

# Physics 2101 Section 3 April 26<sup>th</sup>: Chap. 18-19

## Announcements:

- Exam #4, April 28<sup>th</sup>  
(Ch. 13.6-18.8)
- Final Exam: May 11<sup>th</sup>  
(Tuesday), 7:30 AM
- Make up Final: May 15<sup>th</sup>  
(Saturday) 7:30 AM

## Class Website:

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

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

# The First Law of Thermodynamics

$E_{\text{int}}$  = sum total of the energy of particles (molecules/atoms) in system  
**Internal Energy or Thermal Energy**

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

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

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

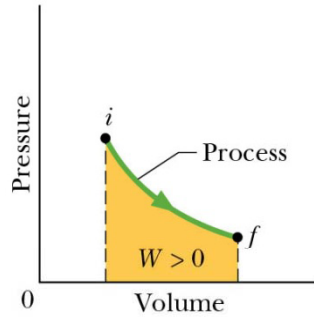
In thermodynamics, Work is defined as done by system:  $\Delta E_{\text{int}} = Q + W_{\text{on}}$

# Path Dependence of Work and $\Delta E_{\text{int}}$

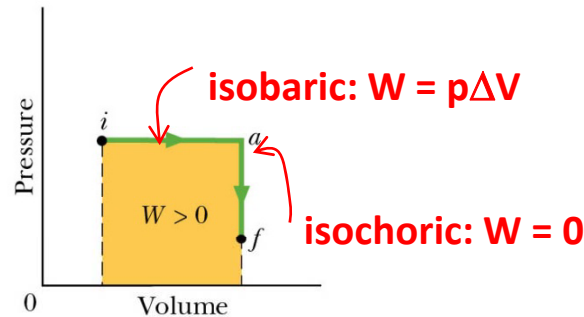
$$W_{\text{by}} = \int dW = \int_{V_i}^{V_f} p dV$$

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

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



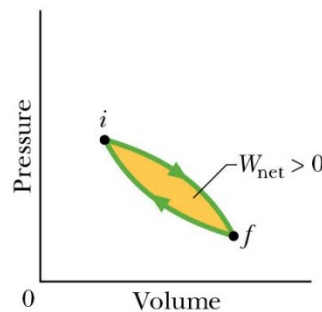
Volume increases,  
Pressure decreases:  
area > 0  $\rightarrow$   $W > 0$   
(gas expands)



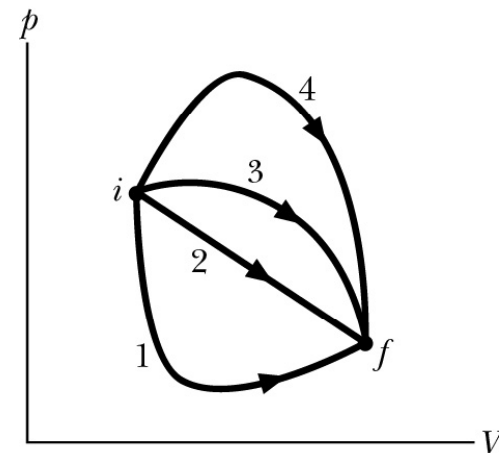
Two step:  
Volume increases **then**  
Pressure decreases:  
area > 0  $\rightarrow$   $W > 0$

**Work and Heat are NOT CONSERVATIVE: depends on path**  
 $\Delta E_{\text{int}}$  **does NOT depend on path !!**

Figure shows four paths on p-V diagram along which a gas can be taken from state i to state f. Rank:  
1)  $\Delta E_{\text{int}}$  ?  
2) Work done by gas?  
3) Heat transferred?



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

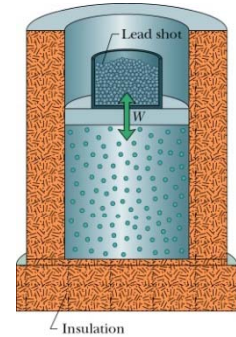


# Special cases of First Law of Thermodynamics

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

- 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  $\Delta E_{\text{int}}$  decreases
  - c) NOTE: temperature changes!!

