TONIGHT'S TEST!

10 MC PROBLEMS (#'s and Concepts)

+

2 WRITTEN PROBLEMS

Questions??

DEPARTMENTAL POLICY!

College of Science
Department of Physics and Astronomy

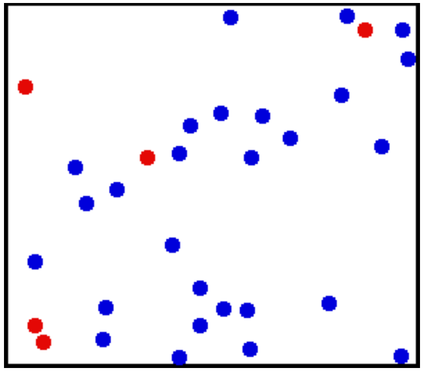
You may not have any personal items with you at your seat during this exam.

Please make sure your phone is turned off, and you have put your phone in your backpack or purse at the front of the room. Turned off does not mean put on silent. It means off.

If you are found with a cell phone, tablet, or any device capable of taking pictures, videos, accessing the Internet, or communicating with other people during this test, and it is turned on and within your reach, you will be reported to the SAA for violating the Student Code of Conduct.

If you need to leave the room for any reason, including but not limited to using the restroom, after you start the test, your test is over. You will have to turn your test in before you leave the room and it will not be returned to you.

Thermodynamics



- Study of thermal energy
- Understanding the internal **ENERGY** of bodies with many molecules
- Understanding the exchange of **ENERGY** between bodies

Two bodies are in thermal equilibrium when their temperatures are the same – i.e. their internal energy is the same!

0^{th} Law of thermodynamics:

If two bodies A and B are in thermal equilibrium with a third body C they are also in equilibrium with each other

Three temperature scales:

- Kelvin: set by triple point of water (273.16 K) and zero internal energy (0 K)
- °Fahrenheit
- °Celsius

$$T_c = T - 273.15 \qquad T_F = \frac{9}{5}T_c + 32$$

Thermal expansion!

1D: $\Delta L = \alpha L_0 \Delta T$

2D: $\Delta A = 2\alpha A_0 \Delta T$

3D: $\Delta V = \beta V_0 \Delta T$

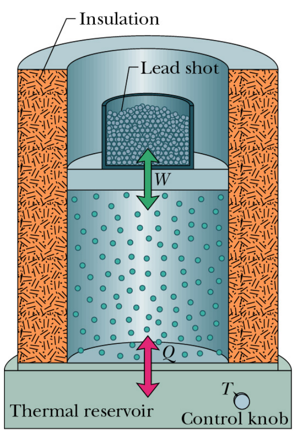
$\boxed{\beta = 3\alpha \text{ for a solid}}$

Heat and Work

Heat: ***energy transferred*** between system and environment due to temperature difference

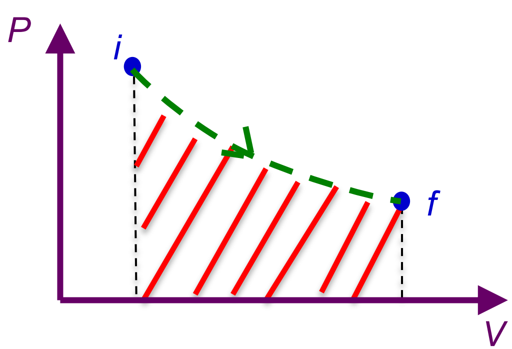
$$Q = C\left(T_f - T_0\right) = cm\left(T_f - T_0\right) = c_{molar}n\left(T_f - T_0\right)$$

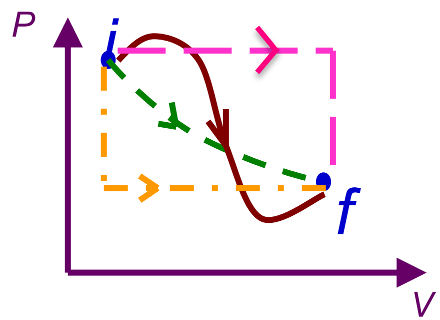
Or to change the phase of the material: $Q = \pm mL$



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

PATH DEPENDENT!!





