Weather and Climate

- If we cannot predict the weather over more than a week, how can we hope to predict climate change of a century?
- If there are equations that describe the weather, why can't we predict where hurricanes will go?
- Why is carbon dioxide so important?
- How certain is the science?

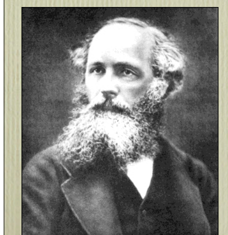
We need to understand heat, temperature and meteorology and energy:

Chaps 15,16, 17, 18 Weeks 3-4

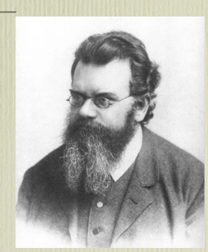
Bicycle Pumps and Rice Pudding

How to think about Heat

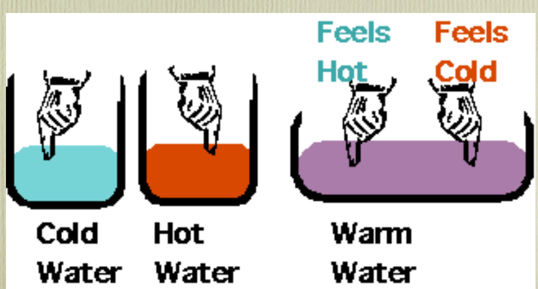
Peter Watson



James Clerk Maxwell

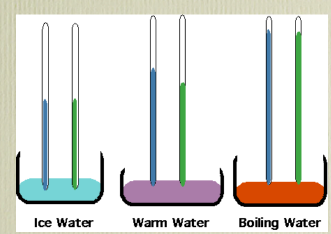


- Temperature can be felt qualitatively, but physiological estimates are notoriously bad.



What is heat?

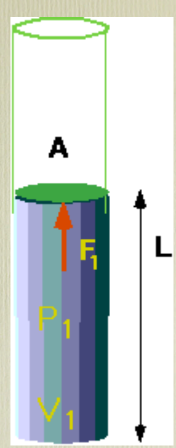
- So the starting question is: what is temperature?
- 0°C is water with ice floating in it
- 100°C is boiling water
- Even using thermometers, there is no guarantee that two thermometers will measure the same value:



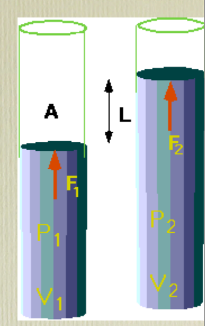
Two Views of Heat

"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:



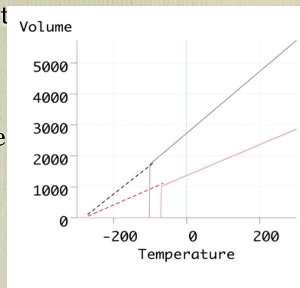
- What happens if you pump on a bicycle pump slowly?
- Boyle found that if the pressure was varied while temp was kept constant.
- $PV=const$
- Pressure ×Volume is constant



What happens if you heat up a balloon?

•Charles found that if the temperature was changed at constant pressure:

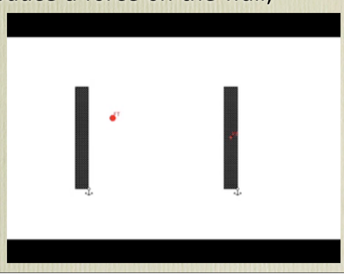
- $V=const(T-T_0)$
- Could only study a small part of the temperature range but found that all gases had the same
- $T_0=-273$ C
- In practice, the gas will liquefy (e.g. N_2 at ~-200°C) or solidify (e.g. CO_2 at -40°C), and the relation no longer works.



