Announcements – 19 Nov 2013

1. **Exam starts Thursday**
   a. Thursday will be the in-class exam review
   b. TA exam review: Thurs 7 – 8:30 pm. Location W112 BNSN

2. **Exam ends on Tuesday 2 pm (Testing Center is closed on Wed)**
   a. late fee after 2 pm Monday

Change! Ends on Dec 2, Monday after break, 3pm

Late fee after Tuesday, 2pm Nov 26

3. **No class on Tuesday (Friday instruction)**

4. **You get two weeks off with no homework. ☺**
   a. HW 23 is due this Thursday (last HW for exam 4)
   b. HW 24 is "Good luck on the exam"
   c. HW 25 is due Dec 5

concert: A Cappella Jam
Thurs 8 pm
JSB Auditorium

$5 at door
$4 in advance
(Wilk Info Desk)

Review

From kinetic theory:

$U = 3/2\ Nk_BT = 3/2\ nRT$ (monoatomic)

$U = 5/2\ Nk_BT = 5/2\ nRT$ (diatomic, around 300K)

From force = pressure × area and work = force × Δx

$$W_{\textbf{by gas}} = P\Delta V$$

$$W_{\textbf{on gas}} = -P\Delta V$$

Only if pressure is constant

$P(V_f - V_i)$

$-P(V_f - V_i)$

$P_{ave}\Delta V$

"system" = gas

1st Law of Thermodynamics

$$\Delta U = Q_{added} + W_{on\ system}$$

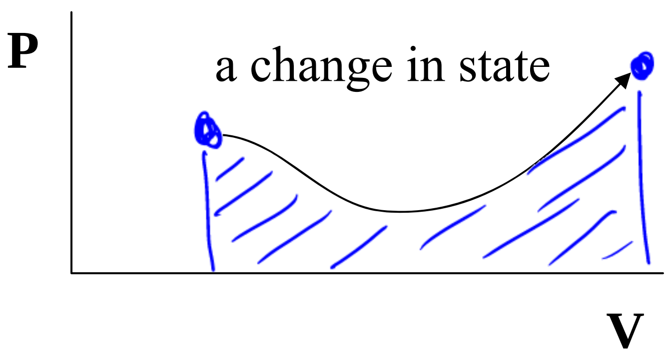
(note: 5th edition uses $-W_{by\ system}$)

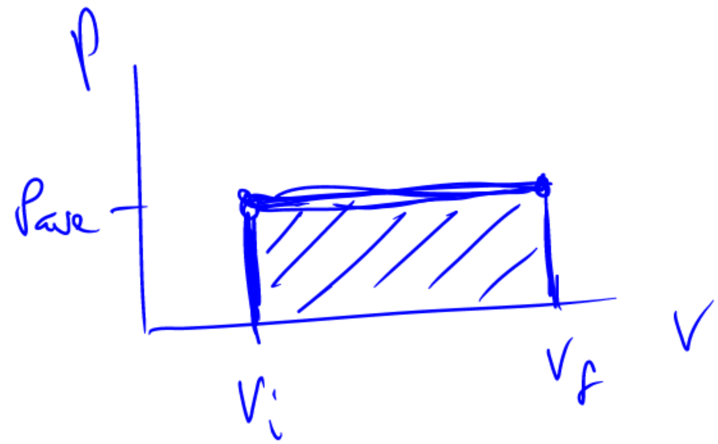
What is ΔU?

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

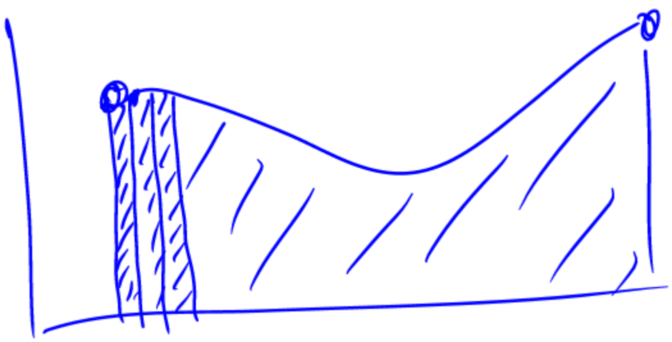
$\Delta U = \frac{5}{2} nR\Delta T$

Review: What if pressure is not constant?



