Last Time:

$\underset{\sim}{E}$ → sum of all potential and kinetic energies.

$\underset{\sim}{Q}$ → heat, flow of Energy from one system to another.

T → temperature, loosely "energy / dot"

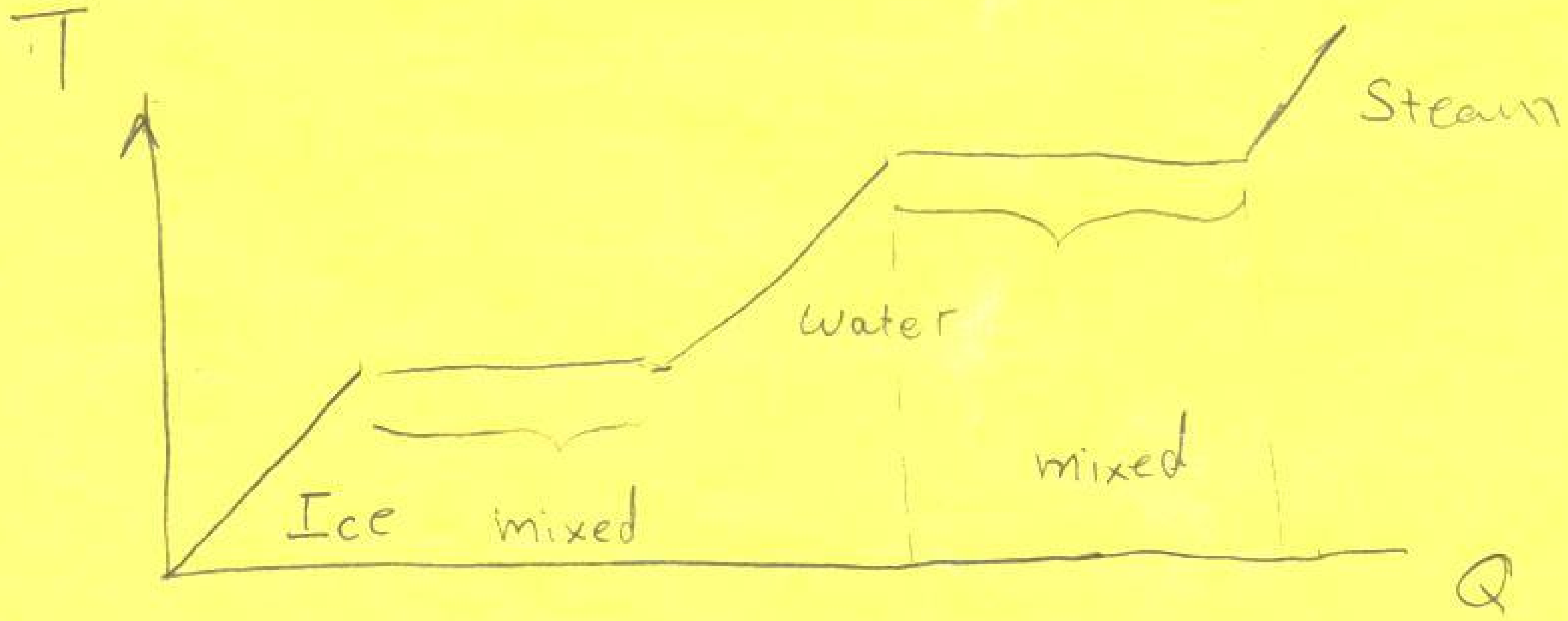
ex.

