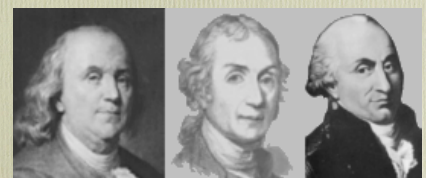
Electricity

Peter Watson

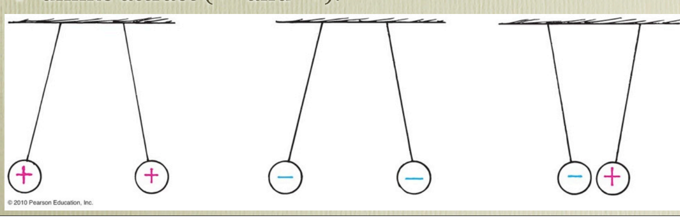
Mostly we'll concern ourselves with current electricity

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



Text

- 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?

Text

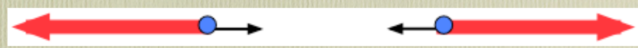
- Now know that charge is conserved, smallest unit of charge is that on electron (or proton)
- Unit is Coulomb (C), which is a huge amount of charge.
- Charge on electron q = -1.6x10-19 C
- Charge on electron = - charge on proton

- Force is like gravity: an inverse square law

$$F = k\frac{q_1 q_2}{r^2}$$

- **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

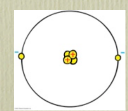
4000000000000000000000000000000000000000000

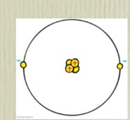
larger

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

PW

- 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



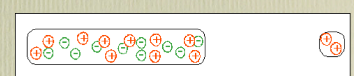


Charging by Induction

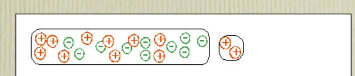
Text

Induction

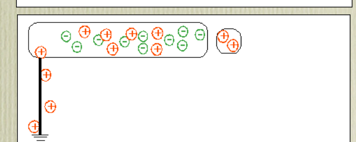
Conductor is neutral



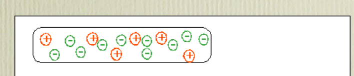
Charged object separates charges on conductor



Earthing conductor allows charges to escape

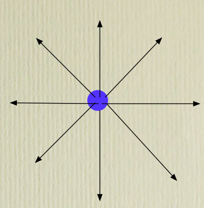


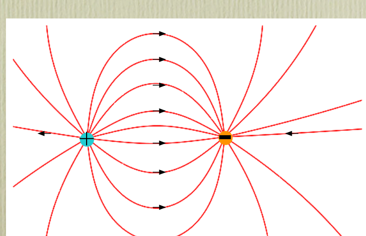
...leaving negatively charged conductor



PW

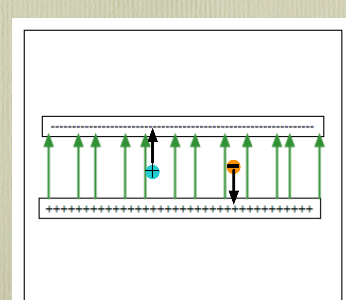
- To visualise the electrical forces, it helps to think of electric **field**.
- e.g a point + charge
- note direction is given by the way a positive charge would move





