delta u_{1\text{-}2''}$
- $\Delta h_{1\text{-}2} = \Delta h_{1\text{-}2'} = \Delta h_{1\text{-}2''}$



Example

1kg air from the initial state of 450 K, to 560 K find: thermodynamic enthalpy changes. Specific heat capacity for air is 1.004kJ/kgK

Solution

$$\Delta h = c_p \Delta T = 1.004(560-450) = 110.5 \text{ kJ/kg}$$

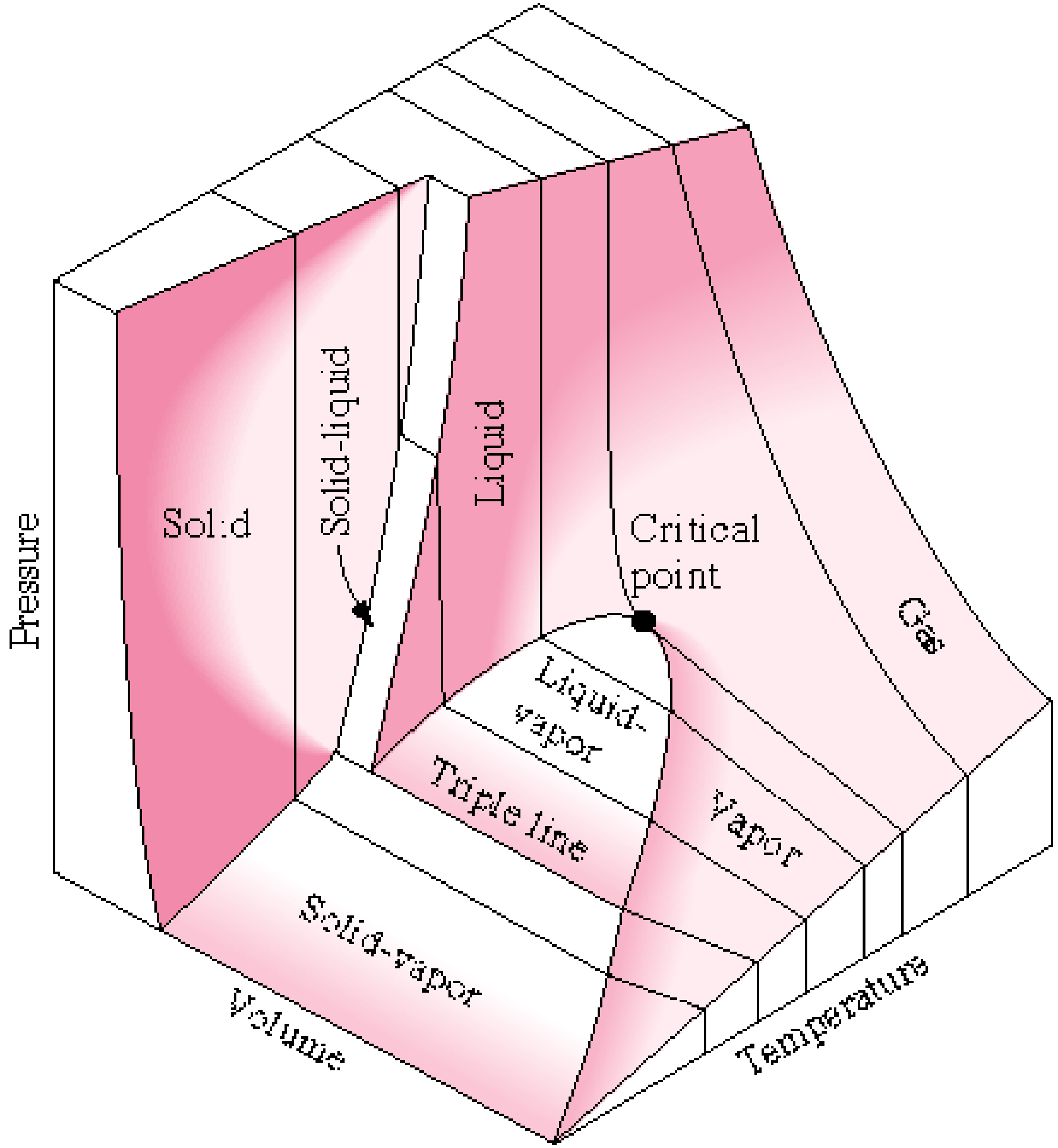
5-3 The p,T,V relations of gases

- We know that matter has three states: gas, liquid and solid. Liquid and solid are also called condensed matter. No matter what state matter is in, there are many macroscopic properties, such as pressure, volume, temperature, density, mass, internal energy, and so on. Among many macroscopic properties, p, T,V are the most basic properties.
- When the quantity of matter is determined, there is a certain functional relationship between p, T and V. This functional relationship is called the state equation of matter.
