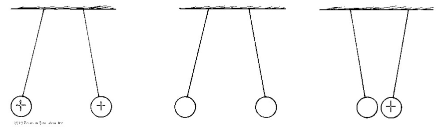
Electricity

Peter Watson

Mostly we'll concern ourselves with current electricity

- However, we'll start with some history
- Franklin, Priestly, Coulomb and others found:

- Electricity came in two kinds (resinous and vitreous) which we now call positive and negative charges.
- Some materials allow charge to move around (conductors: e.g. metals, salt water, flesh ....)
- Some materials will hold a charge, but do not allow it to move (insulators: e.g. plastic, paper, gases ...)
- Like charges (++ and --) repel
- unlike attract (+- and -+).



- So how do they do the experiments?

- Now know that charge is conserved, smallest unit of charge is that on electron (or proton)
- Unit is Coulomb (C), which is a huge amount of charge.
- Charge on electron $q = -1.6 \times 10^{-19}$ C
- Charge on electron = - charge on proton

- Force is like gravity: an inverse square law
- **But**
- charges can be same (repulsive) or opposite (attractive)
- masses can only be positive
- k is very large (electrical forces are strong)

- We don't understand why gravity is so weak
- e.g take two electrons

There are attracted gravitationally

They are repelled electrostatically

However the electric force is

larger

Actually 4.2×10^{42} times larger: Hitchhiker's Guide fans note!

- So why are we so aware of gravity in our daily life?
- Electricity cancels, Gravity adds!
- e.g. helium atom is overall neutral, so (almost) no net E.S. force
- Masses always attract

Charging by Induction

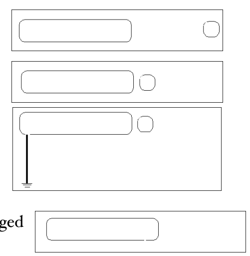
Induction

Conductor is neutral

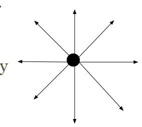
Charged object separates charges on conductor

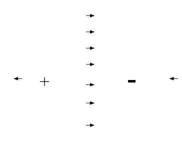
Earthing conductor allows charges to escape

...leaving negatively charged conductor



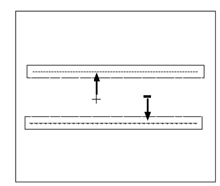
- To visualise the electrical forces, it helps to think of electric **field**.
- e.g a point + charge
- note direction is given by the way a positive charge would move





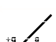
or a positive and a negative charge

- Can make a constant field (like gravity near the earth) by arranging plates of charge.
- Lets us visualise how charges would move

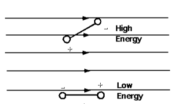


Dipoles

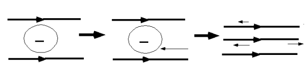
- A lot of molecules consist of two charges
- These will get twisted in the field



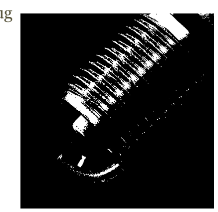
- so that even though they don't move, they get lined up by field



- Air is usually an insulator, but there are always some free electrons
- which can be accelerated by a field
- which collide with atoms with sufficient energy to knock off electrons...
- accelerated by field...
- collide with atoms....
- so the air becomes a conductor.



- This is avalanche process ➠ spark.
- If the field is too low, the electrons will not gain enough energy between atoms to ionize them.
- need ~ 3 million V/m in dry air
- e.g. spark-plug



- Just as we had P.E. with gravity, here we have electric potential (measured in volts)
- Usually called voltage
- e.g. AA batteries have 1.5 V nominal
- e.g. household voltage is 110 V (this is average, since it is AC)
- e.g an electron that moves through a potential of 1 volt gets an energy of 1 electron volt (1 eV)

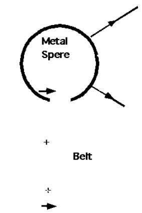
Fluid analogy

- It is useful to have an analogy for charge, field, potential and everything else electrical
- Charge ~ amount of water
- Potential ~ gravitational P.E. of water (think of a dam) ~ height above sea-level
- Field ~ force that would act on the water if it was on sloping ground
- Don't take this too seriously (we don't have negative water!) but it helps

How do we generate large voltages?

Van der Graaf generator

- Friction charge at the base
- The belt transfers charge at a very low voltage to the sphere.
- repulsion between the charges forces them to sit on the exterior of the sphere.
- Maximum voltage is given by $V=RE_{max}$



- Voltage can be 500,000 V
- Charge always tiny ~ 1 μC (microCoulomb)

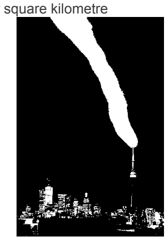
What is Science?

