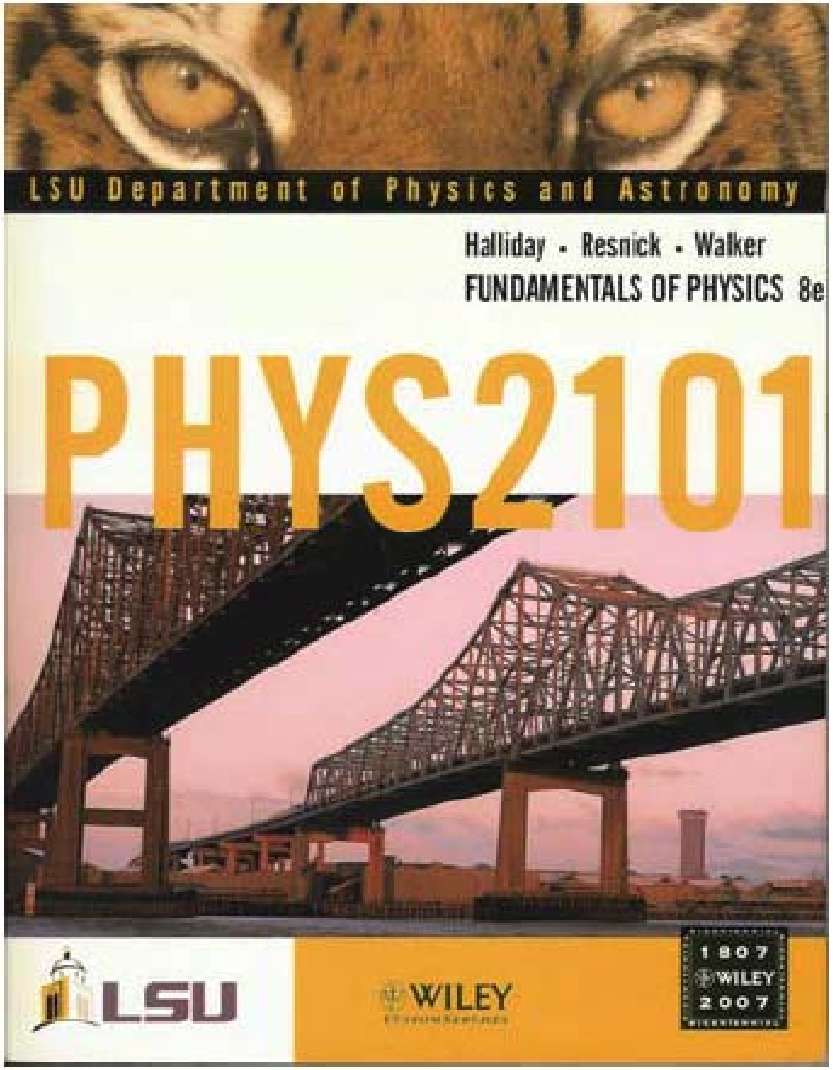


Physics 2101
Section 3
April 23th: Chap. 18

Announcements:

- Quiz #8 Today
- Exam #4, April 28th (Ch. 13.6-18.8)
- Final Exam: May 11th (Tuesday), 7:30 AM
- Make up Final: May 15th (Saturday) 7:30 AM

Class Website:

http://www.phys.lsu.edu/classes/spring2010/phys2101-3/

http://www.phys.lsu.edu/~jzhang/teaching.html

SHW#11 #3

An old mining tunnel disappears into a hillside. You would like to know how long the tunnel is, but it's too dangerous to go inside. However, you figure out a way: using your subsonic amplifier and loudspeaker, you find resonances at 4.5 Hz and 6.3 Hz, and at no frequencies in between these. It's rather chilly inside the tunnel, so you estimate the sound speed to be 335 m/s. What's the result of your measurement?