→ See next page

$$\frac{Q}{m} \sim \text{"}\frac{\text{Energy}}{\#\text{ of dot}}\text{"} \propto \Delta T$$

$$Q = mc\,\Delta T$$

Sometimes it doesn't work that way



Energy in an Ideal mono-atomic gas

Energy in gas

$$\frac{E}{3N} = \frac{1}{2} k_B T \quad \leftarrow \quad T \text{ is energy per d.o.f.}$$

number of molecules

$\underline{3}N \longrightarrow$ number of d.o.f = Number of molecules × (3 directions each molecule can move)

This can also be written

$$E = \frac{3}{2} N k_B T = \frac{3}{2} n R T$$

number of moles

(remember $N k_B = nR$

For an Ideal diatomic gas

$$\frac{E}{5N} = \frac{1}{2} k_B T$$

$$\longrightarrow \quad 5 = 3 + 2$$

$$E = \frac{5}{2} N k_B T$$

$$= \frac{5}{2} n R T$$

3 ways to move

two ways to spi

Roughly

$$T \sim \frac{\text{Energy}}{\text{degrees of freedom}} \sim \frac{\text{Energy goes up} \uparrow}{\text{degree of freedom}}$$

$T \sim$ constant

Specifically, take a hunk of ice mass m

$$Q = m\,L$$

Q: Heat required to melt this hunk

m: mass

L: Latent Heat

① "heat of fusion"

for water to ice $Q = m$

② "heat of vaporization"

water to steam

$$Q = m L_v$$

P21

a) In an insulated vessel 250g of ice at 0°C is added to 600g of H_2O at 18°C, What is the final temperature

b) How much Ice remains

Sol $\quad L_f = 3.33 \times 10^5 \ \frac{J}{kg}$ Table 20.2

$$c_w = 4186 \ \frac{J}{kg\,°C}$$

Heat required to cool water

$$Q = m\, c_w\, \Delta T$$

$$Q = (.600\ kg)\left(4186 \frac{J}{kg\,°K}\right)(-18°K)$$

$$Q = -45{,}208$$

So

$$Q_{in} = m_{melted} L_f$$

$$\frac{Q_{in}}{L_f} = m_{melt}$$

$$+\frac{45208}{3.33\times10^5} = m$$

$$135\,g = m \longrightarrow \frac{135\,g}{250\,g} = \text{frac of ice melted}$$

$$54\% =$$

Liquid Helium has a boiling pnt of 4.2K and a low heat of Vap

$$2.\times 10^4 \frac{J}{kg}$$

How low does it take a 10W electric heater to boil away 5kg of this stuff

$$Q = m L$$

$$Q = (5\,kg)\left(2\times10^4 \frac{J}{kg}\right) = 10^5 J$$

$P = 10\,W = 36 \frac{kW}{h}$

$P = \frac{\text{Energy}}{\text{time}} \Rightarrow \text{time} = \frac{\text{Energy}}{\text{Power}} = \frac{10^5 s}{10} = 10^4$

$= 2.77\,h$

Work:

