Thermodynamics:
The Laws

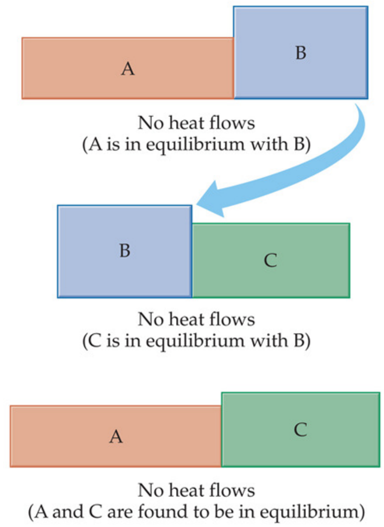
Resources:
Serway
The Laws of Thermodynamics: 12
AP Physics B – Videos
Physics B Lesson 29: Laws of Thermodynamics

Thermodynamics

- Thermodynamics is the study of heat and thermal energy.
- Thermal properties (heat and temperature) are based on the motion of individual molecules, so thermodynamics is a lot like chemistry.
- Branch of both physics and engineering that deals with the conversion of thermal energy into useful work.

Zeroth Law of Thermodynamics

- If body A is in thermal equilibrium with body B and body B is in thermal equilibrium with body C, then body A is in thermal equilibrium with body C.



First Law of Thermodynamics

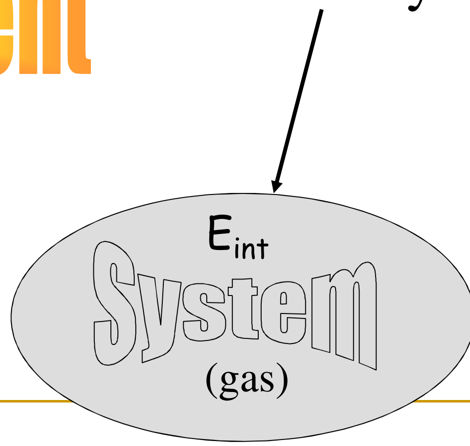
- The First Law of Thermodynamics tells us that the internal energy of a system can be increased by
  - Adding energy to the system
  - Doing work on the system
- There are many processes through which these could be accomplished
  - As long as energy is conserved

System

A set of particles or interacting components considered to be a distinct physical entity for the purpose of study.

Environment

Boundary



For our purposes, the system will almost always be an ideal gas.

System Boundary

- The system boundary controls how the environment affects the system.
- If the boundary is “closed to mass”, that means that mass can’t get in or out.
- If the boundary is “closed to energy”, that means energy can’t get in or out.

First Law of Thermodynamics

- Energy conservation law
- Relates changes in internal energy to energy transfers due to heat and work
- Applicable to all types of processes
- Provides a connection between microscopic and macroscopic worlds

First Law, cont.

- Energy transfers occur
  - By doing work
    - Requires a macroscopic displacement of an object through the application of a force
  - By heat
    - Due to a temperature difference
    - Usually occurs by radiation, conduction and/or convection
  - Other methods are possible
- All result in a change in the internal energy, ΔU, of the system

First Law, Equation

- If a system undergoes a change from an initial state to a final state, then

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

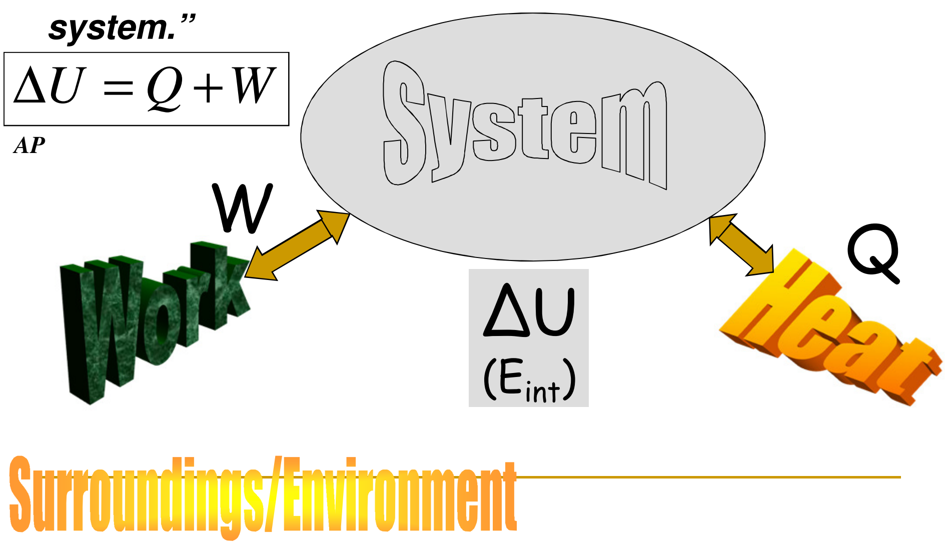
  - Q is the heat transferred between the system and the environment
  - W is the work done on the system
  - ΔU is the change in internal energy

First Law of Thermodynamics

"The internal energy of a system tend to increase when HEAT is added and work is done ON the system."

