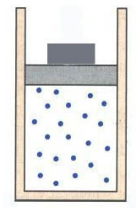
Lecture 23 Announcements

1. Exam starts Thursday
   a. Thursday will be the in-class exam review
      i. No warmup quiz
   b. Thursday evening will be the TA exam review: 7-9 pm, C215 Eyring
2. **Exam ends on Tuesday, not Wednesday**
   a. Testing Center not open on Wed, due to Thanksgiving
3. Homework 19 due tomorrow
   a. Next homework not due until Dec 3! Two weeks off!
4. No class a week from today (Friday classes meet)

Work done by a gas

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



Result: $W_{\text{by gas}} = P\Delta V$ 5^{th} edition

(for constant P)

$W_{\text{by gas}} > 0$ when…

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

$W_{\text{on gas}} = -P\Delta V$ 6^{th}, 7^{th}, 8^{th} editions

(for constant P) $W_{\text{on gas}} > 0$ when…

Internal energy of an ideal gas: U

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 an energy of: ½ k_BT
>
> <u>independent parts</u>: larger for molecules that can
> - rotate
> - vibrate
>
> (requires more than one atom)
>
> → **such molecules have more "internal energy"**

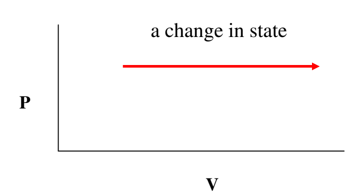
Monatomic ideal gas: only kinetic energy possible (3 directions)
average KE/molecule = 3/2 k_BT
total KE = N × (3/2 k_BT)

→ $\boxed{U = 3/2\ Nk_BT = 3/2\ nRT}$ (monoatomic)

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

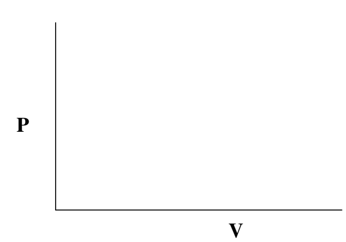
P-V diagrams

> *State postulate*: any two (independent) variables determine the state: P, V, T, U, etc.



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

How to tell at a glance if the temperature has increased or decreased: ***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?

1st Law of Thermodynamics

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

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

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

What does it mean?? Use 5th edition version:

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

Meaning of 1st Law:
Heat added can go either towards
- increasing internal energy (temperature), or
- doing work by the gas

Final warning: Be careful with all the signs!!!

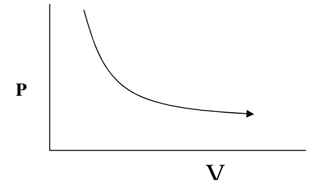
ΔU is positive if:

Q_{added} is positive if:

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

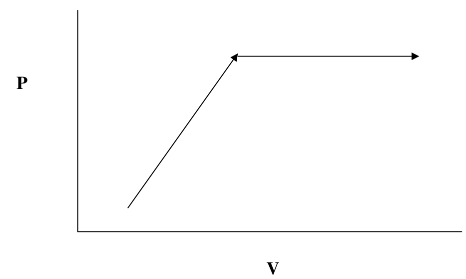
P-V diagram examples

Isothermal process



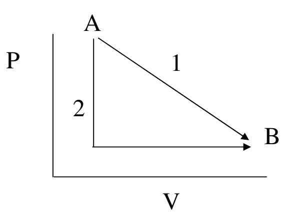
ΔU $\quad W_{on\ gas} \quad$ Q

Another process



ΔU $\quad W_{on\ gas} \quad$ 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.



Clicker quiz 1: The gas does the most work in:
a. path 1
b. path 2
c. neither; it's the same

Clicker quiz 2: In 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

Clicker quiz 3: The process in which ΔU is the greatest (magnitude) is:
a. path 1
b. path 2
c. neither; it's the same

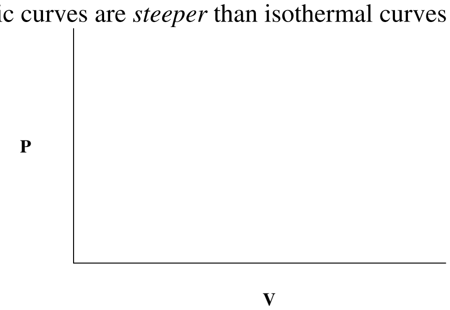
How much work is done in first half of path 2? What is this path physically?

