Announcements

1. Instructor/course evaluations before Dec 13
   http://studentratings.byu.edu

   The three reading quizzes on Dec 13 will be:

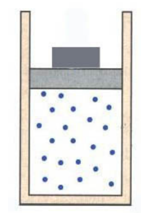
   Q1. Did you fill out the course evaluations?
   A. Yes B. No

   Q2. Did you fill out the course evaluations?
   A. Yes B. No

   Q3. Did you fill out the course evaluations?
   A. Yes B. No

Work done by a gas

1 m^3 of an ideal gas at 300 K supports a weight in a piston such that the gas pressure is 200,000 Pa (about 2 atm). The gas is heated up so it expands to 3 m^3. How much work was done by the gas?



Result: $W_{by\ gas} = P\Delta V$ (for constant P)

5th edition

$W_{by\ gas} > 0$ when…

Work done <u>on</u> a gas

$W_{on\ gas} = -P\Delta V$ (for constant P)

6th, 7th editions

$W_{on\ gas} > 0$ when…

Internal energy ("U") of an ideal gas

Return to Equipartition Theorem:

> The total kinetic energy of a system is shared equally among all of its <u>independent parts</u>, on the average, once the system has reached thermal equilibrium.
>
> Each "degree of freedom", of each molecule, has "thermal energy" of: ½ $k_B T$
>
> <u>independent parts</u>: larger for molecules that can
> - rotate
> - vibrate
>
> (requires more than one atom)
> → **such molecules have more "internal energy"**

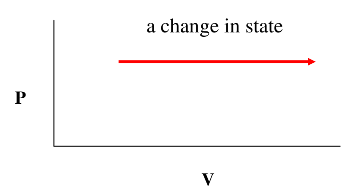
Monatomic ideal gas: only kinetic energy possible (3 directions)
average KE/molecule = 3/2 $k_B T$

→ $U = 3/2\ N k_B T$ (= 3/2 nRT)

Other substances: U is more complicated, depends on temperature
Diatomic, around 300K: U = 5/2 nRT
(2 rotational directions that take energy)

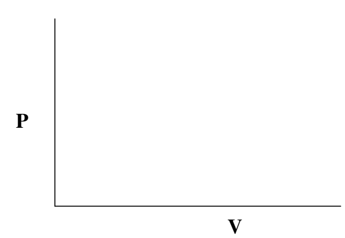
P-V diagrams

State postulate: any two (independent) variables determine the state



Work done: area under curve (but careful with sign)

Isothermal curves: contours of constant T



ΔU for an isothermal process is _____ because…

What is ΔU for the constant P process at top of page?

1^{st} Law of Thermodynamics

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

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

System: the object we are studying.
Environment: what it interacts with

What does it mean?? Use 5^{th} edition version:

$\Delta U = Q_{added} - W_{by\ system}$ → $Q_{added} = \Delta U + W_{by\ system}$

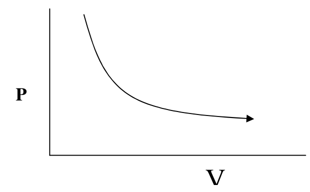
Meaning of 1^{st} Law:
Heat added can go either towards

- increasing internal energy (temperature), or
- doing work by the gas

Warning: Be careful with the signs of Q and W!

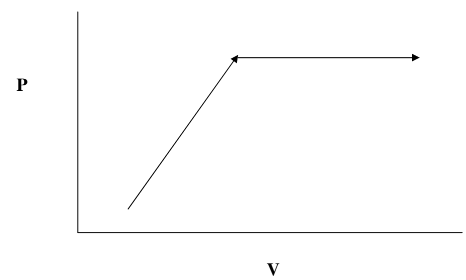
P-V diagram examples

Isothermal process



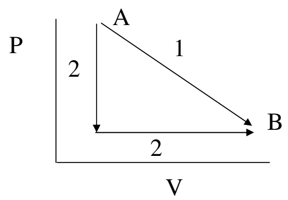
ΔU $W_{on\ gas}$ Q

Another process



ΔU $W_{on\ gas}$ Q

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.

Q4. The process in which the work is the greatest (magnitude)
a. path 1
b. path 2
c. neither; it's the same

Q5. The process in which ΔU is the greatest (magnitude)
a. path 1
b. path 2
c. neither; it's the same

Q6. In the process 1, the *work* done
a. puts energy into the system
b. takes energy out of the system
c. has no effect on the energy of the system

Work done in first half of path 2? What is this path physically?