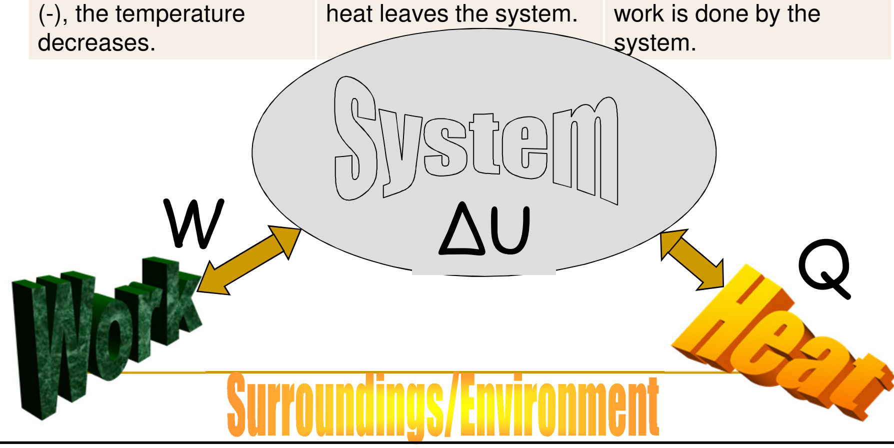
$$\Delta U = Q + W$$

AP



First Law of Thermodynamics - Signs

ΔU	*Q*	*W*
When *ΔU* is positive (+), the temperature increases.	When *Q* is positive (+), heat enters the system.	When *W* is positive (+), work is done on the system.
When *ΔU* is negative (-), the temperature decreases.	When *Q* is negative (-), heat leaves the system.	When *W* is negative (-), work is done by the system.



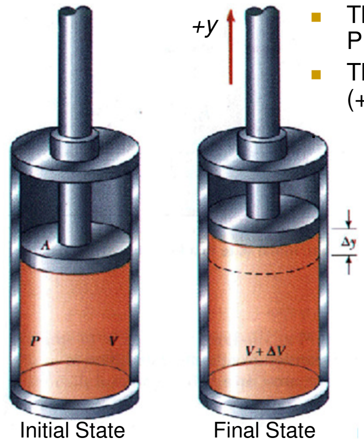
Work in Thermodynamic Processes – Assumptions

- Dealing with a gas (system)
- Assumed to be in thermodynamic equilibrium
  - Every part of the gas is at the same temperature
  - Every part of the gas is at the same pressure
- Ideal gas law applies

Section 12.1

Work in a Gas Cylinder

- The gas is contained in a cylinder with a moveable piston
- The gas occupies a volume V and exerts pressure P on the walls of the cylinder and on the piston
- The gas expands causing the piston to move (+Δy)and the piston exerts a force on the gas (-F)



$Work = Force \times Distance$

$W = -F_{\substack{on\ gas,\\ by\ cylinder}} \times \Delta y$

Recall, $P = \frac{F}{A} \therefore F = PA$

Substituting, $W = -PA\Delta y$

Recall, $Volume_{cylinder} = Height \times Area$

Volume changes, $\Delta V = A\Delta y$

Combining,

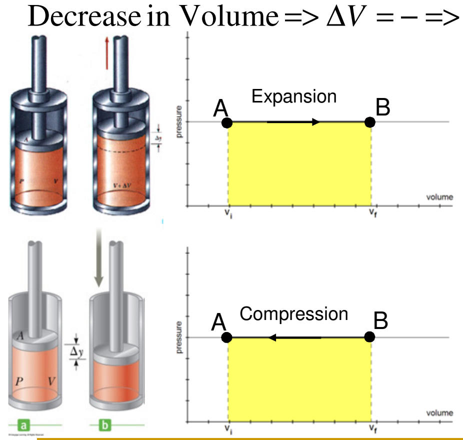
$$W = -P\Delta V$$

Work is the AREA of a P vs. V graph

$W = -P\Delta V$ = Area under PV graph (depends on path)

Increase in Volume => $\Delta V = +$ => Work is done BY the system (-W)

Decrease in Volume => $\Delta V = -$ => Work is done ON the system (+ W)



The "negative" sign in the equation for WORK is often misunderstood. Since work done BY a gas has a positive volume change we must understand that the gas itself is USING UP ENERGY or in other words, it is losing energy, thus the negative sign.

