

Lecture 16

- Temperature change: specific heat
- Phase change: heat of transformation
- Calorimetry: calculating heat exchanges
- Specific heats of gases
- adiabatic processes

Thermal properties of matter (I)

Joule: heat and work are energy transferred; change in thermal energy \rightarrow change in temperature or phase

- Temperature change and Specific Heat

specific heat, c = energy to raise T of 1 kg by 1 K (“thermal inertia”)

$$\Delta E_{th} = Mc\Delta T \text{ (temperature change)}$$

$$\Delta E_{th} = W + Q \text{ for solids/liquids, } W = 0 \Rightarrow$$

$$Q = Mc\Delta T \quad \text{(temperature change)}$$

Molar specific heat, C : $Q = nC\Delta T$

$$\text{Using } n = \frac{M(\text{in g})}{M_{mol}} = \frac{1000(\text{g/kg})}{M_{mol}(\text{in g/mol})} M(\text{in kg}):$$

$$C(\text{in J/mol/K}) = \frac{M_{mol}(\text{in g/mol})}{1000(\text{g/kg})} c(\text{in J/kg/K})$$

Thermal properties of matter (II)

- Phase change and heat of transformation, L

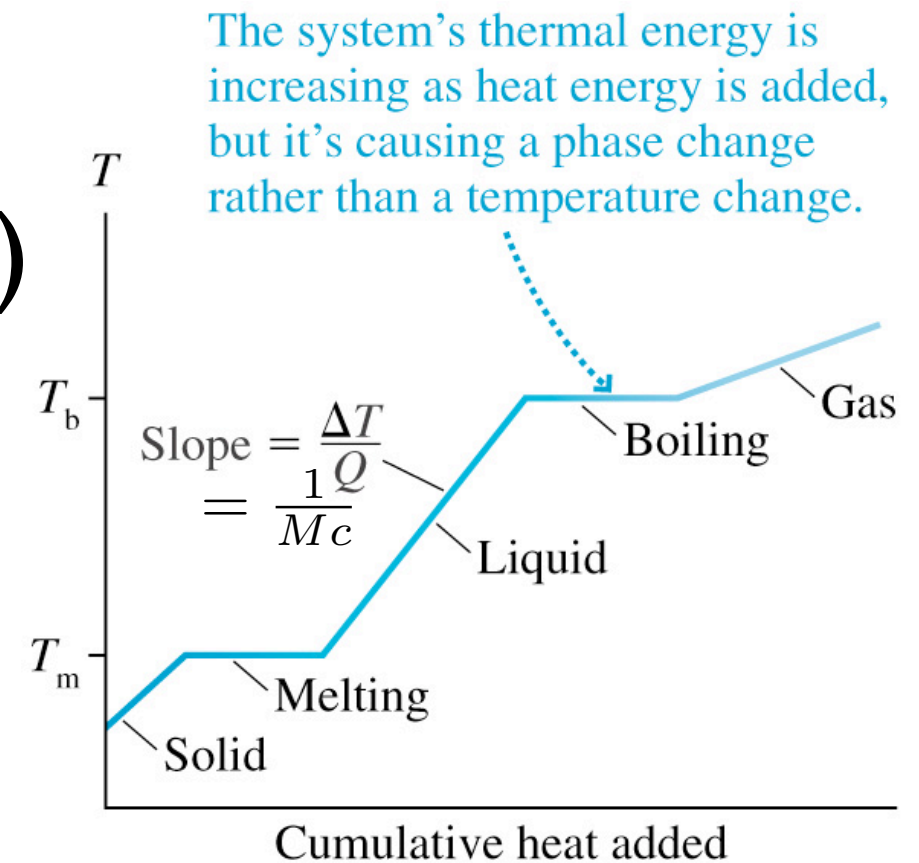
T same, heat transferred breaks bonds (instead of speeding up atoms)

L = heat energy for 1 kg to change phase

$$Q = \begin{cases} \pm ML_f & \text{melt/freeze} \\ \pm ML_v & \text{boil/condense} \end{cases}$$

L_f, v : heat of fusion (solid/liquid) or vaporization (liquid/gas)

$L_v > L_f$: bonds not completely broken during melting...