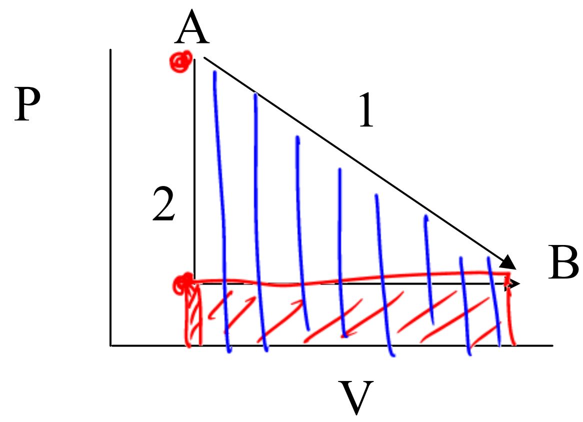


$$|W| = |P_{ave} \Delta V|$$



Clicker Quiz

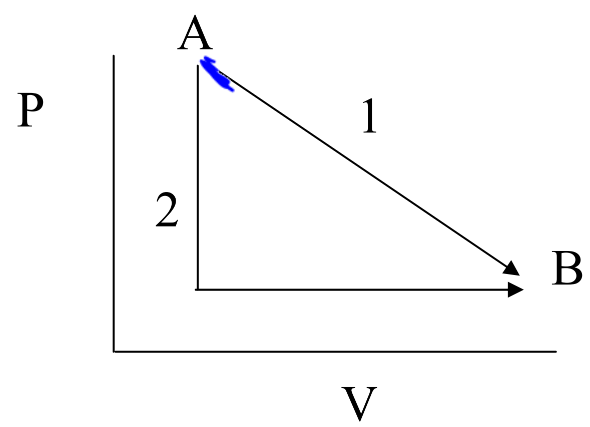
A gas in a piston expands from point A to point B on the P-V plot, via either path 1 or path 2. Path 2 is a “combo path,” going down first then over.



The gas does the most work in:

a. path 1
b. path 2
c. neither; it’s the same

Question



Same situation. How much work is done in first half of path 2?

~ zero

What is a physical description of path 2?

$\Delta U = Q + W_{on}$

Warning

Be careful with all the signs!!!

ΔU is positive if: ΔT is positive $T_f > T_i$

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

Q_{added} is positive if: you're adding heat

$W_{on\ system}$ is positive if: if it's being compressed

i.e. $V_f < V_i$

Isothermal "Contours"

Conceptual Exam Questions: Does temperature increase/decrease/stay the same for some change in state? Is ΔU pos or neg?

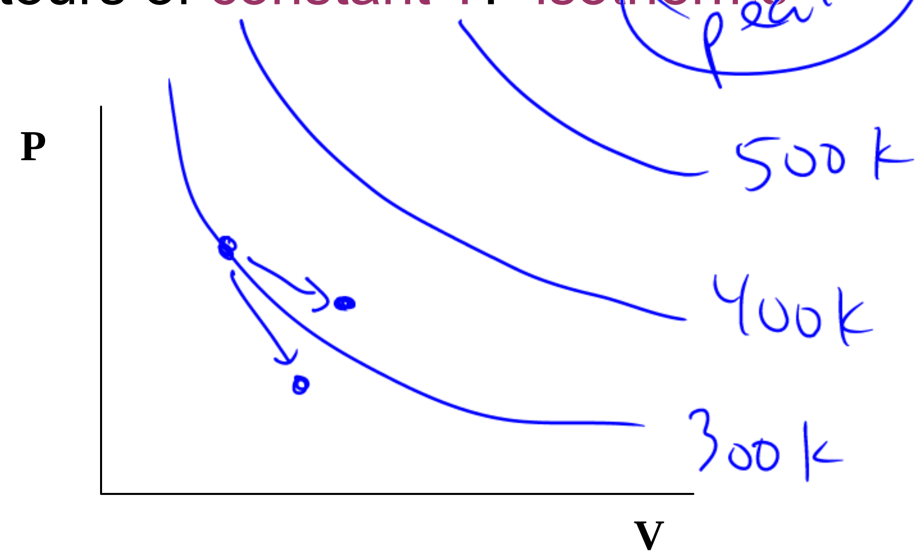
$PV = nRT$

$\rightarrow$ How can you tell if two points are at the same temperature?

