For the ideal gas

$$U = \frac{1}{2} N f k T$$

$$C_v = \left(\frac{\partial U}{\partial T}\right)_v = \frac{1}{2} N f k$$

$$C_p = \left(\frac{\partial U}{\partial T}\right)_p + p\left(\frac{\partial V}{\partial T}\right)_p$$

$$= C_v + p\left(\frac{\partial V}{\partial T}\right)_p$$

$$PV = NkT \Rightarrow V = \frac{NkT}{P}$$

$$C_p = C_v + p\left(\frac{\partial}{\partial T}\frac{NkT}{P}\right)_p$$

$$C_p = C_v + Nk$$

$$\frac{C_p}{C_v} = \frac{\frac{1}{2}Nfk + Nk}{\frac{1}{2}Nfk} = \frac{\frac{1}{2}f + 1}{\frac{1}{2}f} = \frac{2+f}{f} = \gamma$$

Ex: How much heat energy to bring 1.5 L of water to boiling?

$$Q = C_v \Delta T$$

$$c_v = \frac{C_v}{m}, \quad C_v = m c_v$$

$$\rho_w = 10^3 \frac{kg}{m^3} \times 1.5 L \times \frac{1 m^3}{1000 L} = 1.5 kg$$

1 cal

$$c_v = \frac{4.2 J}{g \cdot K}$$

$$C_v = \frac{4.2 J}{g \cdot K} \times 1500 g = 6300 \frac{J}{K}$$

$$Q = 6300\,\Delta T$$

Room temp ($\sim 30°C$) to boiling ($100°C$)

$$Q = (6300)(70)$$

$$\boxed{Q = 4.41 \times 10^{5}\ J}$$

~ 0.12 kWh

avg $\sim$ 12¢ / kWh

$\sim$ 1-2 ¢

OK, now we have 1.5 L of boiling water

- Remove from heat, & throw in 340 g of pasta

What happens to T of water?

- Heat flow from water to pasta

Heat out of water

=

Heat into pasta

$C_{pasta} = 1.8 \frac{J}{g \cdot K}$

$$C_w \Delta T_w = -C_p \Delta T_p$$

$$m_w c_w (T_f - T_w) = -m_p c_p (T_f - T_p)$$

$$m_w c_w (T_f - T_w) = m_p c_p (T_p - T_f)$$

$$m_w c_w T_f - m_w c_w T_w = m_p c_p T_p - m_p c_p T_f$$

$$T_f (m_w c_w + m_p c_p) = m_w c_w T_w + m_p c_p T_p$$

$$T_f = \frac{m_w c_w T_w + m_p c_p T_p}{m_w c_w + m_p c_p}$$

$$= \frac{(1500\,g)\left(4.2\,\frac{J}{g\cdot K}\right)(373) + (340\,g)\left(1.8\,\frac{J}{gK}\right)(303\,K)}{(1500\,g)\left(4.2\,\frac{J}{gK}\right) + (340\,g)\left(1.8\,\frac{J}{gK}\right)}$$

$$T_f = 366.8\ K = 93.8\ ^\circ C$$ (water cools by $\sim 6^\circ C$)

use more water!

Ex

0.5 L of water @ $T = 25°C$

Toss in 50 g of ice ($T = -15°C$)

Final temp of water?

- Heat leaves water & enters ice
- Raises temp of ice & melts it
- Raises temp of melted ice

Heat leaving water:

$$Q = m_w C_w (T_F - T_w)$$

$$Q_{ice} = m_i C_i (273 - T_i) + m_i L_i + m_i C_w (T_f - 273)$$

$$Q_{ice} = -Q_w$$

$$-m_w C_w (T_f - T_w) =$$

$$m_i C_i (273 - T_i) + m_i L_i + m_i C_w (T_f - 273)$$

$$-m_w c_w T_f + m_w c_w T_w$$

$$= m_i c_i (273 - T_i) + m_i L_i + m_i c_w (T_f - 273)$$

$$m_w c_w T_w - m_i c_i (273 - T_i) - m_i L_i$$

$$= m_i c_w (T_f - 273) + m_w c_w T_f$$

$$= (m_i c_w + m_w c_w) T_f - m_i c_w 273$$

$$T_f = \frac{m_w c_w T_w - m_i c_i (273 - T_i) - m_i L_i + 273 m_i c_w}{m_i c_w + m_w c_w}$$