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



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

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

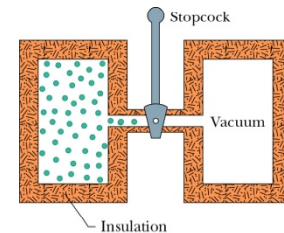
$$\Delta E_{\text{int}} = Q$$

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

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

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

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



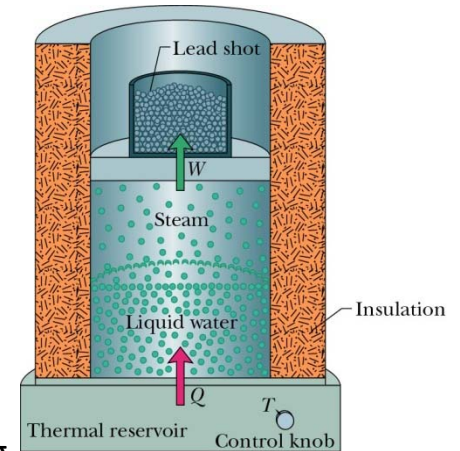
- 5) **Isothermal:** Temperature does not change

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  $1.0 \times 10^{-3} \text{ m}^3$  as a liquid to  $1.671 \text{ m}^3$  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?**

$$W_{by} = \int_{V_i}^{V_f} p dV = p(V_f - V_i)$$

$$= (2 \cdot \text{atm})(1.01 \times 10^5 \cdot \text{N/m}^2/\text{atm})(1.671 \cdot \text{m}^3 - 0.001 \cdot \text{m}^3)$$

$$= \underline{338 \cdot \text{kJ}}$$

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

**What is the heat added?**

no temperature change  $\rightarrow$  only phase change

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

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

**Using 1st Law of Thermo:**

$$\Delta E_{\text{int}} = Q - W_{by}$$

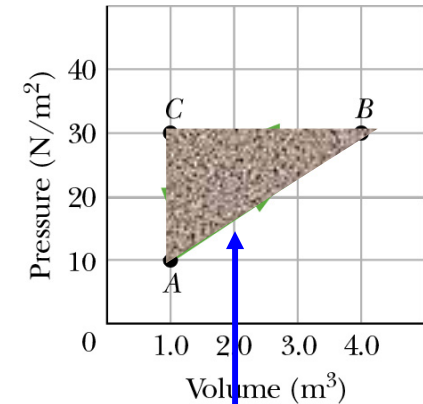
$$= 2260 \cdot \text{kJ} - 338 \cdot \text{kJ} \cong \underline{1920 \cdot \text{kJ}}$$

**Positive! Energy mostly (85 %) goes into separating  $\text{H}_2\text{O}$  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,  $\Delta E_{\text{int,cycle}} = 0$  so  $Q=W$ . To find Q, calculate W!

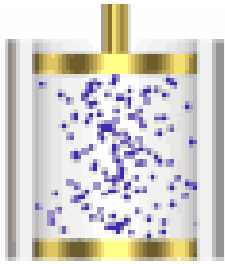


$$\begin{aligned}
 W_{\text{by}} &= W_{A \rightarrow B} + W_{B \rightarrow C} + W_{C \rightarrow A} \\
 &= \int_{V_A}^{V_B} p_{A \rightarrow B} dV + \int_{V_B}^{V_C} p_{B \rightarrow C} dV + \int_{V_C}^{V_A} p_{C \rightarrow A} dV \\
 &= \int_1^4 \left( \frac{20}{3} V + \frac{10}{3} \right) dV + \int_4^1 (30) dV + \int_1^1 p_{C \rightarrow A} dV \\
 &= \left( \frac{20}{3} \left( \frac{1}{2} V^2 \right) + \frac{10}{3} (V) \right) \Big|_{1 \cdot m^3}^{4 \cdot m^3} + (30(V)) \Big|_{4 \cdot m^3}^{1 \cdot m^3} + 0 = -30 \cdot J
 \end{aligned}$$