$\rightarrow$ If temperature is constant, this gives a curve like $xy = 3$

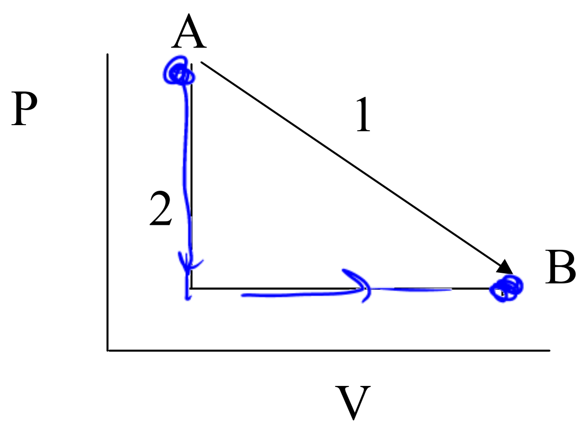
… or $xy = 10$ (for a higher temperature)

Contours of constant T: "isotherms"



Clicker quiz

$\Delta U = \frac{3}{2} nR\Delta T = \frac{3}{2} nR(T_f - T_i)$



$\Delta U = Q + W_{on}$

What is Q?

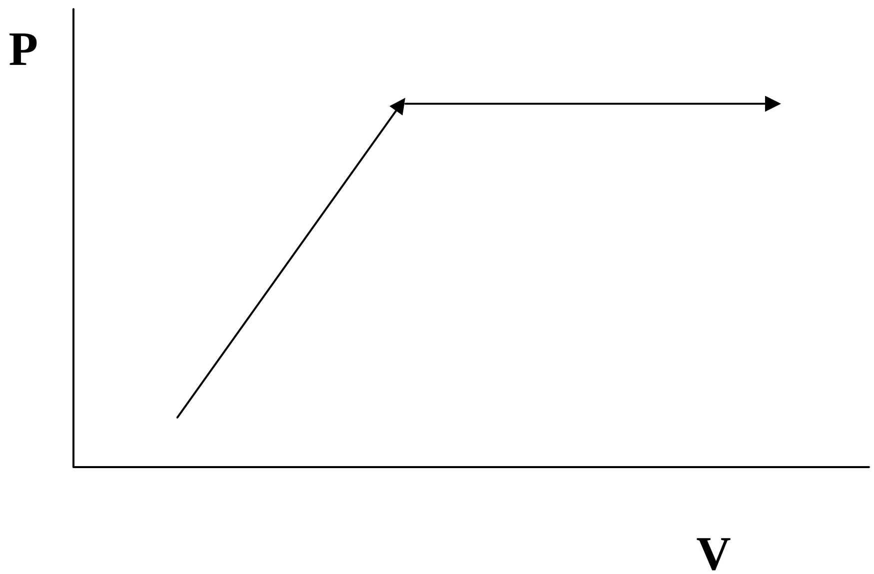
The process in which ΔU from A to B is the greatest (magnitude) is:

a. path 1
b. path 2
c. same

P-V diagram example

Some random process

$PV = nRT$



Clicker #1: Is ΔU (a) positive, (b) negative, or (c) zero?

Clicker #2: Is $W_{on\ gas}$ (a) positive, (b) negative, or (c) zero?

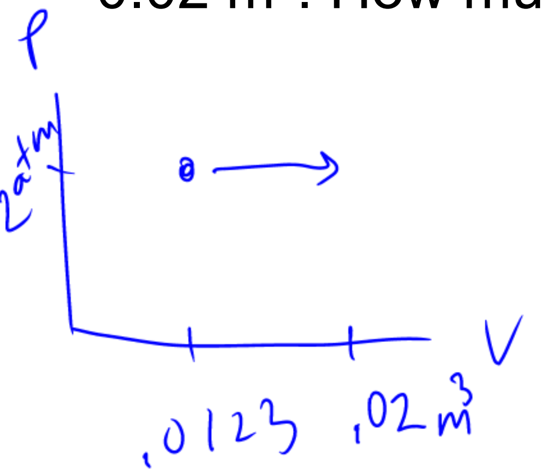
Clicker #3: Is Q_{added} (a) positive, (b) negative, or (c) zero? or (d) can't tell?

