

The Adventures of Archibald Higgins

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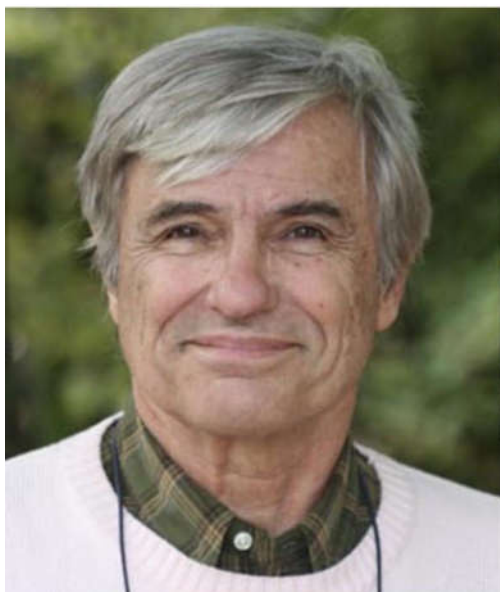
A FISTFUL

OF AMPERES



Knowledge without Borders

Non-profit-making association created in 2005 and managed by two French scientists. Aim: to disseminate scientific knowledge using the band drawn through free downloadable PDFs. In 2020: 565 translations in 40 languages had thus been achieved. With more than 500,000 downloads.



Jean-Pierre Petit



Gilles d'Agostini

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The Association Knowledge without Borders, founded and chaired by Professor Jean-Pierre Petit, astrophysicist, aims at spreading scientific and technical knowledge in as many countries as possible and in as many languages as possible. To this end, all his popular scientific works, which cover a period of thirty years, and more particularly the illustrated albums he has created, are now freely accessible. Anyone is now free to duplicate the present file, either in digital form or in the form of printed copies and circulate these copies to libraries, within the context of schools or universities or associations whose aims would be the same as the association, provided that they do not derive any profit from this circulation and that they do not have any political, sectarian or confessional connotations. These pdf files may also be put on line in the computer networks of school and university libraries.



Jean-Pierre Petit intends to create numerous other works which will be accessible to a larger audience. Even illiterate people will be able to read them because the written parts will “speak” when the readers click on them. Thus it will be possible to use these works to support literacy schemes. Other albums will be "bilingual" in so far as it will be possible to switch from one language to another selected language with a mere click. Hence another tool made available to develop language skills.

Jean-Pierre Petit was born in 1937. He made his career in French research. He worked as a plasma physicist, he directed a computer science centre, he has created softwares, he has published hundreds of articles in scientific magazines, dealing with subjects ranging from fluid mechanics to theoretical cosmology. He has published about thirty books which have been translated in numerous languages.

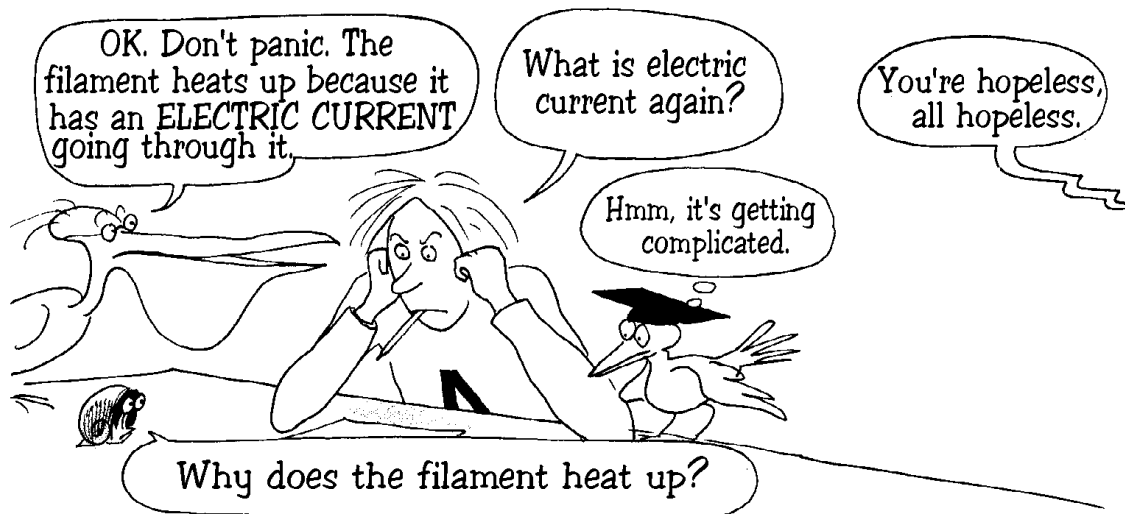
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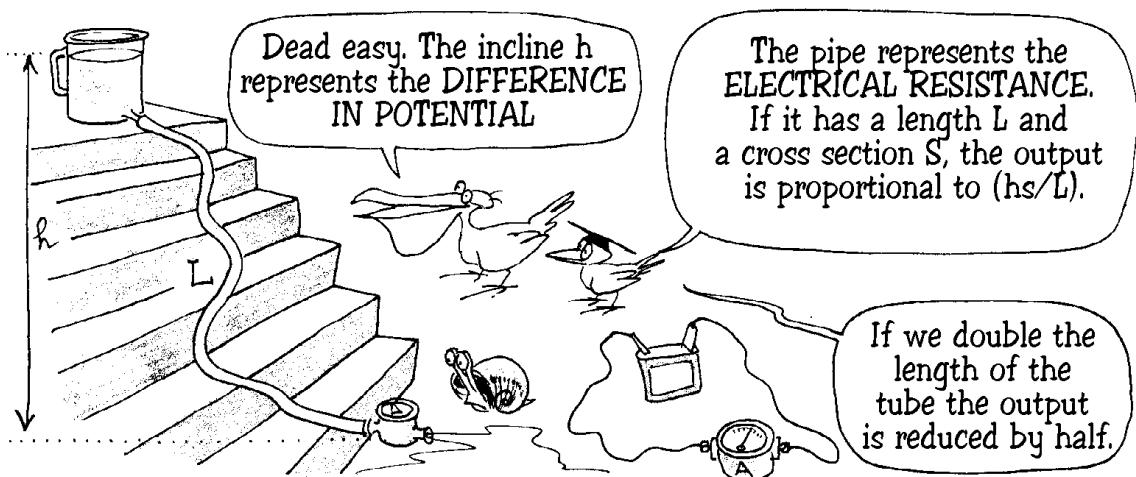
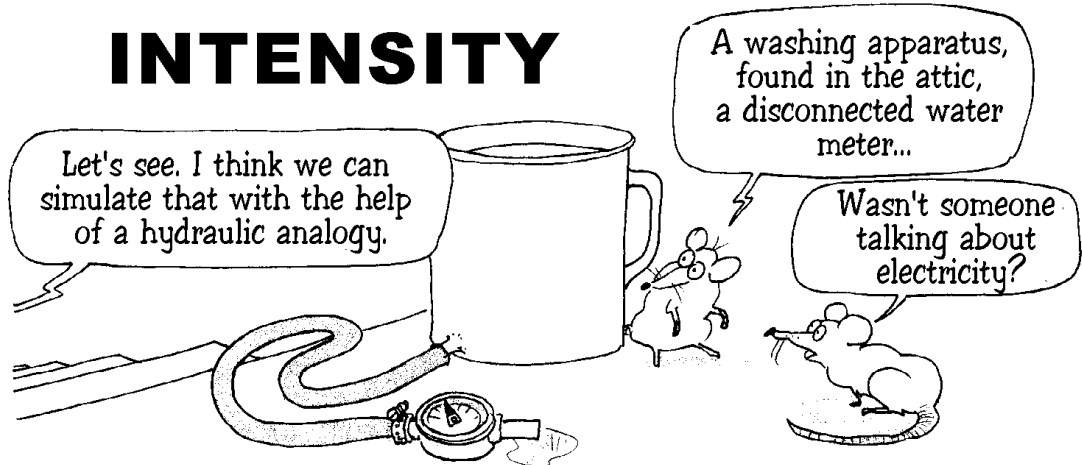
PROLOGUE



(*) ^(*)New Zealand Physicist, discovered the atom in 1905

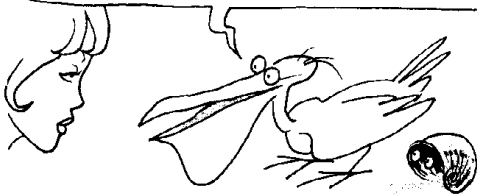


INTENSITY

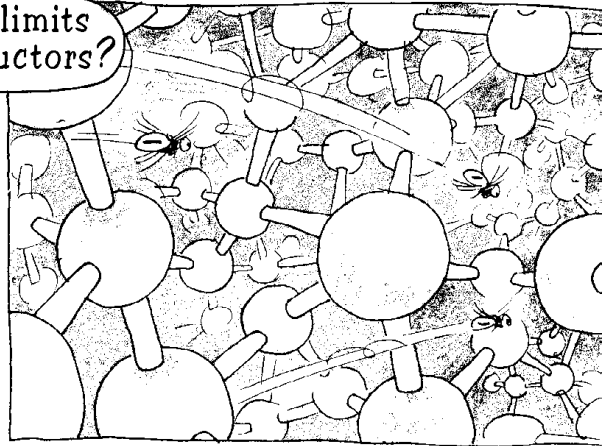


RESISTANCE

Sophie, what type of friction limits the speed of electrons in conductors?



A copper wire isn't an empty tube

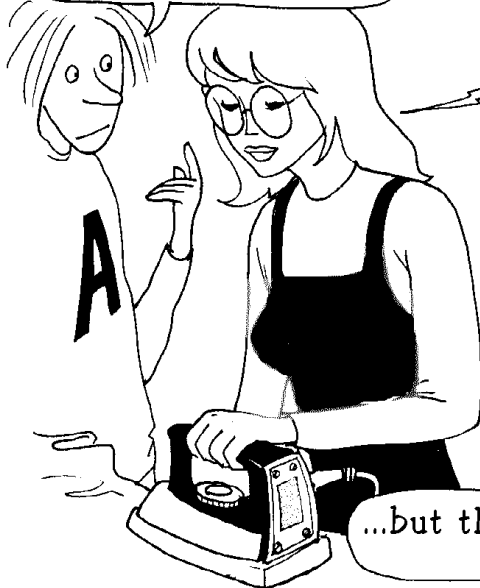


In a metal, atoms are fixed and form a sort of network. Free electrons exist at all temperatures and can move in this network. It is when they collide with atoms that their progress will be hindered and so create an effect of **ELECTRICAL RESISTANCE**.

But why does the metal heat up?



The collisions shake up the atomic structure and the shaking is passed from one atom to another so creating a **THERMAL CONDUCTION** effect.

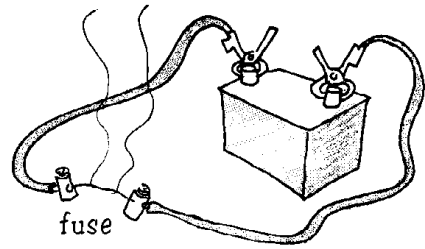


Oh yes, that's what's called the **JOULE EFFECT**

It's all becoming clear

...but that doesn't explain why a bulb's filament emits light...

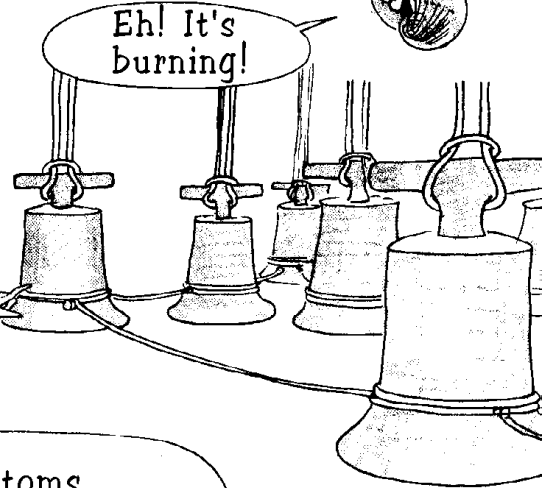
The shaking up can even dislocate the network resulting in fusion.



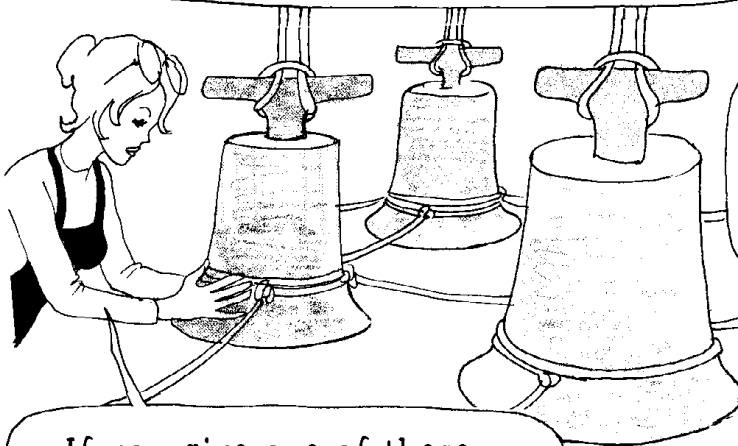
So where does light come from?



Eh! It's burning!



This time imagine atoms represented as bells connected to each other with elastic...



That gives a good picture of the thermal conduction phenomenon in a solid.

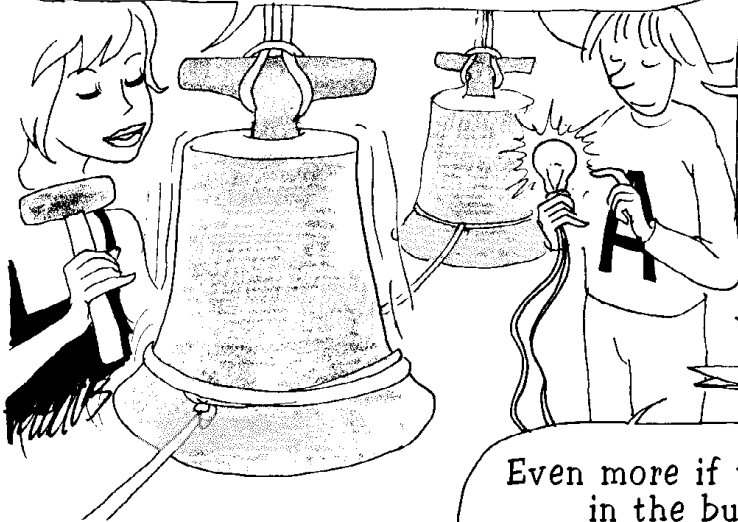


If you give one of these atom-bells a series of gentle pushes they will propagate to the whole structure through the elastic.