- This defines absolute temp. scale or Kelvin scale: 0K =-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 “amount” of gas (actually number of molecules)

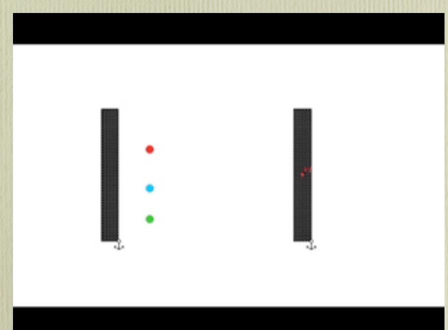
Kinetic Theory

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

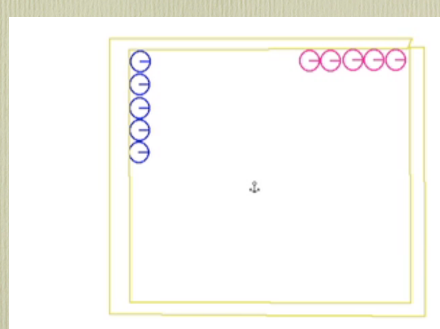


Or 3 atoms: one is moving faster

- So force (and hence pressure) is bigger

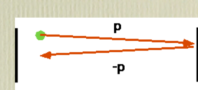


- Collisions redistribute the energy: heavy molecules move slower on average



We can turn this into a theory of gases

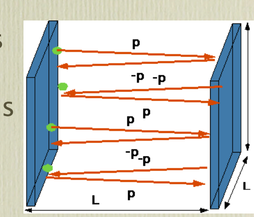
Momentum of molecules changes every time it hits the wall, Energy does not change



Higher velocity ⇔ **more** collisions

More molecules ⇔ **more** collisions

$n = Nv/L$



More collisions ➠ more force ➠ higher pressure

Pressure =(number of collisions/sec)*(change of momentum)/Area

But PV ~ Temperature

$$P=\left(\frac{Nv}{L}\right)\frac{(2mv)}{L^2}\Rightarrow PV\approx Nmv^2$$

and K.E. = 1/2mv²

So temperature is energy!

- Higher velocity ⇔ **more** energy ($1/2mv^2$)
- Higher velocity ⇔ **more** collisions ⇔ higher pressure
- Higher velocity ⇔ **harder** collisions ⇔ higher pressure

Done properly, average energy = const x temp

$$K.E.=\frac{1}{2}mv^2=\frac{3}{2}kT$$

This tells us ...

- Joule was right: energy and heat are the same thing!
- Energy is required to heat anything up
- Zero of temperature is when things stop moving
- Heavier atoms move slowly than lighter atoms
- Molecule of oxygen at room temp has
- v ~ 1/2 km/s

(Simple) States of Matter e.g. H_2O

Ice

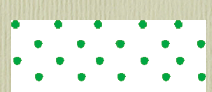
Water

Steam
Actually, a cheat
Steam is transparent

Raising temperature takes energy

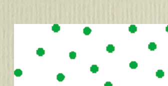
- Heating water:
- to raise 1 kg by 1°C takes 4200 J
- to biol 1 kg water takes 2.3 MJ
- to melt 1kg ice takes 336 kJ

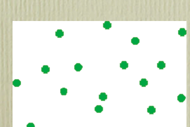
(Simple) States of Matter



Solids: Long range "order"
Forces win over random energy
Atoms fixed (maybe crystal)

Liquids: Short range "order"
Forces ~ random energy,
atoms can move



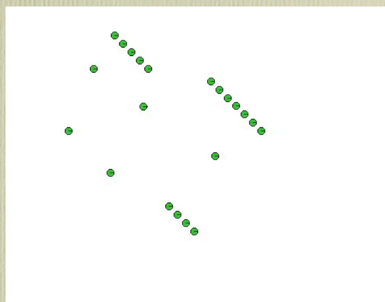


Gases: No "order"
Random energy wins over Forces
Atoms move freely

PW

Can we understand this?

