Classical Statistical Mechanics

Physics 390
Winter 2007

Classical Statistical Mechanics

- Turn from the study of individual objects (atoms, molecules) to something more practical: statistical study of really *enormous* groups of objects
- Atoms are tiny. Everything is made of enormous numbers…
- Following the detailed behavior of each is impossible
- Instead we measure 'macroscopic' properties, like temperature and density
- Today we will revisit Classical statistical mechanics and discuss Quantum statistical mechanics.

Physics and change

- Laws of physics: forces and fields
  - Gravity
  - Electromagnetism
  - Strong and Weak nuclear
- All have time symmetry! Basic processes can all be reversed.
- Conservation laws, things which *never* change
  - Energy
  - Momentum
  - Angular momentum
- Change reduced to ***ex***change, flow of permanent quantities

Energy flow

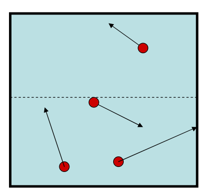
- Energy takes many related forms
  - Kinetic
  - Gravitational
  - Elastic
  - Electric
  - Heat
  - Mass
- Energy is a convertible quantity
- Total energy content is fixed
- Laws tell us what conversions *can* happen, they don't tell us which *will* happen…
- Something more is needed to determine what *will* happen

Irreversibility

- In the world, energy flow constraints *allow* some transformations which never occur
- How do we determine which among the possible outcomes will occur?
- Make the simplest assumption:
  - ⇒ All possible outcomes are equally probable

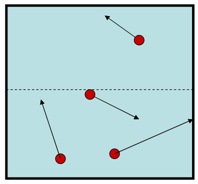
A model system

- Gas atoms in a box
  - Initial positions and velocities
  - Every collision conserves energy and momentum
  - Use laws to predict motion
- Computers can do a 'Monte Carlo simulation' of this
- Prediction here is simple and secure



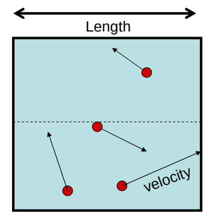
Micro & macrostates

- Microstate: details for each atom
  - Position and velocity
- Macrostate: some feature of positions and velocities of all atoms
  - Average position?
  - Average velocity?
  - Are they all on top?



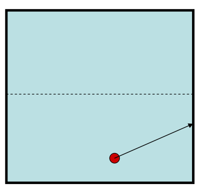
Timescales

- This system rearranges itself on some timescale
  - ~ length / velocity
- Ask too soon, microstate cannot change
- Wait a few characteristic times before asking, the microstate will be rearranged
- All allowed arrangements *will* occur.



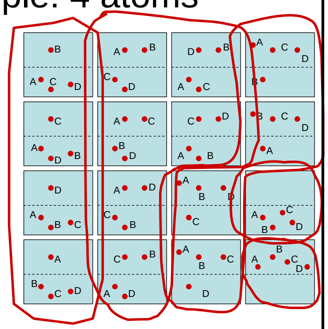
An example: 1 atom

- How often are all the particles on top?
- One atom: can be on top or bottom
  - (# top arrangements / total # arrangements)
  - 50%



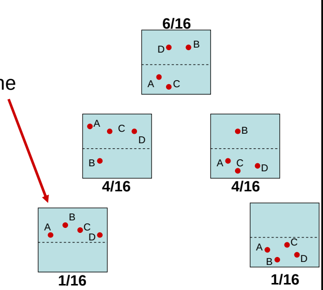
An example: 4 atoms

- How often are all the particles on top?
- Four particles, each on top or bottom
- 16 microstates here
- Each microstate is equally likely
- 1 microstate has them all on top



Macrostates

- Example macrostate, all the atoms on top
- All are on top 1/16th of the time
- Other probabilities from counting microstates
- This is a question about what happens. All are allowed, which ones actually occur?



The point

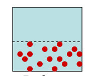
- Some macrostates are made by many microstates (1/2 the atoms on each side)
- Some macrostates are made by very few microstates (all on one side)
- If all microstates are all equally probable, some macrostates will happen a *lot* more often.
- All on one side happens $1/2^N$ of the time (N = # of atoms)

Is this irreversibility?

- 1 atom: 1/2
- 4 atoms: 1/16
- 10 atoms: 1/1024
- 20 atoms: 1/10 million
- 40 atoms: 1/trillion
- 80 atoms: 1/1,200,000,000,000, 000,000,000,000
- Consider an 80 atom system:
  - Assume rearrangement happens a million times a second
  - How long before we see them all on top?
  - 10^{18} seconds
  - 30 billion years……

A realistic example

- 1 cm^3 of air
- ~2×10^{19} atoms
  - Assume rearrangement a million times a second
- All on one side every $10^{7.5x10^{18}}$ seconds
- This is an irreversible process:
  - Start with all on one side
  - Release them
  - They could all come back, but never do…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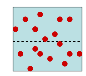
After

A simple Example:

Four identical, distinguishable particles with total Energy E=8

Configuration index (Macrostates)	E1	E2	E3	E4	E5	Number of different combinations for Distinguishable particles (Microstates)	boson	Fermion with spin
1	o	oo	O			4(E1)*3(E3)=12	1	1
2	oo	o		o		4 (E2)*3(E4)=12	1	1
3	oo		oo			6 (E1) =6	1	1
4	ooo				o	4(E5) =4	1	X
5		oooo				1	1	x