Lec #10: finish TE; start Electricity

LAST TIME: Thermal Energy II
- Specific Heat
- Phase Transitions
- Conduction, Convection, Radiation

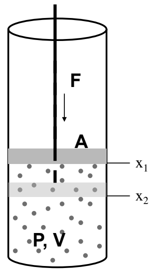
TODAY: (1) Thermodynamics Wrap Up; (2) EMR
- PV plane and Work
- More on Heat Engines Work
- Electromagnetic Radiation and Thermal Equilibrium

THURSDAY: EXAM #1 (in class)

Next Week: Electromagnetism; Motors & Generators (Chaps 10-11)

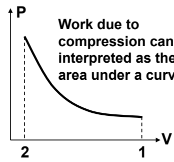
Work Done by an Ideal Gas

$$W_{12} = \int_1^2 F\,dx = \int_1^2 \left(\frac{F}{A}\right) A\,dx \qquad W_{12} = -\int_{V_1}^{V_2} P\,dV$$



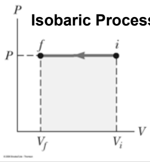
When the gas is compressed (dV is negative), The work done on the gas is positive

When the gas is allowed to expand, The work done on the gas is negative



Work due to compression can be interpreted as the area under a curve.

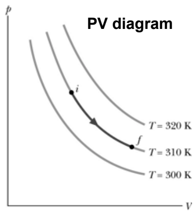
Isobaric Process



Isothermal Expansion and Compression

Isothermal process: The temperature of the system doesn't change

PV diagram



$PV = nRT$

$$P = \frac{nRT}{V} = \frac{\text{a constant}}{V}$$

n = number of moles
R = ideal gas constant = 8.31 J/(mol.K)

ΔU = Q - W

If ΔT = 0, ΔU = 0 Q = W

During expansion, the work done by the gas:

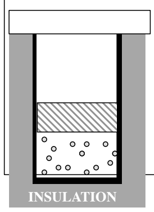
$$W = \int_{V_i}^{V_f} P\,dV = \int_{V_i}^{V_f} \frac{nRT}{V}\,dV$$

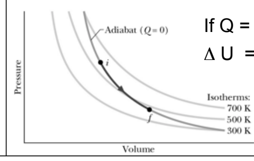
$$W = nRT \ln\left(\frac{V_f}{V_i}\right)$$

Isothermal expansion:	$V_f > V_i$	W > 0
Isothermal compression:	$V_f < V_i$	W < 0
Constant volume:	$V_f = V_i$	W = 0

Adiabatic Expansion and Compression

Isolated System: The internal energy of the isolated system remains constant
It does not interact with its surroundings. No energy transfer takes place.





If Q = 0,
Δ U = W

An adiabatic process in one in which no heat is exchanged between the system and its surroundings

Since it is not mechanically isolated, it can still do work.

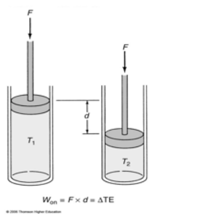
For adiabatic expansion or compression $P_i V_i^{\gamma} = P_f V_f^{\gamma}$ $\quad \gamma = \frac{c_P}{c_V}$

γ is called the adiabatic index of the gas.

Table 4.3 EXAMPLES OF HEAT ENGINES

Vapor or Rankine cycle
Steam engine (electrical power plant, old train locomotive)
Refrigerator, heat pump (using Freon)

Gas cycle
Internal combustion: Otto, Diesel cycles (automobiles, trucks)
External combustion: gas turbine (airplanes, electrical power plant), Stirling cycle



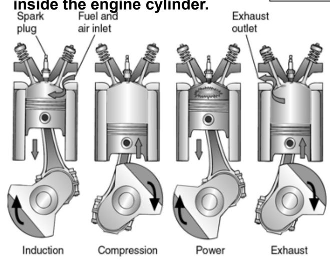
howstuffworks.com

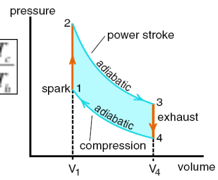
(heat->work)	(work->heat)
steam engine	air conditioners
gasoline engine	dehumidifiers
diesel engine	heat pumps
gas turbine	refrigerators

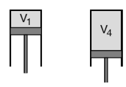
Internal Combustion Engine

Working substance: a mixture of air and vaporized gasoline. No hot reservoir → thermal energy is produced by burning fuel inside the engine cylinder.

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







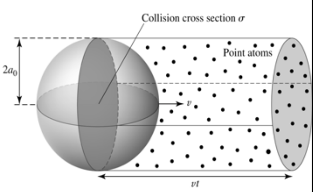
1 → 2: isochoric (v=const) heating (ignition)
2 → 3: isentropic expansion (work done by the gas)
3 → 4: exhaust
4 → 1: isentropic compression (work done on the gas)

Things that go Bump in a Box of Gas

- Particles (mostly electrons, ions, atoms, molecules)
  - Elastic collisions: KE before = KE after
  - Inelastic collisions: KE lost or gained in collision
    - where does it go?
- Photons
  - Emission: creation of photons (where is E from?)
  - Absorption: destruction of photons (where does E go?)
  - Scattering: no net change in photon number, just a change in direction
    - but these processes are extremely important
    - can lead to *apparent* emission or *apparent* absorption