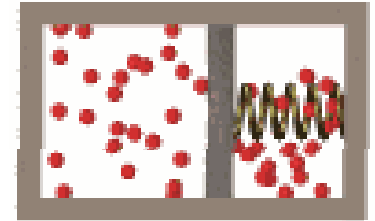
$$\begin{aligned}
 p_{A \rightarrow B}(V) &= \left( \frac{20}{3} V \cdot m^{-3} + \frac{10}{3} \right) \cdot \text{Pa} \\
 p_{B \rightarrow C}(V) &= 30 \cdot \text{Pa} \\
 \Delta V_{C \rightarrow A} &= 0
 \end{aligned}$$

$$W = Q = -30 \text{ J}$$

Or just add up area enclosed!  
 CCW - negative  
 CW - positive



# Chapt. 19: Kinetic Theory of Gases



Thermodynamics = macroscopic picture

Gases = micro -> macro picture

## IDEAL GAS LAW

$n$  = number of moles

$N$  = number of particles

$$pV = nRT \quad pV = NkT$$

$$k = 1.38 \times 10^{-23} \text{ J/K}$$

$$R = kN_A$$

$$R = 8.315 \text{ J/(mol}\cdot\text{K)}$$

$$= 0.0821 \text{ (L}\cdot\text{atm)/(mol}\cdot\text{K)}$$

$$= 1.99 \text{ calories/(mol}\cdot\text{K)}$$

Monoatomic ideal gas : He, Ar, Ne, Kr... (no potential energies)

**Atoms**

$$E_{\text{int,monotonic}} = N \left( \frac{3}{2} kT \right) = \frac{3}{2} nRT$$

$$\Delta E_{\text{int,monotonic}} = \frac{3}{2} nR(\Delta T)$$

**The internal energy of an ideal gas depends only on the temperature**

# Avogadro's Number

One mole is the number of atoms in 12 g sample of carbon-12

C(12)—6 protons, 6 neutrons and 6 electrons  
12 atomic units of mass assuming  $m_p = m_n$

$$N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$$

So the number of moles  $n$  is given by

$$n = N/N_A$$

Another way to do this is to know  
the mass of one molecule: then  
 $N = M(\text{sample})/mN_A$



19-1: Gold has a molar mass of 197 g/mol. (a) How many moles of gold are in 2.50g sample of pure gold? (b) How many atoms are in the sample? Au has 79 protons and ~118 neutrons.

n is number of moles (19-3)

$$n = \frac{M_{\text{sample}}}{M(\text{molar mass})} \equiv \frac{M_{\text{sample}}}{m(\text{one atom}) N_A}$$

$$n = \frac{M_{\text{sample}}}{M(\text{molar mass})} = \frac{2.5 \text{ g}}{197 \text{ g/mol}} = 0.0127 \text{ mol.}$$

(b) Number of atoms Eqn. 19.2

$$n = \frac{N}{N_A} \text{ or } N = n \cdot N_A$$

$$N = (0.0127)(6.02 \times 10^{23}) = 7.64 \times 10^{21}$$

19.2: Find the mass in kilograms of  $7.5 \times 10^{24}$  atoms of arsenic, which has a molar mass of 74.9 g/mole. As has 33 protons and ~42 neutrons

Each atom has a mass  $m = \frac{M}{N_A}$

Where M is the molar mass

The molar mass of As is 74.9 g/mol.

$$\text{Total M} = \frac{(7.5 \times 10^{24})(74.9 \times 10^{-3} \text{ kg / mol})}{(6.02 \times 10^{24} \text{ mol}^{-1})}$$

$$M = 0.933 \text{ kg}$$

19-3: The best laboratory vacuum has a pressure of about  $1.00 \times 10^{-13}$  Pa or  $10^{-18}$  atm. How many gas molecules are there per cubic centimeter in such a vacuum at 293 K?

Get units straight

$$V = 1.0 \times 10^{-6} \text{ m}^3$$

$$p = 10^{-13} \text{ Pa}$$

$$T = 293 \text{ K}$$

Ideal gas Law

$$pV = nRT$$

$R$  gas constant

$$R = 8.31 \text{ J/mol} \cdot \text{K}$$

$$n = \frac{pV}{RT} = \frac{(10^{-13} \text{ Pa})(10^{-6} \text{ m}^3)}{(8.31 \text{ J/mol} \cdot \text{K})(293 \text{ K})} = 4.1 \times 10^{-23} \text{ mole}$$

$$N = nN_A = (4.1 \times 10^{-23} \text{ mole})(6.02 \times 10^{23} \text{ mole}^{-1}) = 25 \text{ molecules}$$