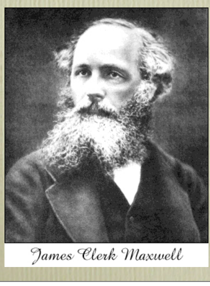
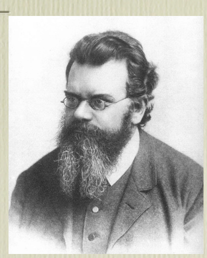
Bicycle Pumps, Rice Pudding: Time's Arrow

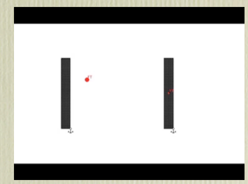
Peter Watson





What tells us what is the direction of time?

- Is this backwards or forwards

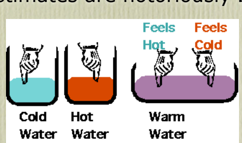


Is this?

Or this

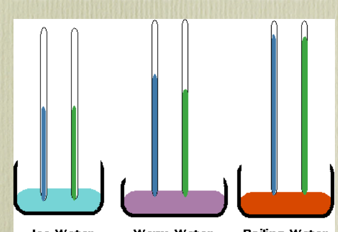
What is heat?

- Temperature can be felt qualitatively, but physiological estimates are notoriously bad.



- Start by defining fixed points:

- 0°C is water with ice floating in it
- 100°C is boiling water
- Even using thermometers, there is no guarantee that two thermometers will measure the same value:

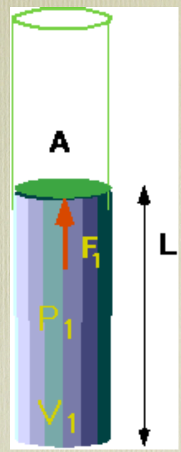


So the starting question is: what is temperature?

Two Views of Heat

"Macroscopic" view of heat: i.e. what quantities can we measure in a lab.

- **"Microscopic"** view: i.e. what happens on the level of atoms and molecules.
- So where is the energy in heat?
- Critical experiments were done with gases:
- First consider a gas in a cylinder, kept in place by a piston that can move up and down. Obviously Volume is
- $V = LA$
  Pressure: gas applies a force to the piston
- $P = F/A$
- Can vary pressure on gas by (e.g.) applying weights to the piston.
- Measure P in Atmospheres, or Pascals
- Nm^{-2} = Pascal : 1 atm = 101.3 kiloPascals



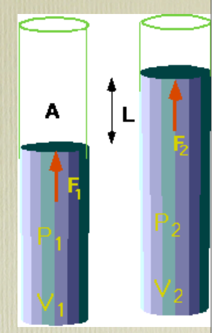
- What happens if you pump on a bicycle pump slowly?
- Boyle found that if the pressure was varied while temp was kept constant.

$$PV = const$$

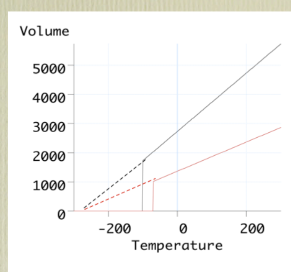
What happens if you heat up a balloon?
Charles found that if the temperature was changed at constant pressure:

$$V = const(T - T_0)$$

- Could only study a small part of the temperature range but found that **all** gases had the same
- $T_0 = -273C$

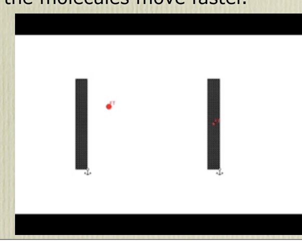


- In practice, the gas will liquefy (e.g. N_2 at ~-200°C) or solidify (e.g. CO_2 at -40°C), and the relation no longer works.
- Obviously simpler if we redefine our temperature scale so that $T_0 = 0$.
- This defines absolute temp. scale or Kelvin scale: 0 K = -273.16 C : the "absolute zero"
- Then $V = const \times T$
- We can combine Charle's law and Boyle's Law to give "Ideal Gas Law"
- $PV = const \times T$
- The constant depends on the number of molecules present.