$\Delta U = Q + W_{on}$

Worked Problem

$$W = -P\Delta V$$

A piston designed to keep the pressure constant ("isobaric") at 2 atm contains one mole of a monatomic ideal gas. The initial temperature is 300K and the initial volume is 0.0123 m^3. Heat is added, causing the gas to increase in temperature and also causing the piston to expand to 0.02 m^3. How much heat was that?



$$\Delta U = Q + W_{on}$$

$$Q = \Delta U - W_{on}$$

$$Q = \frac{3}{2} nR\Delta T - (-P\Delta V)$$

$$= \frac{3}{2}(nRT_f - nRT_i) + P(V_f - V_i)$$

$$= \frac{3}{2}PV_f - \frac{3}{2}PV_i + PV_f - PV_i$$

$$= \frac{5}{2}PV_f - \frac{5}{2}PV_i = \frac{5}{2}P(V_f - V_i)$$

$$= \frac{5}{2}(2 \cdot 1.01\times10^5\ Pa)(.02 - .0123)\ m^3$$

$$= 3889\ J$$

What if diatomic gas?

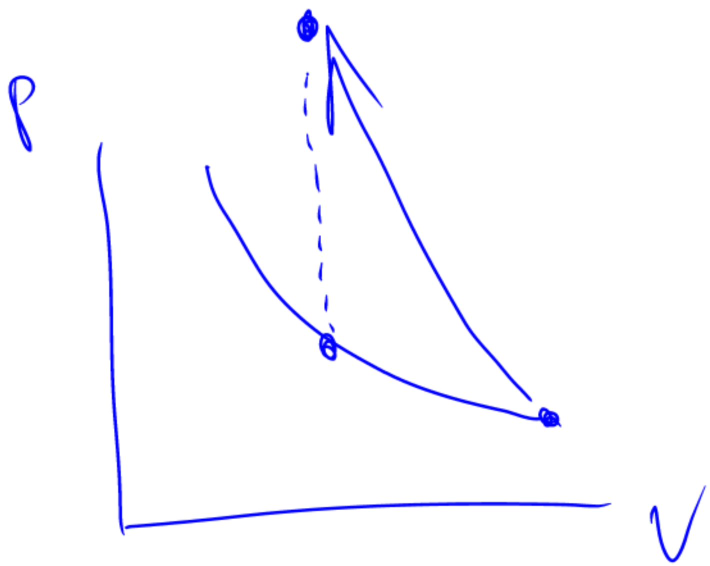
Answer: 3889 J

From warmup

Ralph is confused because he knows that when you compress gases, they tend to heat up. Think of bicycle pumps, for example. So, how are isothermal processes possible? How can you compress a gas without its temperature increasing?

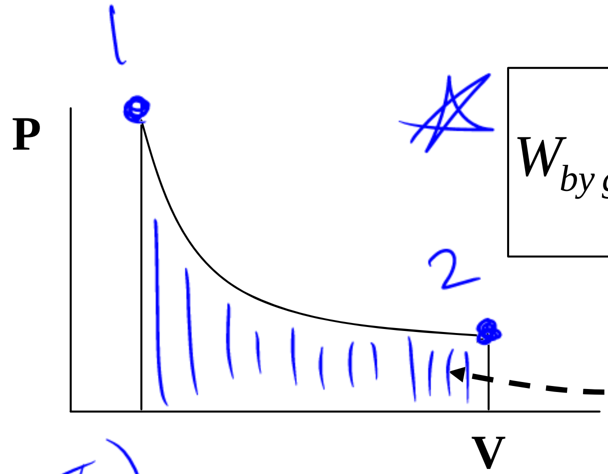
"Pair share"–I am now ready to share my neighbor's answer if called on.

a. Yes



Isothermal Processes

$W_{on} = -P_{ave}\,\Delta V$



$$W_{by\,gas} = nRT \ln\left(\frac{V_2}{V_1}\right) \quad \text{(isothermal)}$$

area

$W_{on} = -nRT\ln\left(\frac{V_2}{V_1}\right)$

(From calculus)

