Announcements

1. On line evaluation forms –
   You have received an email with a PIN number to evaluate this course. Please help us with your candid anonymous opinions.
2. 4^{th} hour exam – Monday, Nov. 25^{th} -- Focusing on Chap. 19-22.
   Bring to exam:
   - Clear head
   - Equation sheet (8 ½ x 11 in^2)
   - Calculator
   - pencil or pen

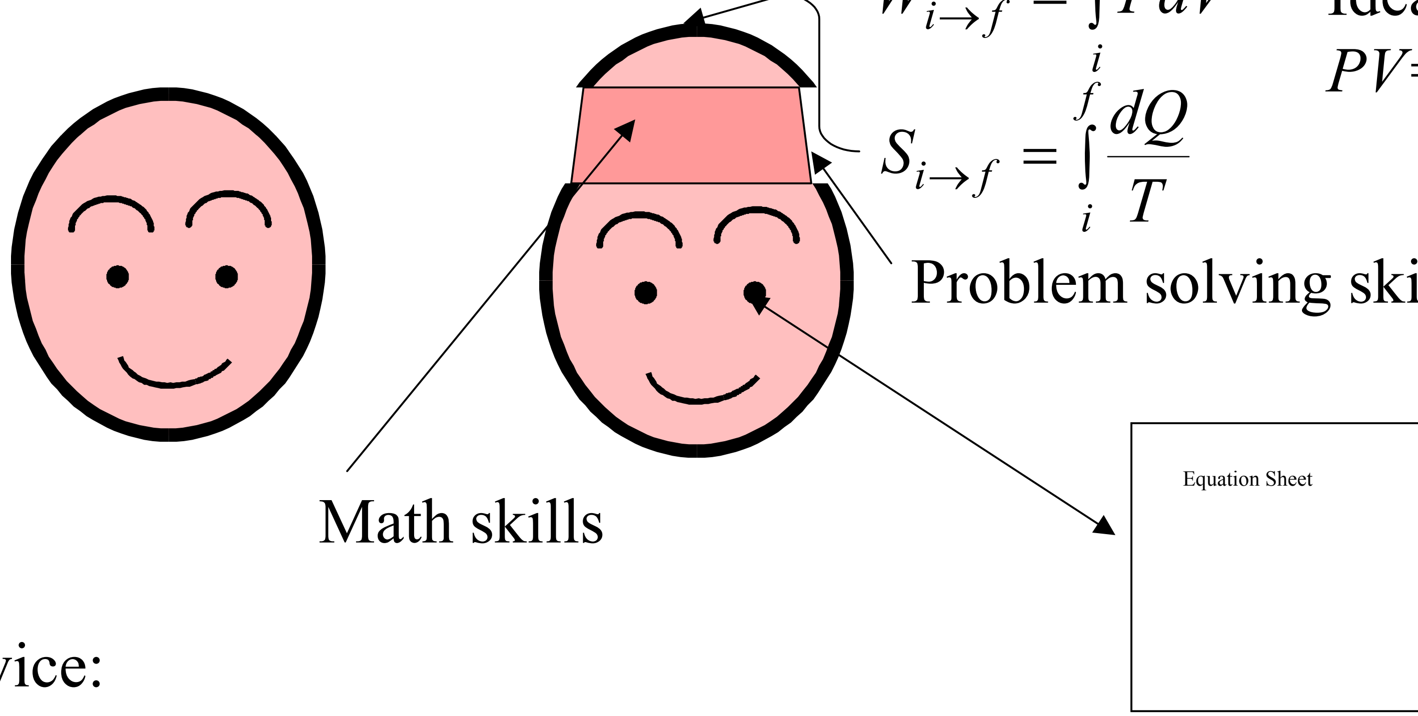
   Exam time: any time after 8 AM (Olin 101).
   1 PM (Olin 300).
   Extra review session – Sunday at 3 PM in Olin 101.
3. Waves after Thanksgiving

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

$$W_{i \to f} = \int_i^f P dV$$

$$S_{i \to f} = \int_i^f \frac{dQ}{T}$$

Ideal gas:
$PV = nRT$



Advice:

1. Keep basic concepts and equations at the top of your head.
2. Practice problem solving and math skills
3. Develop an equation sheet that you can consult.