Eq.16-13 for resonance frequency:

$$f = \frac{v}{\lambda} = n\frac{v}{2L}; \quad n = 1, 2, 3...$$

$$f_n = \frac{nv}{2L}$$

$$f_{n+1} = \frac{(n+1)v}{2L}$$

$$\Delta f = \frac{v}{2L}$$

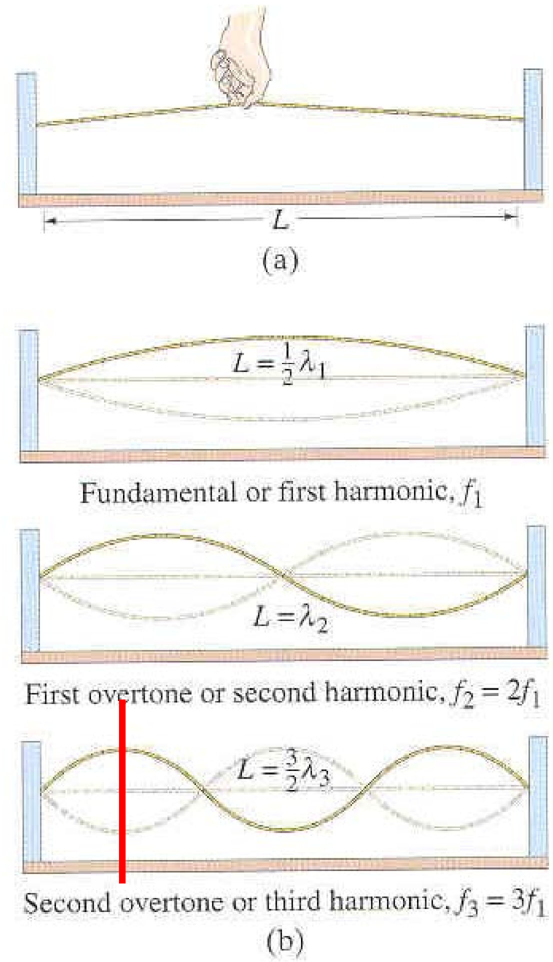
$$L \cong 93m$$

$$4.5 = \frac{n335}{2L}$$

$$6.3 = \frac{(n+1)335}{2L}$$

$$1.8 = \frac{(n+1)}{n}$$

$n = 2.5$ What goes on?



Heat of Transformation

Heat is transferred in or out of system, but temperature may NOT change: Change of phase

sublimation

Solid — Heat of Fusion → **Liquid** — Heat of Vaporization → **Gas**

$\Delta T = 0$

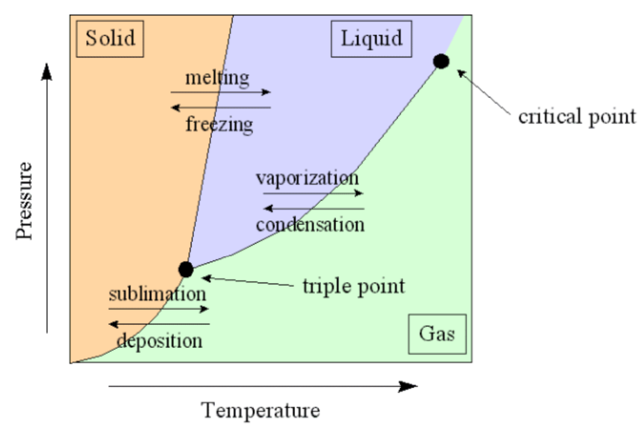
$Q = \pm L\,m$

Amount of heat transferred during phase change depends on L and mass (M)

L_F Heat of fusion → Solid to liquid (heat is adsorbed : atomic bonds are broken

L_V Heat of Vaporization → Liquid to gas (heat is adsorbed)

L_S Heat of Sublimation → Solid to gas (heat is adsorbed)