History, relation to stea / to work

~James Watt ~1785

by gas

$P = \frac{F}{A} = \frac{\text{Force}}{\text{Area}}$

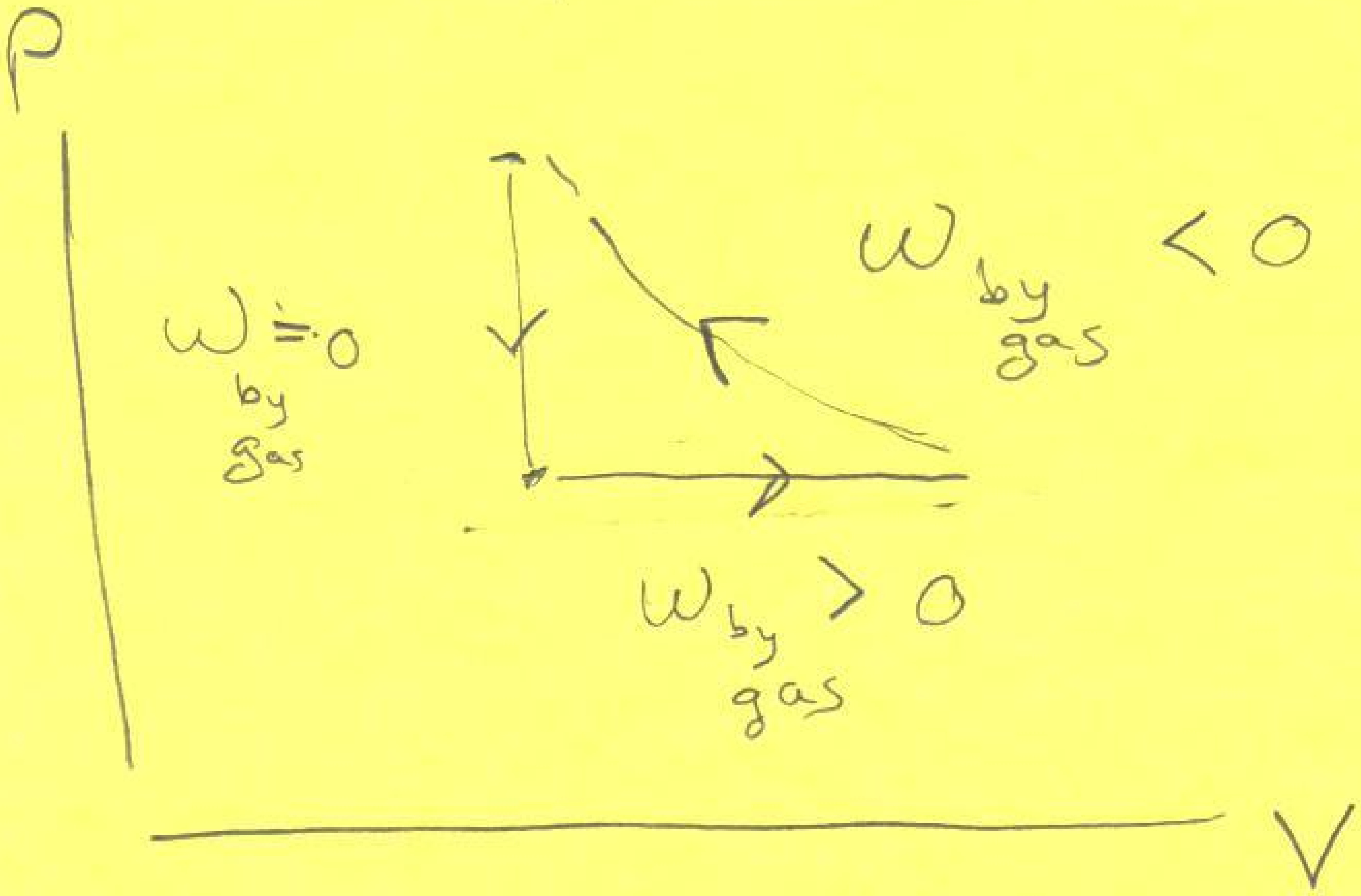
$PA = F$

$P \underbrace{A \Delta x}_{\Delta V} = F \Delta x = W_{\text{by gas}}$

$P \Delta V = W_{\text{by gas}}$