INCANDESCENCE

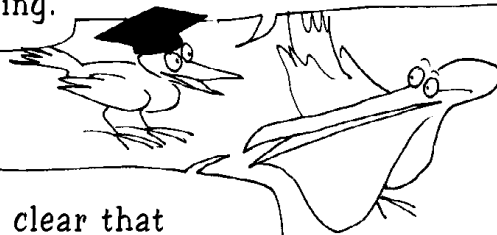
But if the impulsion is sharper, or if a large number of impulsions accumulate, then the bell will shed this ENERGY by emitting sound waves.



OK, understood: in the same way as the atoms of the filament emit luminous energy from a certain temperature upwards, to shed the excess energy that the conduction phenomenon cannot manage to dissipate.

Even more if you make a hole in the bulb to reduce heat losses through thermal conduction.

The emission of energy by radiation will be all the more intense the higher the temperature of the solid. So for filaments we use materials like tungsten which can resist temperatures of 3000°C without melting.



OK. It's clear that heated solids radiate energy but why is this iron RED ?



Because it's at a lower temperature than the lamp's filament. An iron radiates energy too.

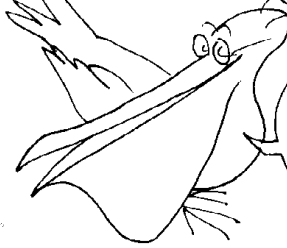
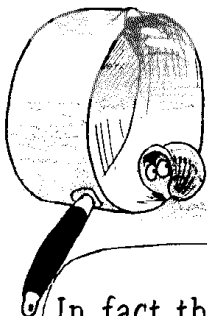
Put your head in this chrome-plated saucepan. You'll see that it reflects the energy radiated* by your skin.



Oh yes, I can feel it.

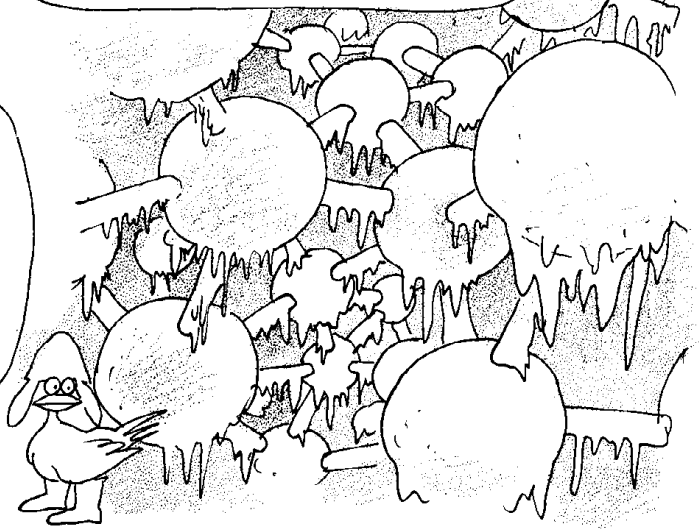
You too, you radiate.

Do I radiate too?



My dear Tiresias, as you are a cold-blooded animal I doubt if you emit much.

In fact the only time the atoms of a solid stop vibrating and emitting energy is when they are at a temperature of **ABSOLUTE ZERO**, which is a state of minimal energy.



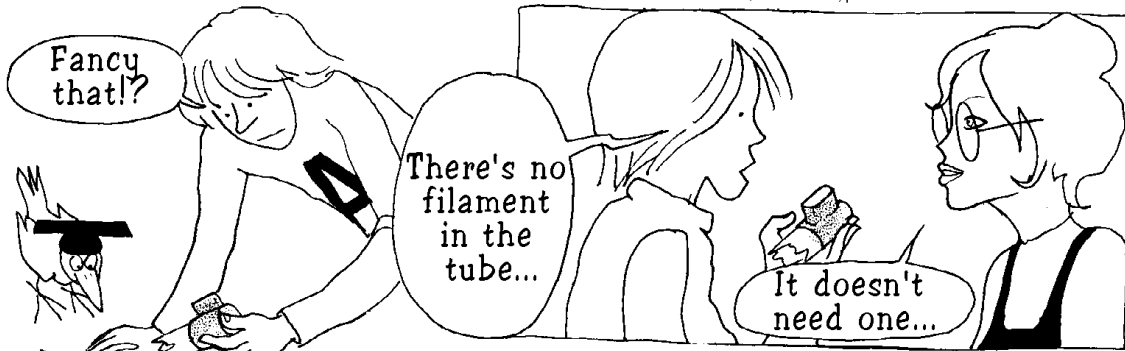
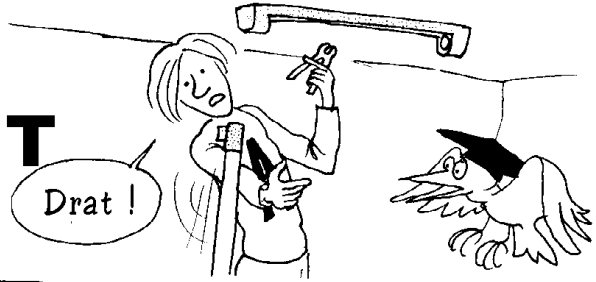
(*) This type of non-visible radiated energy, emitted by medium or low temperature bodies, is called **INFRARED** energy.

Right, now that we know everything about the lightbulb, I think we've finished revealing the mysteries of this simple house.



Archibald, the light in the kitchen has just burnt out. Can you change it?

THE FLUORESCENT TUBE

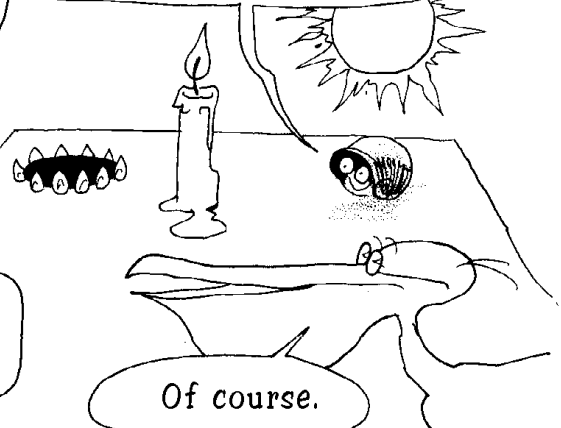


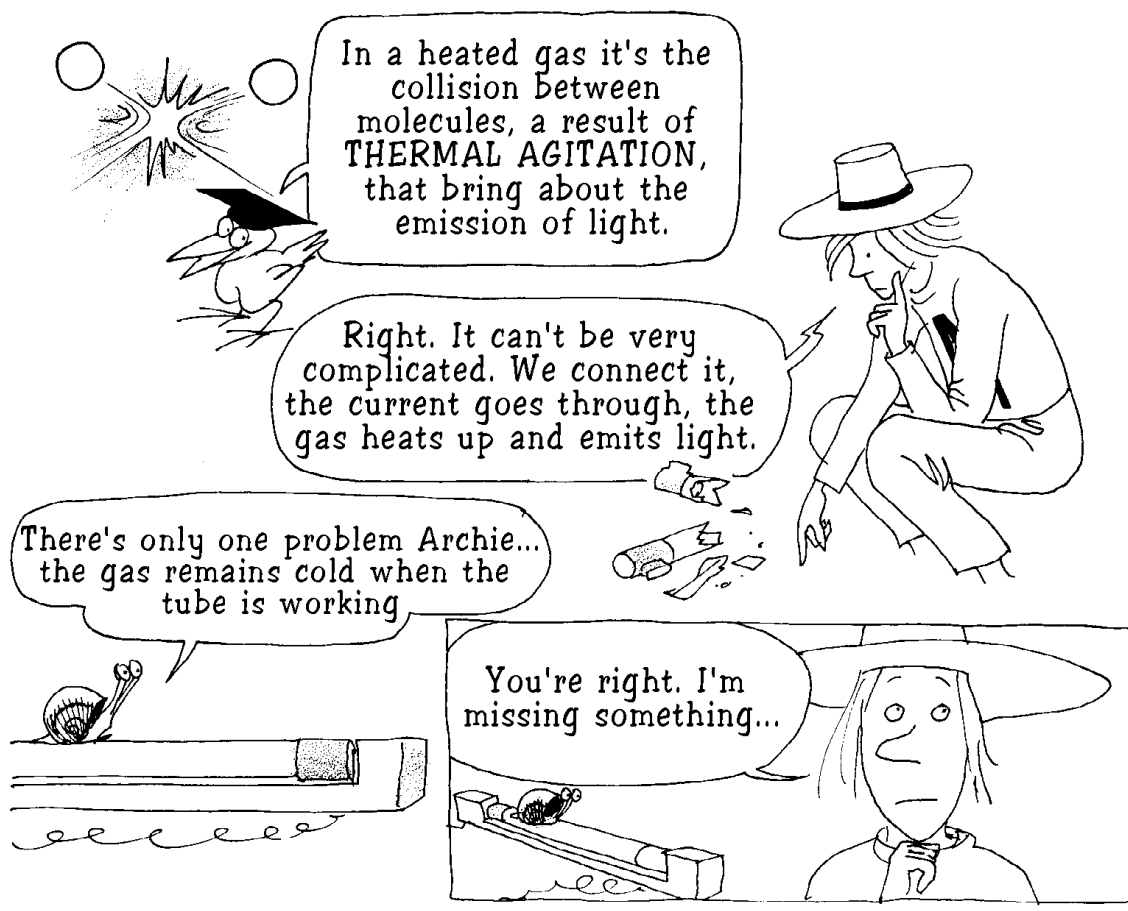
...the atoms of neon in the tube shed the energy they receive from the impacts of electrons going through the tube.

Of course. The gas cooker, the sun, fire, how do you think they work?

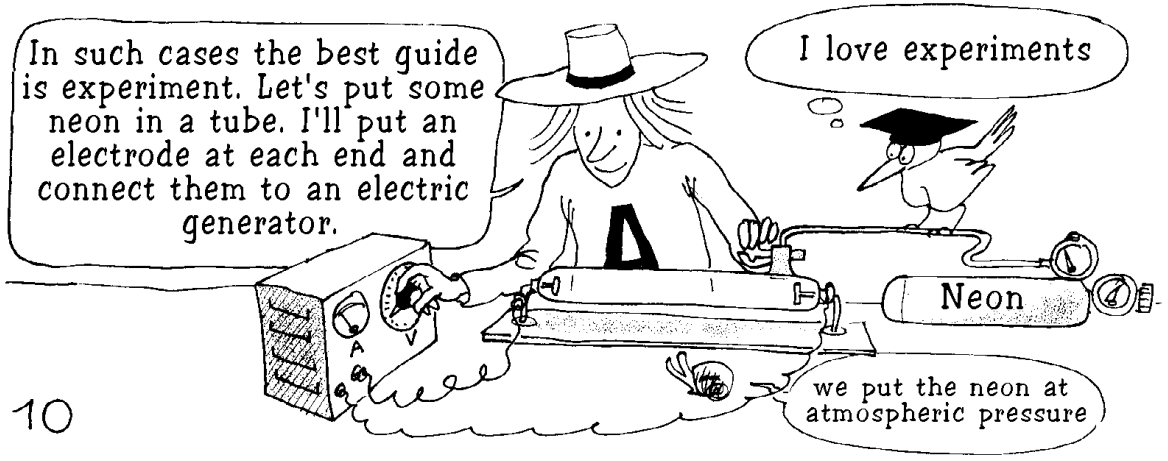


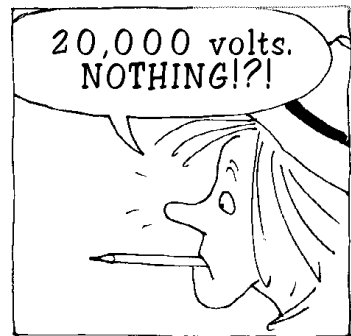
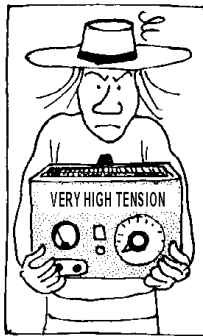
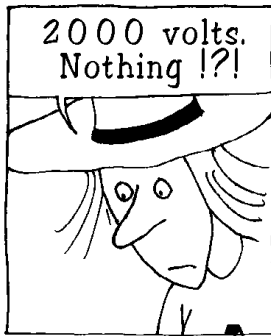
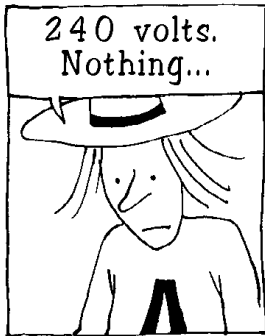
The atoms of a gas can emit light?



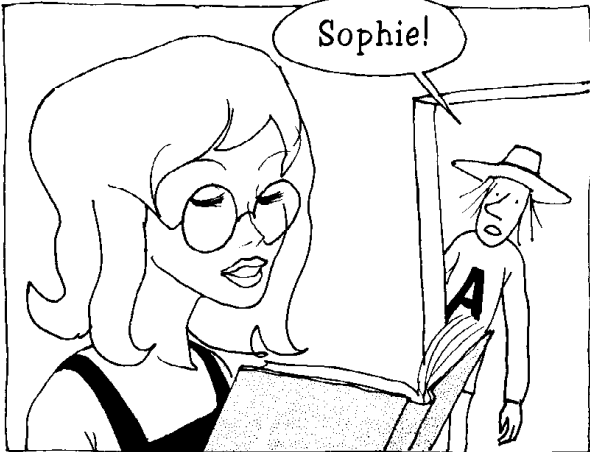
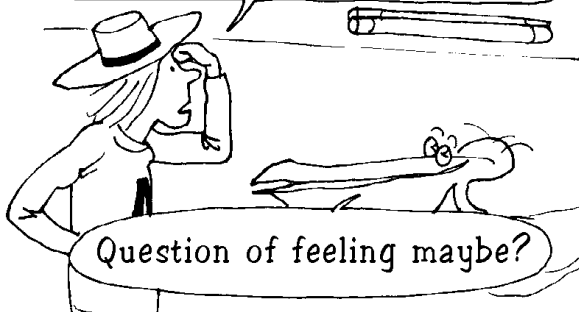


ELECTRIC CONDUCTIVITY





Yet in the tube in the kitchen
it uses just one ampere at
two hundred and twenty volts.



In a **CONDUCTOR**, current
passes by affecting the
movement of free electrons.

And why does current
go through metal?