H_2O

L_F = 79.5 cal/g = 6.01 kJ/mol = 333 kJ/kg

L_V = 539 cal/g = 40.7 kJ/mol = 2256 kJ/kg

Example: H_2O

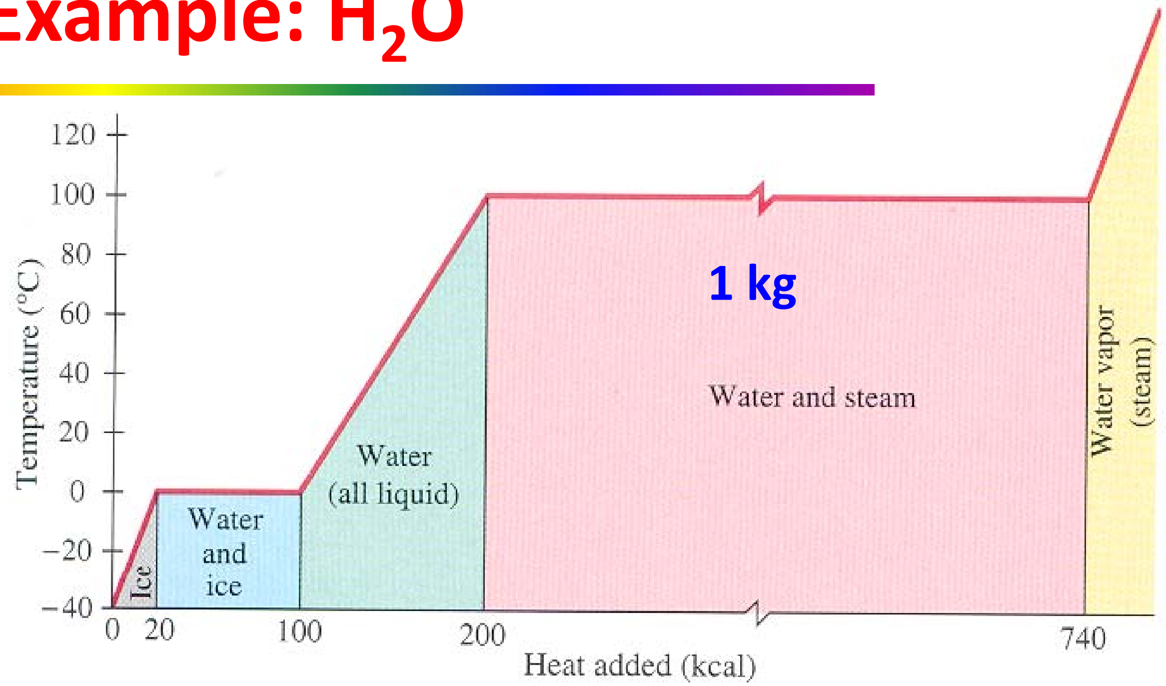
H_2O

c_{ice} = 0.53 cal/g·K

L_F = 79.5 cal/g

c_{water} = 1.0 cal/g·K

L_V = 539 cal/g



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Making Ice

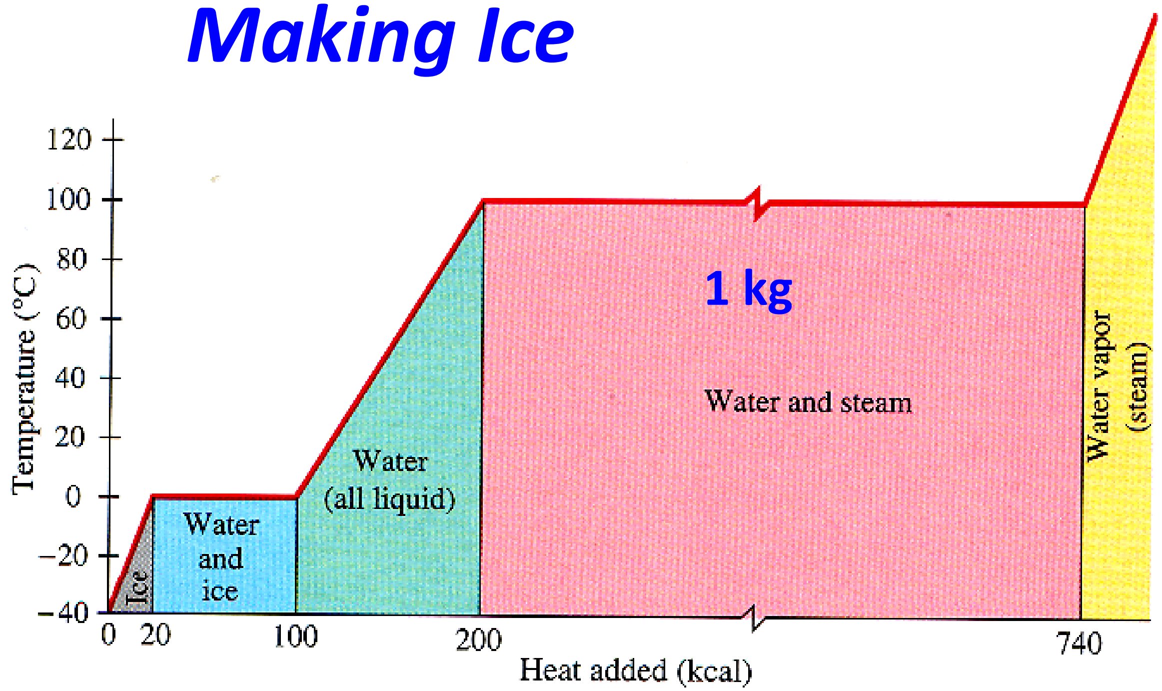
H_2O

c_{ice} = 2000 J/(kg·°C)