Problem solving steps

1. Visualize problem – labeling variables
2. Determine which basic physical principle(s) apply
3. Write down the appropriate equations using the variables defined in step 1.
4. Check whether you have the correct amount of information to solve the problem (same number of knowns and unknowns).
5. Solve the equations.
6. Check whether your answer makes sense (units, order of magnitude, etc.).

General concepts — (always true)	Specialized concepts – (ideal gases)
$\Delta E_{\text{int}} = Q - W$ $W_{i\to f} = \int_i^f P dV$ $S_{i\to f} = \int_i^f \frac{dQ}{T}$ "State quantities": T, V, P, S, E_{int} Quantities that depend on path: Q, W	$PV=nRT$ $E_{\text{int}} = \frac{nRT}{\gamma - 1} = \frac{PV}{\gamma - 1}$ $C_V = \frac{R}{\gamma - 1}$ $C_P = \frac{\gamma R}{\gamma - 1}$ For adiabatic process: $PV^{\gamma} = \text{constant}$

Review

Heat –

Change of temperature within a given phase:

$dQ = m\ C\ dT$ Heat capacity/kg

For ideal gas:

$dQ = n\ C_V\ dT$ Heat capacity/mole

$dQ = n\ C_P\ dT$

Entropy – $S_{i\to f} = \int_i^f \frac{dQ}{T} = \int_i^f \frac{mCdT}{T} = mC\ln\left(\frac{T_f}{T_i}\right)$

Example: 1 kg water, T_i=280 K, T_i=290 K

$Q_{i\to f}$=41860 J $S_{i\to f}$=4186 ln(290/280) J/K= 4335.5 J/K

More heat –

Heat associated with phase change in matter:

$dQ = L\, dm$

"Latent" heat for phase change per mass unit

$$dS = \frac{L dm}{T}$$

Example: Melt 1 kg of ice at 273.15 K

$Q_{i \to f} = 333000$ J

$$S_{i \to f} = \frac{333000 J}{273.15 K} = 1219 \text{ J/K}$$

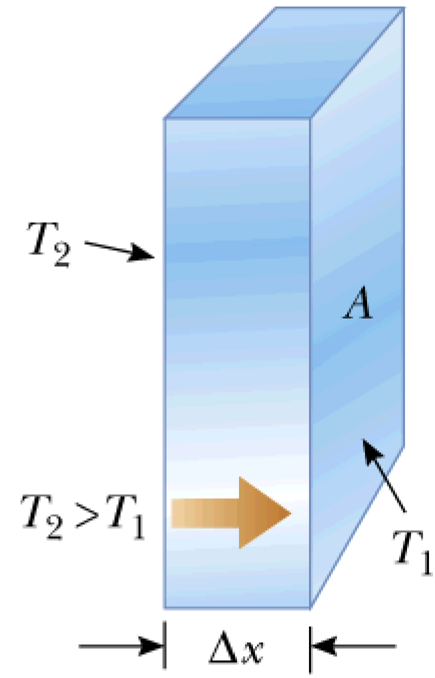
Quantitative statement of thermal conduction:

$$\frac{\Delta Q}{\Delta t} = kA\frac{\Delta T}{\Delta x}$$

Units: 1 J/s = 1 Watt (W)