Pressure is a function of V

Examples



volume of gas decreasing

your doing work

Putting it All together, E-conservation

$$E = Q - W_{by\ gas}$$

E: sum of pot + KE

Q: heat flow into gas

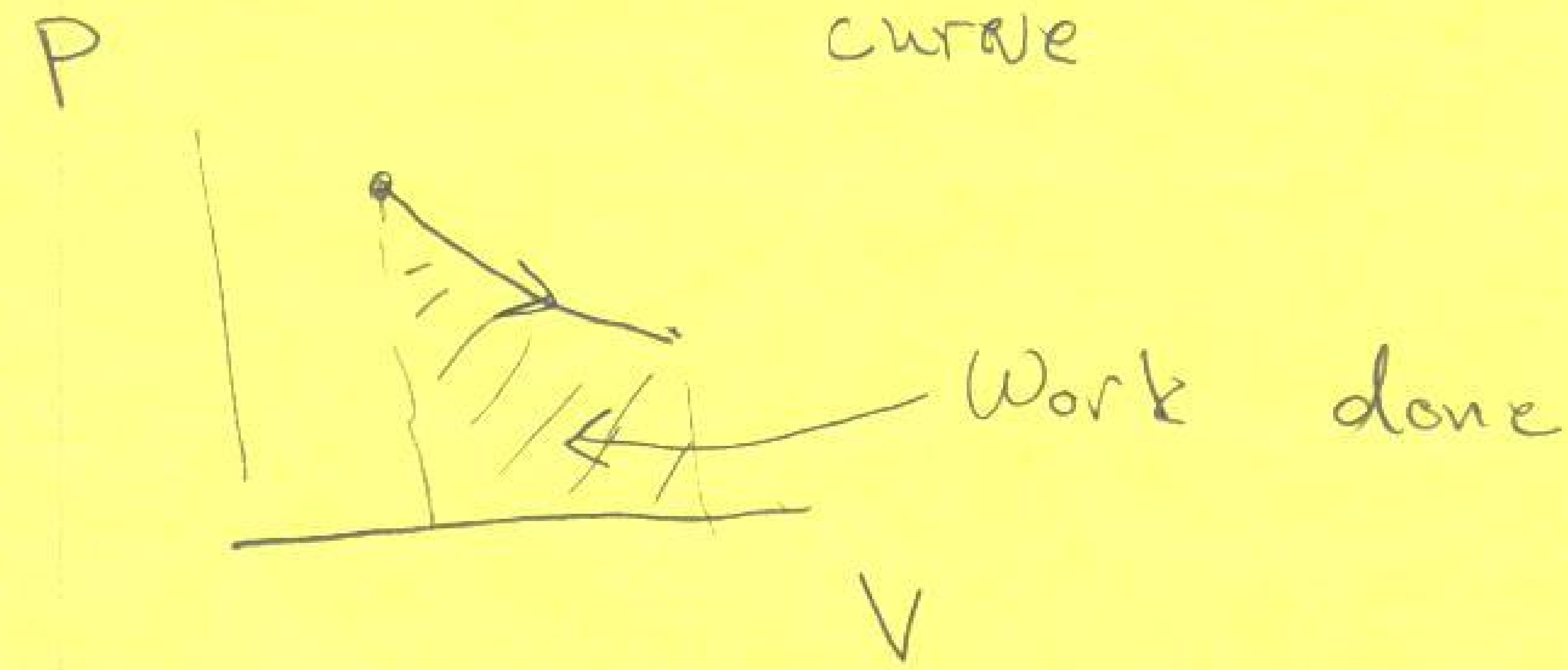
$W_{by\ gas}$: Work done by gas = −W d[illegible] on gas

