Announcements – 18 Nov 2014

A Cappella Jam tonight! 7 pm Varsity Theater in Wilk
$5 in advance
$7 at door

1. Prayer

2. Exam 3 starts on **Mon Nov 24**
   a. Covers Ch 9-12, HW 18-24
   b. Late fee on Wed after Thanksgiving, 3 pm
   c. Closes on Thursday after Thanksgiving, 3 pm
   d. Jerika review sessions, both in C295 ESC
      i. Sat Nov 22, 10 - 11:30 am (before Thanksgiving)
      ii. Mon Dec 1, 5:30 - 7 pm (after Thanksgiving)
   → e) Exam 3 Info sent in Email

3. Thanksgiving week:
   a. Homework is due on Monday, as usual
   b. Tuesday is a virtual Friday → we don't have class
   c. No classes on Wednesday
   d. Testing Center not open on Wed, Thurs, Fri, or Sat

4. Final exam – Tuesday Dec 16, either 7-10 am or 8-11 pm.

"Which of the problems from last night's HW assignment would you most like me to discuss in class today?"

Review

$Q = mc\Delta T$
$Q = mL$
$\frac{Q}{t} =$ (two eqns)

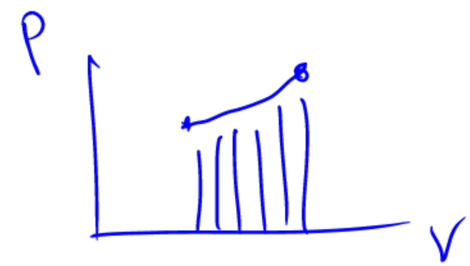
Internal energy

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

monatomic: $U = \frac{3}{2} nRT$, $\Delta U = \frac{3}{2} nR\Delta T$

diatomic, around 300K: $U = \frac{5}{2} nRT$, $\Delta U = \frac{5}{2} nR\Delta T$

Work



constant P: $W_{by} = P\Delta V$, $W_{on} = -W_{by}$

changing P: $W_{by} = P_{ave}\Delta V$, $W_{on} = -W_{by}$

in general: $W = \text{area under curve on PV diagram}$

1st Law of Thermodynamics

$$\Delta U = Q_{added} + W_{on\ system} \quad \text{(blueprint)}$$

Be careful with all the signs!!!

ΔU is positive if: Temp increasing

Q_{added} is positive if: heat flows into gas

$W_{on\ system}$ is positive if: if volume decreasing

Isothermal "Contours"

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

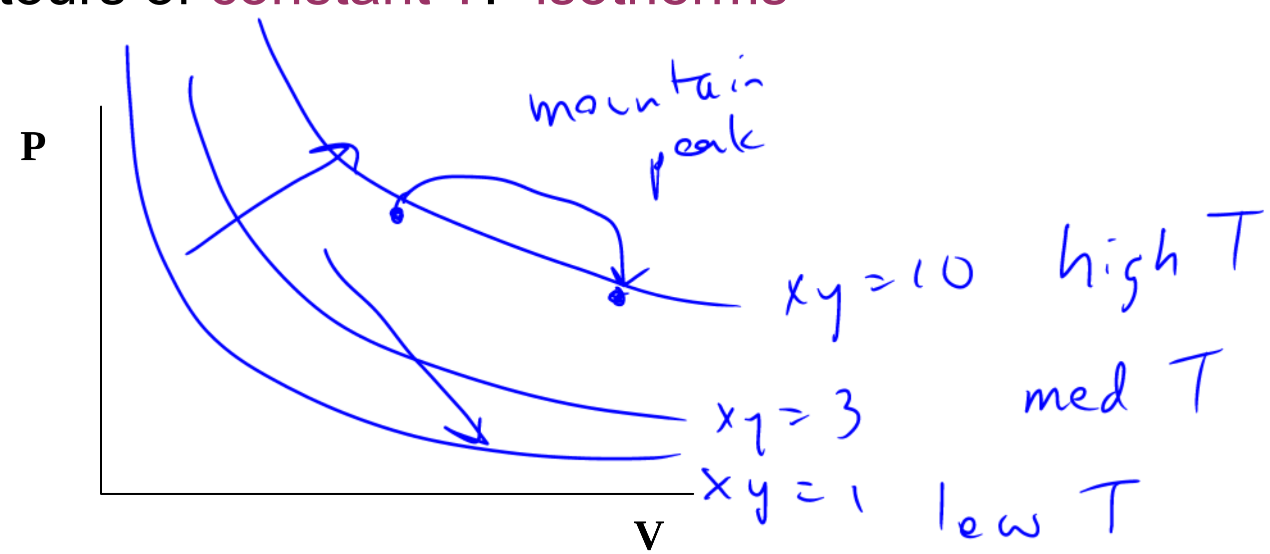
$PV = nRT$

$\rightarrow$ 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)