cross-sectional area

thermal conductivity coefficient



Material	**k (W/(m·°C))**
Copper	238
Glass	0.8
Water	0.6
Air	0.0234

Thermodynamic statement of conservation of energy –

First Law of Thermodynamics

$$\boxed{\Delta E_{int} = Q - W}$$

Work done by system

Heat added to system

"Internal" energy of system

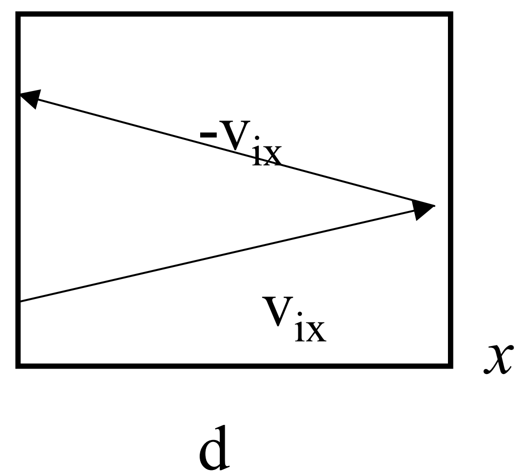
Ideas behind our model of E_{int} for an ideal gas:

For monoatomic ideal gas:

$$E_{int} = N\,K = N\,\tfrac{1}{2}\,m\langle v^2\rangle$$

Force exerted on wall perpendicular to x-axis by an atom which collides with it:

$$F_{ix} = -\frac{\Delta p_{ix}}{\Delta t} = \frac{2mv_{ix}}{\Delta t}$$



If $\quad \Delta t \approx 2d / v_{ix}$

$$\Rightarrow F_{ix} \approx \frac{2mv_{ix}}{2d / v_{ix}} = \frac{mv_{ix}^2}{d}$$

$$P = \sum_i \frac{F_{ix}}{A} = \sum_i \frac{mv_{ix}^2}{V} = \frac{N}{V} m \left\langle v_x^2 \right\rangle$$

Ideal gas energy analysis continued:

$$\left\langle v_x^2 \right\rangle = \frac{1}{3}\left\langle v^2 \right\rangle \qquad PV = nRT = N\frac{R}{N_A}T = Nk_BT$$

$$\Rightarrow PV = \frac{2}{3}N\left\{\frac{1}{2}m\left\langle v^2 \right\rangle\right\} \qquad \Rightarrow \frac{2}{3}N\left\{\frac{1}{2}m\left\langle v^2 \right\rangle\right\} = Nk_BT$$

Therefore: $\left\{\frac{1}{2}m\left\langle v^2 \right\rangle\right\} = \frac{3}{2}k_BT$

$$\Rightarrow v_{rms} = \sqrt{\left\langle v^2 \right\rangle} = \sqrt{\frac{3k_BT}{m}}$$

Also: $\left\{\frac{1}{2}m\left\langle v^2 \right\rangle\right\} = \frac{3}{2}k_BT$

$$\Rightarrow E_{\text{int}} = N\left\{\frac{1}{2}m\left\langle v^2 \right\rangle\right\} = N\frac{3}{2}k_BT = n\frac{3}{2}RT$$

Big leap!

Internal energy of an ideal gas:

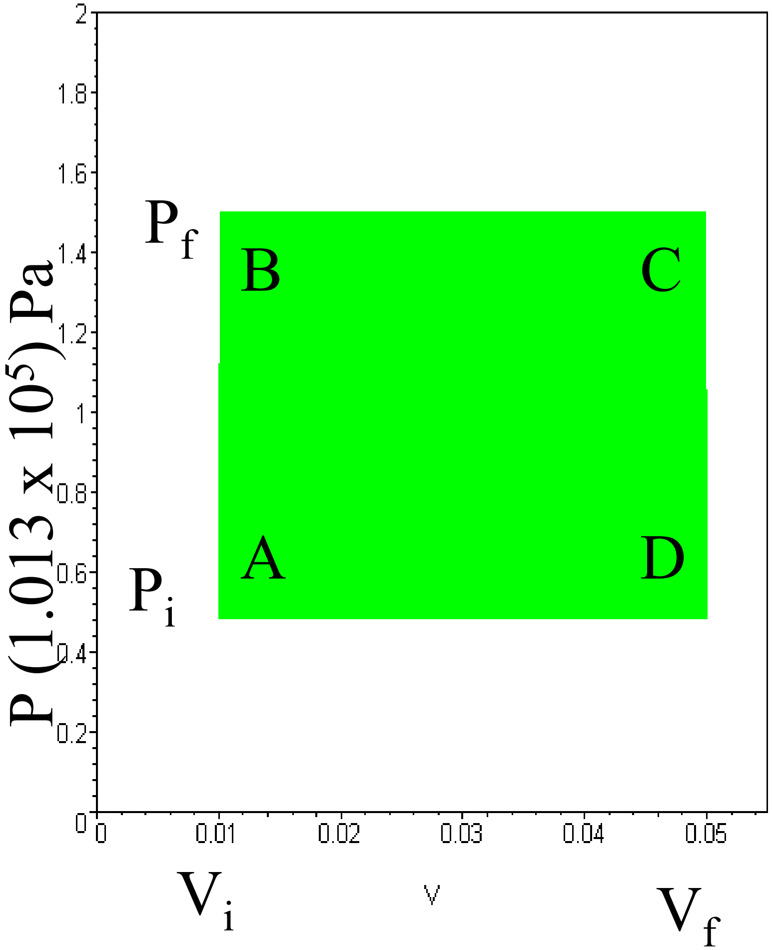
$$E_{\text{int}} = N\left\{\frac{1}{2}m\left\langle v^2\right\rangle\right\} = N\frac{3}{2}k_BT \Rightarrow \frac{N}{\gamma\text{-}1}k_BT = \frac{n}{\gamma\text{-}1}RT$$

derived for monoatomic ideal gas

more general relation for polyatomic ideal gas

Gas	**γ (theory)**	**γ (exp)**
He	5/3	1.67
N_2	7/5	1.41
H_2O	4/3	1.30

Examples process by an ideal gas:

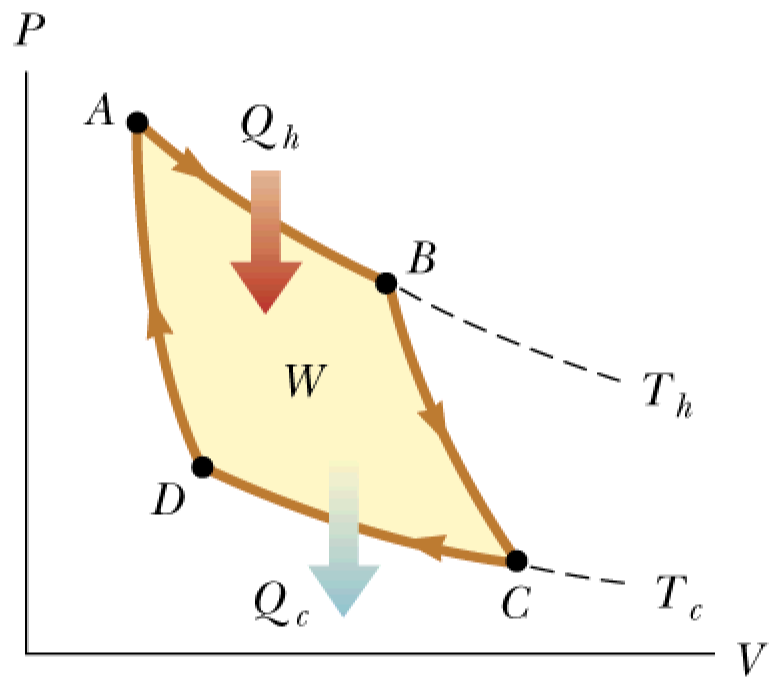


	A→B	B→C	C→D	D→A
Q	$\frac{V_i(P_f - P_i)}{\gamma - 1}$	$\frac{\gamma P_f(V_f - V_i)}{\gamma - 1}$	$\frac{-V_f(P_f - P_i)}{\gamma - 1}$	$\frac{-\gamma P_i(V_f - V_i)}{\gamma - 1}$
W	0	$P_f(V_f - V_i)$	0	$-P_i(V_f - V_i)$
ΔE_{int}	$\frac{V_i(P_f - P_i)}{\gamma - 1}$	$\frac{P_f(V_f - V_i)}{\gamma - 1}$	$\frac{-V_f(P_f - P_i)}{\gamma - 1}$	$\frac{-P_i(V_f - V_i)}{\gamma - 1}$

Efficiency as an engine:

$$e = W_{net/} Q_{input}$$

Carnot cycle



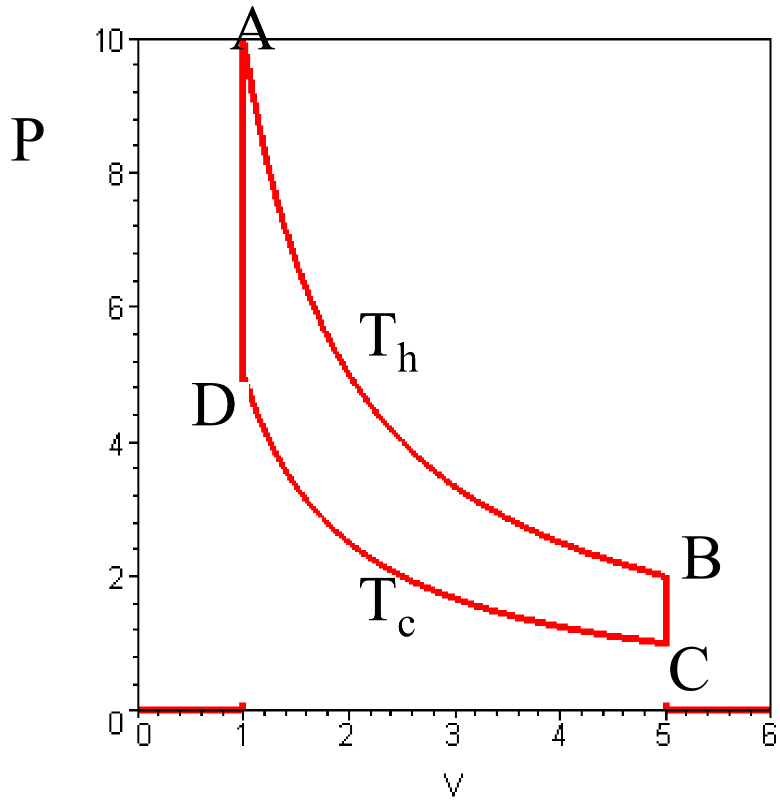
	A→B	B→C	C→D	D→A
Q	$nRT_h \ln\left(\frac{V_B}{V_A}\right)$	0	$-nRT_c \ln\left(\frac{V_C}{V_D}\right)$	0
W	$nRT_h \ln\left(\frac{V_B}{V_A}\right)$	$\frac{nR(T_h - T_c)}{\gamma - 1}$	$-nRT_c \ln\left(\frac{V_C}{V_D}\right)$	$-\frac{nR(T_h - T_c)}{\gamma - 1}$
ΔE_{int}	0	$-\frac{nR(T_h - T_c)}{\gamma - 1}$	0	$\frac{nR(T_h - T_c)}{\gamma - 1}$