$\left(\frac{3}{2}nR\,\Delta T\right)$

$\Delta U = W_{on\ gas} + Q$

$0 = -nRT\ln\left(\frac{V_2}{V_1}\right) + Q$

$Q = nRT\ln\left(\frac{V_2}{V_1}\right) = -W_{on\ gas}$

Adiabatic expansion or compression

$\Delta U = Q + W_{on}$

***Adiabatic*: “no heat added”**, either because…

- system is *insulated* , or
- ΔV is *fast,* so no time for much heat to go in/out of gas

$Q \quad + \quad W_{on} \quad = \quad \Delta U$

$0 + W_{on} = \Delta U$

$\frac{3}{2} n R \Delta T$

+

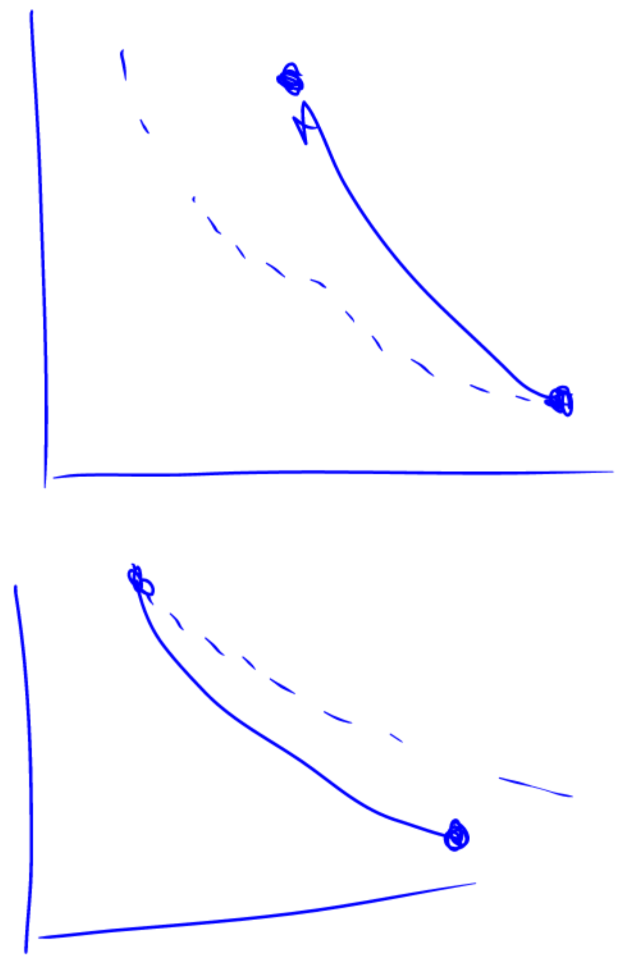
Question: What is ΔT? +

Adiabatic Temperature Change

→ “No heat added” does <u>not</u> mean “no temperature change”

Demos:

adiabatic cotton burner
freeze spray



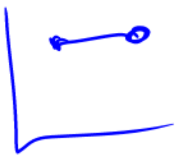
Adiabatic curves

They are *steeper* than isothermal curves

$\Delta U = Q + W_{on}$

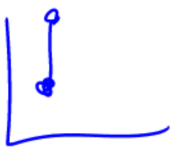
Summary: Four special types of state changes

Constant Pressure: $W_{on} = -P\Delta V$



$Q = \Delta U + P\Delta V$

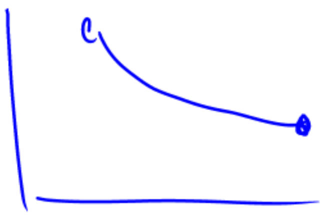
Constant Volume: $W_{on} = 0$



$\Delta U = Q$

$Q = \frac{3}{2} nR\Delta T$ (mona.)