- When *n* is determined, f(p V,T)=0
- Or a four-variable function f (p, V,T, n)=0

- The volume V of solid and liquid substances is very smally affected by pressure p and temperature T, i.e. their compressibility (p$\rightarrow$V) and thermal expansion (T$\rightarrow$V) are very small compared to gaseous substances, and their volume changes with pressure and temperature are often ignored in the usual discussion of physical chemistry.
- The gas substance p, V, T have a great influence on each other, so in this chapter, we first discuss the relationship between pV,T of gas, and gas system is the basic system of physical and chemical research.

The *P-V-T* Surface for a Real Substance

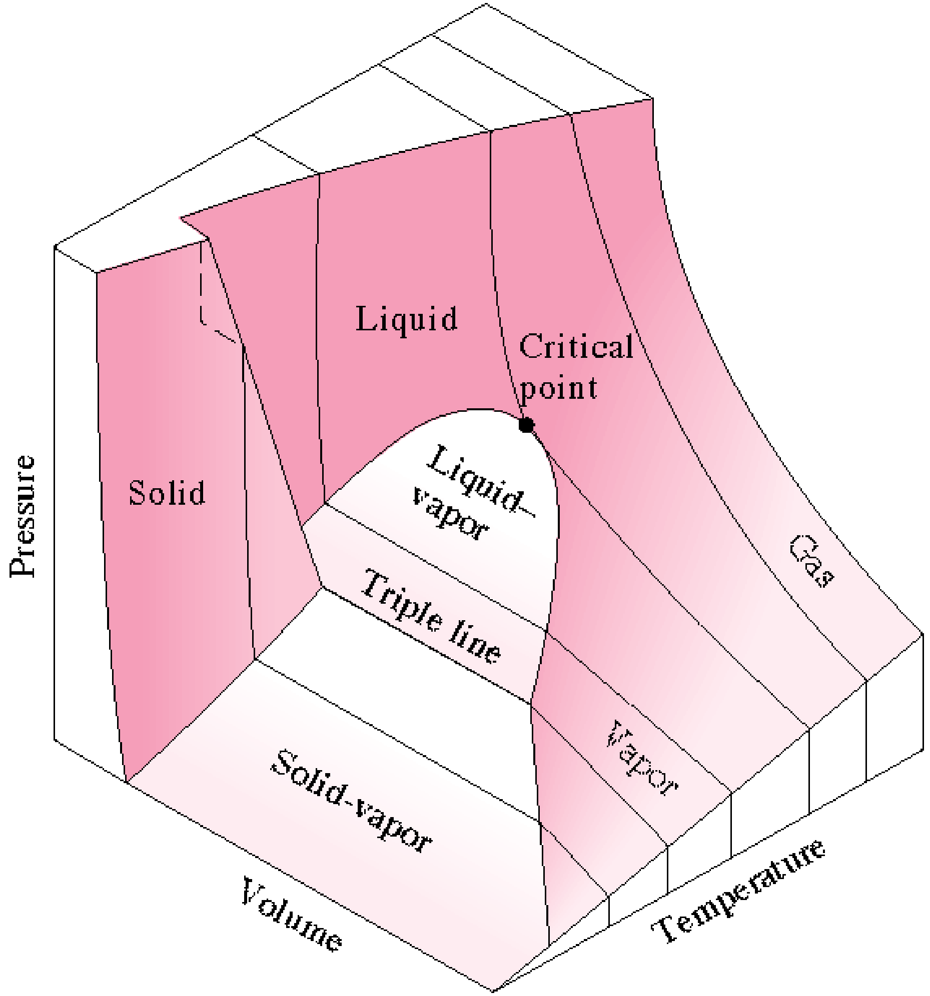
♦ *P-V-T* Surface for a Substance that contracts upon freezing