1[ST] Law of Thermodynamics

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

Notice:

- negative sign between Q and W
- we are talking about work done ***by system***

ΔE_{int} is path INDEPENDENT

Special cases of First Law of Thermodynamics

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

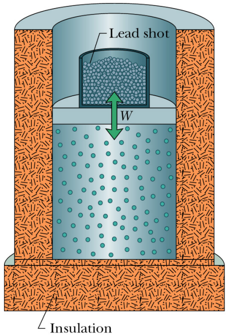
1) Adiabatic processes - NO TRANSFER OF ENERGY AS HEAT **$Q = 0$**

a) rapid expansion of gasses in piston - no time for heat to be transferred

b) if work is done by system ($W>0$), then ΔE_{int} decreases

c) NOTE: temperature changes!!

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



2) Constant-volume processes (isochoric)- NO WORK IS DONE **$W = 0$**

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

a) if heat is absorbed, the internal energy increases

b) NOTE: temperature changes!!

$$\left[\Delta E_{\text{int}} = Q\right]_{isochoric}$$

3) Cyclical process (closed cycle) **$\Delta E_{\text{int,closed cycle}} = 0$**

a) net area in p-V curve is W = Q

$$\left[\Delta E_{\text{int}} = 0 \;\Rightarrow\; Q = W\right]_{cycle}$$

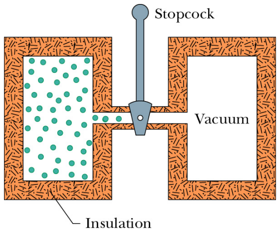
4) Free Expansion (IRREVERSIBLE !!! non equilib)

a) happens suddenly

b) No heat tranfer

c) No work done

$$Q = W = 0$$



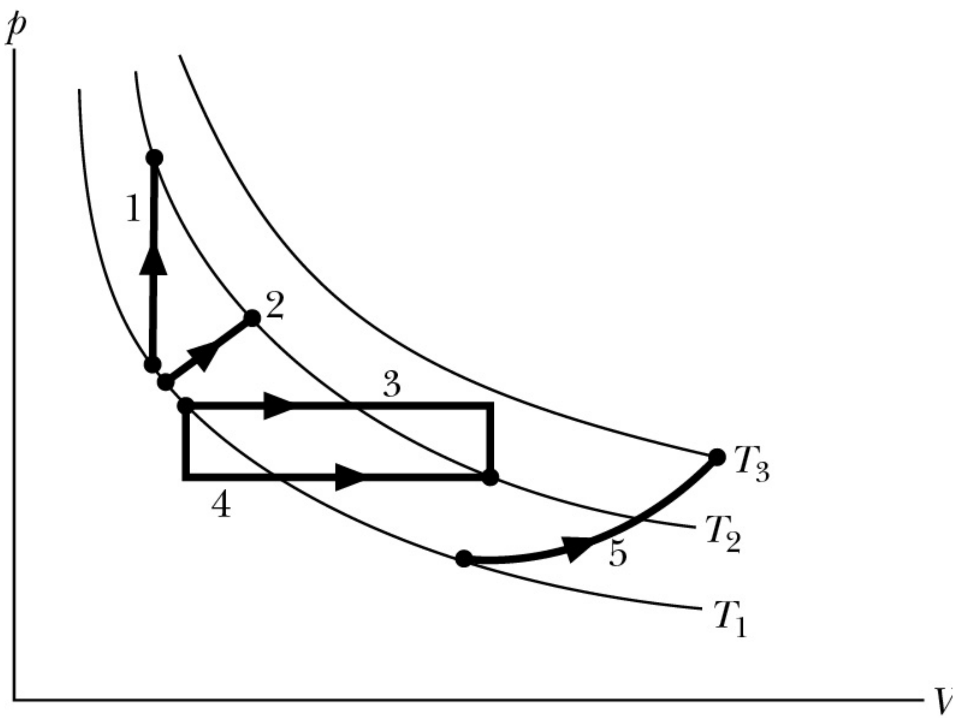
5) Isothermal: **Temperature does not change** **$\Delta T = 0$**

$$\Delta E_{\text{int}-isothermal} = 0$$

We'll talk about this later…

Quiz – Take 2

The figure shows paths traversed by a monatomic ideal gas on a p-V diagram. Rank the paths according to the change in internal energy of the gas, greatest first.