L_F = 33.5×10^4 J/kg

c_{water} = 4186 J/(kg·°C)

L_V = 22.6×10^5 J/kg



Making ice

How much energy does a refrigerator have to remove from 1.5 kg of water at 20°C to make ice at -12°C.

1) Calculate the Q need to remove to cool water to freezing point 0°C

$$Q = c_{water} m \Delta T = (4186\ {}^{J}\!/_{kg \cdot °C})(1.5kg)(0-20°C) = -1.26\times 10^5 J$$

2) Calculate Q needed to fuse water into ice

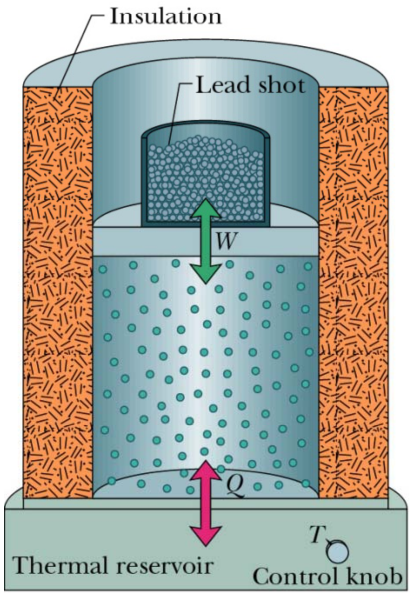
$$Q = -L_F m = -(33.5\times 10^4\ {}^{J}\!/_{kg})(1.5kg) = -5.03\times 10^5 J$$

3) Calculate Q needed to cool ice from 0°C to -12°C

$$Q = c_{ice} m \Delta T = (2000\ {}^{J}\!/_{kg°C})(1.5kg)(-12-0) = -3.6\times 10^4 J$$

$$\begin{aligned} Q_{TOT} &= -1.26\times 10^5 J \\ &\quad -5.03\times 10^5 J \\ &\quad -3.6\times 10^4 J \\ &= -6.65\times 10^5 J \end{aligned}$$

Heat and Work



If piston moves, the <u>differential work done BY the gas</u> is:

$$dW_{by} = \vec{F} \bullet d\vec{s} = (pA)ds = p(Ads)$$
$$= pdV$$

In going from V_i to V_f, the <u>total work done BY the gas</u> is:

$$W_{by} = \int dW = \int_{V_i}^{V_f} \underbrace{pdV}_{}$$

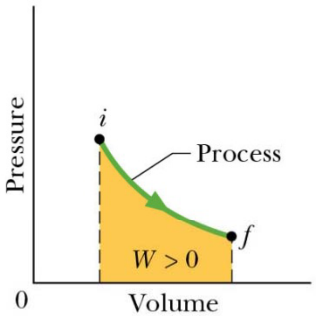
area under p-V graph

During change in volume, the temperature and/or the pressure may change.

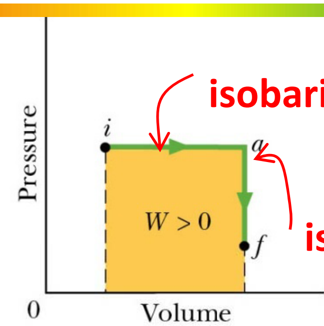
How the system changes from state i to f determines how much work is done BY the system.
WORK (and HEAT) IS (are) PATH DEPENDENT.