Copyright © 2004 Pearson Education, Inc., publishing as Addison Wesley

Calorimetry

- 2 systems interacting thermally, but isolated from others

start at $T_1 \neq T_2$,
heat transferred till equilibrium T_f
(Q_1 is energy transferred to system 1:
 > 0 if energy enters...)

- Strategy for (> 2 systems)

$$Q_{net} = Q_1 + Q_2 + \dots = 0$$

Systems with temperature change:

$$Q = Mc(T_f - T_i) \Rightarrow Q > 0 \text{ if } T_f > T_i$$

Systems with phase change:

$$Q + \pm ML_f \text{ or } v: \text{ for melting/freezing...}$$

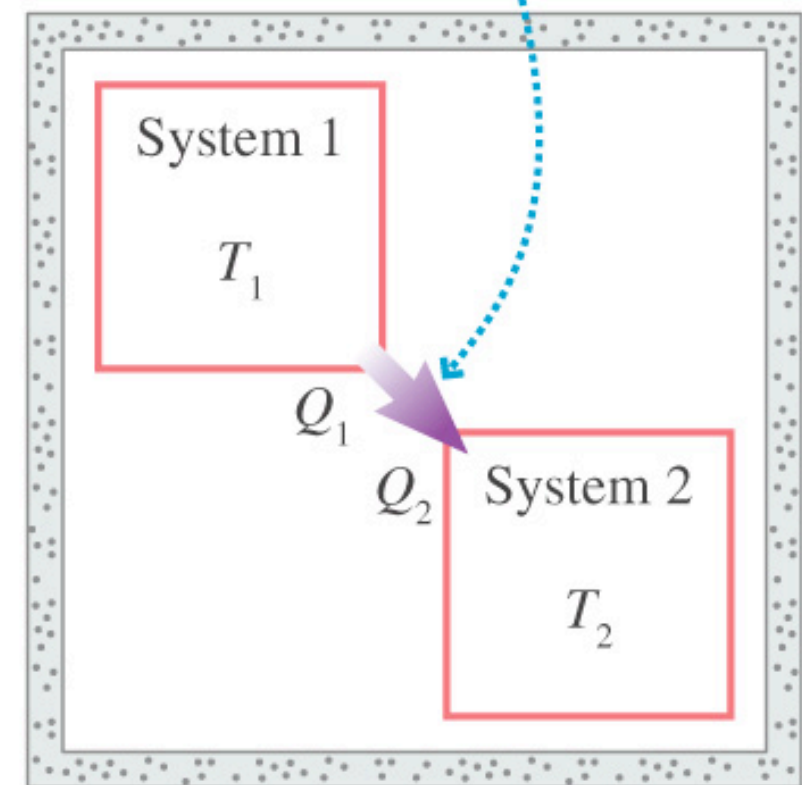
(check: T_f not higher/lower than *all* T_i)

Heat energy is transferred
from system 1 to system 2.
Energy conservation requires

$$|Q_1| = |Q_2|$$

Opposite signs mean that

$$Q_{net} = Q_1 + Q_2 = 0$$



Specific Heats of Gases

- same ΔT , different Q since W different...