A. 5>4>3>2>1
B. 5>1>3=4>2
C. 2>1>3=4>5
D. $\boxed{\text{5>4=3=2=1}}$
E. 5=4=3=2=1

Ch 19: The Kinetic Theory of Gases

Kinetic theory: looks at the microscopic behavior of the molecules and averages over the individual molecules to get the macroscopic properties

For ideal gases:

1. Low density
2. Molecules are free, except for collisions of negligible duration
3. Collisions are elastic (with other particles and walls)

$$PV = nRT = NkT$$

Ideal gases:

$$KE_{avg} = \frac{f}{2}kT \qquad E_{\text{int}} = \frac{f}{2}nRT$$

f = 3, 5, or 6 (monatomic, diatomic, polyatomic)

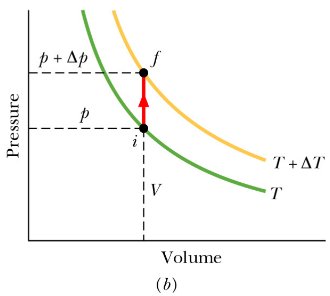
Constant Temperature (isothermal process): $W_{by,isothermal} = nRT\ln\left(\frac{V_f}{V_i}\right) = nRT\ln\left(\frac{p_i}{p_f}\right)$

Constant Volume/Pressure Processes

Molar specific heat for an ideal gas varies:

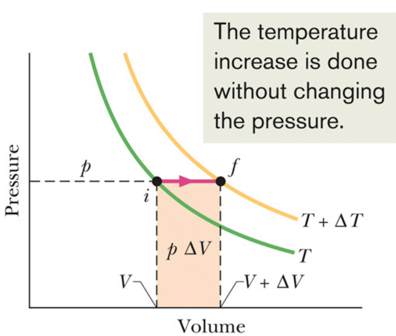
$C_V \rightarrow$ molar specific heat at constant volume $\quad\Rightarrow\quad Q = nC_V \Delta T$

$C_P \rightarrow$ molar specific heat at constant pressure $\quad\Rightarrow\quad Q = nC_P \Delta T$



(b)

$$\left.\begin{aligned} \Delta E_{\text{int}} &= Q - W_{by} = Q = nC_V \Delta T \\ \Delta E_{\text{int}} &= \frac{f}{2} nR\Delta T \end{aligned}\right\} \quad \begin{aligned} nC_V \Delta T &= \frac{f}{2} nR\Delta T \\ C_V &= \frac{f}{2} R \end{aligned}$$



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

$$C_P = C_V + R \qquad \frac{C_P}{C_V} = \gamma$$

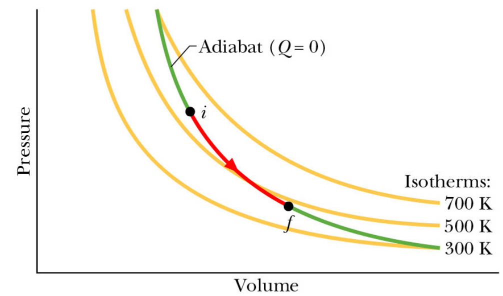
Remember special cases…

***Isothermal* expansion/contraction** – ($\Delta T=0$) $\Delta E_{int} = 0$

$$Q = W_{by,\text{isothermal}} \qquad p_1V_1 = p_2V_2$$

***Adiabatic* expansion/contraction** - *NO TRANSFER OF ENERGY AS HEAT* $Q = 0$

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



$$p_1V_1^{\gamma} = p_2V_2^{\gamma}$$

$$\gamma = \frac{C_P}{C_V}$$

Constant-volume processes (isochoric)-

NO WORK IS DONE $W = 0$

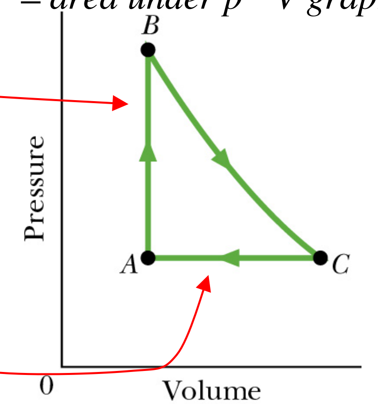
$$\Delta E_{\text{int}} = Q$$

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

$$Q_{\Delta V=0} = nC_V\Delta T$$

$W_{by} = \int pdV$

$= area\ under\ p-V\ graph$



Constant-pressure processes (isobaric)