- A “gas” of 19 atoms,
- Energy is sucked out of the system



- Gas ➟Liquid➟(crystalline) solid

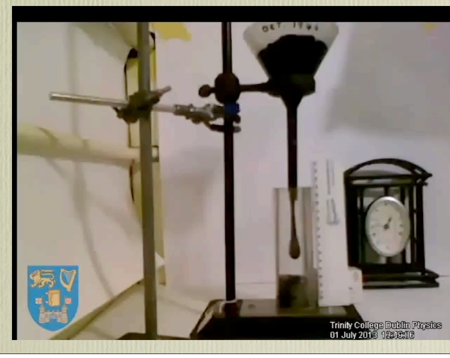
Not all liquids are simple

- Difficulty that atoms move in liquid ➟ viscosity
- Most liquids (e.g. water) have low viscosity until freezing

Pitch has very high viscosity

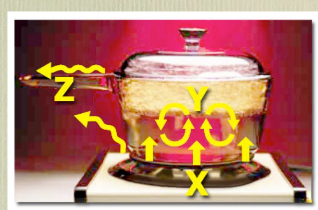
Experiment at Trinity, Dublin started in 1944

Seventh drop just fell



Heat Transfer

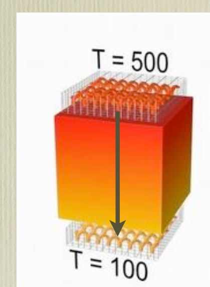
- Radiation : Works in vacuum, best at high temps
- Conduction: all materials, inefficient for gases
- Convection: liquids and gases only



- Evaporation & Condensation
- Radiation is the only method by which heat arrives in the atmosphere

Conduction

- Most efficient in solid
- Energetic atoms in one place share energy with cooler neighbours
- Heat flows from hot to cold
- Rate decreases if distance is increased
- Rate increases if area is increased
- Rate increased if temp diff. is increased:

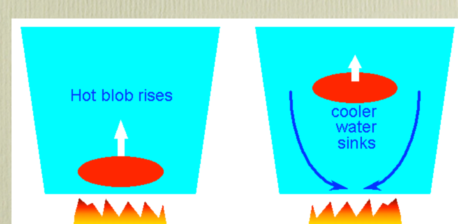


Depends strongly on material

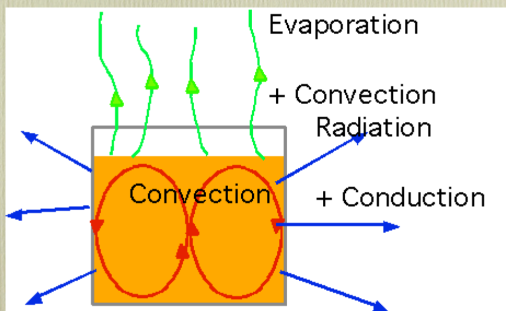
- Metals are excellent conductors
- Solids
- liquids
- gases
- so good insulators (fibreglass) are lots of gas fixed in a little solid
- not important for weather

Convection

- Most fluids expand when heated
- Hot water is less dense than cold, so rises



- Note that all these processes work together
- e.g your coffee!



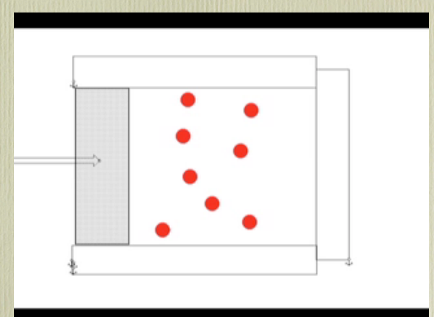
Text

- We can see these effects (convection cells, boiling) at work her

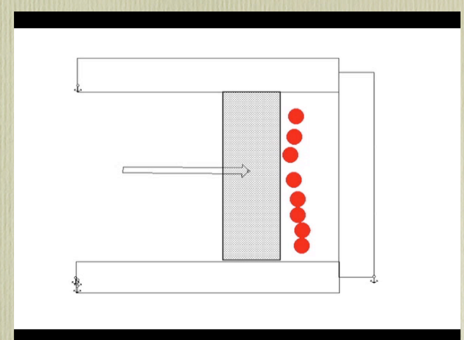
Since you ask, it's a maple syrup/soy sauce glaze for salmon!)