Path dependence of work

$$W_{by} = \int dW = \int_{V_i}^{V_f} p dV$$



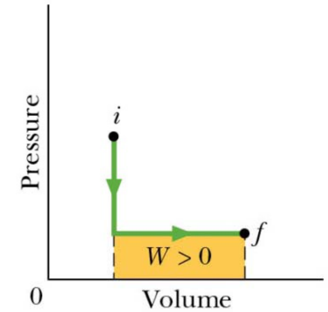
Volume increases,
Pressure decreases:
area > 0 W > 0
(gas expands)



isobaric: W = pΔV

isochoric: W = 0

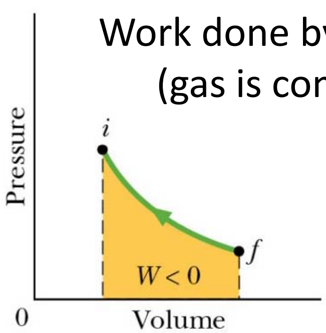
<u>Two step:</u>
Volume increases **then**
Pressure decreases:
area > 0 W > 0



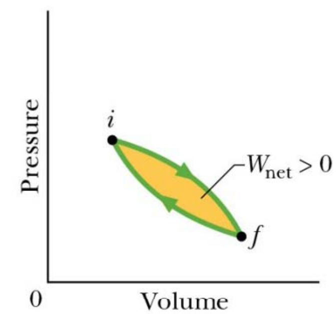
Here W > 0, but less than before

Work is NOT CONSERVATIVE: depends on path

Volume decreases,
Pressure increases:
W < 0
Work done by system is NEGATIVE
(gas is compressed)

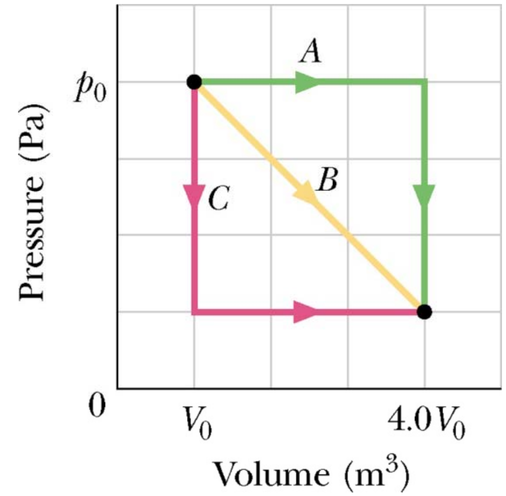


NET WORK, W_{net}, done by system during a complete cycle is shaded area. It can be pos., neg, or zero depending on path



18#45

A gas sample expands from V_0 to $4.0V_0$ while its pressure decreases from p_0 to $p_0/4$. If V_0=1.0m^3 and p_0=40. Pa, how much work is done by the gas if its pressure changes with volume via (a) path A, (b) path B, and (c) path C?



Path A

W=pΔV

No work done constant V

Path B

$$W=\int p\,dV$$

$$p = a + bV$$

Path C: Constant pressure

W=pΔV

The First Law of Thermodynamics

E_{int} = sum total of the energy of particles (molecules/atoms) in system

Internal Energy or Thermal Energy

- E_{int} ↑(increases) if work done to system or heat added to system
- E_{int} ↓(decreases) if work done by system or heat taken from system
- Although W and Q are path-dependent, E_{int} is **not**.

$$\Delta E_{int} = E_{int,f} - E_{int,i} = Q - W_{by}$$

$$dE_{int} = dQ - dW_{by}$$

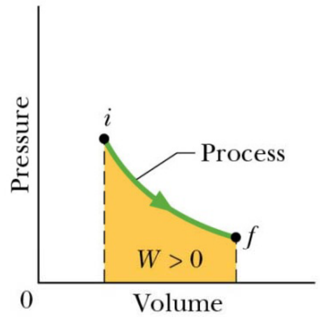
In thermodynamics, Work is defined as done by system: $\Delta E_{int} = Q + W_{on}$