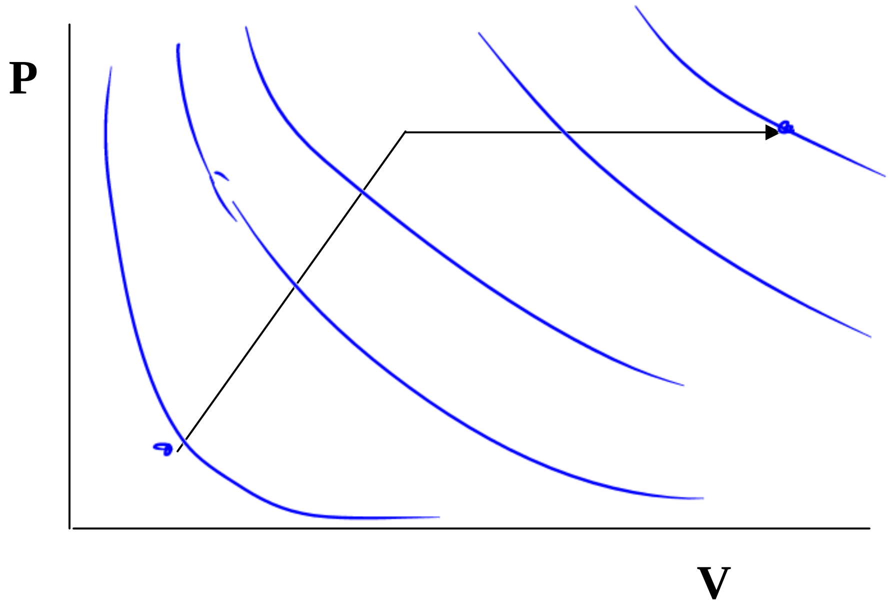
Contours of constant T: "isotherms"

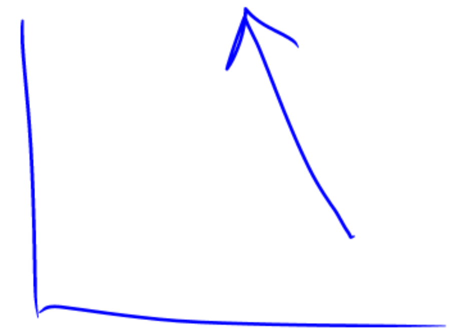


Clicker Quizzes

PV = nRT

Some random process





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?

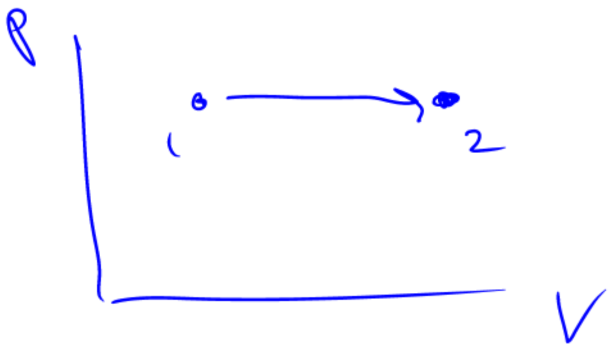
First Law! $\Delta U = Q_{added} + W_{on} \rightarrow Q_{added} = \Delta U - W_{on}$

pos. − (neg)

Worked Problem

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

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?



$$Q_{added} = \Delta U - W_{on}$$
$$= \frac{3}{2} nR\Delta T - (-P\Delta V)$$
$$= \frac{3}{2} nR(T_2 - T_1) + P(V_2 - V_1)$$
$$= \frac{3}{2} nRT_2 - \frac{3}{2} nRT_1 + P(V_2 - V_1)$$
$$= \frac{3}{2} PV_2 - \frac{3}{2} PV_1 + PV_2 - PV_1$$
$$= \frac{5}{2} PV_2 - \frac{5}{2} PV_1$$
$$= \frac{5}{2}(2 \cdot 1.01 \cdot 10^5\,Pa)(.02\,m^3) - \frac{5}{2}(2 \cdot 1.01 \cdot 10^5)(.0123\,m^3)$$
$$= \boxed{3889\,J}$$

$PV = nRT$

$T_2 = \frac{P_2 V_2}{nR}$

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: compressing the air heats up the nozzle of the pump. Yet section 12.3 (8th edition) talks about "isothermal" processes where the temperature doesn't change. How are such processes possible? How can you compress a gas without its temperature increasing?