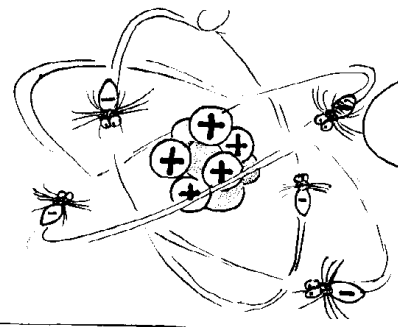
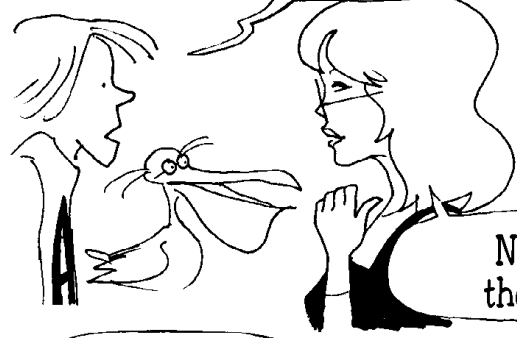


While in neon, at ordinary
temperature, there are very few.

Because it's
naturally rich in
free electrons.



Do you mean that there aren't any electrons in cold gases?



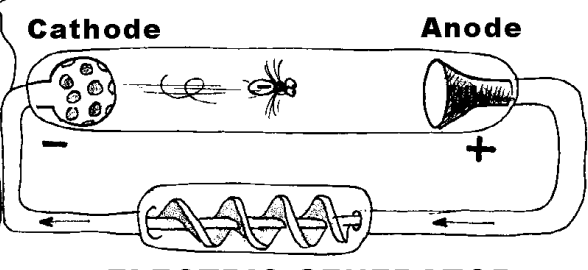
Here are some TIED ELECTRONS.

No, but they're all busy turning on their orbits around the atoms' nuclei

What makes electrons go round?



Their movement is begun by the GENERATOR, which acts like a sort of pump



ELECTRIC GENERATOR

So, what's the problem?



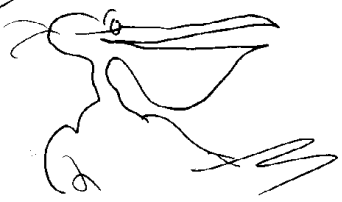
Great, it works.

Tiresias, get out of the way.

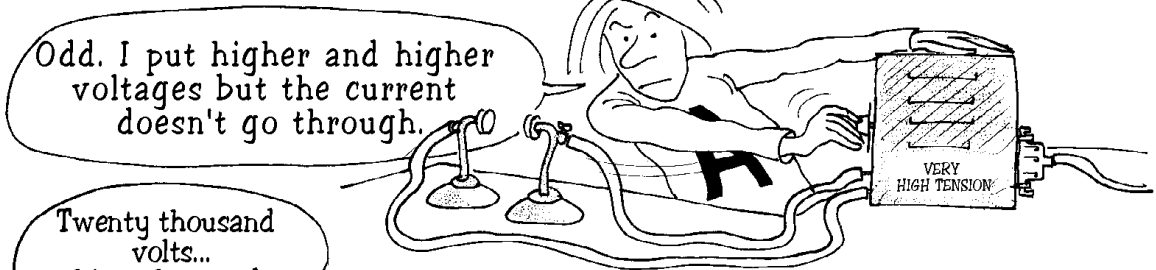
Ouch!

Archibald has found an ELECTRON PUMP.

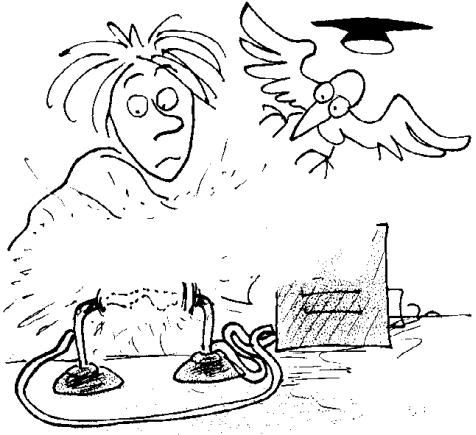
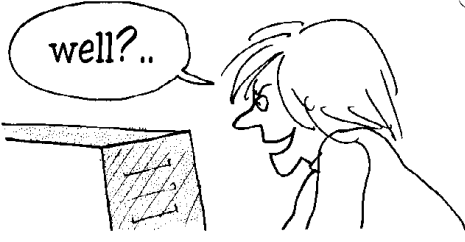
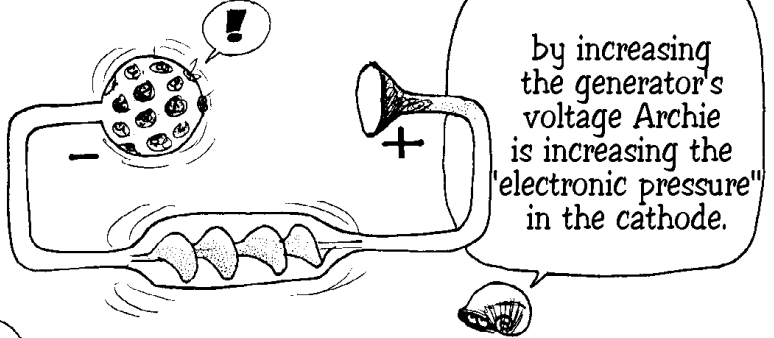
It's a generator of high voltage direct current.



THE ELECTRIC ARC

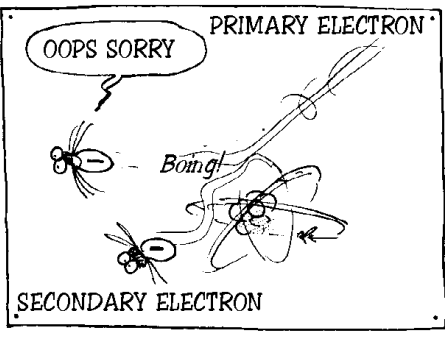
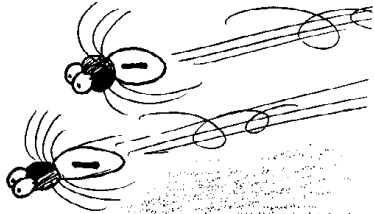


Twenty thousand volts...
thirty thousand...



THE ELECTRONIC AVALANCHE

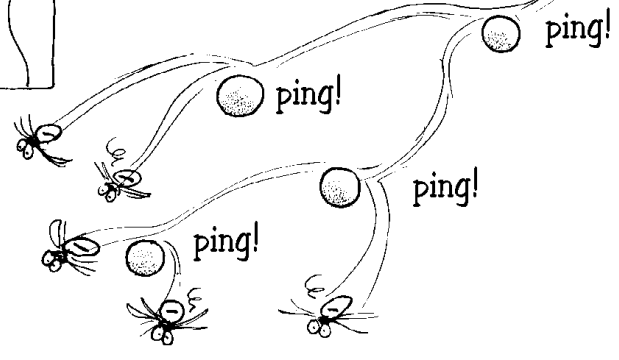
An electric generator creates an ELECTROMOTOR FIELD between its electrodes which tends to move free electrons. Even in a gas at ordinary temperature a few of them will be strongly pulled from the cathode to the anode. These electrons, called primary electrons, which accelerate between collisions with atoms, acquire enough energy (kinetic) to be able to pull off other electrons attached to atoms and turn them into new free electrons.



Each electron that is pulled off becomes a FREE ELECTRON, which begins to accelerate as well.

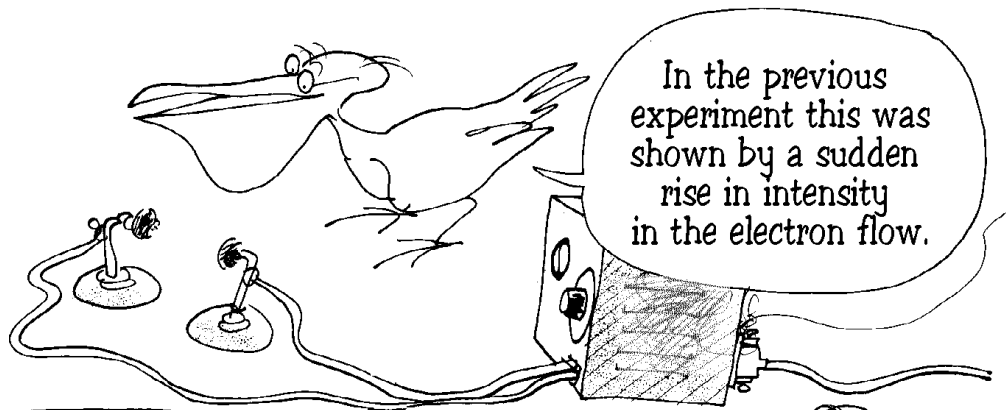


Each initial, primary electron can thus give birth to a very great number of secondary electrons.



We call that the ELECTRONIC AVALANCHE

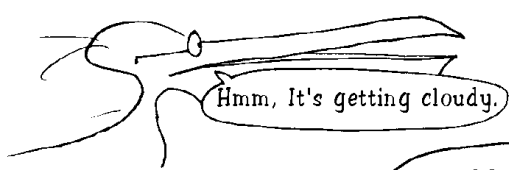




In the previous experiment this was shown by a sudden rise in intensity in the electron flow.

In other words, the gap between the electrodes had suddenly become very conductive. The generator, placed in a short-circuit situation, burnt out.

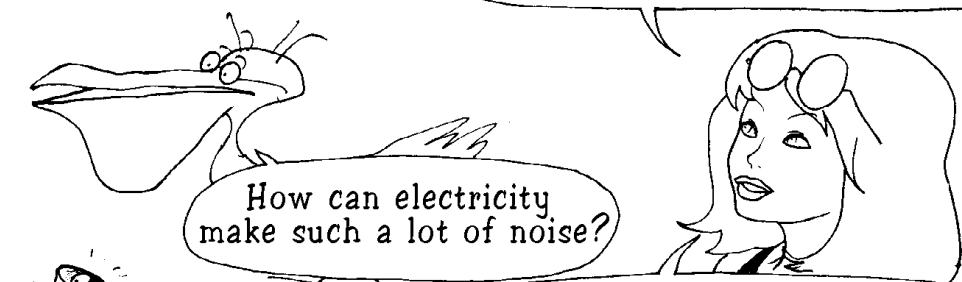
In air the **RELEASE** happens when, at atmospheric pressure, the difference of potential reaches 30,000 volts per centimetre.



Hmm, It's getting cloudy.

LIGHTNING is an electric arc that is created when the difference in potential between a cloud and the earth passes this point of release.

BOUM !



How can electricity make such a lot of noise?

In an electric arc there is a violent release of heat which creates a **SHOCKWAVE**.

MEAN FREE PATH

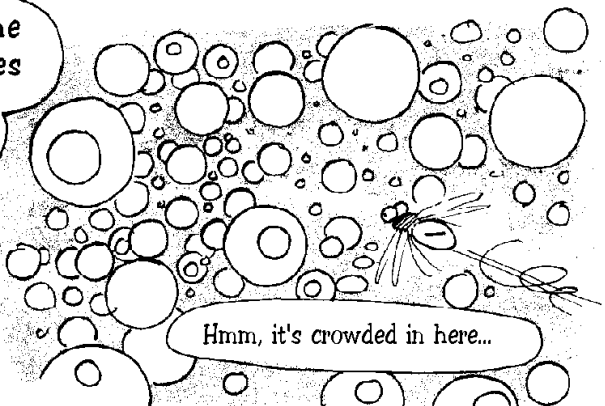
But all that doesn't solve my problem, nor explain why electric current goes through the tube in the kitchen.



The mystery remains!



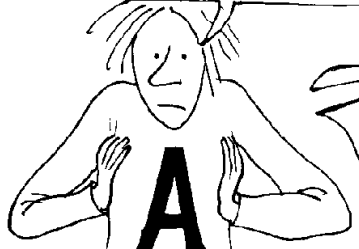
Let's see. The electronic avalanche occurs when the electron manages to acquire enough energy, in relation to the space; on its trajectory.



Hmm, it's crowded in here...

We call that the **MEAN FREE PATH**.

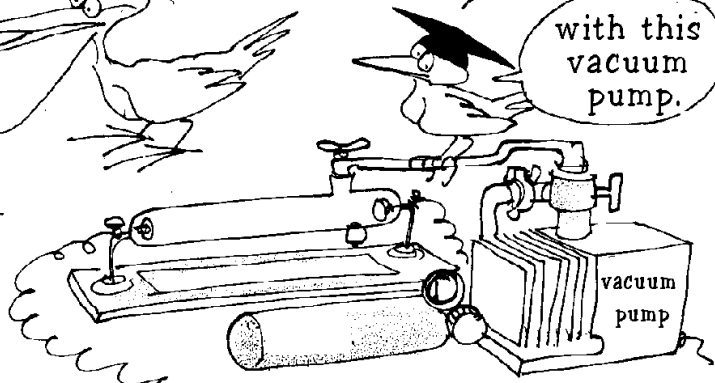
It seems that if I increase this mean free path of an electron, it will accelerate for longer and so acquire more energy.



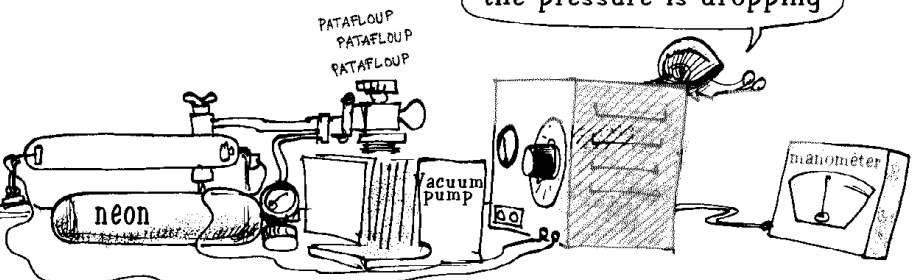
But how do you increase its free path?

Simple...you reduce the density of the gas!

with this vacuum pump.



I feed it two hundred volts and I pump.



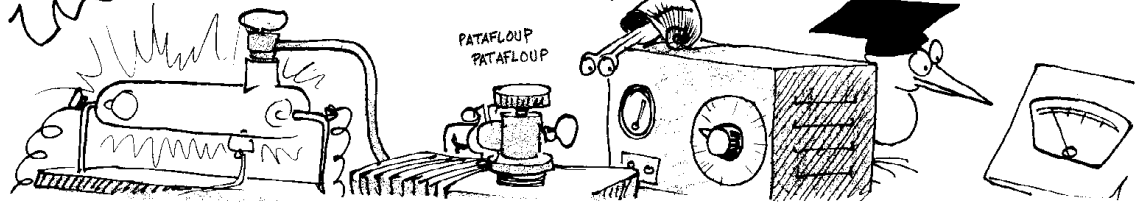
the pressure is dropping

WHOOPEE!