The *P-V-T* Surface for a Real Substance

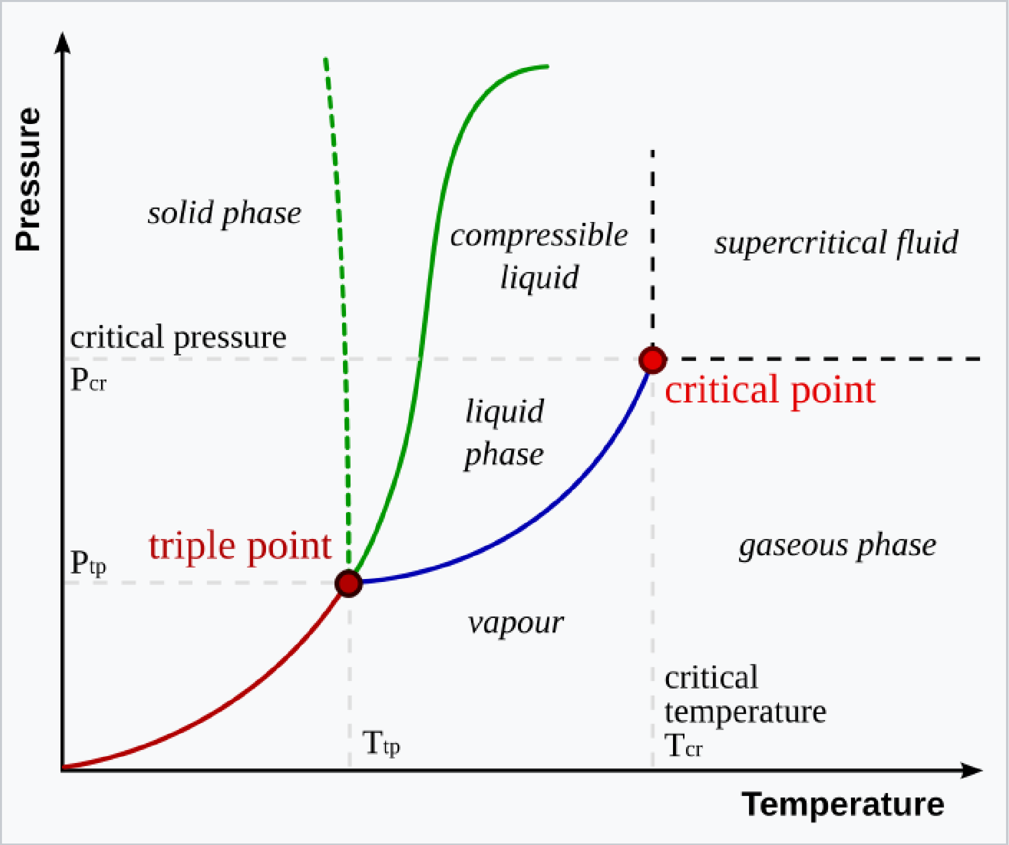
♦*P-V-T* Surface for a Substance that expands upon freezing

Real substances that readily change phase from solid to liquid to gas such as water, refrigerant-134a, and ammonia cannot be treated as ideal gases in general. The pressure, volume, temperature relation, or equation of state for these substances is generally very complicated, and the thermodynamic properties are given in table form. The properties of these substances may be illustrated by the functional relation $F(P,v,T)=0$, called an equation of state. From the two figures illustrate the function for a substance that contracts on freezing and a substance that expands on freezing. Constant pressure curves on a temperature-volume diagram are shown in Figure.



Triple point

- The **triple point** of a substance is the temperature and pressure at which the three phases (gas, liquid, and solid) of that substance coexist in thermodynamic equilibrium.
- It is that temperature and pressure at which the sublimation, fusion, and vaporisation curves meet.
- For example, the triple point of mercury occurs at a temperature of −38.8 °C (−37.8 °F) and a pressure of 0.165 mPa.



A typical phase diagram. The solid green line applies to most substances; the dashed green line gives the anomalous behavior of water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YOU!