Adiabatic expansion or compression

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 $\quad$ W $\quad$ ΔU

Adiabatic curves are *steeper* than isothermal curves



→ "No heat added" does not mean "no temperature change"

Demos: adiabatic compression and cotton
freezing by expansion

Ralph question: how does isothermal compression work?

Two situations…

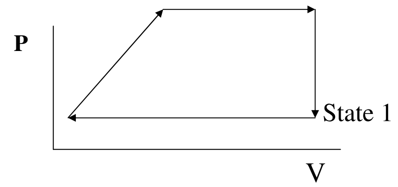
Clicker quiz: You compress air very quickly in an engine cylinder. Determine the signs of Q, W, and ΔU.

a. $Q_{added} = +$ $W_{on\ gas} = +$ $\Delta U = +$
b. $Q_{added} = 0$ $W_{on\ gas} = +$ $\Delta U = +$
c. $Q_{added} = +$ $W_{on\ gas} = -$ $\Delta U = +$
d. $Q_{added} = +$ $W_{on\ gas} = 0$ $\Delta U = +$
e. $Q_{added} = -$ $W_{on\ gas} = +$ $\Delta U = 0$

Clicker quiz: 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.

a. $Q_{added} = +$ $W_{on\ gas} = +$ $\Delta U = +$
b. $Q_{added} = 0$ $W_{on\ gas} = +$ $\Delta U = +$
c. $Q_{added} = +$ $W_{on\ gas} = -$ $\Delta U = +$
d. $Q_{added} = +$ $W_{on\ gas} = 0$ $\Delta U = +$
e. $Q_{added} = -$ $W_{on\ gas} = +$ $\Delta U = 0$

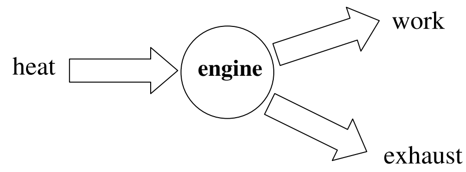
Cyclical Processes



ΔU $W_{on\ gas}$ Q

Engines

The basic idea: energy transformation



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

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

Definition: $e =$

Engine Power: work per time (as usual)

Demo: Thermoelectric converter engine

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

Example: 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"

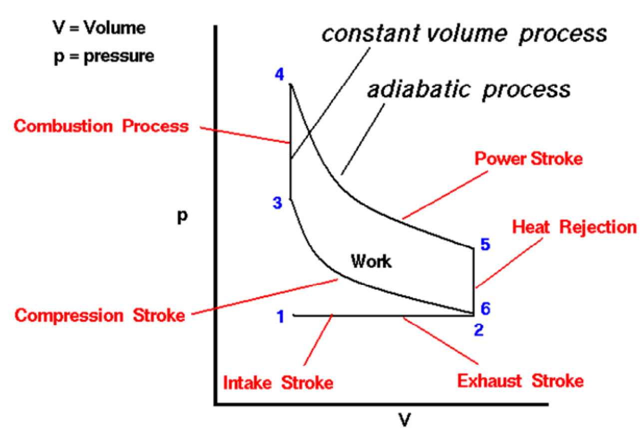


Image credit: http://www.grc.nasa.gov/WWW/K-12/airplane/otto.html

2^{nd} Law of thermodynamics:

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?

→ **Boltzman 3D program revisited; increasing "entropy"**

Another version of the law:

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

Why are they equivalent?

Carnot's Theorem:

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

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

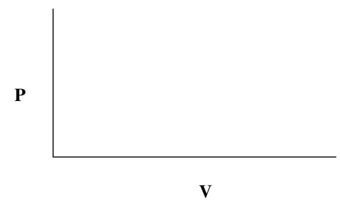
C for Carnot

(Organized) Energy lost by "irreversibilities"

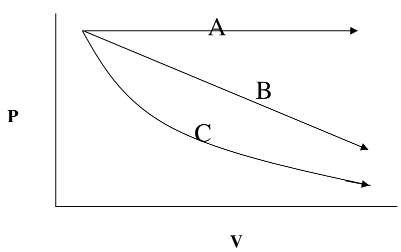
Irreversibilities occur when heat is added during a temperature change

Most efficient engine possible: Carnot engine

→ all heat added during constant temperature processes



How much power? Isothermal = slow, typically



Clicker quiz 1: The process that does the **most work** (magnitude) is _____

Clicker quiz 2: The process that is at **constant temperature** is ______

Clicker quiz 3: The process that leaves the system at the **highest T** is:_______

Clicker quiz 4: The process in which the **magnitudes** of W and Q are the **same** is: ______