$$m_w = 0.5\,L \times \frac{1\,m^3}{1000\,L} \times \frac{1000\,kg}{m^3} = 0.5\,kg = 500\,g$$

$$c_w = 4.2\,\frac{J}{gK}$$

$$T_w = 293\,K$$

$$m_i = 50\,g$$

$$c_i = 2.1\,\frac{J}{gK}$$

$$L_i = 333\,\frac{J}{g}$$

$$m_{w2} = m_i = 50\,g$$

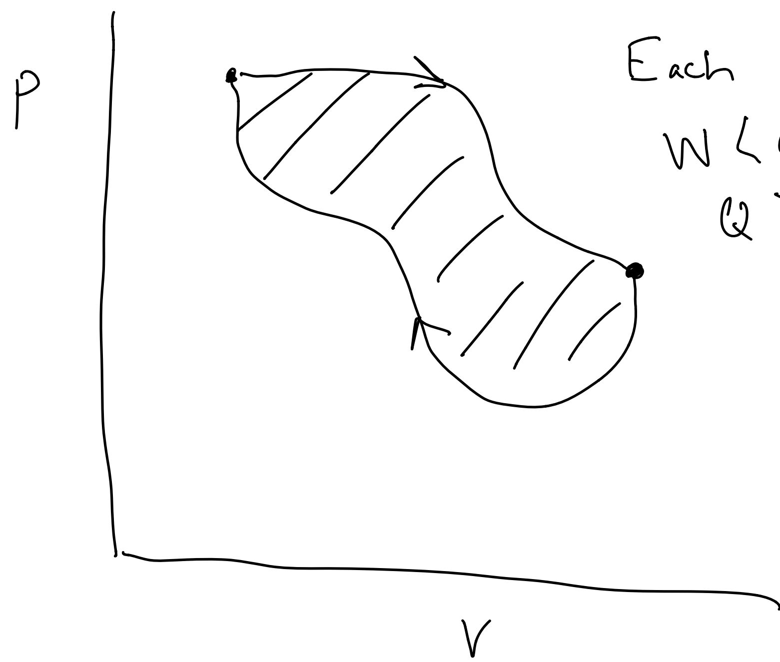
$$T_F = 282.6\,K = 9.6\,°C$$

Ice brings water down

by ~10 °C

State variables

Properties of a system that don't depend on how the system came to be



Each cycle
$W < 0$
$Q > 0$

U, P, V, T vs W, Q

$$\Delta U = Q + W$$

Consider a new state variable:

$$H = U + PV$$

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

$$= Q + W + \Delta(PV)$$

$$\Delta H = Q - P\Delta V + \Delta(PV)$$

IF P is constant

then $\Delta(PV) = V\Delta P + P\Delta V = P\Delta V$

$$\Delta H = Q - P\Delta V + P\Delta V = Q$$

*

$\Delta H = Q$

in reality, there are other types of work

$$\boxed{\Delta H = Q + W_{other}}$$

How to interpret?

$H = U + PV$

U: internal "thermal energy"

kinetic

PV: Energy needed to create room for our system

If our system has volume V, we need to expand it against the atmosphere

- Atmosphere collapsing after system is destroyed

In practice, it's useful bc many processes occur @ constant pressure (reactions)

$$C_p = \left(\frac{\partial U}{\partial T}\right)_p + P\left(\frac{\partial V}{\partial T}\right)_p$$

$$C_p = \left(\frac{\partial H}{\partial T}\right)_p$$

$$H = U + PV$$

$$\left(\frac{\partial H}{\partial T}\right)_p = \left(\frac{\partial U}{\partial T}\right)_p + P\left(\frac{\partial V}{\partial T}\right)_p$$