Path Dependence of Work and ΔE_{int}

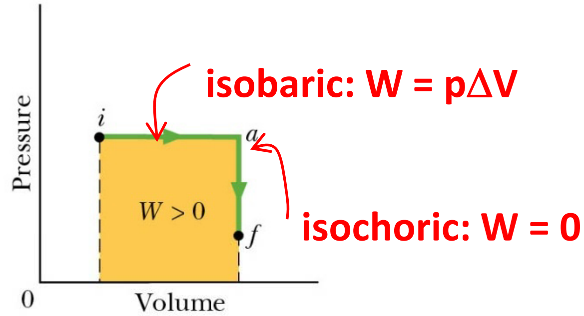
$$W_{by} = \int dW = \int_{V_i}^{V_f} p\,dV$$

$$\Delta E_{int} = E_{int,f} - E_{int,i} = Q - W$$

$$dE_{int} = dQ - dW_{by}$$

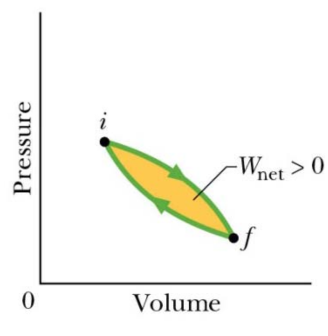


Volume increases,
Pressure decreases:
area > 0 -> W > 0
(gas expands)



Two step:
Volume increases **then**
Pressure decreases:
area > 0 -> W > 0

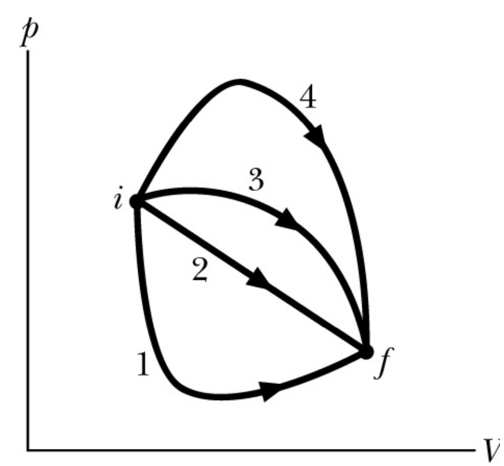
Work and Heat are NOT CONSERVATIVE: depends on path
ΔE_{int} does NOT depend on path !!



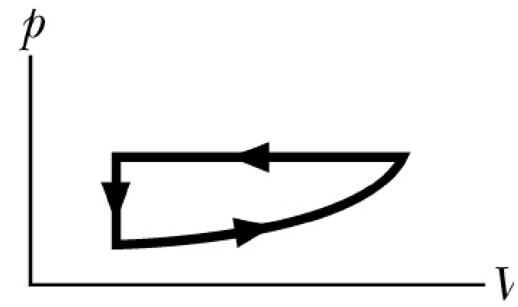
NET WORK, W_{net}, done by system during a complete cycle is shaded area. It can be pos., neg, or zero depending on path. Around a closed cycle ΔE_{int} is zero.

Figure shows four paths on p-V diagram along which a gas can be taken from state i to state f. Rank:

1) ΔE_{int} ?
2) Work done by gas?
3) Heat transferred?



Checkpoint

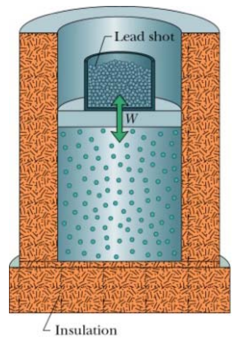


For one complete cycle as shown in the p-V diagram,
Which ones are positive? Negative? Or Zero?

ΔE_{int} ? Net work done by gas W? Net energy transferred Q ?

Special cases of First Law of Thermodynamics

$$\Delta E_{int} = E_{int,f} - E_{int,i} = Q - W$$



1) **Adiabatic processes** - NO TRANSFER OF ENERGY AS HEAT Q = 0
   a) rapid expansion of gasses in piston - no time for heat to be transferred
   b) if work is done by system (W>0), then ΔE_{int} decreases
   c) NOTE: temperature changes!!

$$[\Delta E_{int} = -W]_{adiabatic}$$

2) **Constant-volume processes** (isochoric)- NO WORK IS DONE W = 0
   a) if heat is absorbed, the internal energy increases
   b) NOTE: temperature changes!!