Collisions

- Number density, n (cm^{-3})
- Column density, N (cm^{-2})
- Cross Section, σ (cm^2)
- Mean free path, l (cm)
  - $l = 1/n\sigma$
- Collision time, t_c (s)
  - $t_c = l/v_t = 1/n\sigma v_t$



Examples:

- $\sigma_H = \pi a_o^2 = 8.75E\text{-}15\ cm^2$
- $\sigma_{HH} = 3.5E\text{-}16\ cm^2$
- $\sigma_T = (2/3)E\text{-}26\ cm^2$

Air in room:	ISM:
• n~10^{19} cm^{-3}	• n~10^{-3} cm^{-3}
• σ~10^{-15} cm^2	• l ~10^{14} cm
• l ~10^{-4} cm	~ 5 AU
• t_c~10^{-9} sec	• but L~10^{19} cm

TE Distribution Functions

- *Maxwell-Boltzmann Distribution:*
  $$N_v/N\ (T_k)\ dv = [m/2\pi kT_K]^{3/2}\ e^{-mv^2/2kT_K}\ 4\pi v^2\ dv$$
- *Boltzmann Distribution:*
  $$N_b/N_a\ (T_x) = (g_b/g_a)\ e^{-(E_b-E_a)/kT_x}$$
- *Saha Equation:*
  $$N_{i+1}/N_i\ (T_i) = (2/n_e)\ (Z_{i+1}/Z_i)\ (2\pi m_e kT_i/h^2)^{3/2}\ e^{-\chi_i/kT_i}$$
- *Planck Function:*
  $$B_\nu(T_r) = 2h\nu^3/c^2\ [e^{h\nu/KT_r} - 1]^{-1}$$
- **Where does this $e^{-\Delta E/kT}$ come from?**

Probability and Statistical Physics

- Probability =
  (# of ways to achieve desired result) /
  (# of ways to achieve any result)
- # of ways energy can be distributed among states with kT per degree of freedom increases exponentially with Energy (i.e. temperature)
- so # of states ~ $e^{\Delta E/kT}$
- postulate: all possible states are equally likely
- so P is # of ways to put energy in desired state divided by number of possible states ~ $e^{-\Delta E/kT}$

Maxwellian Distribution of Speeds

$$N_v/N\ dv = [m/2\pi kT_K]^{3/2}\ e^{-mv^2/2kT_K}\ 4\pi v^2\ dv$$

- each "species" establishes its own Maxwellian

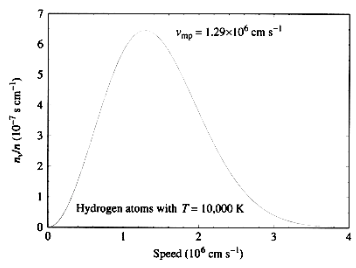
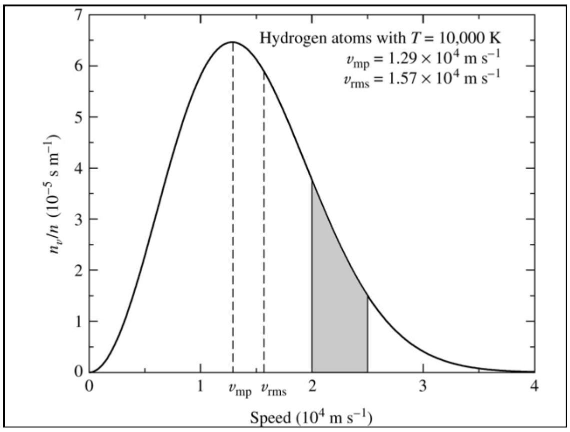
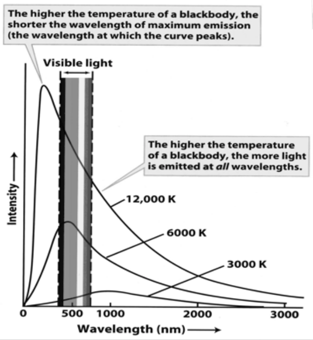


Figure 8.4 Maxwell–Boltzmann distribution function, n_v/n.

- most probable: $[2kT/m]^{1/2}$
- rms average: $[3kT/m]^{1/2}$
- velocity distribution is gaussian



1) Wien's Law: Inverse *linear* relation between Temperature and *Peak* Wavelength



Explore for yourself:

1. applet on our website
2. download "Spectrum Explorer" for your computer (or use it in 104)

- 2) Stephan's Law: The bolometric surface flux is directly proportional to the fourth power of temperature
  - Surface Flux: $F = \sigma T^4$
  - Luminosity: $L = (\text{Surface Area})\ \sigma T_{eff}^4$
    $= 4\pi R^2\ \sigma T^4$

    $\sigma = 5.67E\text{-}5$ (cgs) E-8 (mks)

- 3) Planckian Brightness Distribution:
  The functional form of intensity v. wavelength exactly matches an analytic expression...

$B_\lambda(T) = 2hc^2/\ \lambda^5\ [e^{hc/\lambda KT} - 1]^{-1}$ erg/s cm^{-2} Å^{-1} sr^{-1}

or...

$B_\nu(T) = 2h\nu^3/c^2\ \ [e^{h\nu/KT} - 1]^{-1}$ erg/s cm^{-2} Hz^{-1} sr^{-1}