I use an opposite sign convention from the book

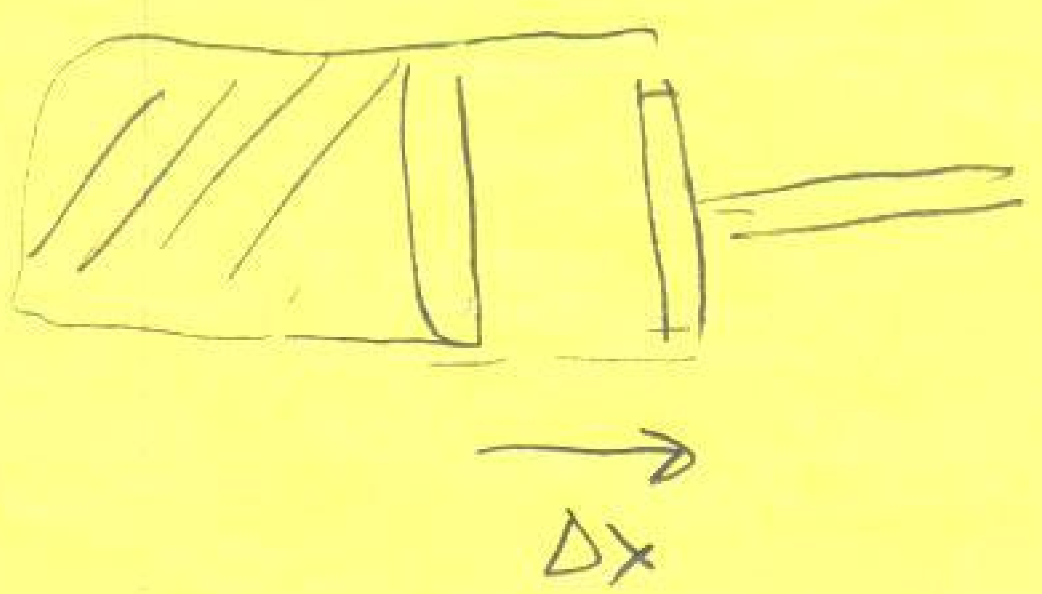
see below

$$W_{\text{by gas}} = \int_{V_i}^{V_f} P(V)\, dV$$

= Area under P vs V curve

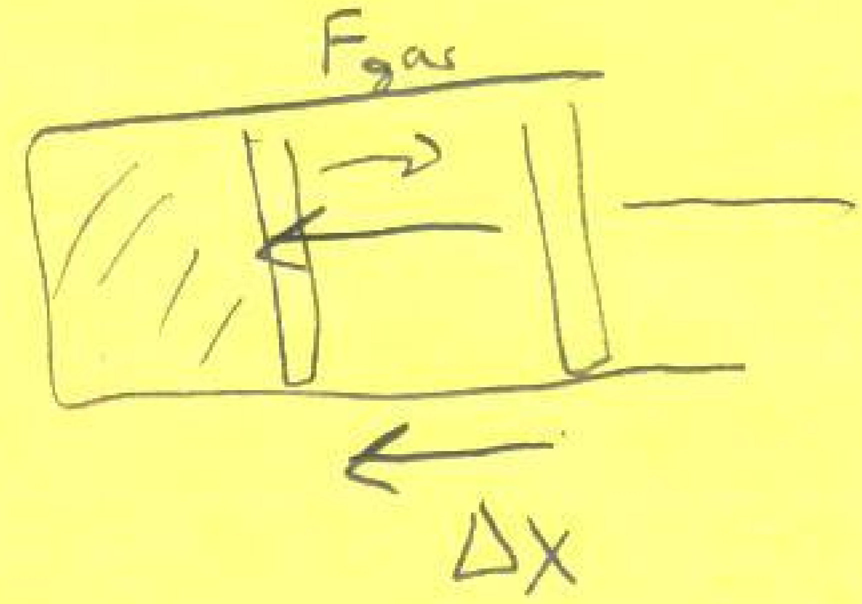


What is this "by gas", "on gas" nonsense .



Gas does work = $P\Delta V$

Work done by you on gas = $-P\Delta$



You do work on gas:

$W_{\text{on gas}} = P|\Delta V|$

$W_{\text{by gas}} = P\,\Delta V$

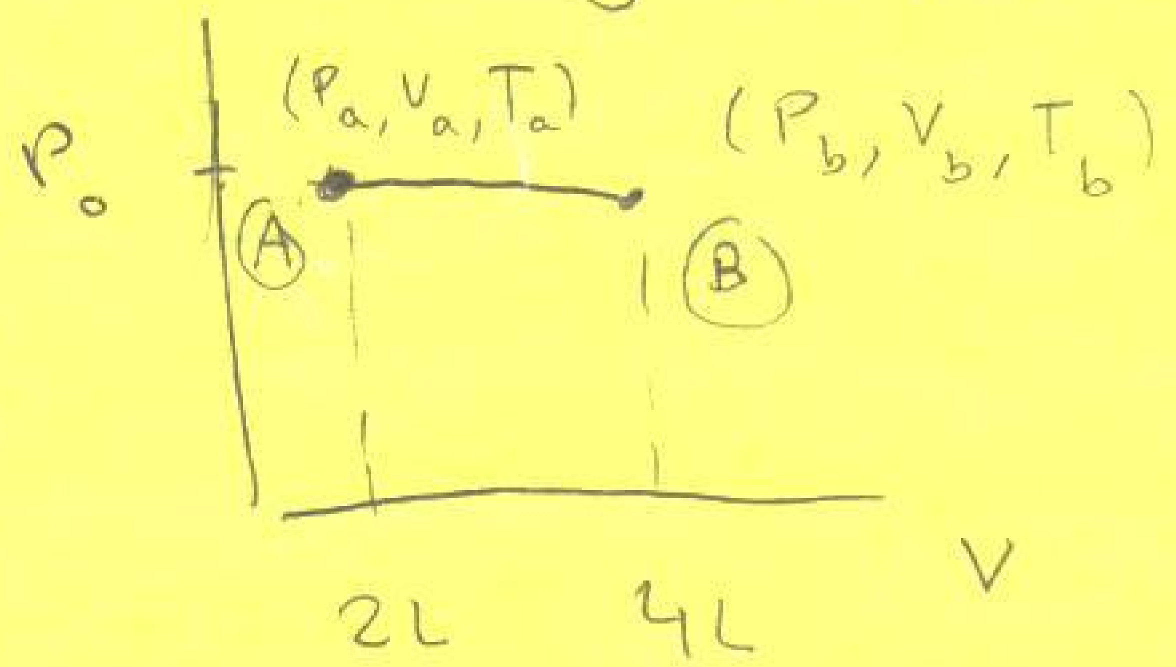
ΔV neg

①

Example Iso thermal expansion

2 mole of mono atomic ideal gas undergoes an isobaric (constant pressure) expansion from 2 L to 4L at 15.7° C

① Calculate the work done and necessary heat flow



$$W_{\text{by gas}} = \int^{V_f} P\,\Delta V = P_o\,\Delta V$$

$1\ L = 10^{-3}\ m^3$

$$P_o V_o = nRT_o$$

$$P_o = \frac{nRT_o}{V_o} = \frac{(2\ \text{moles})\left(8.31\ \frac{J}{mol\ °K}\right)(288.8°K)}{2 \times 10^{-3}\ m^3}$$

$P_o \cong 24$ bar $\quad P_o V_o = 4800\,J$

$$W_{\text{by gas}} = 24 \times 10^5\ \frac{N}{m^2} \times \underbrace{(2 \times 10^{-3}\ m^3)}_{\Delta V = 4L - 2L = 2L} = 4800\ J$$

Then

$$\Delta E = \frac{3}{2} n R \ \Delta T$$

$$P_b V_b = n R T_b$$

$$\left(24 \times 10^5 \ \frac{N}{m^2}\right)\left(4 \times 10^{-3} \ m^3\right) = (2 \text{ mole}) \times \left(8.31 \ \frac{J}{mol \ ^\circ K}\right) T_b$$

$$577 \ ^\circ K = T_b$$

$$\Delta E = \frac{3}{2} n R \left(T_b - T_a\right) = \frac{3}{2}(2 \text{mole})\left(8.31 \frac{J}{mol \, K}\right) \cdot (288 ^\circ K)$$