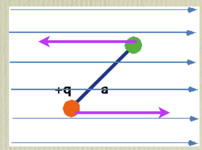
or a positive and a negative charge

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

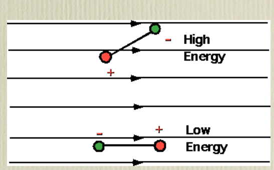


Dipoles

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

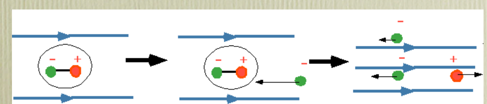


- so that even though they don't move, they get lined up by field

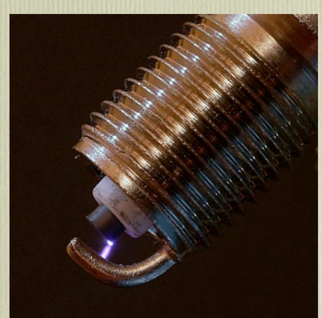


PW

- 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

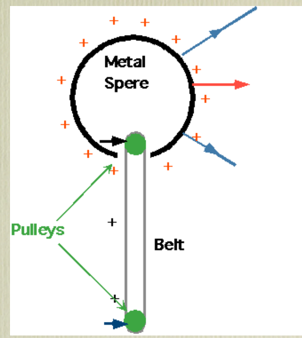
- It is useful to have an analogy for charge, field, potential and everything else electrical
- Charge ~ amount of water
- Potential ~ gravitational P.E. of water (think of a dam) ~ height above sea-level
- Field ~ force that would act on the water if it was on sloping ground
- Don't take this too seriously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

How do we generate large voltages?

Text

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 $V=RE_{max}$



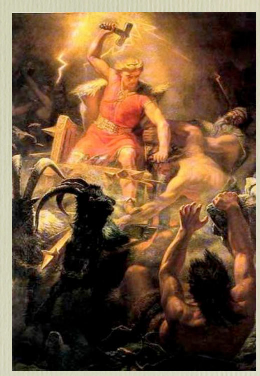
- Voltage can be 500,000 V
- Charge always tiny ~ 1 μC (microCoulomb)

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 ....

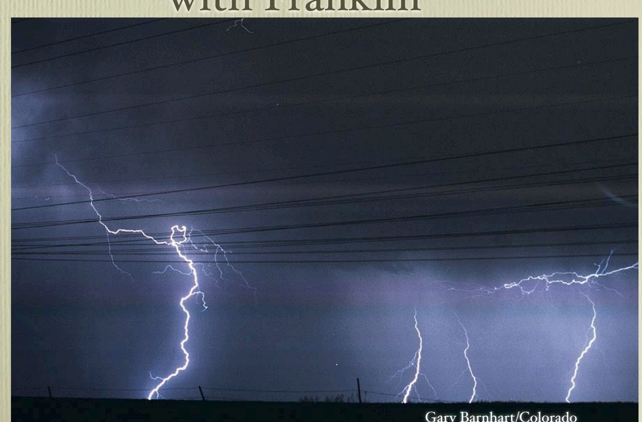
But thunder and lightning is scary!

- Thor had lightning from hammer Mjölnir



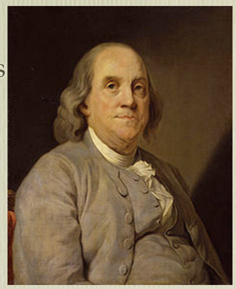
- "Lightning never strikes twice"
- Unfortunately it hits the CN tower about 40 to 50 times annually
- Rest of Toronto has two strikes per square kilometre every year.

Modern understanding starts with Franklin



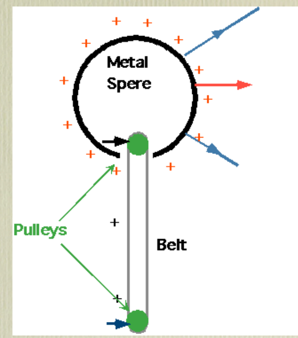
DO not attempt this at home

- 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

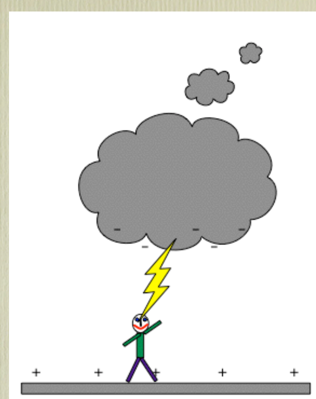


Thunderclouds

- 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

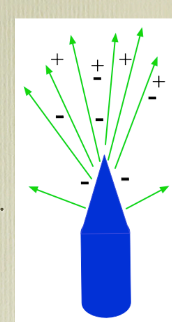


- Critical parameter is electric field
- Wet air breaks down (we have a spark) at one million V/m
- so if cloud is 500 m above
- need V ~ 500 MV (!)