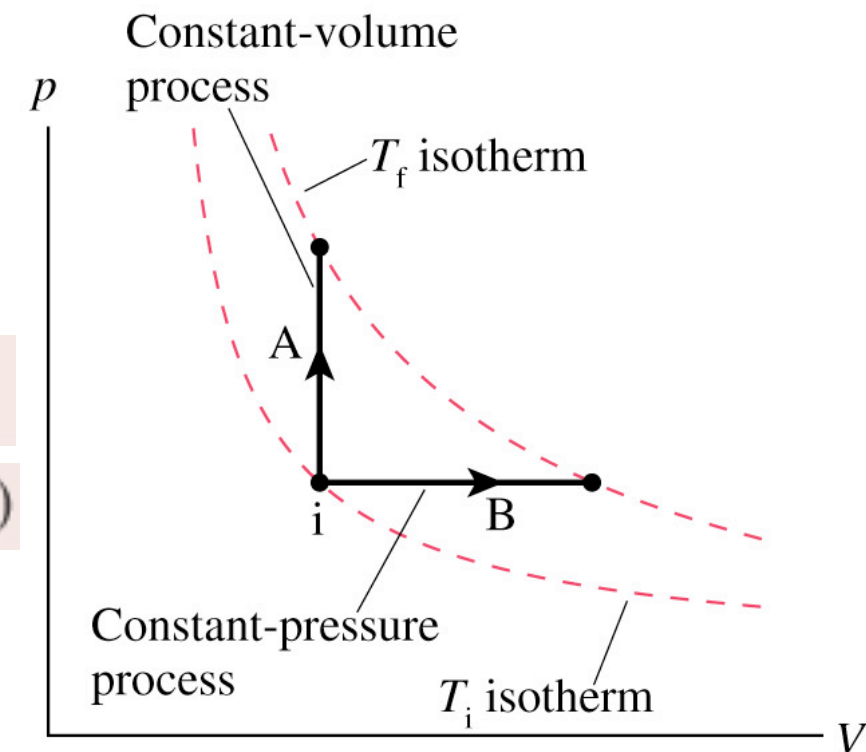
- Two versions of molar specific heat

$$Q = nC_p\Delta T \quad (\text{temperature change at constant pressure})$$

$$Q = nC_v\Delta T \quad (\text{temperature change at constant volume})$$

(if p or V not constant, use $Q = W - \Delta E_{th}$)

Relation between C_P and C_V



Copyright © 2004 Pearson Education, Inc., publishing as Addison Wesley

- ΔE_{th} depends only on ΔT

$$\Delta E_{th} = Q + W \Rightarrow \text{no distinction between } Q, W$$

$$\text{isochoric: } (\Delta E_{th})_A = W + Q = 0 + Q_{\text{const vol}} = nC_v\Delta T$$

$$\text{isobaric: } (\Delta E_{th})_B = W + Q = -p\Delta V + Q_{\text{const vol}} = -nR\Delta T + nC_p\Delta T$$

(using ideal gas law: $pV = nRT$)

$$\Delta (E_{th})_A = (\Delta E_{th})_B \Rightarrow$$

$$C_p = C_v + R$$

$$\Delta E_{th} = nC_v\Delta T \quad (\text{any ideal-gas process})$$

0 for isochoric,
< 0 for isobaric
expansion

- Q not same even if ΔT same: $Q = W - \Delta E_{th}$ ← same

Heat depends on path

$\Delta E_{th} = E_{th\ f} - E_{th\ i}$ same (E_{th} is state variable)

$$\Rightarrow W_A + Q_A = W_B + Q_B$$

$|W_B| > |W_A|$ (area under curve); $W_{A, B} < 0$

$\Rightarrow Q_B > Q_A$ (Q, W are *not* state variables)

Adiabatic Process ($Q=0$)

- e.g. gas in thermally insulated cylinder or rapid expansion/compression (no time for heat transfer via atomic-level collisions) (can be slow enough to be quasi-static)
- $\Delta E_{th} = W \Rightarrow$ expansion lowers T ...

