

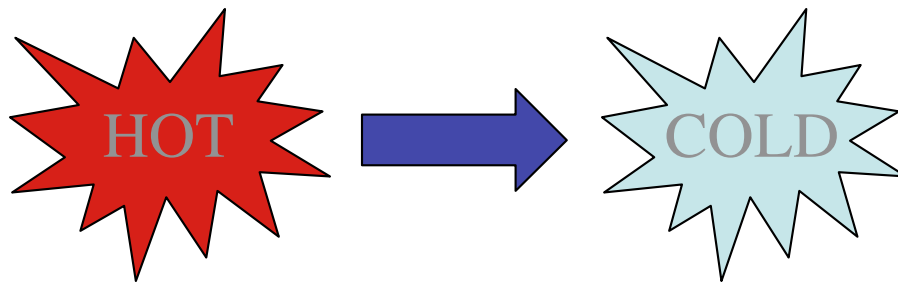
## THE STATISTICAL WORLD

- First time atomic/discrete nature of matter enters physics in a quantitative way
- First time probability laws are used in physics
  - ➡ bridge between micro and macroscopic
- 6 hypotheses of kinetic theory:
  - i) Gases consist of molecules
  - ii) Molecules occupy negligible volume in container (as opposed to liquids and solids)
  - iii) Number of molecules in gas is very large
  - iv) Molecules are in random motion
  - v) Forces between molecules are negligible
  - vi) Collisions between molecules are elastic

(All confirmed later, in early 20<sup>th</sup> century.)

## Carnot's waterwheel analogy:

- Heat flows from hot to cold as water from high to low elevation
  - As it does so it can do work
  - Some heat is always lost: to surroundings  
to friction  
just lost
- ➔ not all heat generated is “useful heat”:  
\*need a heat source to keep things going  
\*there is no such thing as a perpetual motion machine!(or a free lunch)

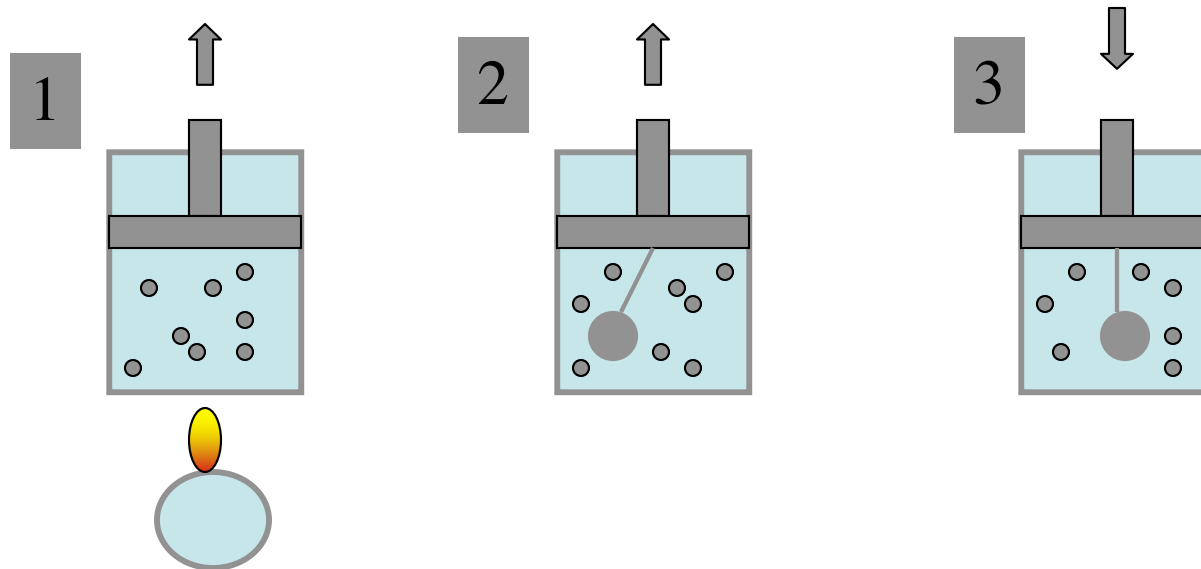


## **THE SECOND LAW: CHANGE AND DECAY**

- **3 PRINCIPLES OF CARNOT** (1796 - 1832)
  - i) Perpetual motion is impossible
  - ii) Heat emitted and absorbed by system can be measured by examining initial and final states
  - iii) Useful work can be produced whenever temperature difference exists
- But it's not so easy to make heat into work (pendulum)
- **2 Versions of the Second Law** (equivalent)
  - i) Lord Kelvin: No work can be done unless heat flows due to temperature difference
  - ii) Rudolf Clausius: Work is impossible by heat flowing from cold to hot body.

# THE WORLD ACCORDING TO ENTROPY

- the pendulum-in-the-piston example: 3 experiments
  - 1) First law: Heat raises the piston
  - 2) First law: Moving pendulum
    - ➔ friction ➔ heat ➔ raises piston
  - 3) Second law: Heat does not make pendulum move!
    - ➔ irreversibility ➔ arrow of time!



- Heat is disorganized energy: hard to transform into organized behavior
- ENTROPY measures efficiency of system to generate organized motion

# KINETIC THEORY

- Outgrow of first law:  
if energy starting as heat is conserved and appears as internal energy of gas, it must be energy of the constituents of the gas
- Daniel Bernouilli (1700-1782)  
1738 - hydrodynamics: \*air consists of innumerable molecules  
in rapid random motion  
\*pressure comes from collisions of molecules with container
- James Waterson (1845):  $T \sim v^2$   
 $P \sim Nv^2$  (N=number of molecules)
- James Clerk Maxwell (1860): **HEAT IS MOTION!!**  
internal energy  
pressure      ➡ EXPLAINED BY RANDOM MOTION  
temperature      OF MOLECULES

ELASTIC SPHERES FOLLOWING NEWTON'S LAWS

(The invisible becomes essential and real!)  
[demos: smoke and random molecules]

# BOLTZMANN AND THE SECOND LAW

- Boltzmann (1844-1906) provides microscopic explanation for 2nd law based on probabilities  
[The H-theorem: possible to go back, but highly improbable]  
ex: eggs, perfumes, and life

- Must think in terms of the constituents of the system and their possible arrangements (configurations or “states”)

➔ second law: most probable state is that of highest entropy (equilibrium state)

➔ time flows as system approaches equilibrium: and stops!

\*thus, in equilibrium there is no time

(think of mixture of fluids a different T)

\*a living organism must be out of equilibrium!

- **growth in entropy implies in the arrow of time!!!**