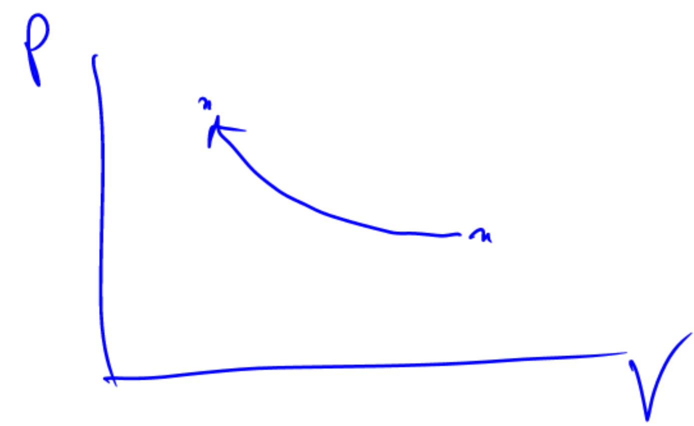
“Think-pair-share”

- Think about it for a bit
- Talk to your neighbor, find out if he/she thinks the same as you
- Be prepared to share your answer with the class if called on

Clicker: I am now ready to share my answer if randomly selected.

a. Yes

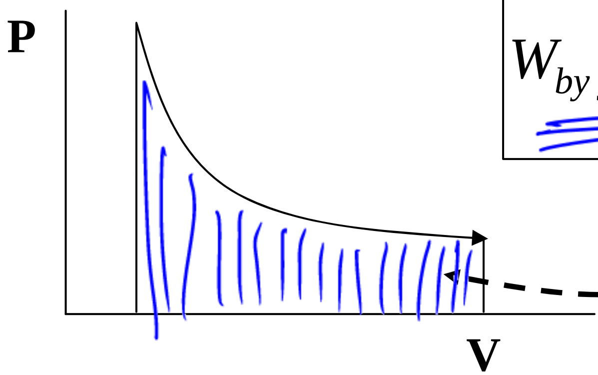
Note: you are allowed to "pass" if you would really not answer.



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

0 neg pos

Isothermal Processes



natural log

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

(From calculus)

ΔU	$W_{on\,gas}$	Q
0	pos	neg

Adiabatic expansion or compression

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

$0 + \text{pos}$

Adiabatic: **"no heat added"**, typically either because…

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

compression

$\Delta U = W_{on}$

Q	W	ΔU
0	pos.	pos

Question: What is ΔT? positive

Adiabatic temperature change

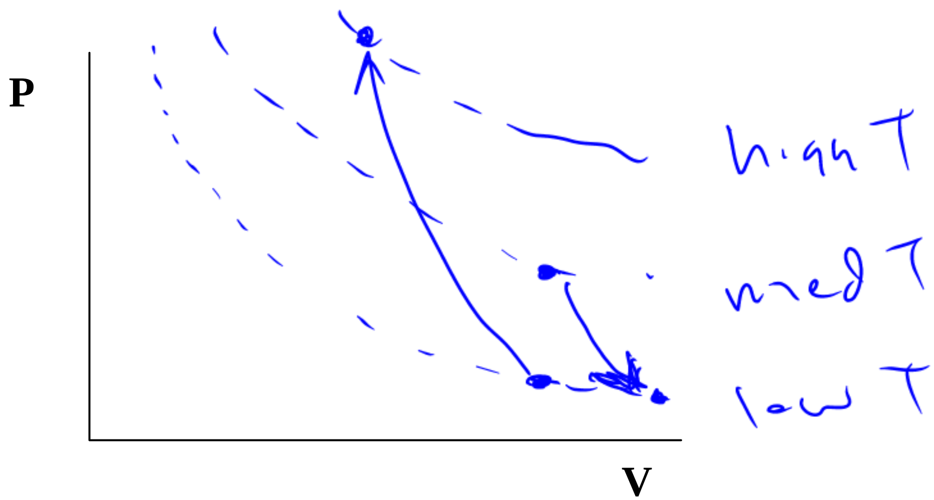
→ “No heat added” does <u>not</u> mean “no temperature change”

Demos:

adiabatic cotton burner
freeze spray

Adiabatic curves

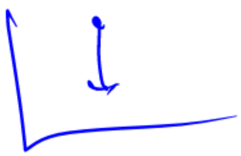
They are *steeper* than isothermal curves