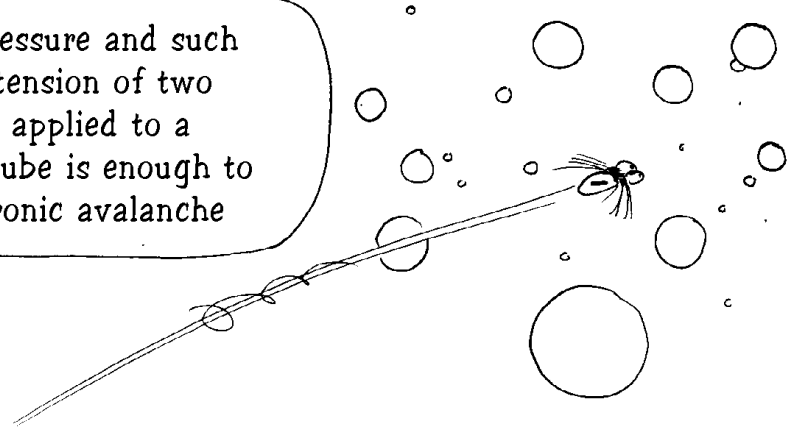
Sophie, the tube is lighting up!

The current is getting through!

The pressure has dropped by a ten thousandth of an atmosphere



With so low a pressure and such low density, a tension of two hundred volts applied to a fifty centimetre tube is enough to create an electronic avalanche



IONISATION DE-IONISATION

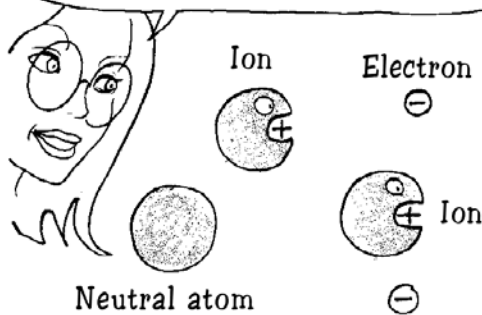
In this avalanche that you've been talking about, there is a continuous creation of free electrons. But, if the discharge continues, in the end there won't be any more free electrons left will there?



No

You see Leon, every electron that leaves an atom leaves an orphan positive charge, this charged atom is called an ION.

All the atoms are ionised in the end.



but...charges with opposite signs attract each other don't they?

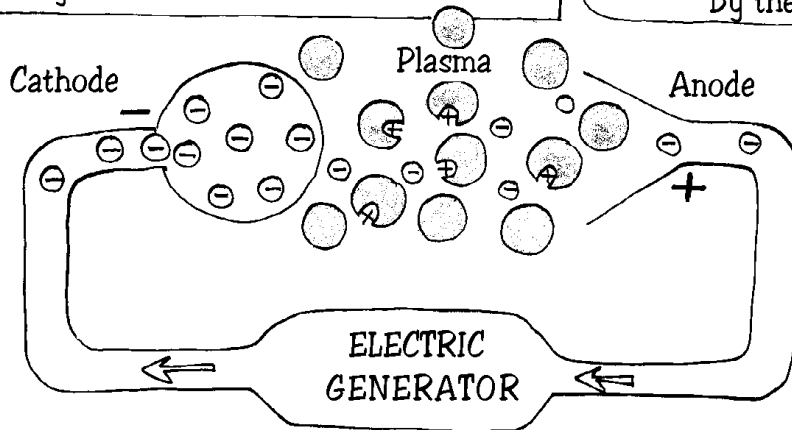
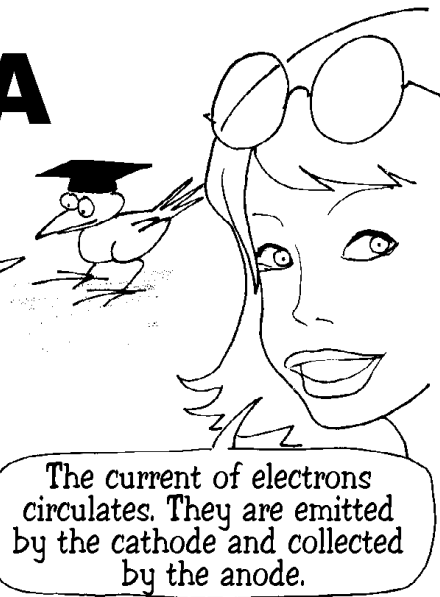
Quite right. Electrons continually tend to return to the ions, thus neutralising them. This is called the DEIONISATION phenomenon.

So the simultaneous creation of free electrons and ions is the IONISATION phenomenon.

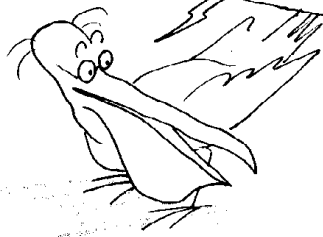
In deionisation, the eventual excess of kinetic energy is dissipated through radiation which contributes to the emission of light and gas.

PLASMA

Let's recapitulate: A sort of electron pump, called an electric generator enriches a **CATHODE** with electrons. This cathodic charge acts on the electrons in a gas, accelerates them and continually creates new free electrons by an electronic avalanche effect. When the **IONISATION** and **DEIONISATION** phenomenon balance out, we get a mix of ions that we call plasma, electrically neutral.



Goodness. So when I turn on a fluorescent light I'm creating **PLASMA**!



It's amazing what you can find in a house!

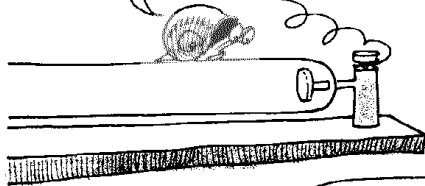


Plasma!



A working fluorescent tube contains plasma. Max says that the sun is also plasma, a big ball of ionised gas. But why is the sun hot and the fluorescent tube is cold?

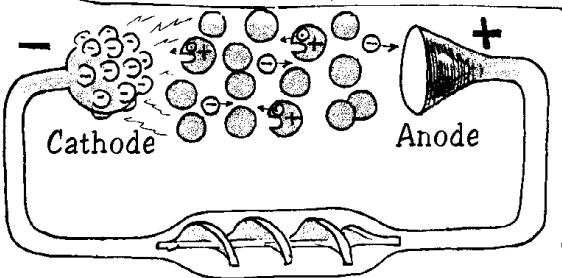
In this type of 'cold' plasma it's the collisions between electrons and atoms that keep the ionisation going, whereas in the sun it is collisions between atoms. They are necessarily in a state of agitation so the gas is hot.



In the fluorescent tube we have **NON-THERMIC IONISATION**

But in this plasma there are two type of charge, electrons and ions. In theory electric force acts on them both doesn't it?

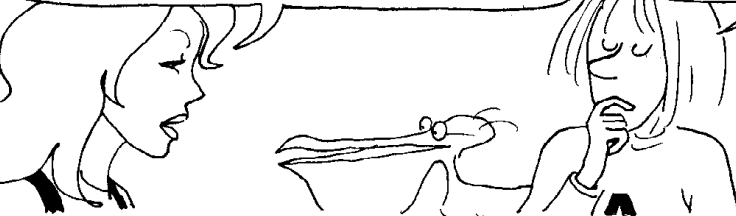
Yes. The electric field in the tube that starts moving electrons pulls them in one direction and ions in the other.



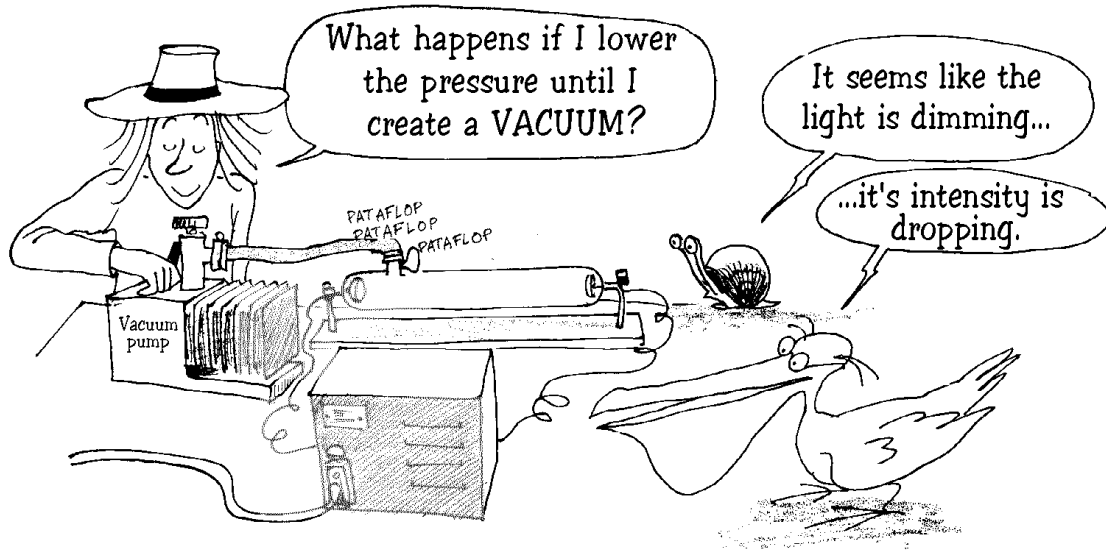
The field is due to the accumulation of electrons in the cathode because of the electronic "pressure".

Collisions with neutral atoms slow the progress of the charges. Only electrons, light and mobile, manage to make their way through the disorder.

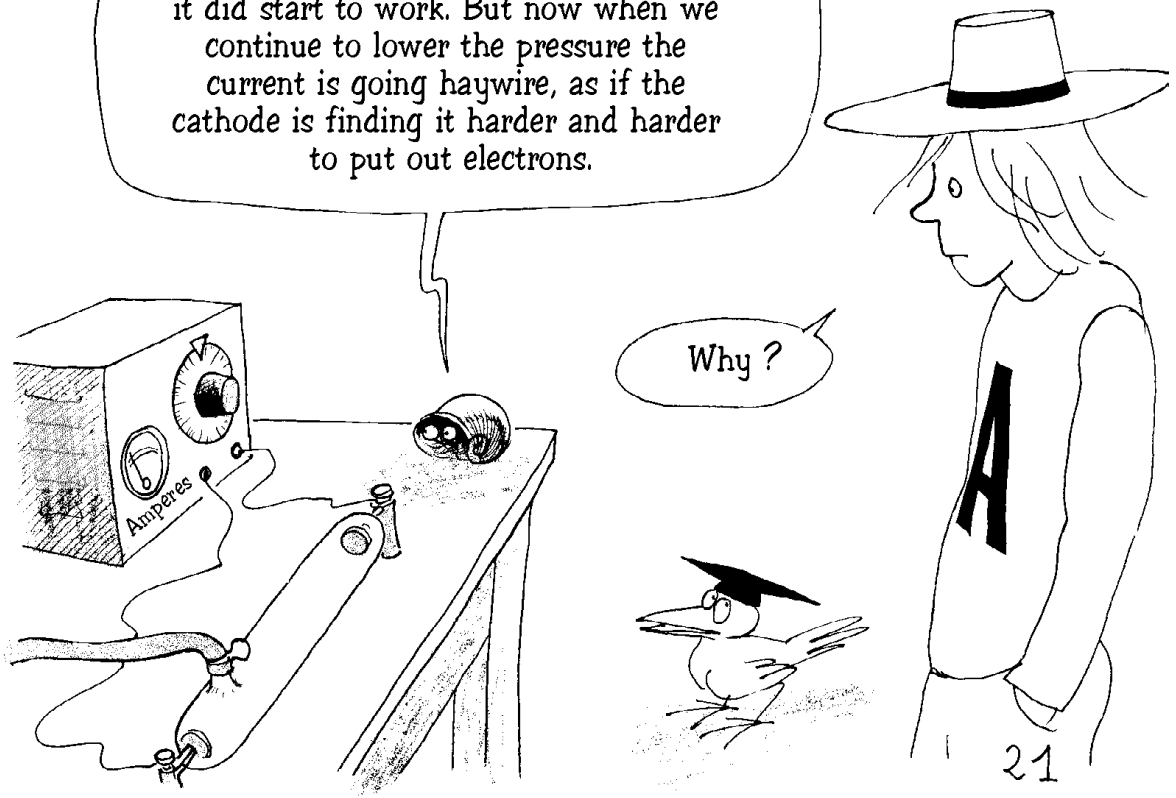
Which means that in a fluorescent tube the **IONIC CURRENT** remains negligible compared with the **ELECTRIC CURRENT**.

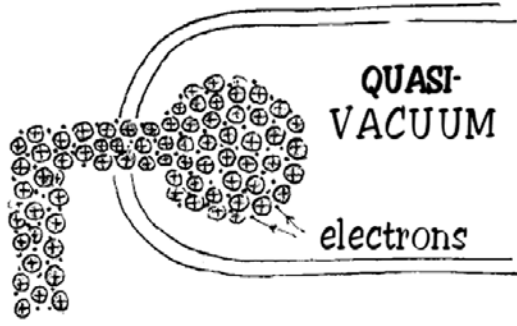


CATHODIC EMISSION

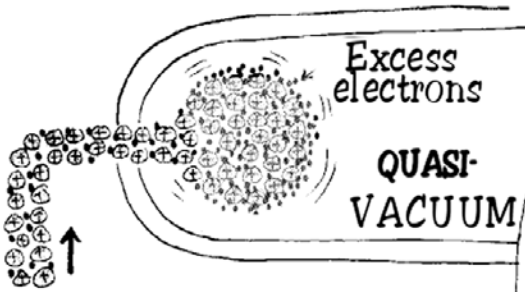


I don't understand. At high pressure nothing worked then at a lower pressure it did start to work. But now when we continue to lower the pressure the current is going haywire, as if the cathode is finding it harder and harder to put out electrons.

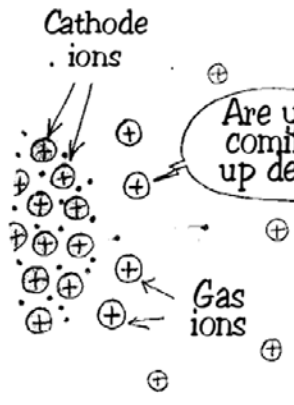




The cathode is a piece of metal made up of nuclei of atoms with a positive charge and electrons.



An electric generator has an effect of making free electrons accumulate in the metal of the cathode. But if the voltage is insufficient, this electronic pressure is too weak to allow the electrons to hook on to the metal's atoms.