$$W_{by} = \int_{V_i}^{V_f = V_i} p dV = 0$$

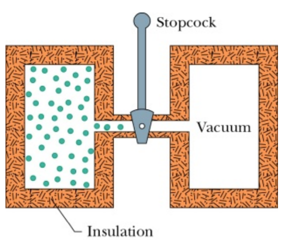
$$\Delta E_{int} = Q$$

3) **Cyclical process (closed cycle)** $\Delta E_{int,closed\ cycle} = 0$
   a) net area in p-V curve is Q

$$\Delta E_{int} = 0 \Rightarrow Q = W$$

4) **Free Expansion :** **adiabatic process with no transfer of heat**
   a) happens suddenly
   b) no work done against vacuum
   c) non-thermal equilibrium process

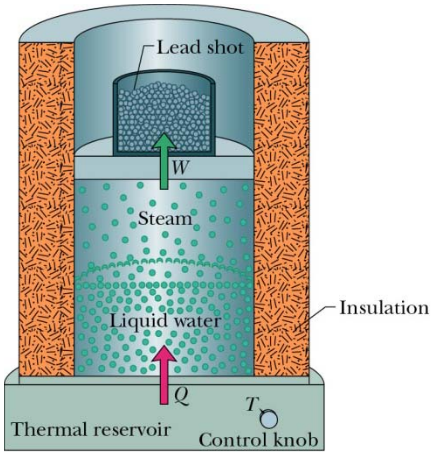
$$\Delta E_{int} = Q = W = 0$$



5) **Isothermal:** **Temperature does not change** We'll talk about this later…

Sample Problem 18-5

Let 1.0 kg of liquid at 100°C be converted to steam at 100°C by boiling at twice atmospheric pressure (2 atm) as shown. The volume of the water changes from an initial value of 1.0×10^{-3} m^3 as a liquid to 1.671 m^3 as a gas.



Here, energy is transferred from the thermal reservoir as heat until the liquid water is changed completely to steam. Work is done by the expanding gas as it lifts the loaded piston against a constant atmospheric pressure.

a) How much work is done by the system during the process?

How do we calculate work?

$$W_{by} = \int_{V_i}^{V_f} p\,dV = p(V_f - V_i)$$
$$= (2\cdot\text{atm})(1.01\times10^5\cdot\text{N/m}^2/\text{atm})(1.671\cdot\text{m}^3 - 0.001\cdot\text{m}^3)$$
$$= 338\cdot\text{kJ}$$

b) How much energy is transferred as heat during the process?

What is the heat added?

no temperature change $\rightarrow$ only phase change

$$Q = mL_V = (1.0\cdot\text{kg})(2256\cdot\text{kJ/kg}) \cong 2260\cdot\text{kJ}$$

c) What is the change in the system's internal energy during the process?

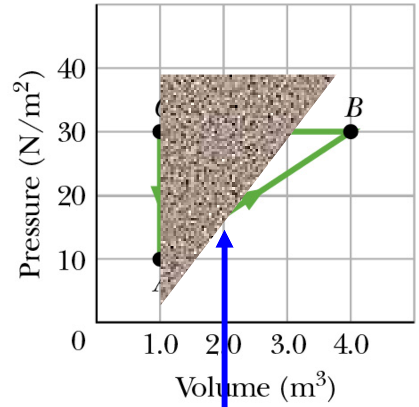
Using 1st Law of Thermo:

$$\Delta E_{\text{int}} = Q - W_{by}$$
$$= 2260\cdot\text{kJ} - 338\cdot\text{kJ} \cong 1920\cdot\text{kJ}$$

Positive! Energy mostly (85 %) goes into separating H_2O molecules

More Example…

18-43: Gas within a closed chamber undergoes the cycle shown in the p-V diagram. Calculate the net energy added to the system as heat (Q) during on complete cycle.



In one complete cycle, $\Delta E_{int,cycle} = 0$ so Q=W. To find Q, calculate W!

$$W_{by} = W_{A\to B} + W_{B\to C} + W_{C\to A}$$

$$= \int_{V_A}^{V_B} p_{A\to B}\, dV + \int_{V_B}^{V_C} p_{B\to C}\, dV + \int_{V_C}^{V_A} p_{C\to A}\, dV$$

$$= \int_{1}^{4} \left(\tfrac{20}{3} V + \tfrac{10}{3}\right) dV + \int_{4}^{1} (30)\, dV + \int_{1}^{1} p_{C\to A}\, dV$$

$$= \left(\tfrac{20}{3}\left(\tfrac{1}{2}V^2\right) + \tfrac{10}{3}(V)\right)\Big|_{1\cdot m^3}^{4\cdot m^3} + \left(30(V)\right)\Big|_{4\cdot m^3}^{1\cdot m^3} + 0 = -30\cdot J$$