$$= 7200 \ J$$

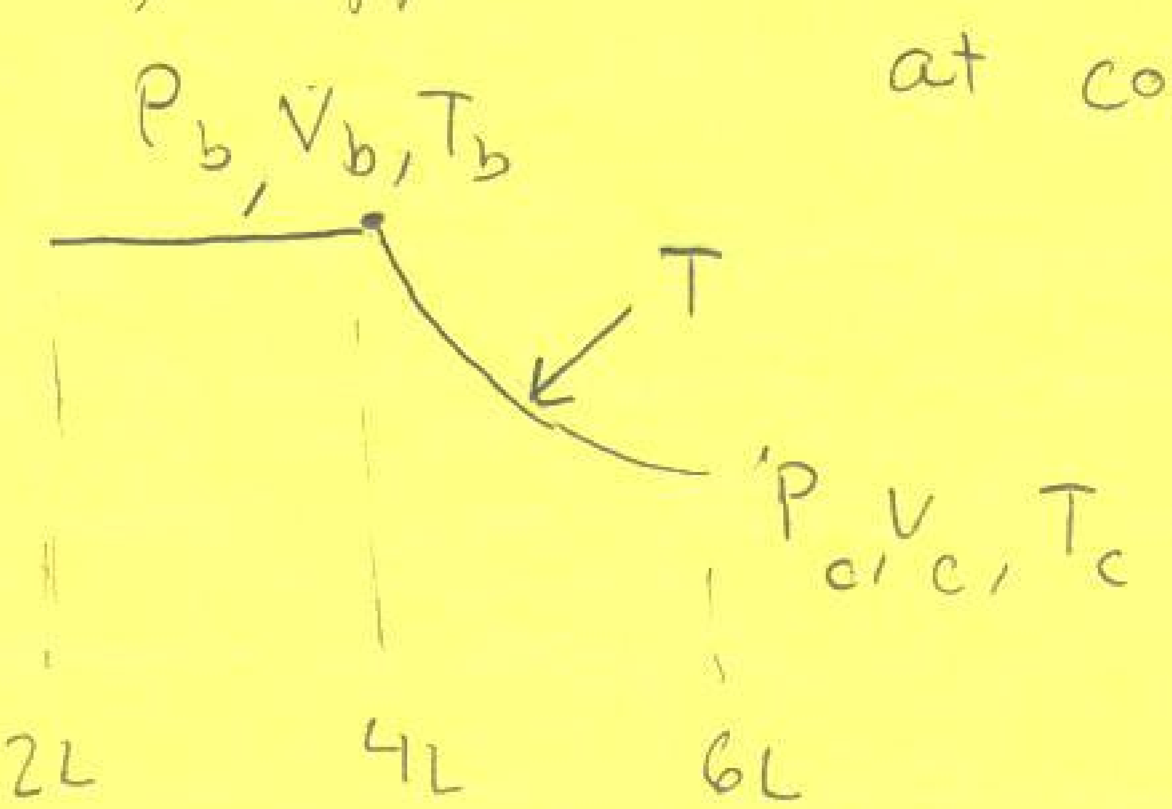
Then

$$\Delta E = Q - W$$

$$\Delta E + W = Q$$

$$12000 \ J = Q$$

Now, suppose we make another expansio at constant temperature



$$W = \int_{V_b}^{V_c} p \, dV = \int_{V_b}^{V_c} n \frac{RT}{V} \, dV$$

$$= nRT \log V \Big|_{V_b}^{V_c}$$

$$\boxed{W = nRT \log \frac{V_c}{V_b}}$$ ← Work done in an iso-thermal expansion

$$W = 2_{\text{mole}} \, 8.31 \frac{J}{\text{mol}\,^\circ K} (586^\circ K) \log \frac{6\cancel{L}}{4\cancel{L}}$$