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........



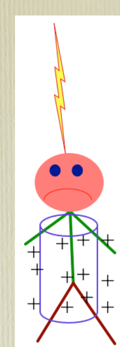
- Do we understand it?
- More or less

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

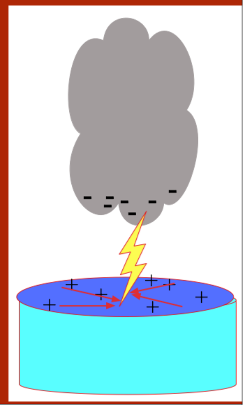
Lie down, away from trees



A matter of life and death...

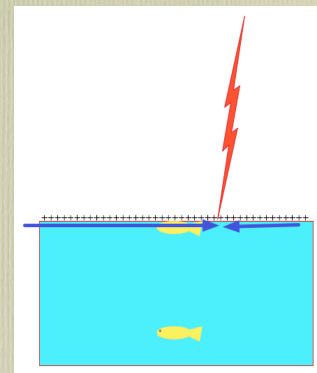
What should you do if you are out on a lake in a canoe and a thunderstorm hits?

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



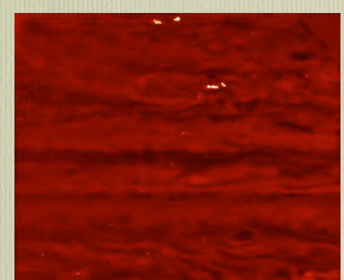
What happens to the fish

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



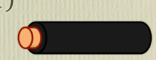
- Volcanoes provide rapid up-drafts + lots of friction between particles so...
- This is the volcano no-one can pronounce

- 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



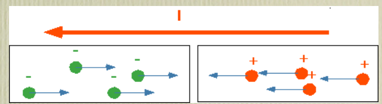
- Current flows in conductor
- Insulator stops it escaping

Like water flowing through pipe

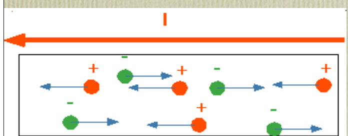
Electric current

- 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

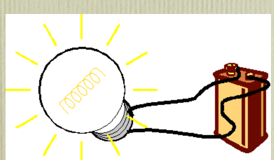


PW

- 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

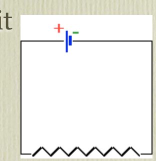
- to keep a current moving we need a battery
- water pressure keeps fluid flowing
- voltage keeps current flowing



Wikimedia

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

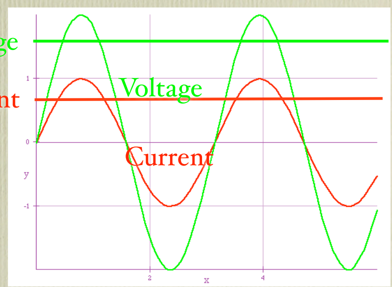
Text

Electrical Power = Voltage×Current

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

Alternating Current (AC)

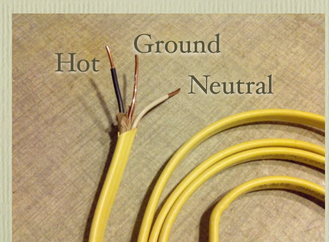
- Universally used in houses
- Easy to change voltage (via transformer)



- 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?
  - $P = IV \Rightarrow I = P/V = 60/110 \approx .55A$
  - What is resistance?
  - $V = IR \Rightarrow R = V/I \approx 200\Omega$

