# Some basic points in thermodynamics

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## 1 Always true

$$\begin{aligned} \Delta U &= \Delta Q + \Delta W + \Delta(\text{chemical energy}) & (1) \\ &= \Delta Q + \Delta W \qquad \text{for closed system} & (2) \end{aligned}$$

The chemical energy part is the energy associated with material moving into or out of the system, which does not happen for a closed system.

$$\begin{aligned} \mathrm{d}U &= T\mathrm{d}S - p\mathrm{d}V + \mu\mathrm{d}N \qquad \text{for } pV \text{ system} & (3) \\ &= T\mathrm{d}S - p\mathrm{d}V \qquad \text{for closed } pV \text{ system} & (4) \end{aligned}$$

For closed system:

$$\begin{aligned} C_v \equiv \frac{đQ_V}{dT} &= T\left(\frac{\partial S}{\partial T}\right)_V = \left(\frac{\partial U}{\partial T}\right)_V, & (5) \\ C_p \equiv \frac{đQ_p}{dT} &= T\left(\frac{\partial S}{\partial T}\right)_p = \left(\frac{\partial U}{\partial T}\right)_p + p\left(\frac{\partial V}{\partial T}\right)_p. & (6) \end{aligned}$$

$$\gamma \equiv \frac{C_p}{C_v} \tag{7}$$

## 2 Ideal gas

Definition: Boyle's law and $U = U(T)$.

In consequence:

$$pV = nRT, \qquad \Delta U = \int C_V \mathrm{d}T \tag{8}$$

So

$$C_p = C_V + p\left(\frac{\partial V}{\partial T}\right)_p = C_V + nR \tag{9}$$

and therefore

$$\gamma = 1 + \frac{nR}{C_V} \tag{10}$$

It is often assumed, but it is not necessarily true (for an ideal gas), that $C_V$ is independent of temperature. If it is, then clearly so is $C_p$ and $\gamma$. In this case, $pV^\gamma$ is constant for an adiabatic process.

For a monatomic gas, one finds to very good approximation $C_V = (3/2)nR$ so then $\gamma = 5/3$.