

THERMODYNAMICS: 5.2.2 (d)

The Relationship between C_p and C_v

A mathematical derivation and conceptual
breakdown for an Ideal Gas.



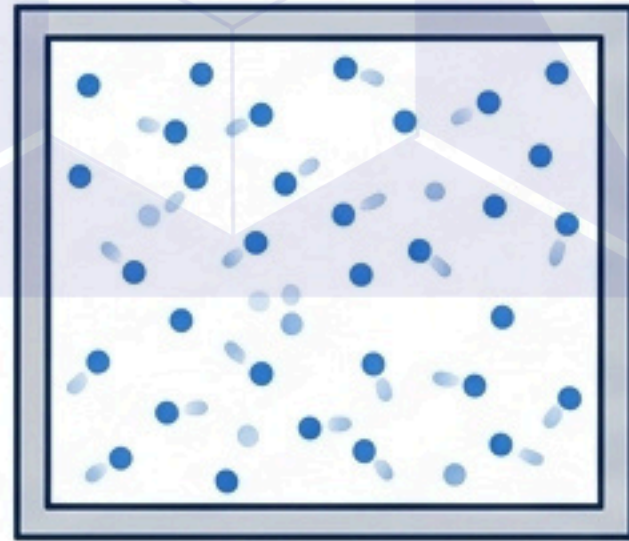
[Exam Revision]

[Ideal Gas Model]

Constant-Volume Heating (C_V)

The Physical Process

When heat is supplied to a system at a constant volume, the system cannot expand. Therefore, no expansion work ($p\Delta V$) is done. All supplied heat goes directly into increasing the internal energy of the system.



$$\Delta V = 0$$

$$w = 0$$

The heat (q_v) absorbed at constant volume is equal to the change in internal energy (ΔU).

$$q_v = C_v \Delta T = \Delta U$$

C_v = Heat capacity at constant volume

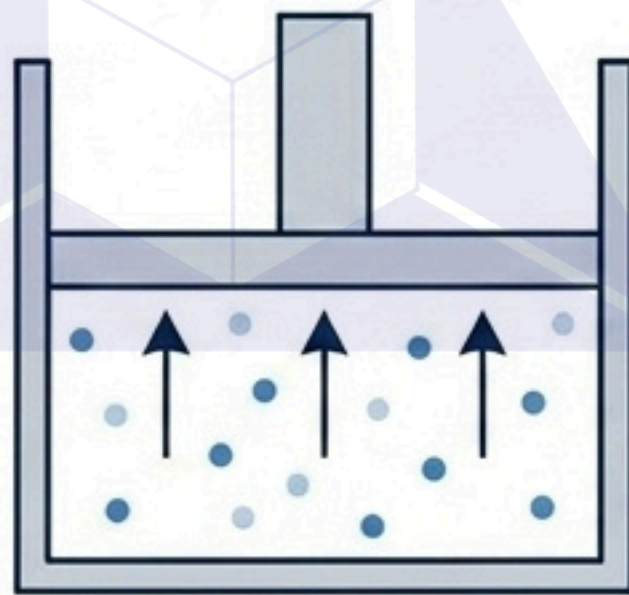
ΔT = Change in temperature

ΔU = Change in internal energy

Constant-Pressure Heating (C_p)

The Physical Process

When heat is supplied at a constant pressure, the gas expands. The system uses the absorbed heat to do two things: increase its internal energy AND perform expansion work on its surroundings.



$$\Delta p = 0$$

$$w = -p\Delta V$$



The heat (q_p) absorbed at constant pressure is equal to the change in enthalpy (ΔH).

$$q_p = C_p \Delta T = \Delta H$$

C_p = Heat capacity at constant pressure

ΔH = Change in enthalpy



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Derivation for 1 Mole of Ideal Gas

Step 1: Enthalpy Definition

$$\Delta H = \Delta U + \Delta(pV)$$

Step 2: Ideal Gas Law

For 1 mole of an ideal gas, $pV = RT$. Therefore, the change in pV depends only on Temperature.

$$\Delta(pV) = \Delta(RT) = R\Delta T$$

Step 3: Substitution

Substitute Step 2 into Step 1.

$$\Delta H = \Delta U + R\Delta T$$

Step 4: Introduce Heat Capacities

Substitute the foundational equations from Premise 1 ($\Delta U = C_v\Delta T$) and Premise 2 ($\Delta H = C_p\Delta T$).

$$C_p\Delta T = C_v\Delta T + R\Delta T$$

Mayer's Relation

$$C_p - C_v = R$$

(Derived by dividing the Step 4 equation by ΔT)

The Question

Why is C_p always greater than C_v ?

The Answer

At constant volume, all heat goes toward raising the temperature. At constant pressure, the gas must do expansion work against the atmosphere. Therefore, extra heat is required to achieve the exact same temperature rise. For an ideal gas, this exact difference in required heat is R (the universal gas constant).



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