$$\Delta E_{\text{int}} = Q - p\Delta V$$

$$C_V = C_P - R$$

$$W_{by} = \int_{V_i}^{V_f=V_i} pdV = p\Delta V$$

$$Q_{\Delta P=0} = nC_P\Delta T$$

3)*Cyclical* process (closed cycle) $\Delta E_{int,closed\ cycle} = 0$

a) net area in p-V curve is Q

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

Entropy: Different processes

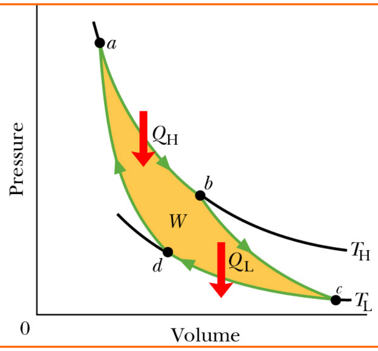
1) For isothermal process:

$$\Delta S_{isothermal} = \frac{Q}{T}$$

Q is total energy transferred as heat during the process (note: heat must be transferred from reservoir to keep temperature constant

2) For reversible process:

$$\Delta S_{cycle,rev} = 0 = \oint \frac{dQ}{T}$$



3) In general for a "small" change in temperature:

$$\Delta S = S_f - S_i \approx \frac{Q}{T_{avg}}$$

Entropy in various processes

Solids/Liquids

1) For phase changes:
Temperature = constant

$$\Delta S_{phase\ change} \equiv \int \frac{dQ}{T} = \frac{Q_{phase\ change}}{T} = \frac{mL}{T}$$

2) For temperature changes:

$$\Delta S_{liquid/solid} = S_f - S_i = \int \frac{dQ}{T} = \int \frac{mcdT}{T} = mc\ln\left(\frac{T_f}{T_i}\right)$$

Ideal Gases

1) For reversible process:

$$\Delta S_{cycle,rev} = 0 = \oint \frac{dQ}{T}$$

2) For isothermal process:

$$\Delta S_{rev,isothermal} = \frac{Q}{T}$$

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

$$W = nRT\ln\left(\frac{V_f}{V_i}\right)$$

$$\Rightarrow \quad \Delta S_{isothermal} = nR\ln\left(\frac{V_f}{V_i}\right)$$

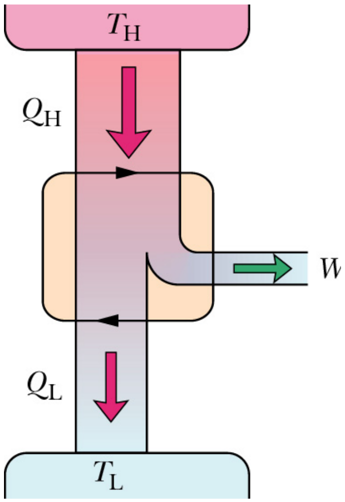
3) In general for gas, using 1st law:

$$\Delta S_{rev,gas} = S_f - S_i = nR\ln\left(\frac{V_f}{V_i}\right) + nC_V\ln\left(\frac{T_f}{T_i}\right)$$

4) For (reversible) adiabatic compression/expansion:

$$\Delta S_{rev,adiabatic} = 0$$

Heat Engines and Entropy



-Easy to produce thermal energy by doing work. How?

-Much harder to get work from thermal energy ➔ ***engine***

<u>Conservation of energy</u>

$|Q_H| = |Q_L| + |W|$

$|Q_H|$ = heat added

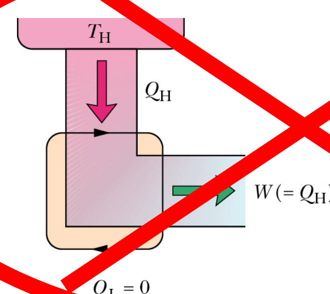
$|Q_L|$ = heat released

2nd Law: There is no perfect heat engine (Kelvin-Plank statement)