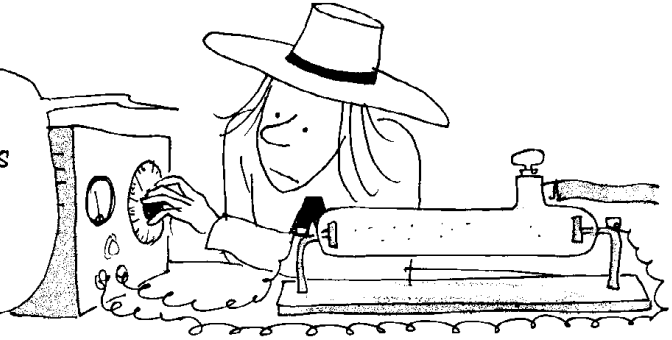


But if gas atoms in an ionised state are present they will help the electrons escape.

However if the gas is too dense the current still won't get through so there is an optimum level of pressure*

(*)Paschen's minimum.

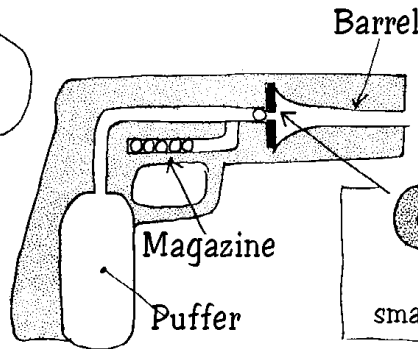
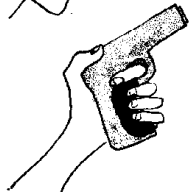
When there is a **quasivacuum** in the tube, several thousand volts have to be applied to get the cathode to release just a few electrons.



The metal used for the cathode does not affect the voltage required.



This is an old **PNEUMASHOOT** pistol



Rubber membrane with a hole in the centre slightly smaller than the ball shot.

When the puffer is pressed, the membrane is deformed and the ball expelled with some force.

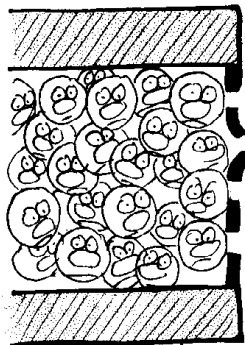


PTIUP

Just like when you spit out a cherry stone.

Mind out in front!

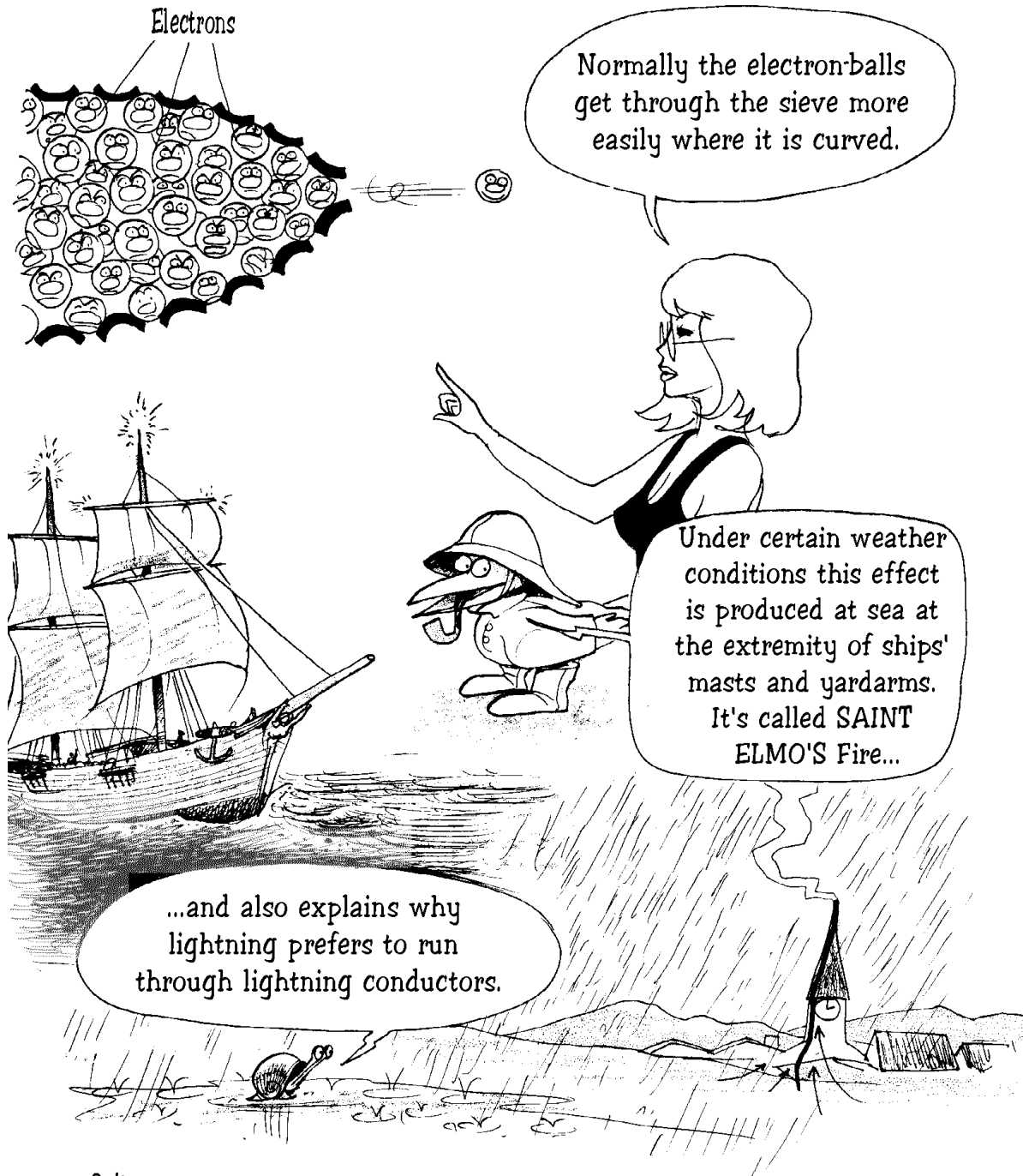
FTIUP!



When a cathode is emitting, it behaves like a sort of sieve with a multitude of small holes through which the electrons are pushed violently by an "electronic pressure".

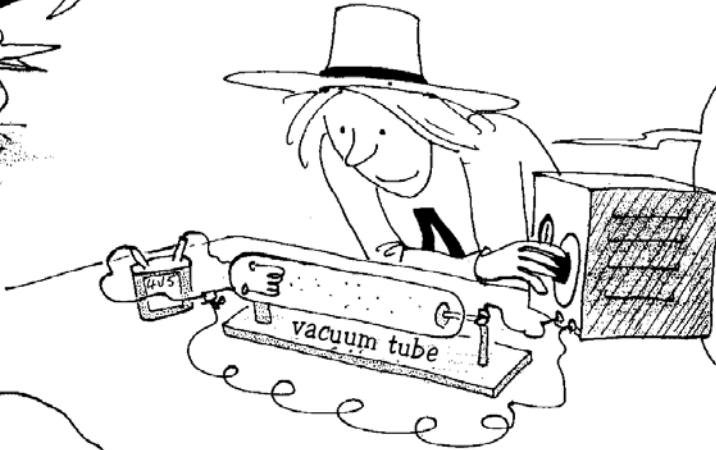
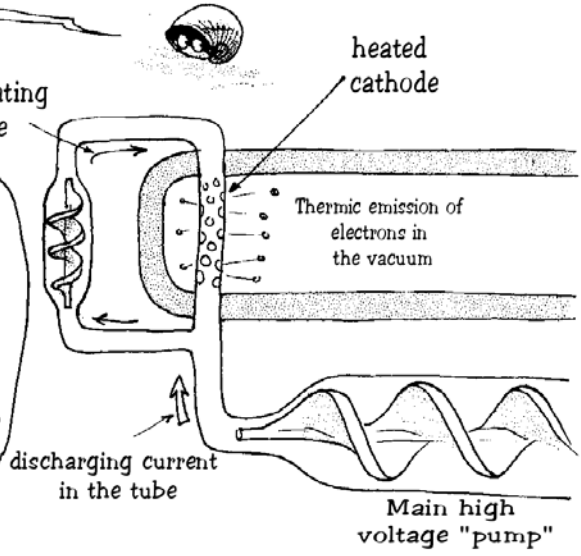


THE POINTS EFFECT



Let's get back to discharges in vacuum tubes.

We can greatly assist the electronic emission by heating the cathode by putting a current through it like this, for example, using a second low voltage generator (a battery would do).



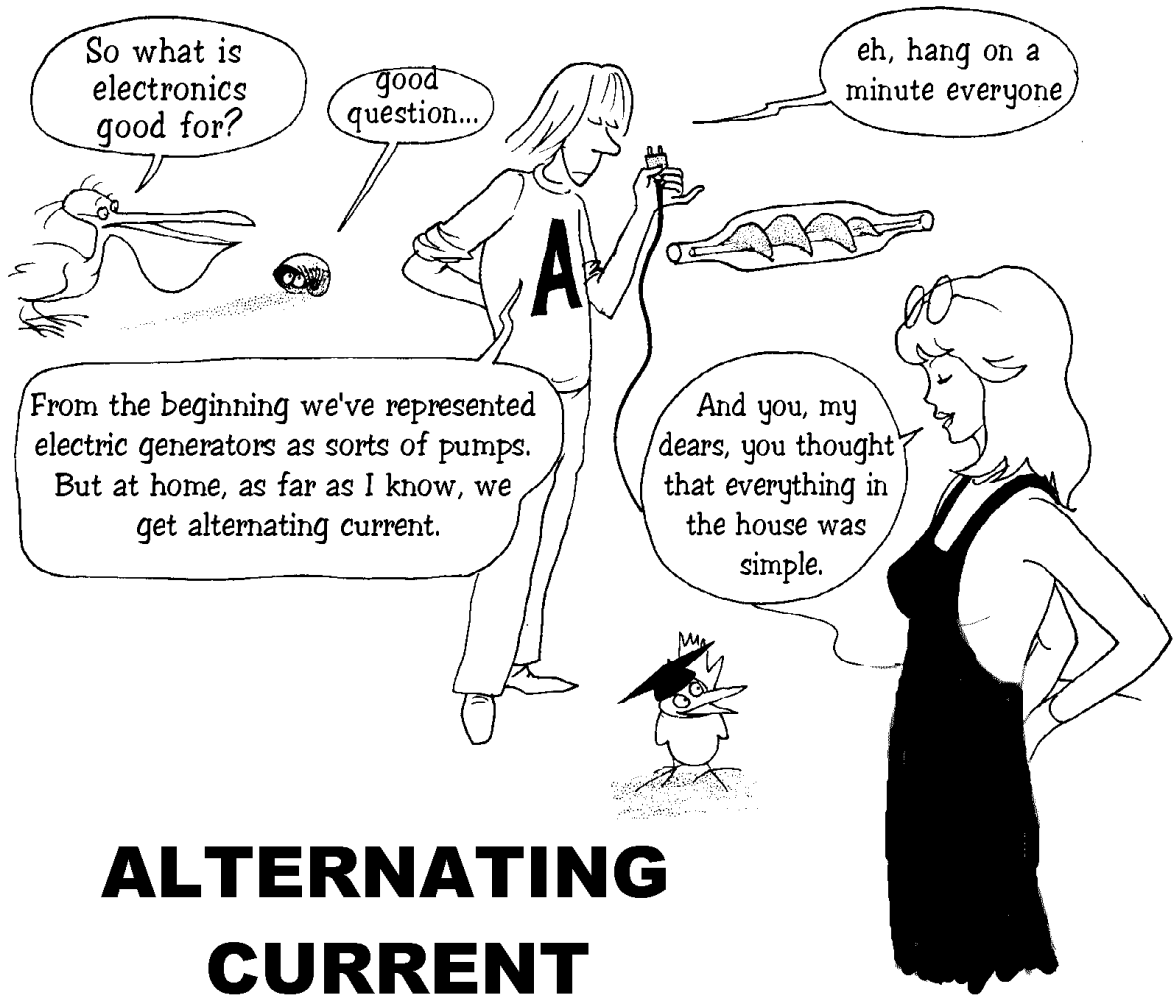
Wow, that's pretty efficient. I can send a current through the tube with less than one hundred volts.



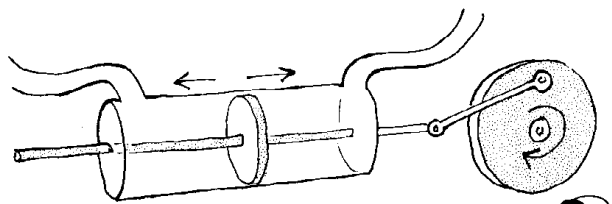
Sophie, what are we doing exactly?

All this playing about with electrons...

It's called **ELECTRONICS** !



ALTERNATING CURRENT



Here's another type of electric-pump generator that works in an alternative way.

It's a funny 'pump' that sucks and blows alternatively!?



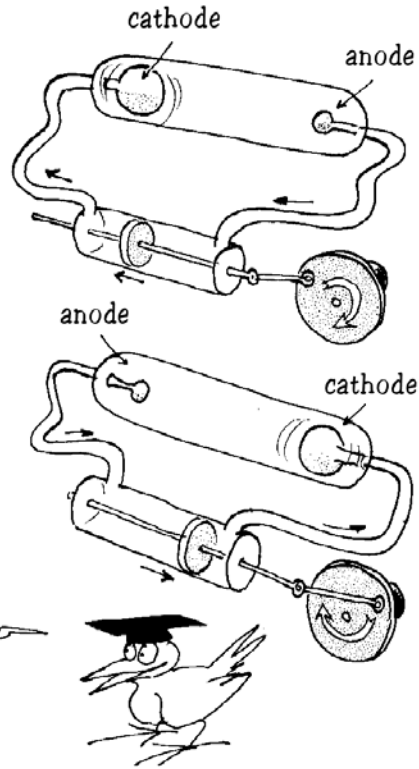
so where do you put the anode and where do you put the cathode?

The electrodes take turns to be both.



So everything we said before can be adapted?

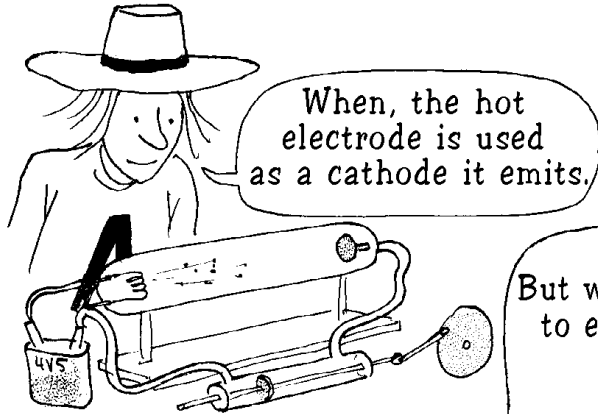
The electronic avalanche, non thermal ionisation and all the rest?