Isothermal:



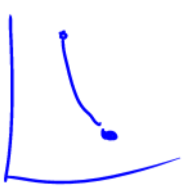
$W_{on} = -nRT\ln(V_f/V_i)$ ☆

$\Delta U = 0 \rightarrow Q = -W_{on}$

Adiabatic: $Q = 0$

$\Delta U = W_{on}$

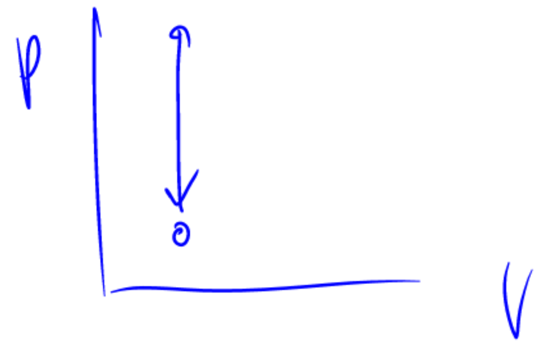
$W_{on} = \frac{3}{2} nR\Delta T$ (mona.)



From warmup

A gas has its pressure reduced while its volume is kept constant. What does this look like on a PV diagram?

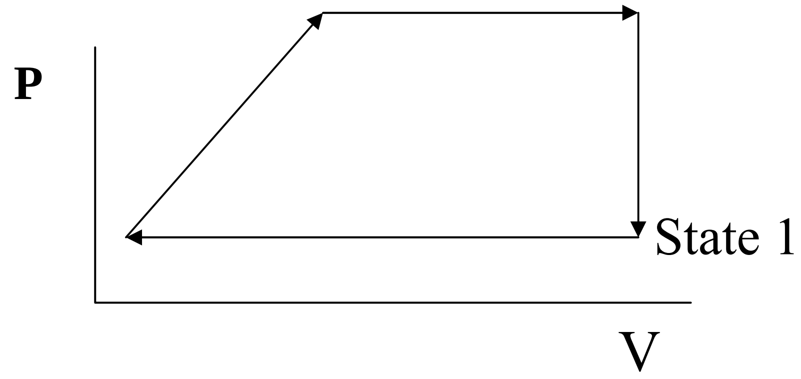
a. a horizontal line going to the right
b. a horizontal line going to the left
c. a vertical line going up
d. a vertical line going down



Same situation. How did the temperature of the gas change during that process?

a. the temperature increased
b. the temperature decreased
c. the temperature stayed the same
d. the temperature change cannot be determined from the information given

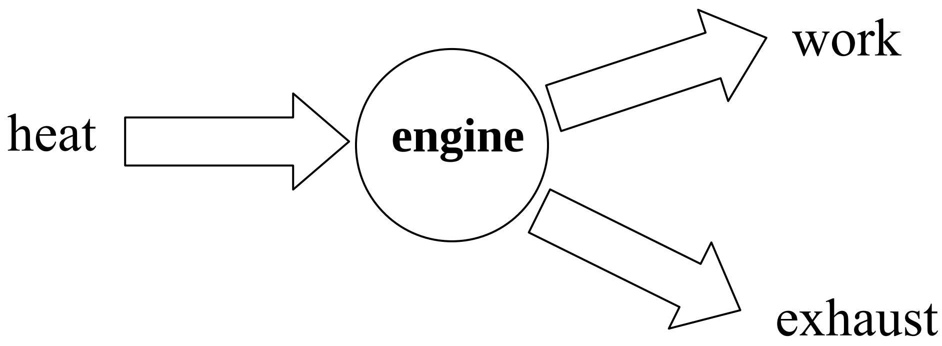
Cyclical Processes



ΔU $W_{on\ gas}$ Q

Engines

The basic idea: energy transformation



Notation: Q_h, Q_c, T_h, T_c, $|W_{net}|$

Demo

Stirling engine

Efficiency

Engine efficiency: how good is your engine at converting heat to work?

Definition: $e =$

Power

Engine Power: how *fast* can your engine convert heat to work?

Definition: $P =$

Worked Problem

An engine produces power of 5000 W, at 20 cycles/second. Its efficiency is 20%. What are $|W_{net}|$, Q_h, and Q_c per cycle?

What do those quantities represent?