PW

- 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!)



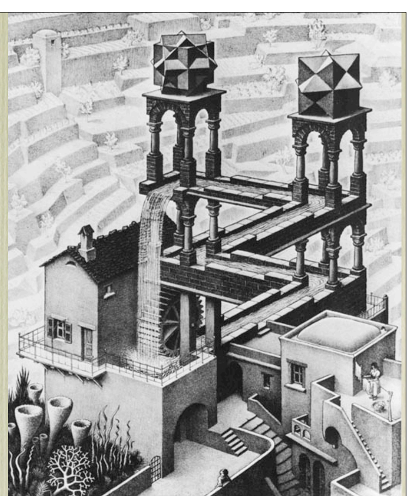
- and how an expanding gas can do work, and the gas cools down (like an auto engine



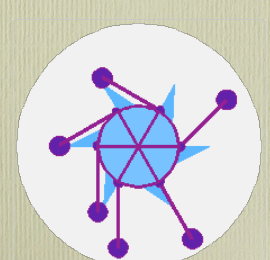
- and this leads to .....

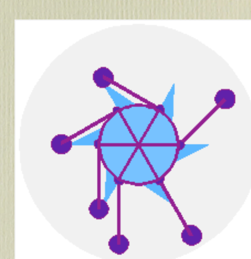
There's no such thing as a free lunch......

Milton Freedman, after Robert Heinlein in "The Moon is a Harsh Mistress"

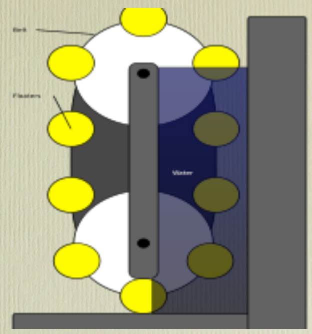


- Lots of people have thought of the over-balancing wheel
- Here is a modern version which turns for ever



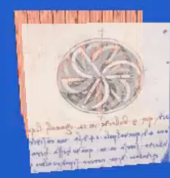


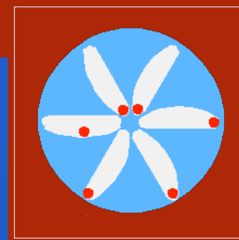
Or using floating blocks



Why doesn’t it work?

Leonardo da Vinci invented one

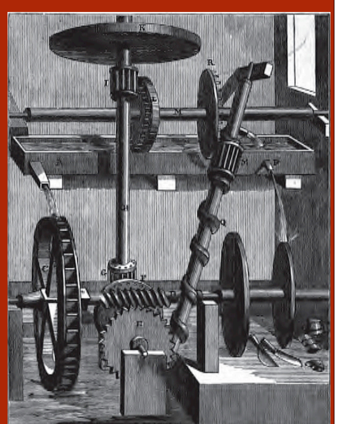




Which also runs for ever

Why doesn’t it work?

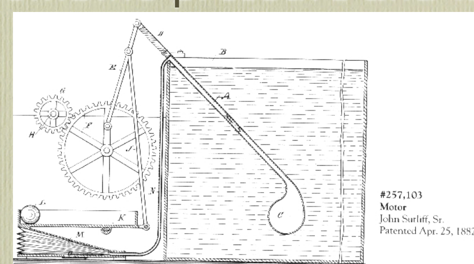
But maybe water would work better: this is Robert Fludd’s device



Why doesn’t it work?

Wikipedia

But actually it will work better if we combine pressure and liquids



With the exception of cases involving perpetual motion, a model is not ordinarily required by the Office to demonstrate the operability of a device. If operability of a device is questioned, the applicant must establish it to the satisfaction of the examiner, but he or she may choose his or her own way of so doing.

USPTO Manual of Patent Examining Practice

Like this

Why ~~doesn’t~~ does it work?