- The scientific approach to the examination of phenomena is a defence against the pure emotion of fear....This made for a kind of harmony and confidence. The sun came up about as often as it went down, in the long run...
- Tom Stoppard, Rosencrantz and Guildernstern are Dead
- By and large, it works ....

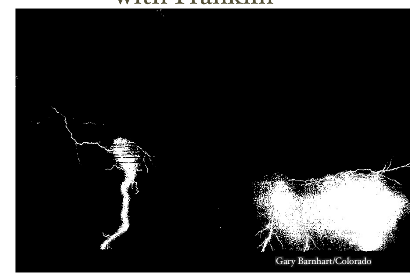
But thunder and lightning is scary!

- Thor had lightning from hammer Mjölnir

- "Lightning never strikes twice"
- Unfortunately it hits the CN tower about 40 to 50 times annually
- Rest of Toronto has two strikes per square kilometre every year.



Modern understanding starts with Franklin

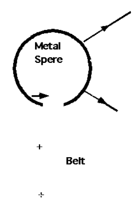


DO not attempt this at home

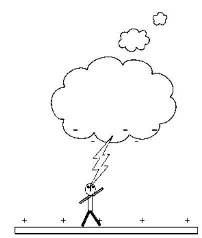
- Franklin's famous experiment: fly a kite in a thunderstorm, with a metal key
- Current travels down line & jumps gap
- Except maybe he had to much sense: experiment seems to have been performed by Dalibert in 1752
- The same experiment killed Georg Richmann

Thunderclouds

- works a bit like a Van der Graaf
- positive charge is carried up by the up-drafts.
- so top of cloud (and ground) are positive
- Bottom of cloud is negative



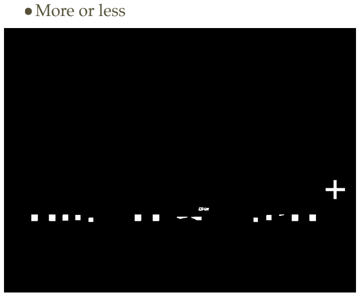
- Critical parameter is electric field
- Wet air breaks down (we have a spark) at one million V/m
- so if cloud is 500 m above
- need V ~ 500 MV (!)



Lightning conductors

- Invented by Franklin
- Electric field very strong around point, ionizes air, allows current to flow
- hence allowing strike to hit conductor.
- Unfortunately Franklin was American, so patriotic Englishmen used round lightning conductors........

- Do we understand it?
- More or less

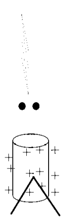


People killed by lightning are often found naked

- Large charge on body repels large charge on clothes
- Note you are a better conductor than air, so lightning will always flow through you in preference

Shelter in buildings

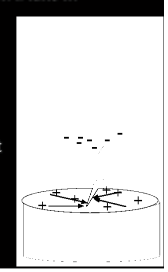
Lie down, away from trees



A matter of life and death...

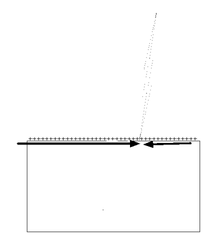
What should you do if you are out on a lake in a canoe and a thunderstorm hits?

1. Get into the water as fast as possible
2. If you are in a aluminum canoe, get into the water as fast as possible
3. If you are in a fibreglass canoe, get into the water as fast as possible
4. Stay where you are and lie down

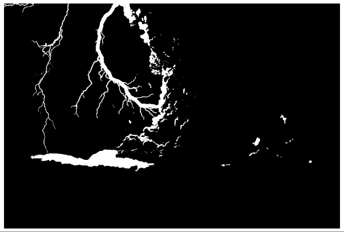


What happens to the fish

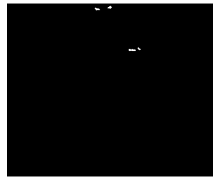
- **Nothing** unless they are on the surface.
- Katie Gilmour points out that cisco are often found dead after a storm (they are surface feeders)



- Volcanoes provide rapid up-drafts + lots of friction between particles so...
- This is the volcano no-one can pronounce



- and there is nothing special about Earth: this is lightning on the night-side of Jupiter (from Galileo)



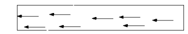
Conductors in practice

- Wires are good conductor (copper) surrounded by good insulator
- Current flows in conductor
- Insulator stops it escaping

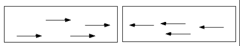
Like water flowing through pipe

Electric current

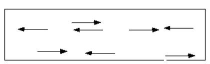
- is (usually) just the flow of electrons in a wire
- Current: the rate at which charge moves through a wire ($C\ s^{-1}$), but this is so important that it gets its own name
- 1 Ampere = 1 Amp = 1 Coulomb/s
- Think of current as the flow of a liquid.so a wire consists of a large number of charges, which all flow with the same speed.



Note (very important!) you cannot distinguish a positive charge moving in one direction with a negative charge moving in the other: qv is a constant.