$$\boxed{W = 3\,892\,J}$$

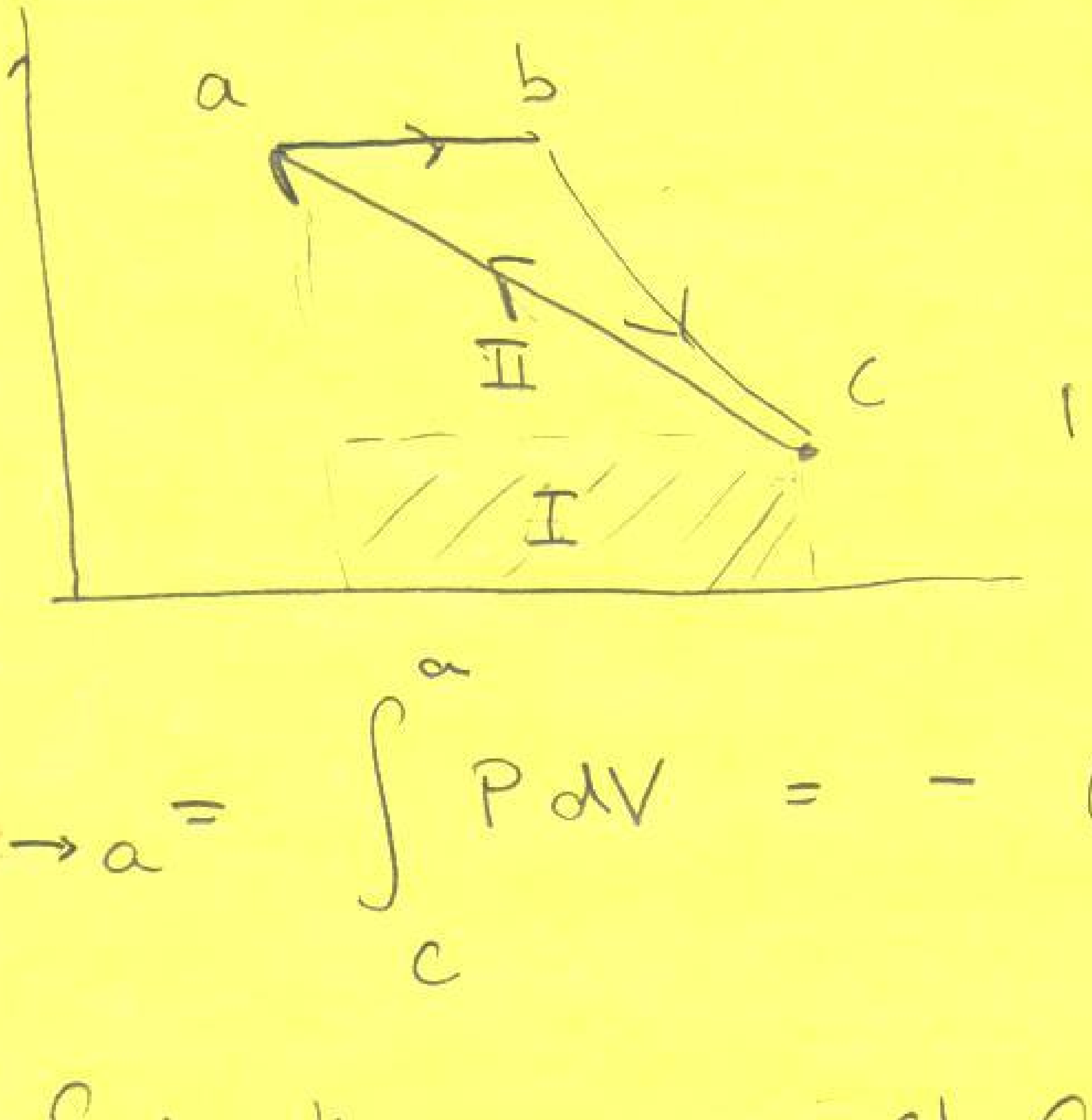
$$\Delta E = \frac{3}{2} nR\, \Delta T \qquad \Delta T = 0$$

$$\Delta E = 0$$

$$\cancel{\Delta E} = Q - W_{\text{by gas}}$$

$$W_{\text{by gas}} = Q = 3892\ \text{J}$$

Now Suppose we make one more step



$$W_{c \to a} = \int_c^a P\, dV = -\ (\text{Area under curve})$$

first find the pressure at C

$$P_c = \frac{nRT_c}{V_c} \qquad T_c = 2T_0 \qquad V_c = 2V_0$$

$$P_c = \frac{nR\, 2T_0}{3V_0} = \frac{2}{3} P_0 = 16\ \text{bar}$$

$$\text{Area} = P_c(V_c - V_a) + \frac{1}{2}(V_c - V_a)(P_a - P_c)$$

$$= \frac{2}{3}P_0(2V_0) + \frac{1}{2}(2V_0)\left(\frac{1}{3}P_0\right)$$

$$\text{Area} = \left(\frac{4}{3} + \frac{1}{3}\right) P_0 V_0$$

$$= \frac{5}{3} P_0 V_0$$

$$W = -8000\,J$$

$$\underline{\text{Net Work}} = 4800 + 3892 - 8000\,J$$

$$= 692\,J$$

$$\text{Intake of Heat} = 12000 + 3892 = Q_{In}$$

$$\text{Effic} = \frac{W}{Q_{In}} = 4.3\%$$

Last Time:

E → sum of all potential and kinetic energies.

Q → heat, flow of Energy from one system to another.

T → temperature, loosely "energy / dot"

ex.

→ See next page

$$\frac{Q}{m} \sim \text{"}\frac{\text{Energy}}{\#\text{ of dot}}\text{"} \propto \Delta T$$

$$Q = mc\,\Delta T$$

Sometimes it doesn't work that way