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

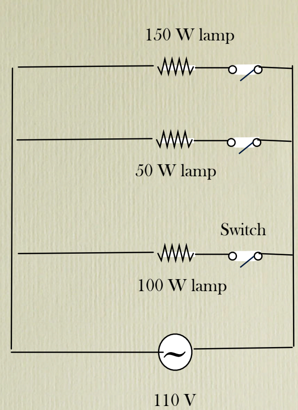
Household circuits



Text

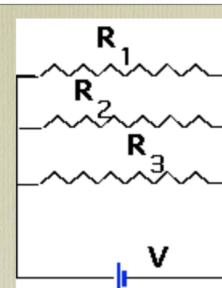
e.g.

- 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?

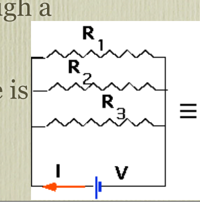


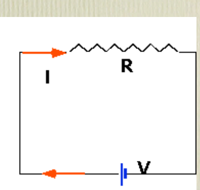
PW

Parallel & Series

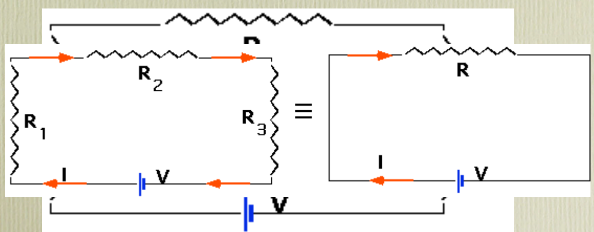


- We normally arrange circuits so that the resistances are "in parallel"
- This means we have the same voltage across all of them
- The current will always be larger than that through a single one
- so effective resistance is smaller





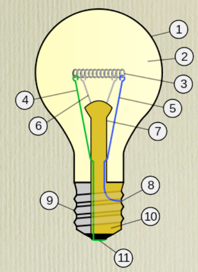
- We can put our resistors so they are "in series"
- Current will always be smaller
- so effective resistance is larger
- $R = R_1 + R_2 + R_3$



PW

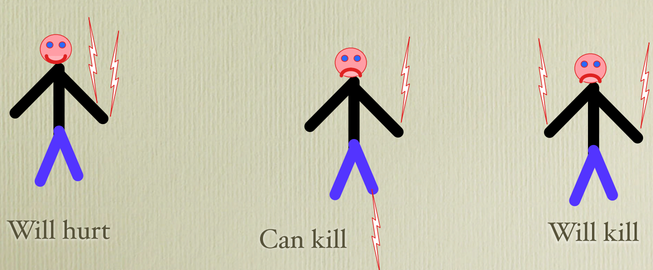
Light bulb

- 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

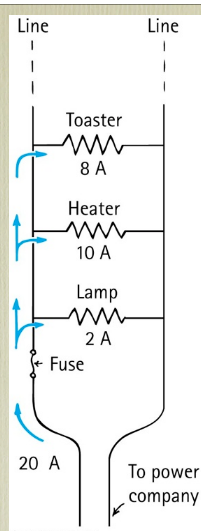


Shocks

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

Text

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



Text

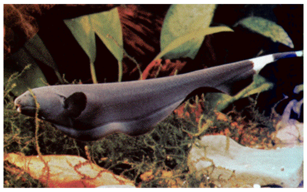
How do fuses work?

Well, OK, not quite like this!

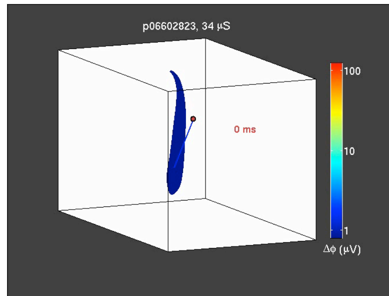
PW

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

Weakly Electric Fish



Andre Longtin,
U of O



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

Which allows you to hunt