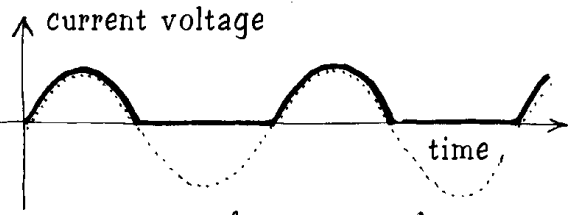
It's logical, otherwise I can't see how the fluorescent tube in the kitchen could work with 220v alternating current.



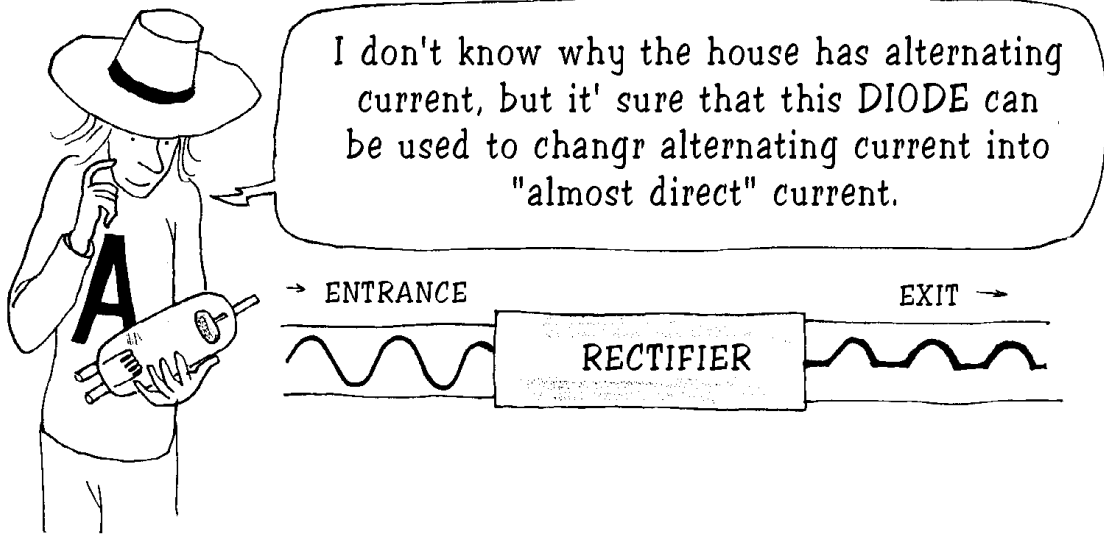
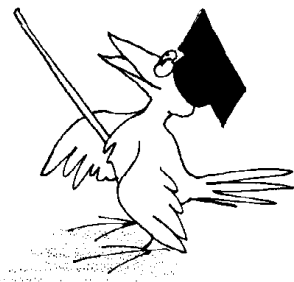
But what happens if I send alternating current into the circuit with a hot electrode and a cold one that we made earlier?



But when we want the cold electrode to emit it refuses, and the current doesn't get through. Archibald, you've made a RECTIFIER



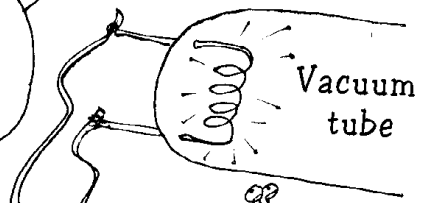
The dotted lines are meant to show the "electronic pressure" in the hot cathode and the black line the electrons it emits.



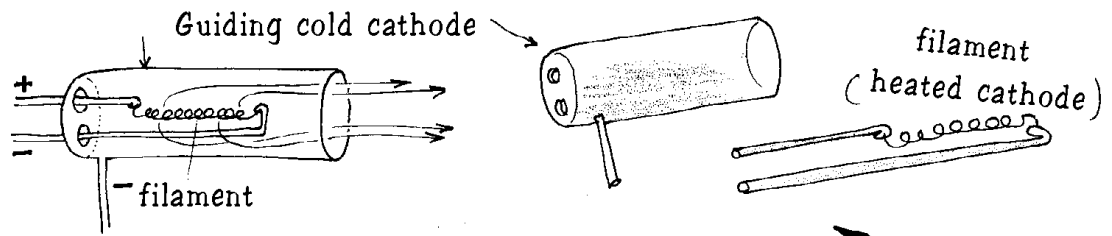
THE ELECTRON GUN



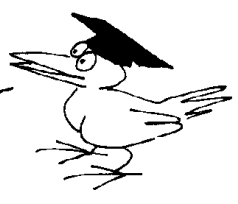
So, there are two sorts of cathodes but only hot cathodes can emit electrons, produce a current. The cold cathode can only carry negative charges.



Your hot cathode emits electrons in every direction.



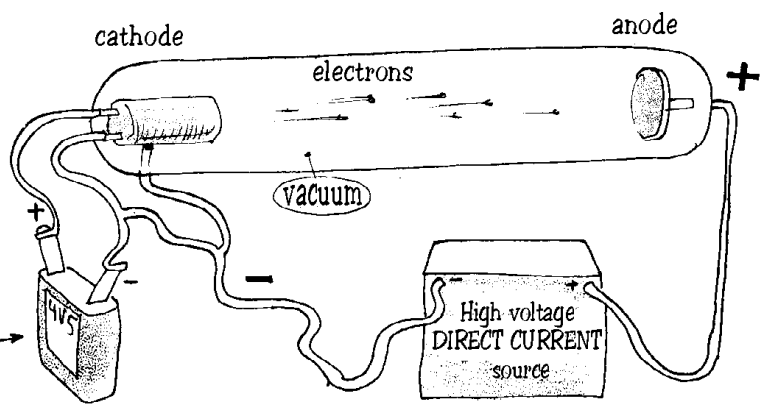
With this cold cathode, whose current output is infinitesimal, Archibald is obliging the electrons emitted by the hot cathode to come out according to the axis of the ELECTRON GUN. Their only way out.



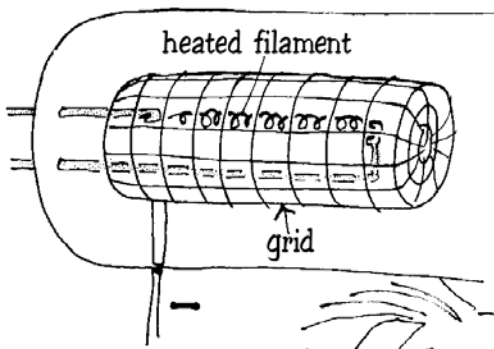
So here it all is inside a vacuum tube



Low voltage source to heat the filament cathode.



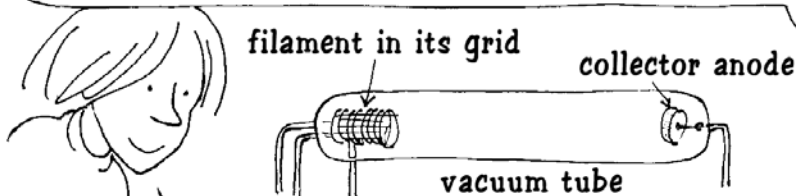
THE TRIODE



Look: I've enclosed my cathode, my electron emitting filament, inside a sort of grid cage. When this is uncharged, electrons pass freely, but if I apply a negative charge it pushes away the electrons that are trying to tear themselves away from the filament and they then fall back. I'm turning the current off.

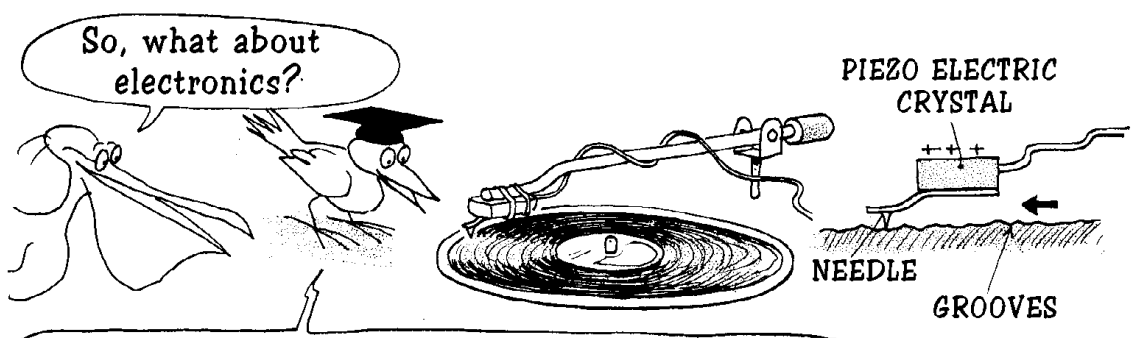
You've made a **CONTROL GRID**

By varying the grid's electric charge, its voltage, you can adjust a strong current as you wish while using only a tiny amount of energy.

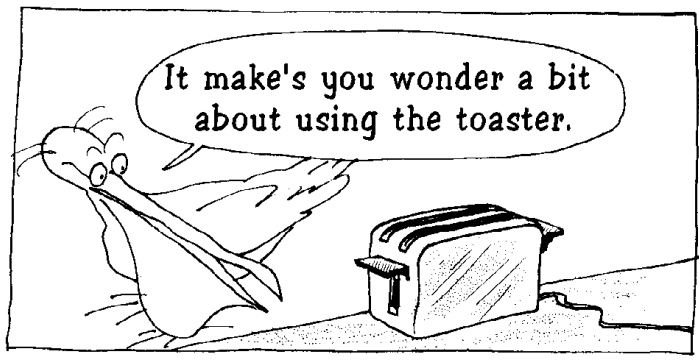
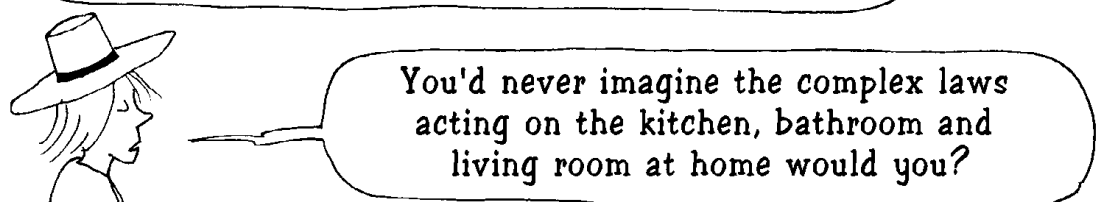


Ah yes, just like when you open and close a tap.

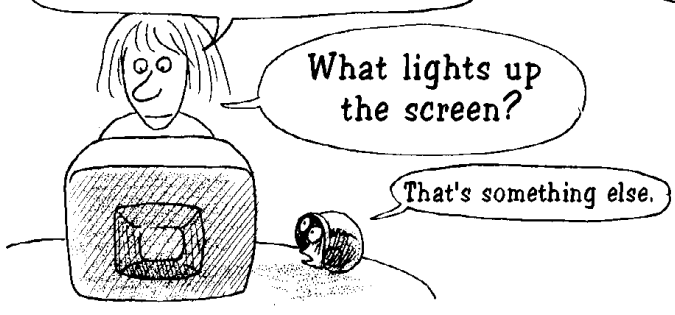
The **TRIODE**, which has three electrodes: its hot cathode, its collector anode and its grid, forms the basis of **CURRENT AMPLIFIERS**.



Here, you see, weak electrical impulses from a piezo-electric crystal, attached to the needle on a record-player pick-up head, are used to vary the current produced by an amplifying triode.



While we're at it... how does a television work?



FLUORESCENCE



Some substances have the capacity to absorb radiation at certain frequencies and emit it at others.

Ah yes, FLUORESCINE absorbs white light, which is a mix of all the colours of the rainbow and emits it in the green band.



Nylon absorbs ultra-violet and re-emits in blue. I saw that in a night-club. Everyone's collar was luminous.



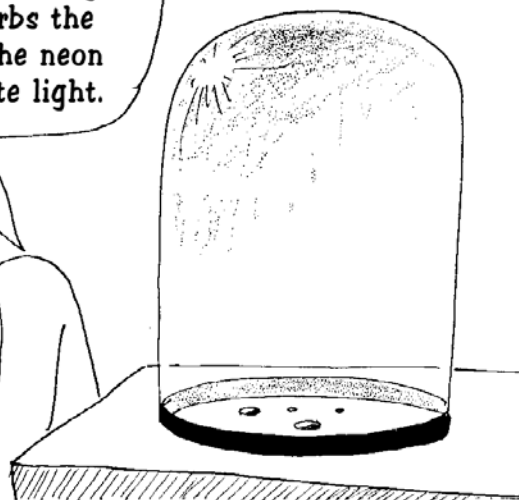
Goodness Tiresias!
You go to night clubs?



The fluorescent tube is lined on the inside with a product that acts in the opposite way to fluorescine. It absorbs the blue light emitted by the neon and re-emits it as white light.



I've found a vacuum bell.
It will be more practical
for experiments than a tube.





I've put a touch of a fluorescent product on the inside face of the bell. The pump is underneath.

I can see the cathode electron-gun and the collector anode.

Nice equipment

we create a vacuum and...well I never!?!

Remember the airpistol we used earlier. The cathode ejects electrons at high speed and with high kinetic energy, against which the attractive power of the anode doesn't count for much.

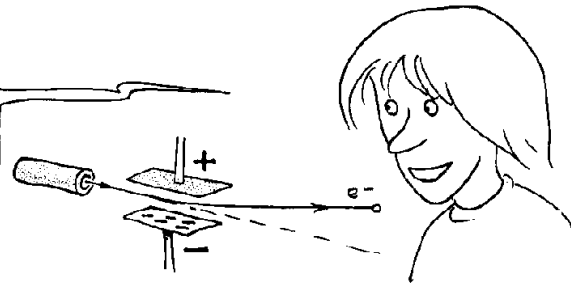
the electrons don't seem to care where the anode is.

But in the end the electrons will have to be collected by the anode.