When work is done ON a gas the change in volume is negative. This cancels out the negative sign in the equation. This makes sense as some EXTERNAL agent is ADDING energy to the gas.

More about Work on a Gas Cylinder

- When the gas is compressed
  - ΔV is negative
  - The work done on the gas is positive
- When the gas is allowed to expand
  - ΔV is positive
  - The work done on the gas is negative
- When the volume remains constant
  - No work is done on the gas

Notes about the Work Equation

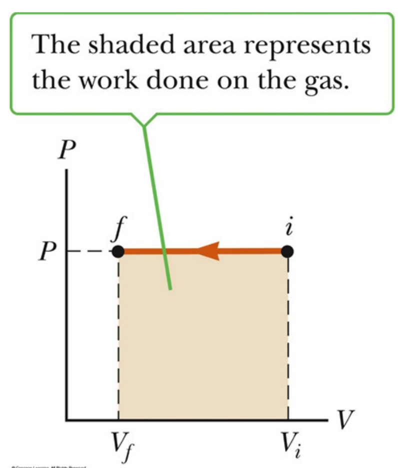
- The pressure remains constant during the expansion or compression
  - This is called an *isobaric* process
- The previous work equation can be used only for an isobaric process

Notes About Work

- Positive work increases the internal energy of the system
- Negative work decreases the internal energy of the system
- This is consistent with the definition of mechanical work

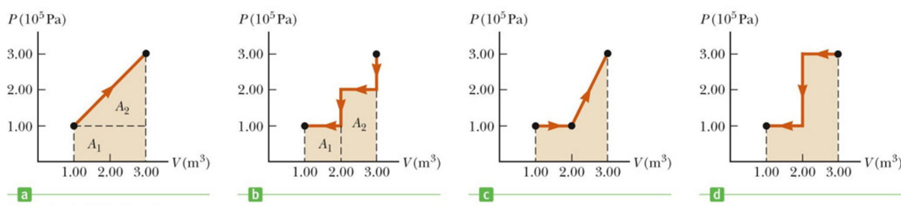
PV Diagrams

- Used when the pressure and volume are known at each step of the process
- The work done on a gas that takes it from some initial state to some final state is equal in magnitude to the area under the curve on the PV diagram
  - This is true whether or not the pressure stays constant



PV Diagrams

- The curve on the diagram is called the *path* taken between the initial and final states
- The work done depends on the particular path
  - Same initial and final states, but different amounts of work are done



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Internal Energy of an Ideal Gas

$$U = \frac{3}{2} N k_B T$$

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

Where,

U - Internal Energy (J)

T - Temperature (K)

N - number of molecules of gas

n - number of moles

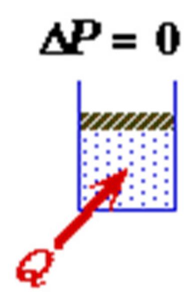
k_B - Boltzmann's constant, 1.38x10-23 J/K

R - Universal gas constant, 8.31 J/(mol·K)

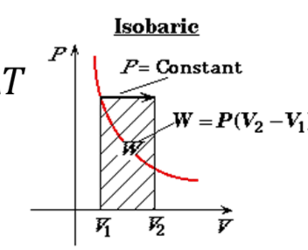
Types of Thermal Processes

- *Isobaric*
  - Pressure stays constant
  - Horizontal line on the PV diagram
- *Adiabatic*
  - No heat is exchanged with the surroundings
- *Isovolumetric or isochoric*
  - Volume stays constant
  - Vertical line on the PV diagram
- *Isothermal*
  - Temperature stays the same

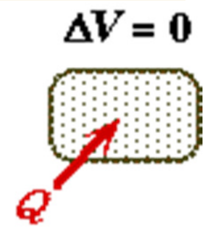
Isobaric Processes



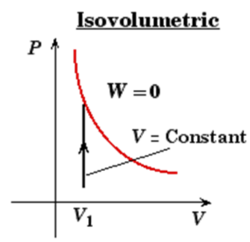
- The work done by an expanding gas in an isobaric process is at the expense of the internal energy of the gas
- $\Delta U = Q + W$; $Q = \Delta U - W$
- Since $W = -P\Delta V$; $\Delta U = \frac{3}{2}nR\Delta T$
- And $P\Delta V = nR\Delta T$
- Q = 5/2nRΔT