Text

Complicated: filled with Dichloromethane

1. Water evaporates from the felt on the head, lowers temperature
2. Vapour condenses in the head.
3. Pressure drops in the head, liquid is pushed up from the base into head, tipping bird over
4. Bottom end of the neck rises above the surface of the liquid, produces bubble of vapour.
5. Liquid flows back to the bottom bulb, restoring the bird to its vertical position and is heated by air

Note what we have is a (very inefficient) heat engine

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 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

The First Law of Thermodynamics

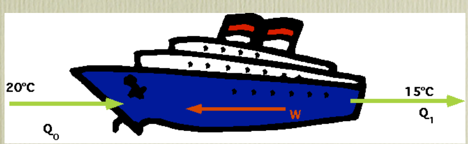
e.g suppose we burn gasoline in a car: the heat energy in the hot gases ⇒ mechanical energy transmitted to the tires ⇒ mechanical energy (and the gas gets cold)

- e.g suppose you eat food before running: the food energy is stored in ATP in your muscles, and ⇒ kinetic energy when you run ⇒ heat
- Done properly:
- Work done externally = heat added - change in internal energy

The Second Law of Thermodynamics

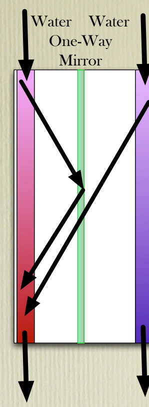
For example, why can't we have (e.g) a boat that takes in water at 20°C, extracts some heat, turns it into energy and exhausts cold water

- Doesn't violate first law



How could we do it in practice?

- Two pipes with water flowing with one-way mirror between them
- Radiation from the left pipe will be reflected back and reabsorbed.
- Radiation from the right pipe passes through the one-way mirror to be absorbed by the other pipe.
- Water on left heats up & boils, water on right cools down
- Can run a steam engine



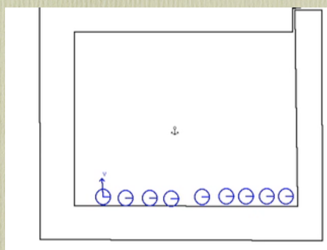
Shares in the company will be available after class

- *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***

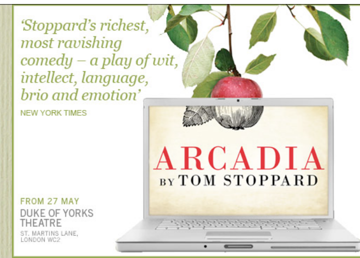
- In order to get work out of a system, one must have a very asymmetrical system
- e.g. High pressure one side of a piston, low pressure the other side. Can this arise by chance?
- e.g. high temp. one side of a piston Can this arise by chance?
- Given 6 atoms, what is probability of finding them all 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!

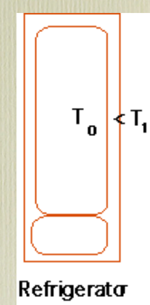
- High Entropy Macintosh!
- It is very probable that dropping a Mac will rearrange it in a more randomly ordered form!
- Dropping it again (once or one million times) is not likely to get it working again!

Another version of the 2nd Law:

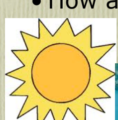
Entropy tends to increase in a closed system.

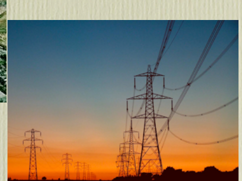
Of course we can decrease entropy **locally**:

- 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

- A paraphrase of 2nd Law is
- **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

Sor

- If it
- If it
- If th
out

- A consequence
- Mostly engines are designed to produce useful work and the heat is a useless byproduct
- e.g auto engines are about 35% efficient
- Most efficient possible heat engine has

$$\eta = 1 - \frac{T_{exhaust}}{T_{input}}$$

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!

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*

Now we need to look at radiation

If you have no air-conditioning, you can always cool yourself down by taking a bucket of ice out of the fridge and blowing a fan across it

1. Good idea?