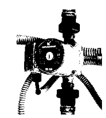
- or even a mixture

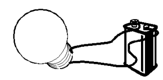


- Unfortunately Franklin guessed that current consists of positive charges, but in most metals a current consists of electrons.
- However, currents can occur in many forms: e.g.
- Electrons in vacuum
- Protons in an accelerator
- Electrons and holes in a semiconductor
- positive and negative ions in (e.g.) a salt
- so maybe Franklin wasn't so wrong after all!

To keep a fluid moving we'd need a pump

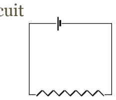
- to keep a current moving we need a battery
- water pressure keeps fluid flowing
- voltage keeps current flowing





Resistance

- Narrow pipe impedes flow of water
- High resistance reduces current
- Measure in ohms Ω (Greek omega)
- Usually draw circuits as "schematics"
- this is the battery-light circuit



Ohm's Law

Voltage = Current× Resistance

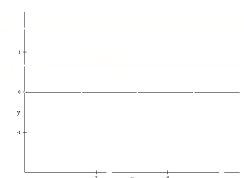
- V = IR
- so (e.g) 2 AA batteries give a voltage of 3 V
- If we have a flashlight bulb with a resistance of 5Ω
- Current is 0.6A

Electrical Power = Voltage×Current

- P = IV
- so our flashlight bulb would consume 1.8 W

Alternating Current (AC)

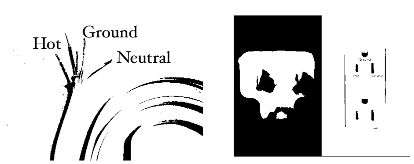
- Universally used in houses
- Easy to change voltage (via transformer)



- What we are calling "average" is actually root-mean-square (rms) value
- Note maximum current/voltage is $I_{max} \approx 1.4 \times I_{rms}$
- e.g. 'old-style' 60 W incandescent bulb
  - What is current?
  - P = IV ➡ I = P/V = 60/110 ≈.55A
  - What is resistance?
  - V = IR ➡R = V/I ≈200Ω

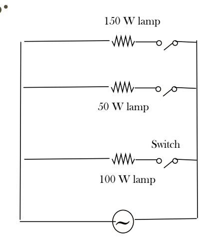
- Note there are a couple of other ways of writing the power:
  - P = IV
  - V=IR
- so that power
- $P = I^2R = V^2/R$

Household circuits



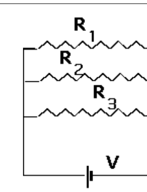
e.g.

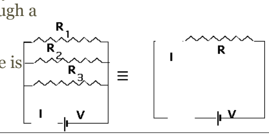
- A plug with 3 lamps
- 110 V supply is constant
- If switches are closed, current flows through lamps
- what would total current be if all the switches are closed?



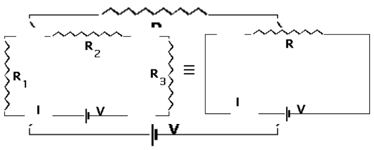
Parallel & Series

- We normally arrange circuits so that the resistances are "in parallel"
- This means we have the same voltage across all of them
- The current will always be larger than that through a single one
- so effective resistance is smaller



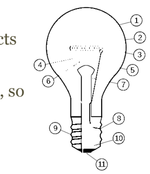


- We can put our resistors so they are "in series"
- Current will always be smaller
- so effective resistance is larger
- $R = R_1 + R_2 + R_3$



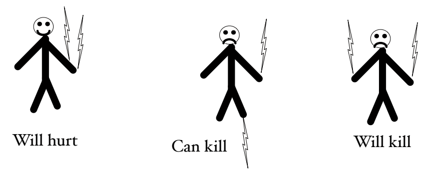
Light bulb

- Incandescent
- Heated tungsten filament (3) acts as black body
- Resistance increases with temp, so limits current
- Gas (2) must be inert (argon)
- current flows between base (11) and sleeve (9)



Electrical Safety

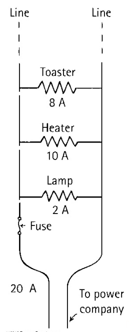
- Do not connect yourself to a power supply!
- Danger depends on how current flows
- lethal shocks involve current through heart



Shocks

- .001 A Tingles
- .01 A Hurts
- .1 A (through the heart) kills
- note falling power-lines can be lethal (can be transmitting ±1000 V)

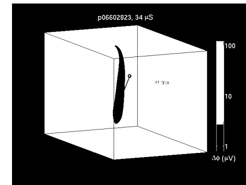
- Circuit can overload (and overheat)
- protected by fuses or circuit breakers



How do fuses work?

Some animals have figured out how to use electricity.
If you live in a muddy river, how do you see anything?

Weakly Electric Fish



- Create a dipole field; prey (or mates) produce distortions in the field

Which allows you to hunt