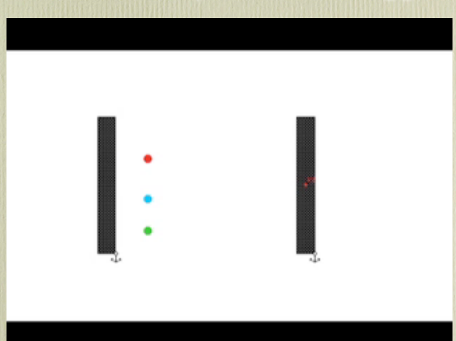
Kinetic Theory

- We will look at a model first: a gas of a few atoms.
- The atoms interact only as hard spheres with a rigid wall, all collisions are totally elastic.
- Collisions with the wall will produce a force on the wall, which is the pressure of the gas.
- Note that collisions increase as the molecules move faster.
- Start with one atom in 1-D!

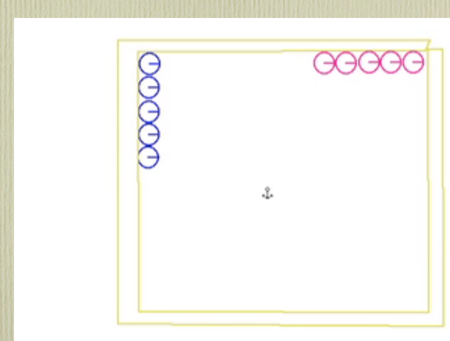


Or 3 atoms: one is moving faster

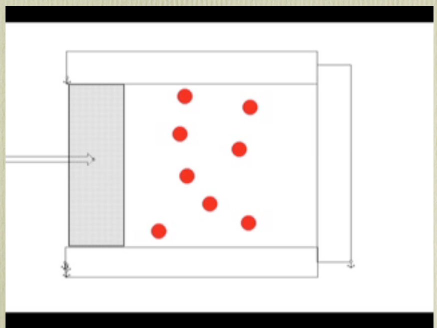
- So force (and hence pressure) is bigger



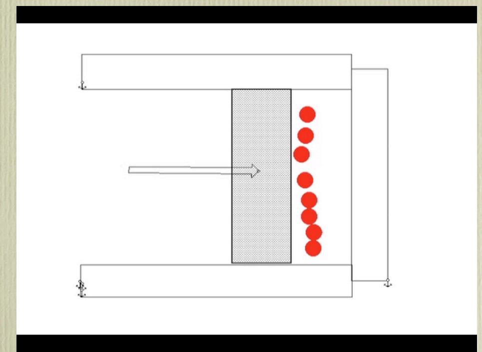
- Collisions redistribute the energy: heavy molecules move slower on average



- We can understand a number of things from the kinetic theory: e.g. how compressing a gas makes it heat up (think of a bicycle pump!)



- and how an expanding gas can do work, and the gas cools down (like an auto engine



- and this leads to .....

The First Law of Thermodynamics

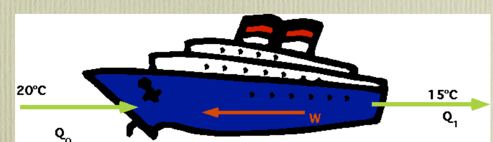
Effectively: energy is conserved. When a gas expands, its energy can change, and it can change the energy of its surroundings

- If the piston is allowed to move,then the gas will do heat or cool.
- e.g suppose we paddle a canoe: mechanical energy in the paddle ⇒ motion in the water⇒ motion of the individual molecules ⇒ heat
- e.g suppose we burn gasoline in a car: the heat energy in the hot gases ⇒ mechanical energy transmitted to the tires ⇒ mechanical energy (and the gas gets cold)
- e.g suppose you eat food before running: the food energy is stored in ATP in your muscles, and ⇒ kinetic energy when you run
- This is pretty obvious: it's essentially conservation of energy: **what has it got to do with time?**

The Second Law of Thermodynamics

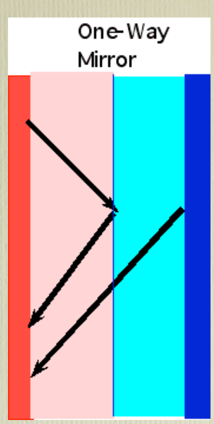
For example, why can't we have (e.g) a boat that takes in water at 20°C, extracts some heat, turns it into energy and exhausts cold water

- Doesn't violate first law



How could we do it in practice?