<u>*What is the thermal efficiency, ε, of an engine?*</u>

$$\varepsilon = \frac{\text{energy we get}}{\text{energy we pay for}} = \frac{|W|}{|Q_H|}$$

$$\varepsilon = \frac{|Q_H| - |Q_L|}{|Q_H|} = 1 - \frac{|Q_L|}{|Q_H|}$$



Perfect engine, ε <u>=1</u>

Carnot Cycle

For a complete cycle:

$$\Delta S_{cycle} = 0 \Rightarrow \frac{|Q_H|}{T_H} = \frac{|Q_L|}{T_L}$$

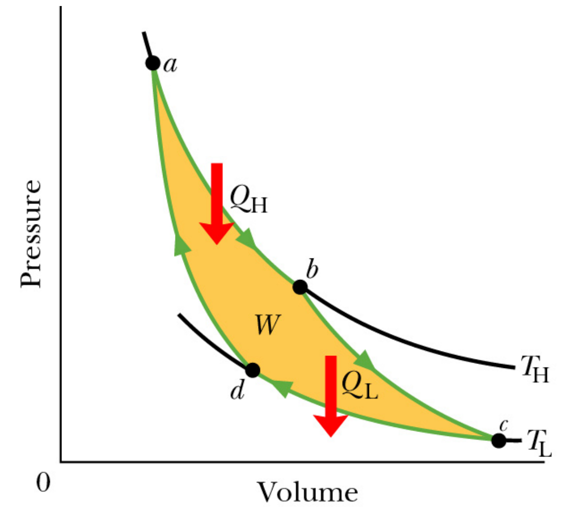
Carnot Engine Efficiency:

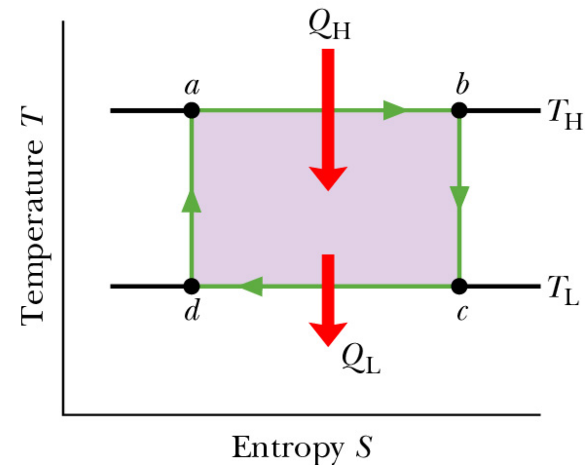
$$\varepsilon = \frac{|Q_H| + |Q_L|}{|Q_H|} = 1 - \frac{|Q_L|}{|Q_H|} = 1 - \frac{T_L}{T_H}$$

Carnot Refrigerator

$$\frac{\text{what you get}}{\text{what you pay for}} = \frac{|Q_L|}{|W|} = K$$

$$K = \frac{|Q_L|}{|Q_H| - |Q_L|} \Rightarrow K = \frac{|T_L|}{|T_H| - |T_L|}$$





Thermodynamics

0th Law of thermodynamics:

- Two bodies are in thermal equilibrium when their temperatures are the same – i.e. their internal energy is the same!
- If two bodies A and B are in thermal equilibrium with a third body C they are also in equilibrium with each other

1st Law of Thermodynamics

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

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

2nd Law of Thermodynamics

$$\Delta S_{total} \geq 0$$

system

$$\Delta S_{reversible} = \int_i^f \frac{dQ}{T}$$

TABLE 20-4 Four Special Processes

Path in Fig. 20-14	Constant Quantity	Process Type	Some Special Results ($\Delta E_{\text{int}} = Q - W$ and $\Delta E_{\text{int}} = nC_V\,\Delta T$ for all paths)
1	p	Isobaric	$Q = nC_p\,\Delta T$; $W = p\,\Delta V$
2	T	Isothermal	$Q = W = nRT\ln(V_f/V_i)$; $\Delta E_{\text{int}} = 0$
3	pV^γ, $TV^{\gamma-1}$	Adiabatic	$Q = 0$; $W = -\Delta E_{\text{int}}$
4	V	Isochoric	$Q = \Delta E_{\text{int}} = nC_V\,\Delta T$; $W = 0$