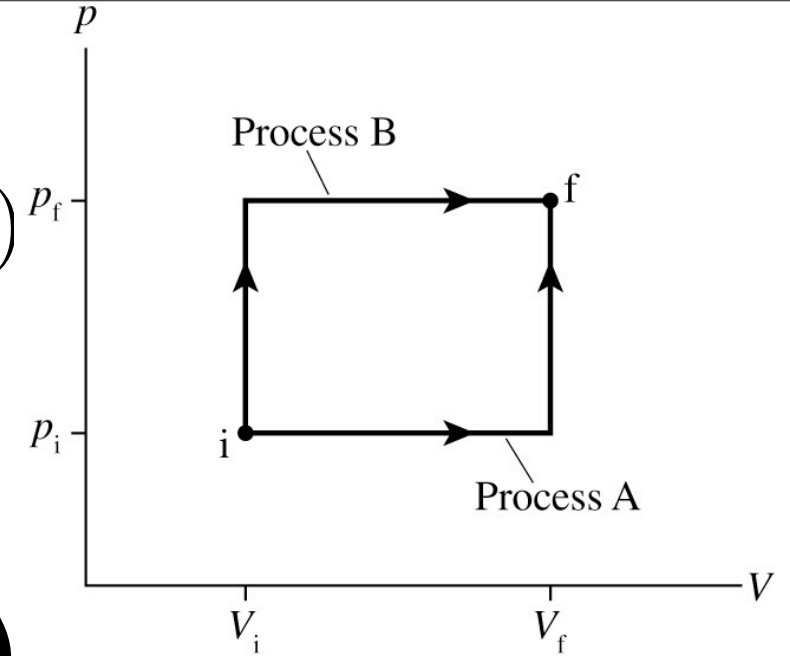
$$W = nC_V\Delta T \quad (\text{adiabatic process})$$

- pV diagram (adiabat: steeper than isotherm)

$$\gamma = \frac{C_P}{C_V} = \begin{array}{ll} 1.67 & \text{monoatomic gas} \\ 1.40 & \text{diatomic gas} \end{array}$$

$$pV^\gamma = \text{constant} \quad \text{or} \quad p_f V_f^\gamma = p_i V_i^\gamma$$

Using ideal gas law $p = nRT/V$: $TV^{\gamma-1} = \text{constant}$



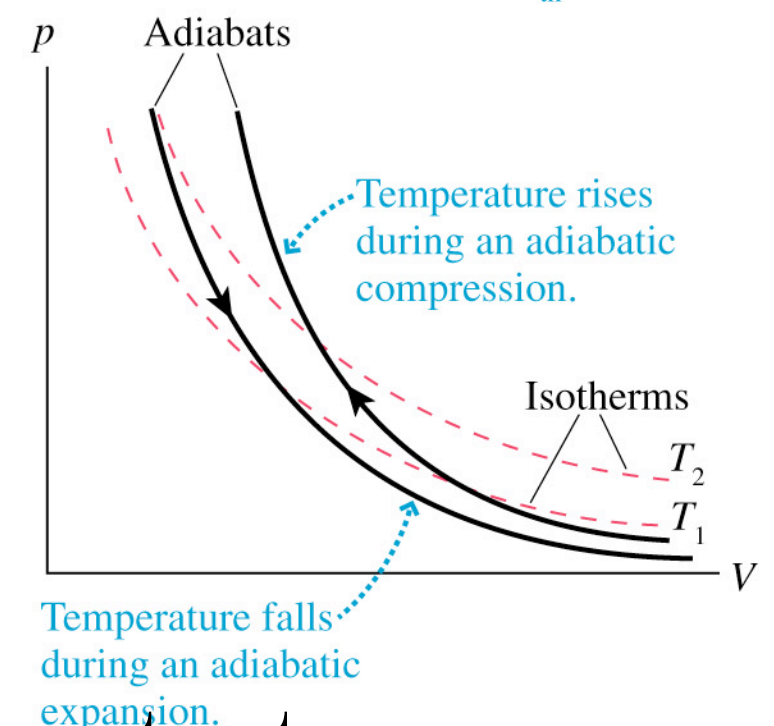
Copyright © 2004 Pearson Education, Inc., publishing as Addison Wesley

An *isothermal* process has $\Delta E_{th} = 0$, so $W = -Q$.

An *isochoric* process has $W = 0$, so $\Delta E_{th} = Q$.

$$\Delta E_{th} = W + Q$$

An *adiabatic* process has $Q = 0$, so $\Delta E_{th} = W$.



Copyright © 2004 Pearson Education, Inc., publishing as Addison Wesley