- Two plates of material (dark red and blue in the figure) with one-way mirror between them
- Radiation from the left plate will be reflected back and reabsorbed.
- Radiation from the right plate passes through the one-way mirror to be absorbed by the other plate.
- Pass water over both plates: water on left heats up & boils, water on right cools down
- Can run a steam engine

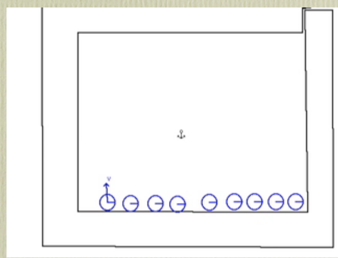


Shares in the company will be available after class

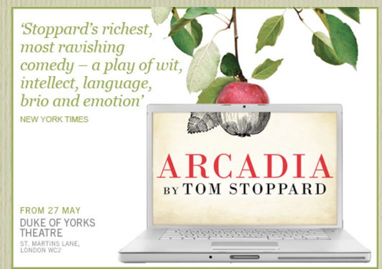
- *A good many times I have been present at gatherings of people who, by the standards of the traditional culture, are thought highly educated and who have with considerable gusto been expressing their incredulity at the illiteracy of scientists. Once or twice I have been provoked and have asked the company how many of them could describe the Second Law of Thermodynamics, the law of entropy. The response was cold: it was also negative. Yet I was asking something which is about the scientific equivalent of: 'Have you read a work of Shakespeare's?'* ***C. P. Snow***
- In order to get work out of a system, one must have a very asymmetrical system
- e.g. High pressure one side of a piston, low pressure the other side. Can this arise by chance?
- e.g. high temp. one side of a piston Can this arise by chance?
- Given 6 atoms, what is probability of finding them all one side of a room?
- Can model this via coin tossing

Entropy

- Essentially the relative probability of finding a particular arrangement by chance. If arrangement is improbable, we can always get work out of it.

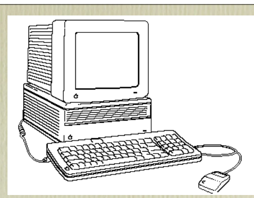


- Hot gas + cold gas ⇒ warm gas
- Gas molecules will randomize themselves very fast
- a system will always tend towards the most random arrangement

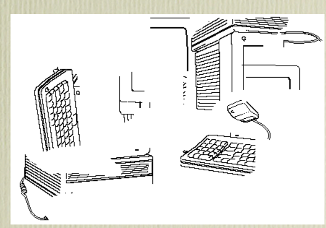


- THOMASINA: When you stir your rice pudding, Septimus, the spoonful of jam spreads itself round making red trails like the picture of a meteor in my astronomical atlas. But if you need stir backward, the jam will not come together again. Indeed, the pudding does not notice and continues to turn pink just as before. Do you think this odd?

- Low entropy Macintosh!



- High Entropy Macintosh!
- It is very probable that dropping a Mac will rearrange it in a more randomly ordered form!
- Dropping it again (once or one million times) is not likely to get it working again!

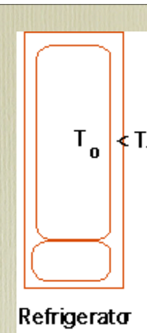


Another version of the 2nd Law:

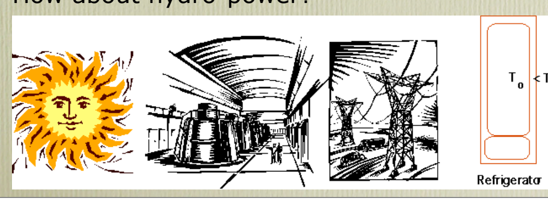
Entropy tends to increase in a closed system.

Of course we can decrease entropy **locally**:

- How about a fridge? Initially room and fridge at same temp., afterwards $T_0 < T_1$



- Fridge is not a closed system: must include power station.
- How about hydro-power?



Degradation of energy:
high temp. energy in sun ⇒ low temp. Energy on earth

- Note that the nomenclature complicates things unnecessarily: it would be easier if heat was called energy (or maybe heat energy) and entropy was called heat.
- Then paraphrase of 2nd Law would be
- **All forms of energy get converted into heat energy.**
- **Once all the heat is at the same temperature, can get no further work.**

Murphy's versions of the laws of thermodynamics

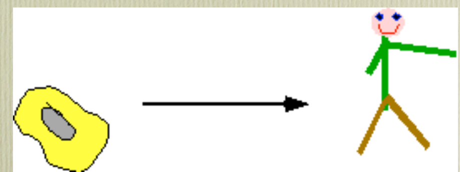
1st: You can't win

- 2nd: You can't break even
- 3rd: You can't quit the game

2nd law and evolution

Clearly complexity of animals has increased over history of earth.