Answers: 250 J, 1250 J, 1000 J

Real engines

modeled by PV-diagram cycles

Gasoline engines

- Piston is compressed quickly
- Heat is then added quickly by igniting fuel
- Piston then expands quickly
- Heat is then expelled quickly (by getting rid of old air)
  - → Same air is not re-used; the cycle is just an approximation

The "Otto cycle"

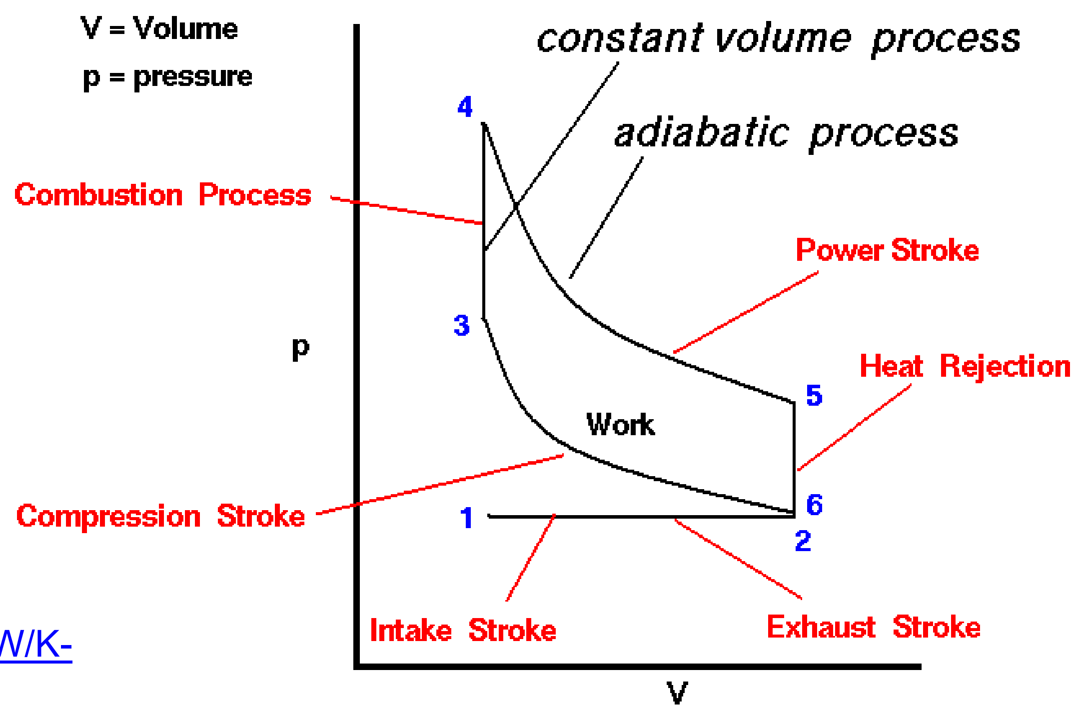


Image credit: http://www.grc.nasa.gov/WWW/K-12/airplane/otto.html

Refrigerators/Heat Pumps

Refrigerator picture:

Heat pump picture:

Admission:

From warmup

The second law of thermodynamics says for a heat engine:

a. You get more work energy out than you put in as heat
b. You get the same work energy out as you put in as heat
c. You get less work energy out than you put in as heat

2^{nd} Law of thermodynamics (alternate)

Heat spontaneously flows from hot to cold, not the other way around.

Why? **<u>Order.</u>** From textbook: which hand is more likely?

… but which is more likely, a straight flush or a garbage hand?

Entropy concept

Question: You separate a deck into two halves: one is 70% red, 30% black; the other is 30% red, 70% black. What will happen if you randomly exchange cards between the two?

Entropy equation: you don't need to know

Second Law, Two versions

In an engine, you can't convert all the heat into usable work

Heat doesn't flow from cold to hot

Why are they equivalent?

1. If you had a process whereby heat flows from cold to hot…

2. If you had an engine that completely converts heat to usable work…

Carnot's Theorem:

You can't even convert *most* of the heat into work

$$e_{\max} = "e_C" = 1 - \frac{T_c}{T_h}$$

C for Carnot

Carnot Engine

(Usable) Energy lost by "irreversibilities"

Irreversibilities occur when heat is added during a temperature change

Most efficient engine possible for given T_{max} and T_{min}: Carnot engine

→ all heat added during constant temperature processes

Drawback: Isothermal = slow, typically

(end of chapter 12 !)