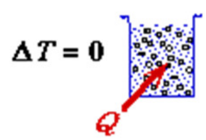
Isochoric (Isovolumetric) Process



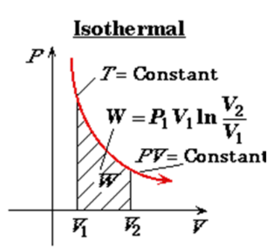
- Constant volume
  - Vertical line on PV diagram
- W = 0 (since ΔV = 0)
- First Law becomes ΔU = Q
  - The change in internal energy equals the energy transferred to the system by heat

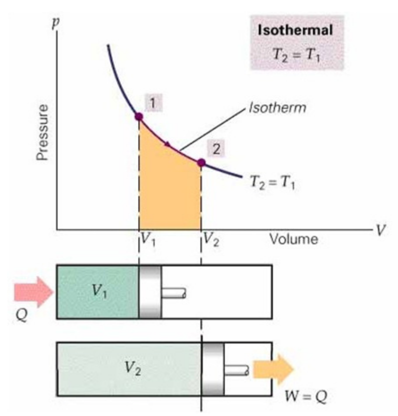


Isothermal Process

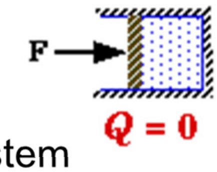


- The temperature doesn't change
  - In an ideal gas, since ΔT = 0, the ΔU = 0
- First Law becomes W = - Q

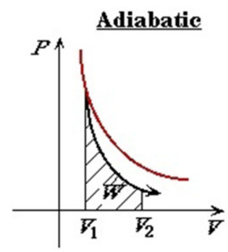




Adiabatic Processes



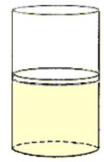
- No heat flows into or out of the system
- So for an adiabatic process, Q = 0
- First Law becomes ΔU = W
- So, $W = \frac{3}{2}nR\Delta T$



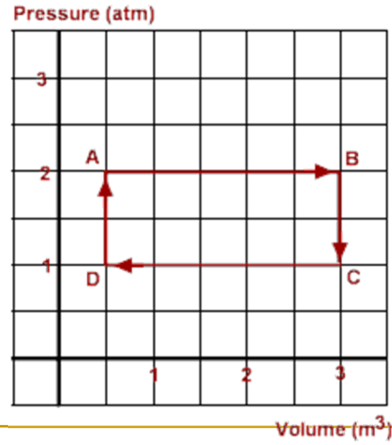
Problem Solving Tips

- Can still use the First Law to get information about the processes
- Work can be computed from the PV diagram
- If the temperatures at the endpoints can be found, ΔU can be found (use equation for internal energy of an ideal gas)

Example (Copy in notes!)



A monatomic gas is confined to a cylindrical container having a movable, yet "snuggly-fitting," lid that slides up and down to accommodate changes in pressure and volume. The diagram shown below, outlines the steps in a heat cycle starting at position A and moving through positions B, C, D and then back to A.



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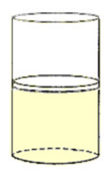

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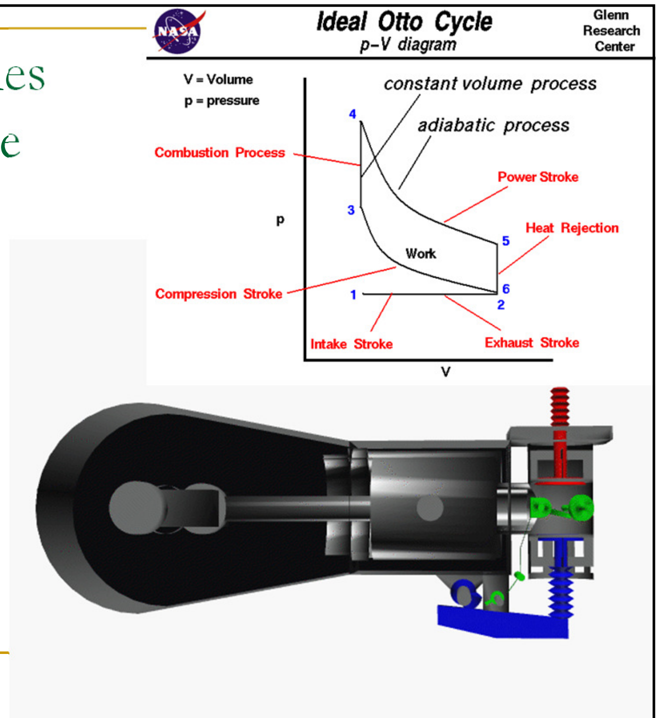
Questions:

1. How many moles of gas are present in the cylinder?
2. If the temperature of point C is 900 K, what is the temperature of point A?
3. What is the change in internal energy of the gas during process BC?
4. What is the change in internal energy of the gas for an entire cycle, ABCDA?
5. What net work is done by the gas on the piston during one complete cycle, ABCDA?
6. During which processes is heat being removed from the system?
   AB BC CD DA
7. During which process is the greatest amount of heat added?