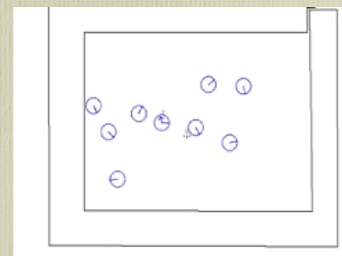
- We are more ordered than amoebas (no moral judgments here!)
- Therefore evolution contradicts 2nd law?



- Not a closed system!

Time and Entropy..

- how is tomorrow different from yesterday
- Or better, how do you know if a movie film is being run backwards?



- The "arrow of time" is defined via an increase in entropy.
- e.g "Time's Arrow" Martin Amis

What happens in the end?

i.e how does the universe evolve, assuming that it is expands for ever?

- All processes increase entropy, hence end of universe will come when entropy becomes a maximum
- When temperature of everything is the same, then can do no work, hence .....nothing!
- Heat Death of the Universe
- *"This is the way World ends,*

  not with a Bang, but a Whimper"

  T.S. Eliot

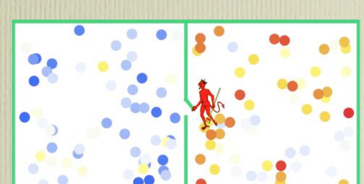
- *THOMASINA: "Well, it is odd. Heat goes to cold. It's a one-way street. Your tea will end up at room temperature. What's happening to your tea is happening to everything everywhere. The sun and the stars. It'll take a while but we're all going to end up at room temperature."*
- *Stoppard, Arcadia*
- Can we beat this?

Maxwell's Demon

- Suppose we could see single atoms
- (we can, this is IBM constructed in Xenon atoms by Scanning Tunnelling Electron microscope!)

The demon can see atoms, and open a trap-door if they are hot

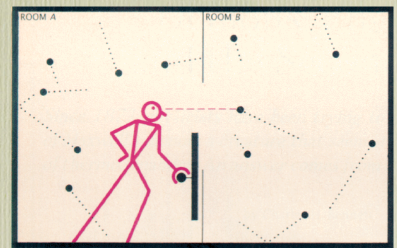
Allows us to separate warm into hot and cold



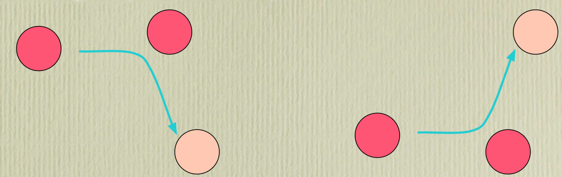
And hence to reverse time!!!!!!!!!!!!

Violates Second law?

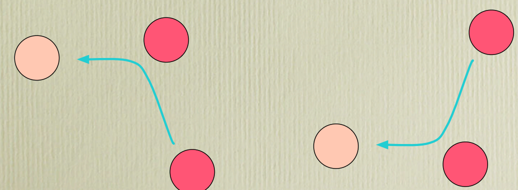
No: the demon has to use energy to look at atoms: extra energy heats up gas and nullifies effect!



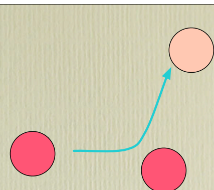
- Entropy seems to require many objects. Can we define the direction of time with one or two
- e.g a symmetrical system



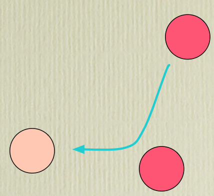
can be reversed and you can't tell



- But suspose the system is only left-handed?



- Then when you time-reverse it, it becomes right-handed!



i.e. you can tell which way time flows if things have a "handness" (proper word is "parity")
so London becomes "nodnoL"!
and neutrinos become anti-neutrinos!

- # Can we beat the second law?

- Freeman Dyson: Time without end: Physics and biology in an open universe
- Will look at this in last lecture
- Now we need to improve our understanding of the link between <u>space and time</u>