Summary: Four special types of state changes

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

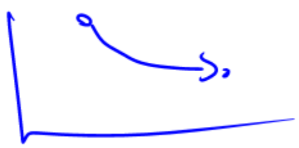
Constant Volume:



$W = 0$

Isothermal:

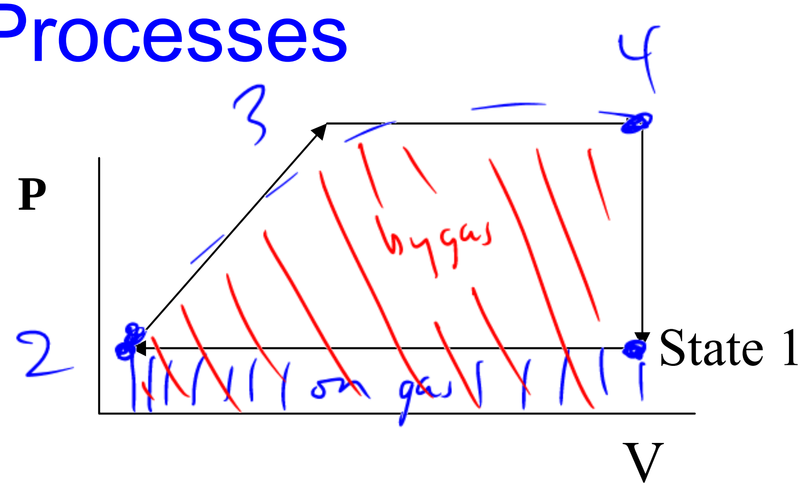
$\Delta U = 0$



Adiabatic:

$Q = 0$

Cyclical Processes



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

$0 = Q_{added} + W_{on}$

$W_{on} = -Q_{added}$

$W_{by} = +Q_{added}$

ΔU	$W_{on\ gas}$	Q
0		

$W_{net\ on\ gas} = neg = W_{on} - W_{by}$

$W_{net\ by\ gas} = pos = W_{by} - W_{on}$

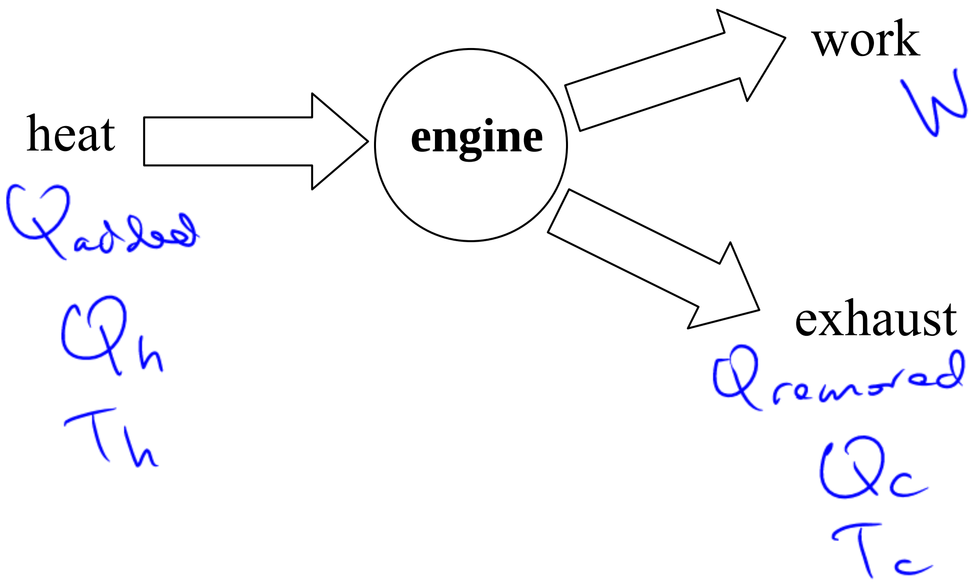
$W_{net\ by\ gas}$ = area enclosed by cycle

Engines

The basic idea: energy transformation

$$W_{net\ by} = Q_{added} - Q_{removed}$$

$$W_{eng} = Q_{net\ added}$$



Notation: Q_h, Q_c, T_h, T_c, W_{eng}

$$|Q_h| = |W_{eng}| + |Q_c|$$

Demo

Stirling engine

Efficiency

$$|Q_h| = |W_{eng}| + |Q_c|$$

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

Definition: $e = \dfrac{|W_{eng}|}{|Q_h|} = \dfrac{|Q_h| - |Q_c|}{|Q_h|}$

$$= 1 - \frac{|Q_c|}{|Q_h|}$$

Power

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

Definition: $P = \frac{|W_{net}|}{\text{time of cycle}}$

Worked Problem

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

$5000\ \text{J/sec}$; $t = .05\ \text{sec}$

$$P = \frac{W}{t} \rightarrow W = P \cdot t = (5000\ \text{J/s})(.05\ \text{s}) = 250\ \text{J}$$

$$e = \frac{W}{Q_h} \rightarrow Q_h = \frac{W}{e} = \frac{250\ \text{J}}{.2} = 1250\ \text{J}$$

$$Q_h = W + Q_c \rightarrow Q_c = Q_h - W = 1250\ \text{J} - 250\ \text{J} = 1000\ \text{J}$$