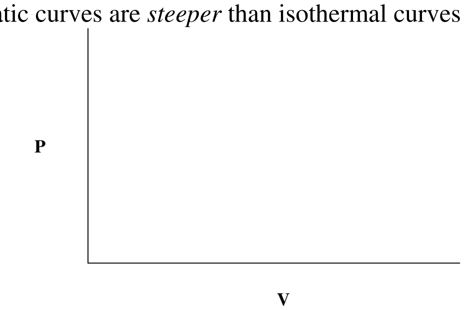
Adiabatic expansion or compression

Adiabatic: **no heat added**, via:

- system is *insulated* , or
- ΔV is *fast,* so no time for much heat to come in

Q W ΔU

Adiabatic curves are *steeper* than isothermal curves



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

Demo: adiabatic compression and cotton,
freezing by expansion

Various situations…

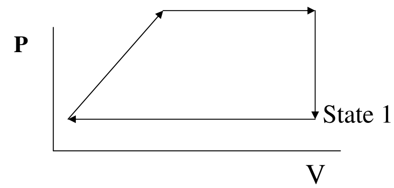
Q7. You boil water on a stove. System = water. The steam must displace the atmosphere. U is higher for steam than water because you pull molecules apart (adding PE) to make steam, and the speed of the molecules is higher. Determine the signs of Q, W, and ΔU.

Choice	Q_{added}	$W_{on\ system}$	ΔU
A	+	+	+
B	0	+	+
C	+	–	+
D	+	0	+
E	–	+	0

Q8. Compressing air very quickly in an engine cylinder. System = air. Determine the signs of Q, W, and ΔU; same choices as Q7.

Q9. You heat a spray can in a fire, and volume stays about the same (it doesn't explode). System = gas in the can. Determine the signs of Q, W, and ΔU; same choices as Q7.

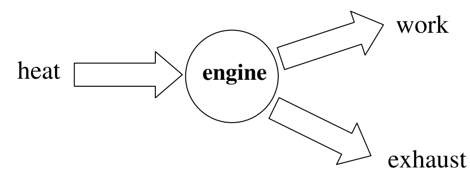
Cyclical Processes



ΔU $\quad$ $W_{on\ gas}$ $\quad$ Q

Engines

The basic idea: energy transformation



Notation: Q_h, Q_c, T_h, T_c

Demo: rubber bands and heat lamp

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

Definition: $e =$

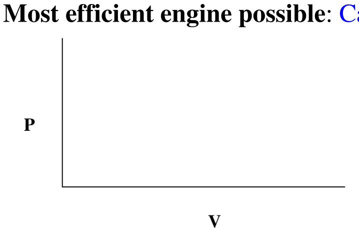
Engine Power: work per time (as usual)

Worked Problem: An engine power output (W/time) is 5000 Watts at 20 cycles/second. Its efficiency is 15%. What are W, Q_h, Q_c per cycle?

2nd Law of thermodynamics

- Can't convert all of heat into work
  - → Entropy & Statistics

Most efficient engine possible: Carnot engine



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

C for Carnot

How much power? Isothermal = slow, typically

Demo: rubber band + human Carnot refrigerator

Efficiencies in real life

Car engines (gas)

Typical efficiency: 30%

T_{hot}?

T_{cold}?

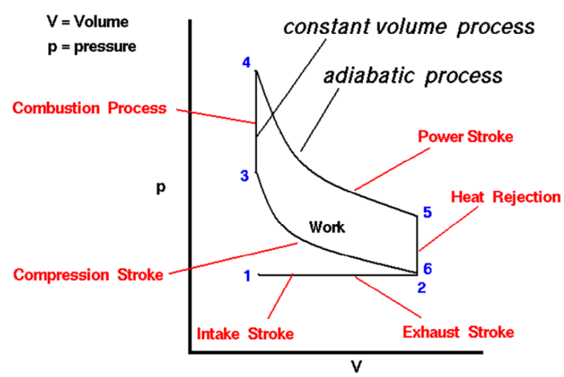
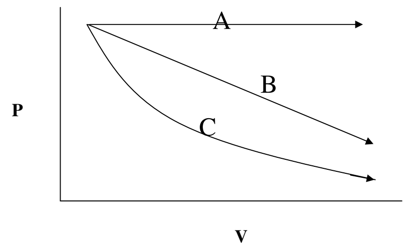


Image credit: http://www.grc.nasa.gov/WWW/K-12/airplane/otto.html

Hybrid cars and better mileage:
- ♦ charge battery with brakes
- ♦ turn off engine, use battery (charge later) when slow, stopped

Demo: Thermoelectric converter engine

Steam engine (www.howstuffworks.com/steam1.htm):



Q10. The process that does the **most work** (magnitude) is _____

Q11. The process that is at **constant temperature** is ______

Q12. The process that leaves the system at the **highest T** is:_______

Q13. The process in which the **magnitudes** of W and Q are the **same** is: ______

Q14. Did you discuss at least half of the discussion quiz questions today with a neighbor?
a. Yes b. No