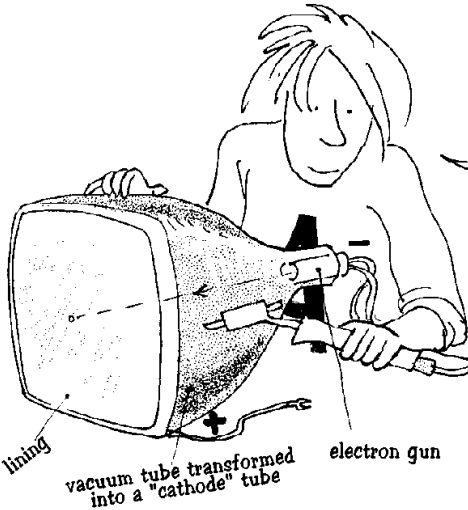
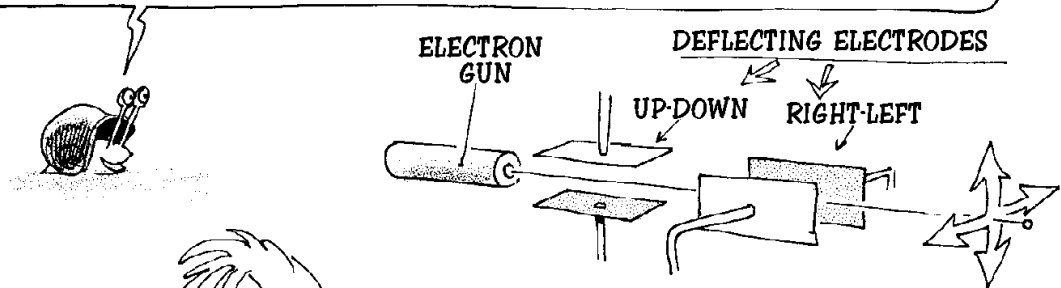
bing

They'll slowly flow towards it after losing their energy when hitting the bell jar.

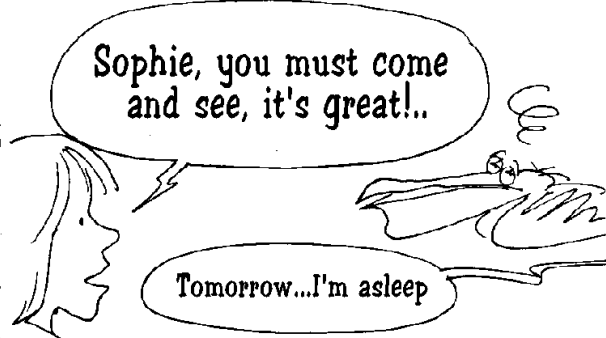
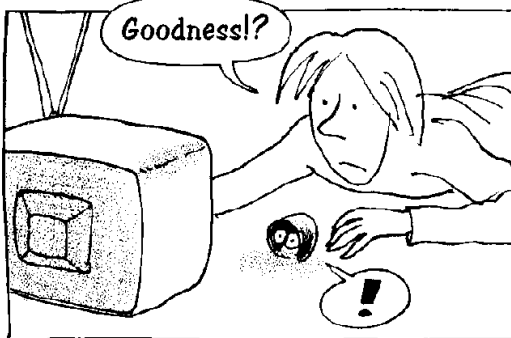
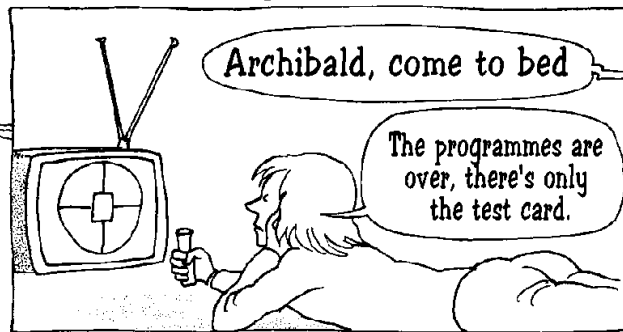
With an electron gun I can canalise electrons emitted by a filament. Then cold cathodes can allow me to deflect a fine paintbrush line of electrons at will.

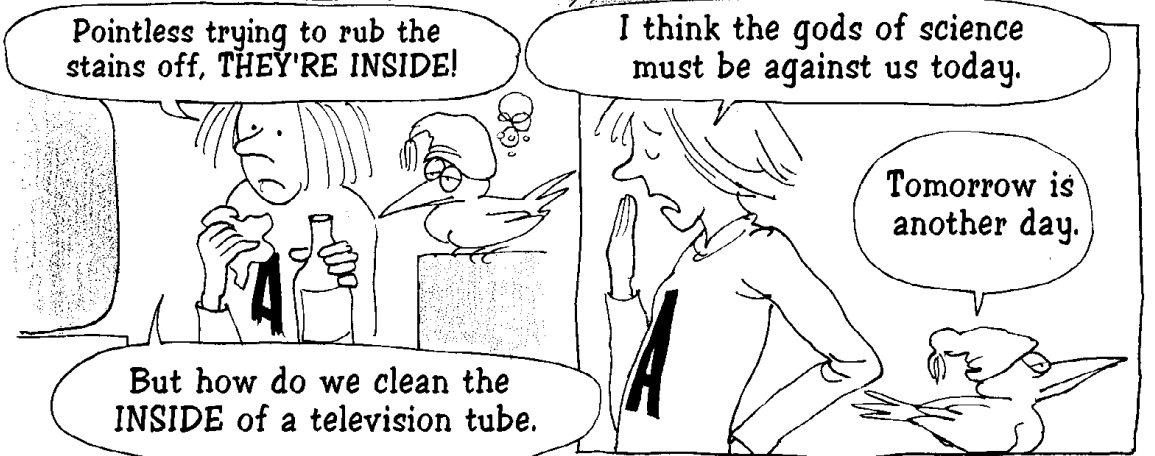
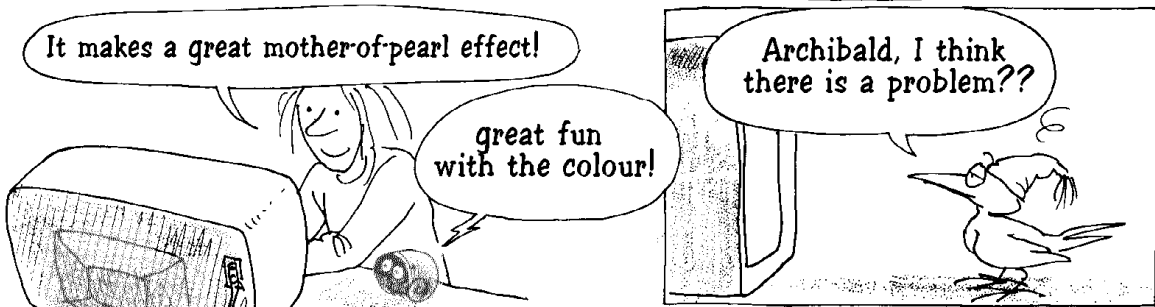


With two sets of electrodes we have complete and precise control of the brush



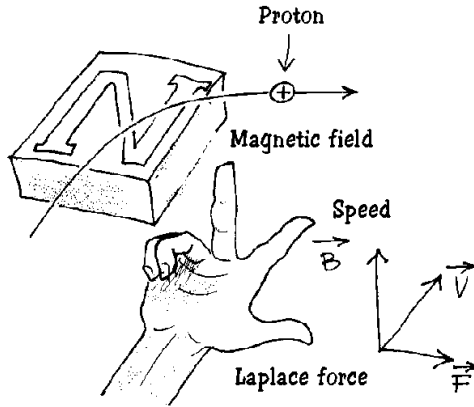
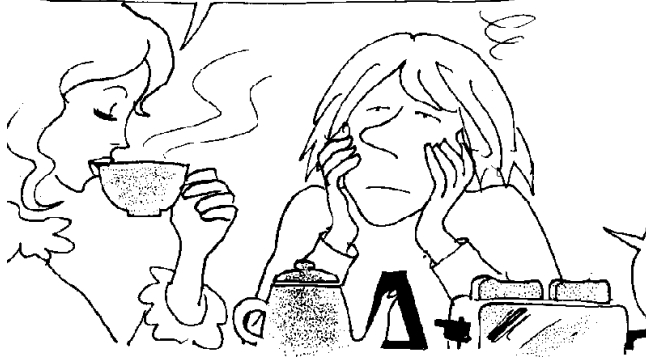
This television is the right sort of modification of a vacuum bell's geometry.





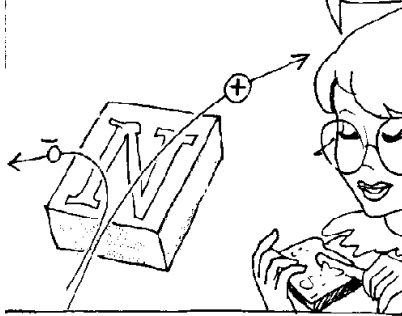
THE LAPLACE FORCE

Simple! Any charged particle that moves and crosses the force lines of a magnetic field will be subjected to a force corresponding to the **THREE FINGER RULE**

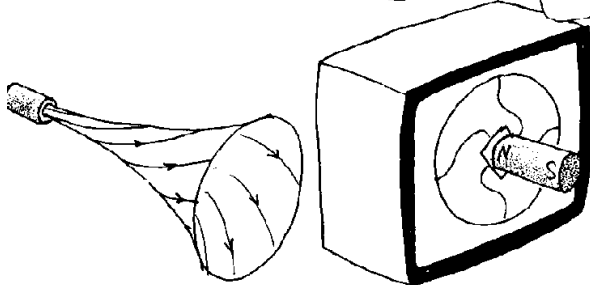
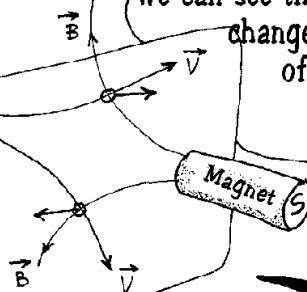


Yes, but what about negatively charged electrons?

In that case the force changes direction.

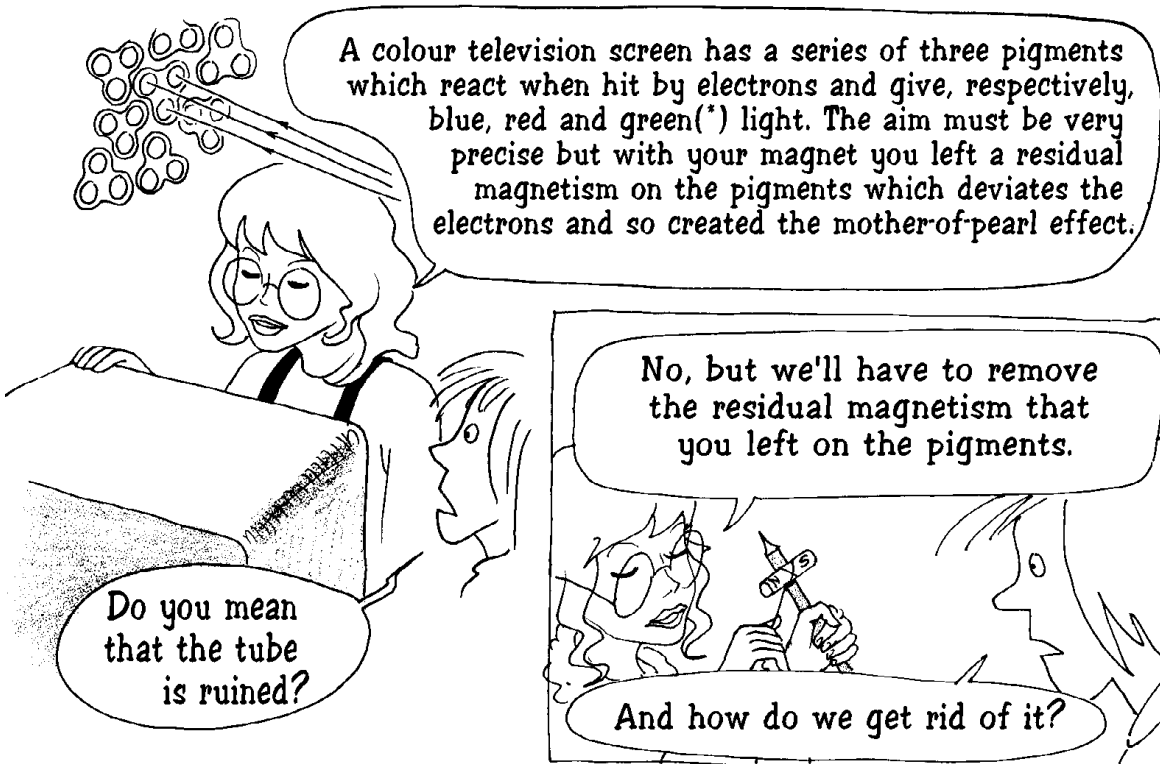


when that's applied to television we can see that the magnet changes the direction of the electrons' trajectories



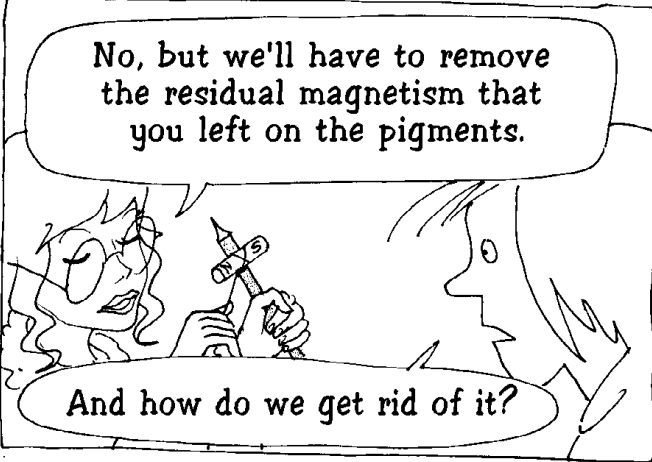
...which explains why the image is twisted on the screen.