$$e = \frac{Q_{AB} + Q_{CD}}{Q_{AB}}$$

$$= 1 - \frac{T_c}{T_h} \frac{\ln(V_D / V_C)}{\ln(V_B / V_A)}$$

$$= 1 - \frac{T_c}{T_h}$$

Stirling engine



$$e = \frac{Q_{AB} + Q_{CD}}{Q_{AB} + Q_{DA}}$$

	A→B	B→C	C→D	D→A
Q	$nRT_h \ln\left(\frac{V_B}{V_A}\right)$	$-\frac{nR(T_h - T_c)}{\gamma - 1}$	$-nRT_c \ln\left(\frac{V_C}{V_D}\right)$	$\frac{nR(T_h - T_c)}{\gamma - 1}$
W	$nRT_h \ln\left(\frac{V_B}{V_A}\right)$	0	$-nRT_c \ln\left(\frac{V_C}{V_D}\right)$	0
ΔE_{int}	0	$-\frac{nR(T_h - T_c)}{\gamma - 1}$	0	$\frac{nR(T_h - T_c)}{\gamma - 1}$

Example:

$T_h = 3T_c \quad V_B = V_C = 5V_A = 5V_D \quad \gamma = 1.3$

$$e = \frac{nR(T_h - T_c)\ln(V_B / V_A)}{nRT_h \ln(V_B / V_A) + \frac{nR(T_h - T_c)}{\gamma - 1}} = 50.6\%$$

$$e_{\text{Carnot}} = 66.7\%$$

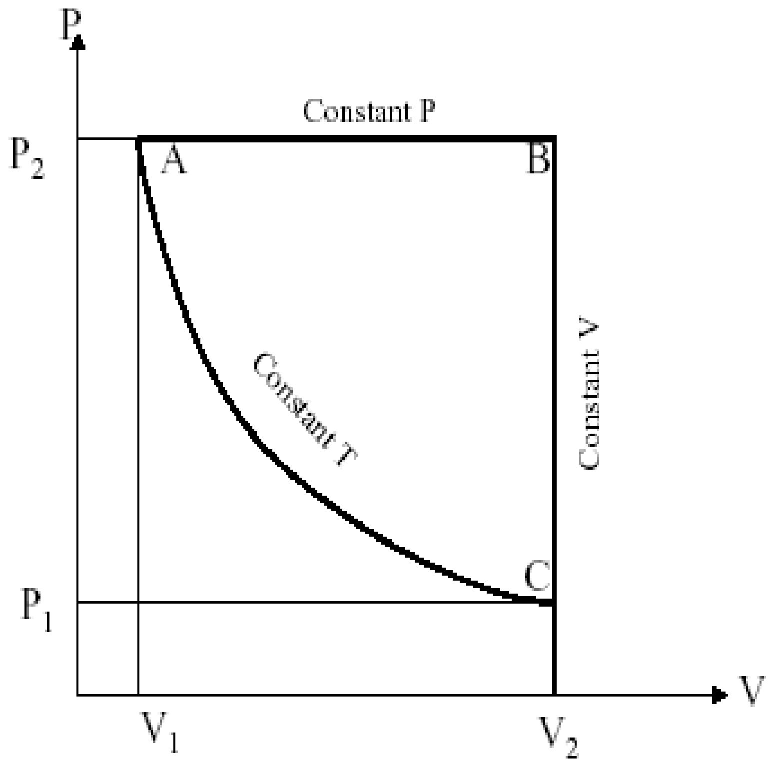
2. [SB5 22.P.21.] A 1.60 liter gasoline engine with a compression ratio of 8.20 has a power output of 92 hp. Assume that the engine operates in an idealized Otto cycle and that the fuel-air mixture behaves like an ideal gas with $\gamma = 1.40$.

Find the energy absorbed each second.

[0.16666666666666667] ______ kW

Find the energy exhausted each second.

[0.16666666666666667] ______ kW



Consider the process described by the P-V diagram shown above. Assume that medium for this process is one mole of an ideal gas containing a mixture of molecules with an effective heat capacity ratio is $\gamma \equiv \frac{C_P}{C_V} = 1.5$. The pressure and volume values are: $P_1 = 101300 Pa$, $P_2 = 303900 Pa$, $V_1 = 0.010209 m^3$, and $V_2 = 0.030627 m^3$.