

# Ch 12

Problems # 2, 3, 7, 8, 35, 37, 44

# Work in thermodynamic processes

- Energy can be transferred to a system in 2 ways.
  - By heat exchange
  - having work done on the system

We will define a system as the material that is absorbing or giving off energy. For example, a volume of gas.

# Work done on a gas

$$W = - F \Delta y = - PA \Delta y \quad \text{see fig. 12.1}$$

$$A\Delta y = \Delta V$$

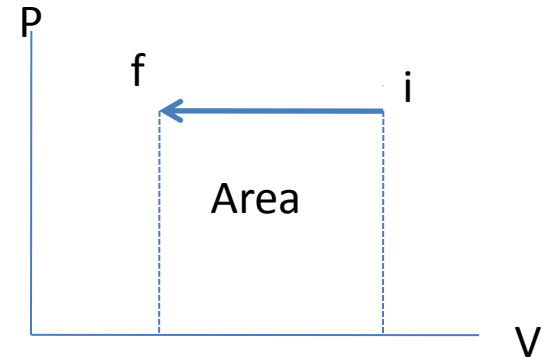
$$W = - P \Delta V$$

Positive work is done on a gas when it is compressed ( $\Delta V < 0$ ).

If  $\Delta V > 0$ , then the work on the gas is negative. The gas did work on the environment.

# Isobaric process

- Isobaric processes occur when the pressure is held constant.
- P-V diagram
- $\text{Area} = P (V_f - V_i) = P\Delta V$
- The area under the curve in the PV diagram is equal in magnitude to the work done on the gas.  
see quick quiz 12.1



# 1<sup>st</sup> Law of Thermodynamics

- relates changes in internal energy to the energy transfers due to work and heat
- “If a system undergoes a change from an initial state to a final state, where  $Q$  is the heat,  $W$  is the work, the change in internal energy is:

$$\Delta U = U_f - U_i = Q + W$$

- From Ch. 10 (for monatomic ideal gas)

$$U = \frac{3}{2} nRT$$

$$\Delta U = \frac{3}{2} nR\Delta T$$

do example 12.3

## Molar specific heat at constant volume

The specific heat of a gas per mole when the volume is held fixed.

$$C_v = 3/2 R$$

$$\Delta U = nC_v\Delta T$$

Also have the molar specific heat at constant pressure.  
( for an Isobaric process)

$$C_p = C_v + R$$

$$\text{for ideal gas } C_p = 5/2 R$$

$$Q = nC_p\Delta T$$

this is found by applying the 1<sup>st</sup> Law of TD and substituting in for  $\Delta U$  and  $W$ .

# Adiabatic process

- Adiabatic means no heat transfer
- If you let a gas expand fast enough, there is no time for energy to leave the gas as a loss of heat.
- The system is thermally insulated ( $Q = 0$ )

$$\Delta U = Q + W = W$$

$$PV^\gamma = \text{constant}$$

$\gamma =$  adiabatic index

$$\gamma = C_p / C_v$$

# Isovolumetric (isometric) process

- constant volume

– no work done

$$\Delta U = Q + W = Q + 0$$

$$\Delta U = Q$$

$$Q = nC_v\Delta T$$

# Isothermal process

isothermal process, no change in temperature

$$\Delta U = Q + W$$

$$\Delta U = 0$$

$$Q = -W$$

$$PV = nRT$$

$$P = nRT/V$$

Work done on the environment:

$$W_{\text{env}} = nRT \ln (V_f/V_i)$$

- More P-V diagrams, look at the different curves based on the type of process.

Constant pressure or volume processes are straight lines.

Constant temperature or adiabatic processes are curves.

- [http://en.wikipedia.org/wiki/Cyclic\\_process](http://en.wikipedia.org/wiki/Cyclic_process)

# Heat Engines and the 2<sup>nd</sup> Law of Thermodynamics

- Heat engines take in energy by heat and partially converts that energy to other forms.
  - electrical energy (power plant)
  - mechanical energy (internal combustion engine)

- Heat engines carry some working substance through a cyclic process.
- Cyclic process – after one cycle the substance is back to its initial point on the P-V diagram.
  1. Heat energy is taken from a source at high temperature.
  2. Work is done by the engine.
  3. Energy is expelled by heat to a source at lower temperature.

see figure 12.9

For a complete cyclic process,  $\Delta U = 0$

$$\Delta U = Q + W \quad \Rightarrow \quad Q_{\text{net}} = -W = W_{\text{eng}}$$

negative work is done on the engine

## Work

$$Q_{\text{net}} = |Q_{\text{h}}| - |Q_{\text{c}}|$$

If the working substance is a gas, the work done by the engine for a cycle is the area enclosed by the curve representing the process on a P-V diagram.

# Efficiency

- thermal efficiency is defined as the work done, divided by the heat absorbed during one cycle.

- $$e = \frac{W_{eng}}{|Q_h|} = \frac{|Q_h| - |Q_c|}{|Q_h|} = 1 - \frac{|Q_c|}{|Q_h|}$$

do example 12.10

- Heat engines take heat from a hot source, produce work and expels excess heat to a cooler source.
- Heat can't naturally flow from cold source to hot source.
- Heat pumps and refrigerators remove heat from a cooler source to make colder. (see fig 12.12)
- Heat pumps do work on a gas to increase the energy, then that warmer energy is expelled.

2<sup>nd</sup> Law of Thermodynamics limits the efficiencies of engines.

No heat engine can absorb energy from a reservoir and use it entirely for work output.

100% efficiency is impossible

- Reversible and irreversible processes
- In a reversible process, every state along the path, on the P-V diagram is an equilibrium state.
- The system can return to its initial conditions by going along the same path in the opposite direction.
- otherwise the process is irreversible

reversible processes occur slowly.

- The slow isothermal compression showed in figure 12.14 is a reversible process.
- Carnot Engine operates in an ideal reversible cycle. (Carnot cycle). See fig. 12.16
- This puts an upper limit on the efficiencies of all real engines.

For a Carnot engine

$$\frac{|Q_c|}{|Q_h|} = \frac{T_c}{T_h}$$

For a Carnot Engine efficiency

$$e_c = 1 - T_c/T_h$$

$T_c$  and  $T_h$  are the temperatures of the hot and cold reservoirs.

Carnot engines are not real. they would have to run infinitely slowly to perform reversible processes. Thus the power would be zero.

# Entropy

- entropy is a quantitative description of the disorganization of a system.
- 1 kg of water has more entropy than 1kg of ice because in the water the molecules are not organized into a regular crystal lattice.
- 2<sup>nd</sup> Law of TD stated as entropy. The total entropy of a system in any physical process cannot decrease, but it can increase. (also can stay the same, but need to be very careful to do so.)

Law of entropy predicts that most processes are irreversible.

Irreversible processes will not naturally occur in the opposite direction.

Mix hot water with cold water. You get a mass of water at some intermediate temperature.

The water will not naturally un-mix into hot and cold water again.

# Entropy

Deck of cards example. Start is organized deck.  
If you shuffle them, they get disorganized.  
Shuffle again, they get more disorganized.  
The entropy of the deck of cards is increased.

Easy to disorganize things, but it takes  
considerable effort and lots of luck to organize  
them.

As universe ages, its entropy increases.