$$p_{A\to B}(V) = \left(\frac{20}{3} V \cdot \mathrm{m}^{-3} + \frac{10}{3}\right)\cdot \mathrm{Pa}$$

$$p_{B\to C}(V) = 30\cdot \mathrm{Pa}$$

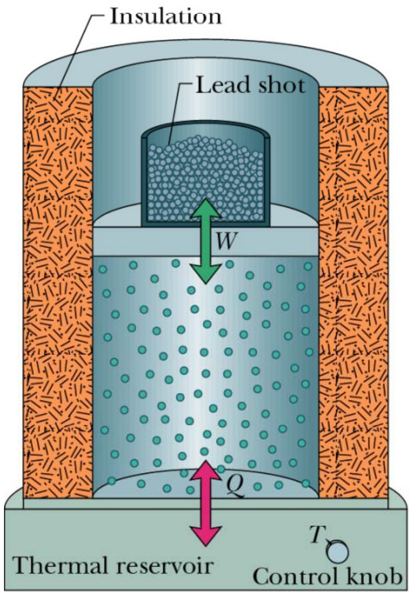
$$\Delta V_{C\to A} = 0$$

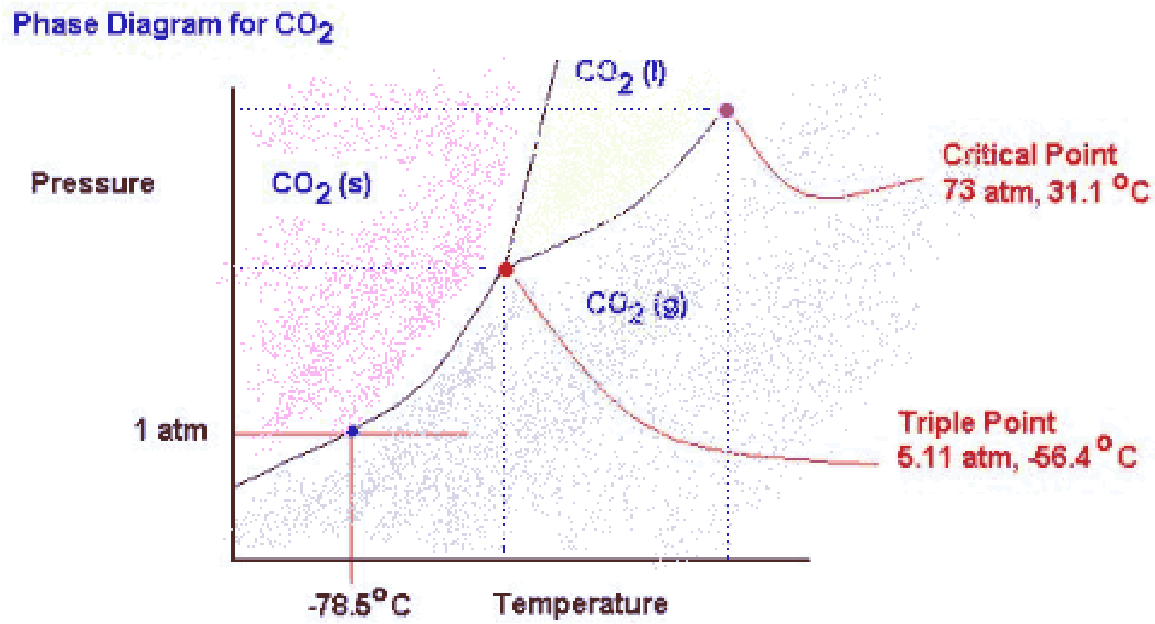
W = Q = - 30 J

Or just add up area enclosed!

CCW - negative

CW - positive





In going from V_i to V_f, the <u>total work done BY the gas</u> is:

$$W_{by} = \int dW = \underbrace{\int_{V_i}^{V_f} p\,dV}_{\text{area under p-V graph}}$$

area under p-V graph

During change in volume, the temperature and/or the pressure may change.

How the system changes from state i to f determines how much work is done BY the system.
WORK (and HEAT) IS (are) PATH DEPENDENT.