Heat Engines - Otto Cycle

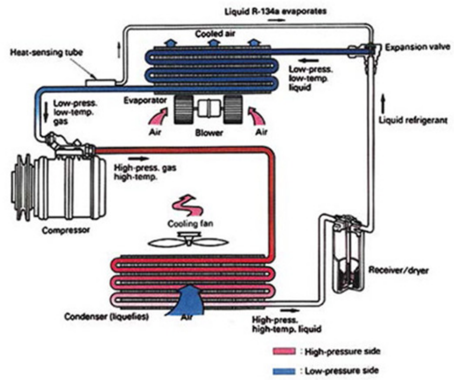
- Internal combustion engine (automobiles)
- Used by Wright Brothers in first self-propelled, piloted aircraft; the Wright 1903 Flyer
- A 4-stroke engine is shown, meaning there are 4 strokes of the piston before the engine firing sequence repeats.



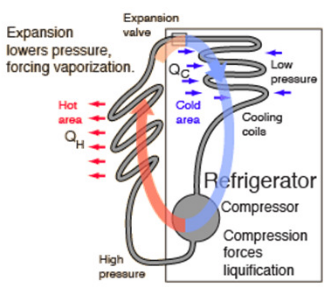
Heat Engines - Otto Cycle

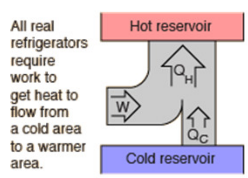
2nd Law of Thermodynamics

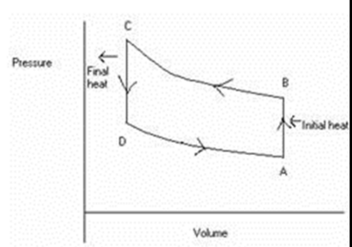
- Heat never flows spontaneously from a colder body to a hotter body.
  - Work has to done to allow this happen.
  - Compressors in refrigerators and air conditioning.



Refrigeration



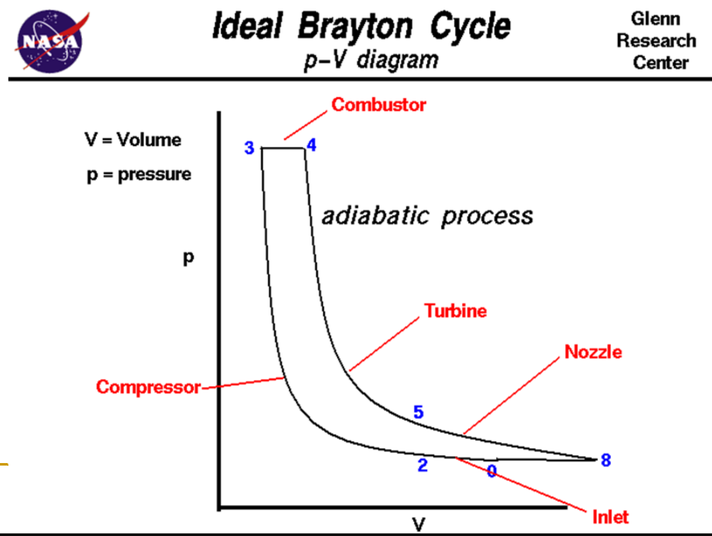




- Referring to the PV diagram, the stages for the heat pump or refrigerator are as follows. Let the initial heat be denoted as Q_c and the final heat as Q_h.
  - Between 'A' and 'B' the pressure increases isovolumetrically and the heat is Q_c.
  - Stage 'B' to 'C' is an isothermal compression. Work is done by the surroundings.
  - From 'C' to 'D', the pressure decreases isovolumetrically with Q_h greater than Q_c .
  - From 'D' to 'A', the gas does work in expanding itself isothermally.

Heat Engines – Brayton Cycle

- Gas turbine engines (jet engines)



Heat Engines – Carnot Cycle

- Ideal engine not a real engine (very e