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

The "Otto cycle"

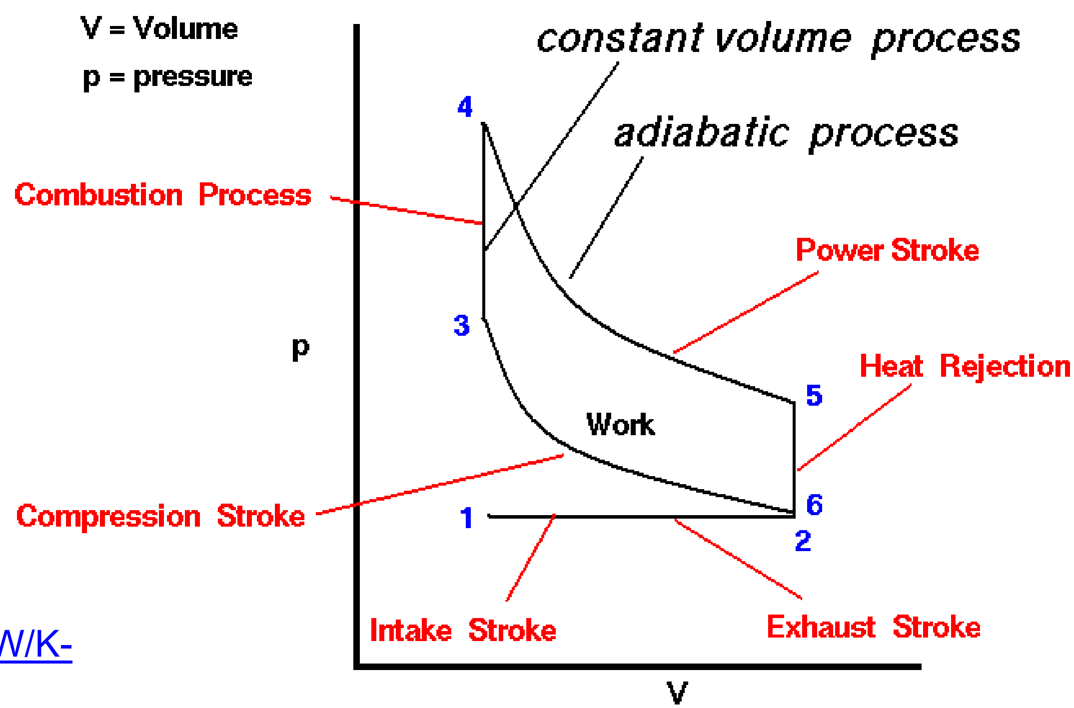


Image credit: http://www.grc.nasa.gov/WWW/K-12/airplane/otto.html

Refrigerators/Heat Pumps

Refrigerator picture:

Heat pump picture:

From warmup

The second law of thermodynamics says that for a heat engine:

a. The efficiency is always 100% because energy is conserved.
b. The efficiency must always be less than 100%, because not all of the heat energy can be turned into work.
c. The efficiency must in general be substantially less than 100%, because T_c is not zero and/or T_h is not infinity.

2nd Law of thermodynamics (alternate)

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

Why? **Order.** 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 in section 12.5 (8th edition):
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…

From warmup

Carnot's theorem says that for a heat engine:

a. The efficiency is always 100% because energy is conserved.
b. The efficiency must always be less than 100%, because not all of the heat energy can be turned into work.
c. The efficiency must in general be substantially less than 100%, because T_c is not zero and/or T_h is not infinity.

Carnot's Theorem:

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

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

C for Carnot

Why? Usable energy lost through "irreversibilities"

Exam/HW guidance: If the problem says "theoretical maximum efficiency", that's a code phrase telling you to find the Carnot efficiency for the min and max temperatures of the cycle.

Song

http://www.physics.byu.edu/faculty/colton/courses/PHY105resources/song/first_second_law.mp3

(4 minutes)

End of chapter 12!

End of exam 3 material!