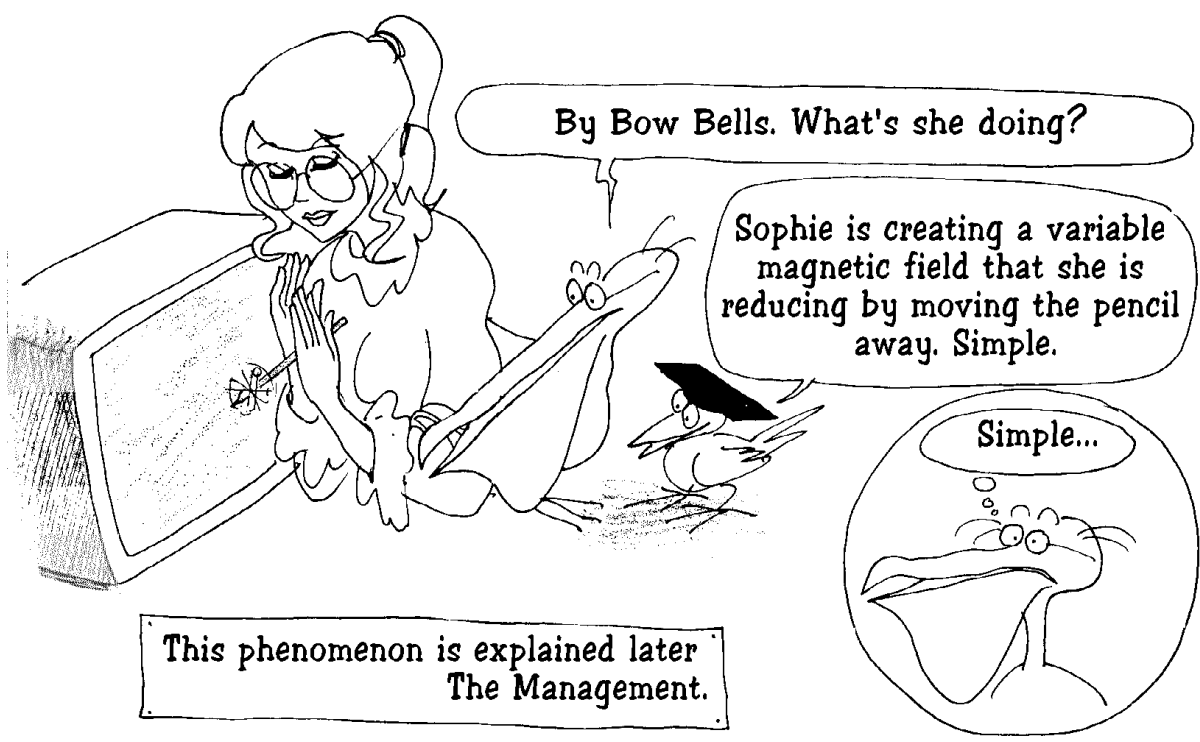
A colour television screen has a series of three pigments which react when hit by electrons and give, respectively, blue, red and green(*) light. The aim must be very precise but with your magnet you left a residual magnetism on the pigments which deviates the electrons and so created the mother-of-pearl effect.

Do you mean that the tube is ruined?



No, but we'll have to remove the residual magnetism that you left on the pigments.

And how do we get rid of it?



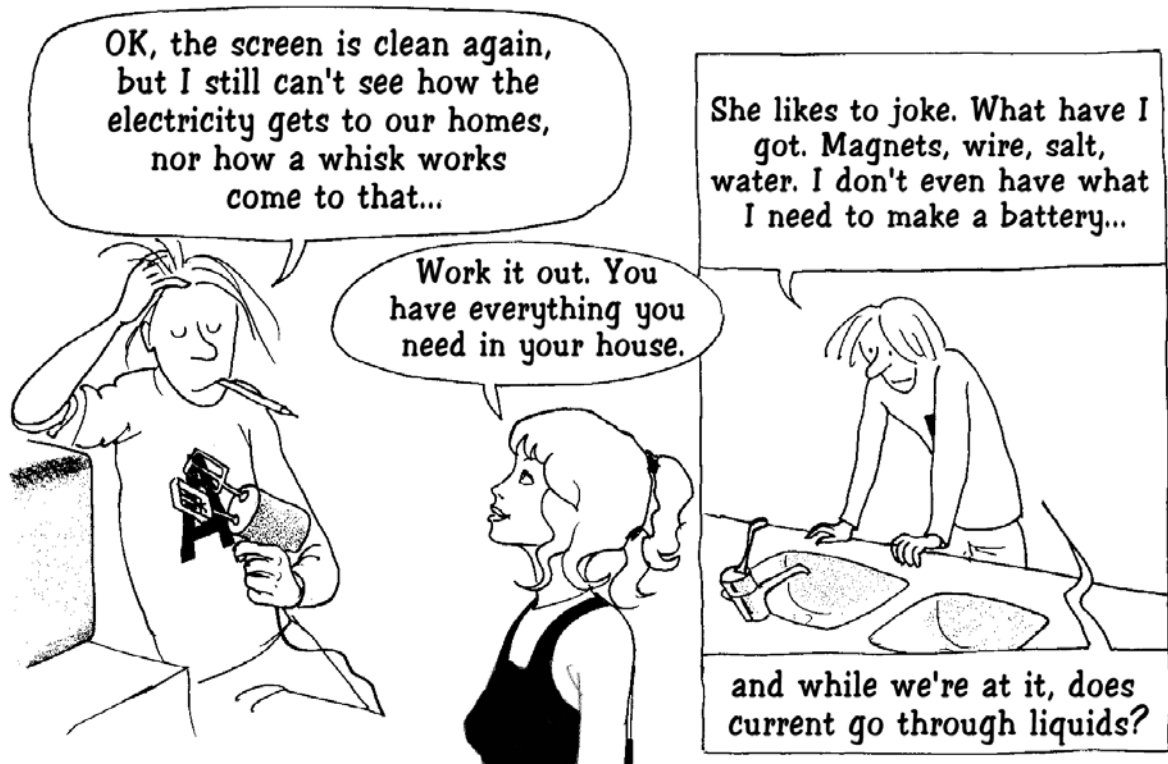
By Bow Bells. What's she doing?

Sophie is creating a variable magnetic field that she is reducing by moving the pencil away. Simple.

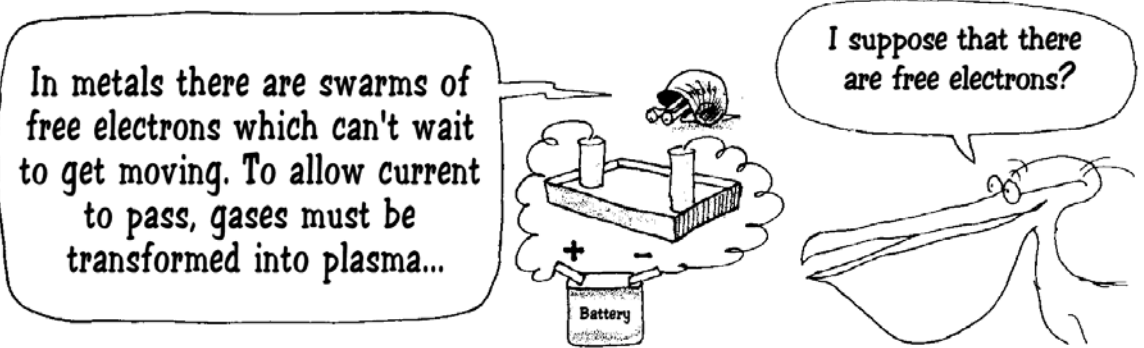
Simple...

This phenomenon is explained later
The Management.

(*) by combining them we can get all the colours of the rainbow. 37



ELECTROLITES



When domestic salt, sodium chloride, ClNa , is dissolved in water its atoms are dispersed in the liquid the chlorine takes over a sodium electron. This Chlorine ION Cl^- moves towards the anode while the Na^+ ion moves towards the cathode.

The Management.

Cl^-
 \ominus

\leftarrow

\oplus
 Na^+

\rightarrow

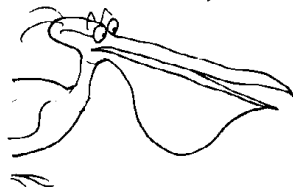
So, in liquids the electric current isn't due to the movement of free electrons, as it is in metals, but ION TRANSPORT.



What happens to these ions? Do they penetrate the electrodes?

No, the chlorine ion abandons its electron and another electron, emitted by the cathode, neutralises the sodium ion...

...the circle is complete.



And what's Higgins up to in the meantime?

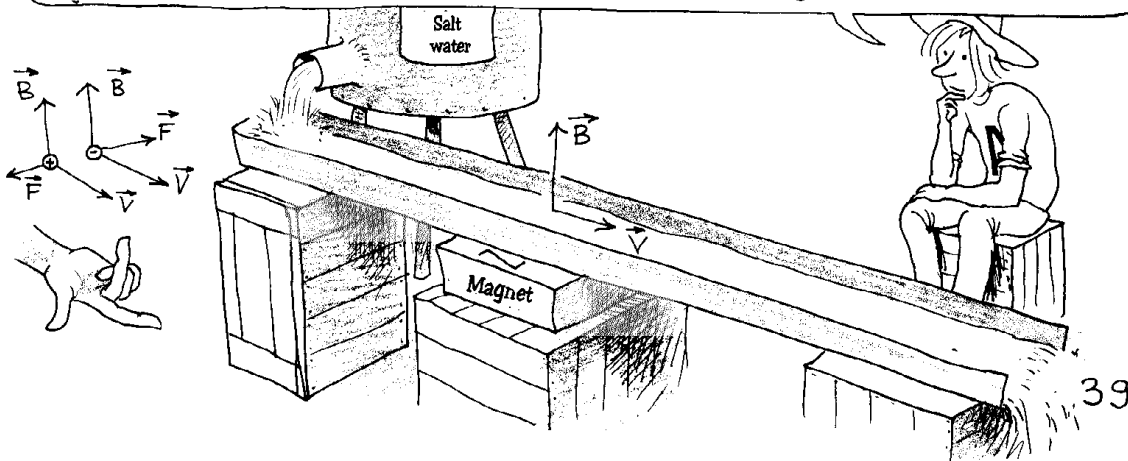
It looks like he's doing a Return to Hydraulics.

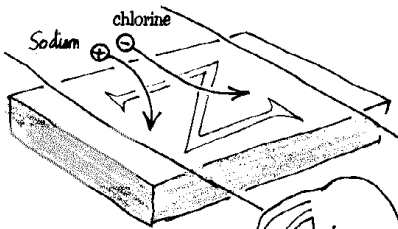
let's get the mops ready.



ELECTROMOTIVE FORCE

Sophie says that every electric charge which moves in a magnetic field is subjected to the LAPLACE FORCE. Logically, this force must act on the Cl^- and Na^+ ions contained in the moving salt water.



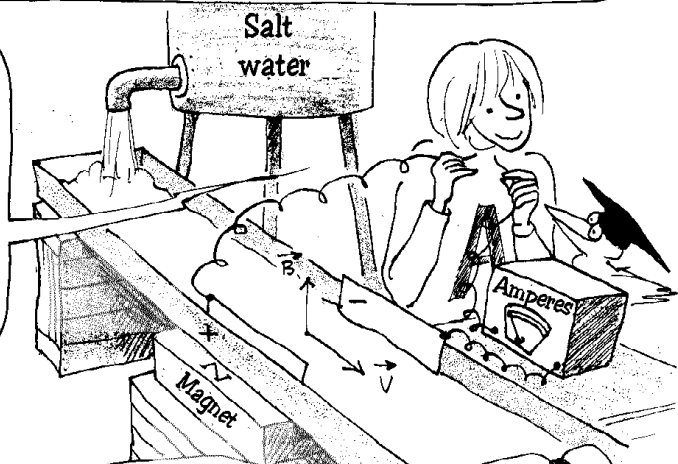


Let's see. In a vertical magnetic field, going from bottom to top, my sodium ions will turn right and my chlorine ions will turn left. I should be able to see some charge separation.

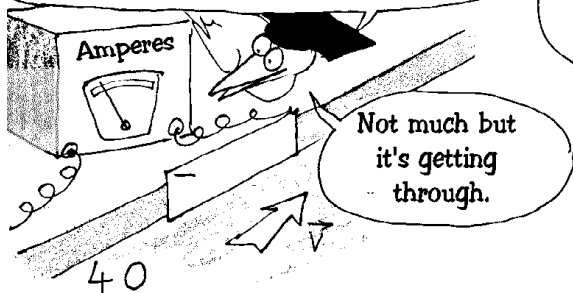


That's a very schematic view because, in a liquid, the ions are involved in numerous collisions with water molecules, which slows them down considerably. As well as that, the forces are proportionally very low in comparison with the speed of flow and the strength of the magnetic field.

Nevertheless my dear Max, you have to agree that there is an effective migration of the charged things in the opposite directions. Therefore I should observe the passage of an electric current by placing two electrodes in the flowing water.



You're right, the current is getting through.

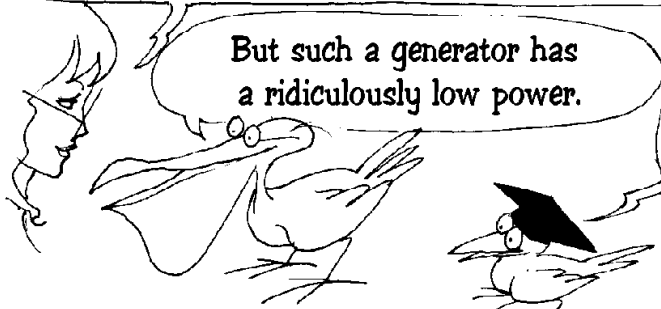


Not much but it's getting through.

Do you know who was the first to do this experiment?

No...

The Englishman Michael Faraday in 1857. He used the salty water of the Thames when the tide rose and fell ...and the vertical component of the Earth's magnetic field: barely a tenth of a Gauss (*). He thus invented the type of electric generator called MAGNETOHYDRODYNAMIC, or MHD for short.



But such a generator has a ridiculously low power.

Maybe water isn't the best ingredient for making an electric generator.

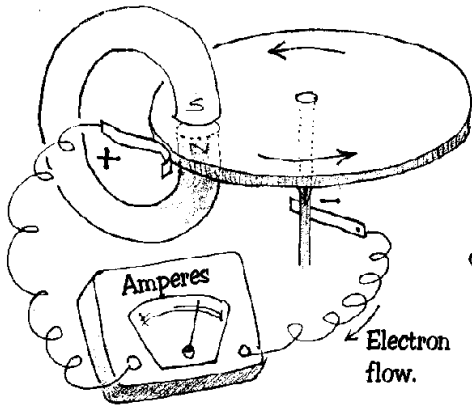
So what should we use? Copper in fusion?



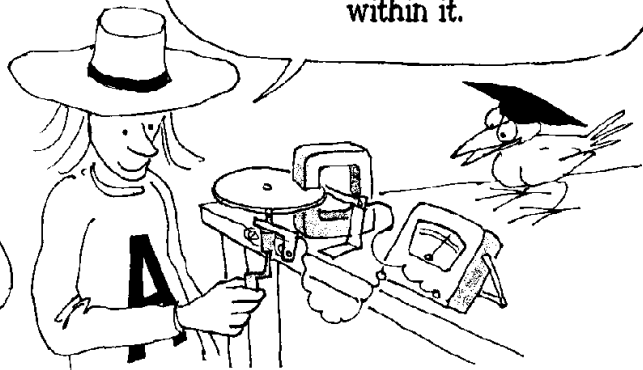
Why just stick with a liquid?

BARLOW'S WHEEL

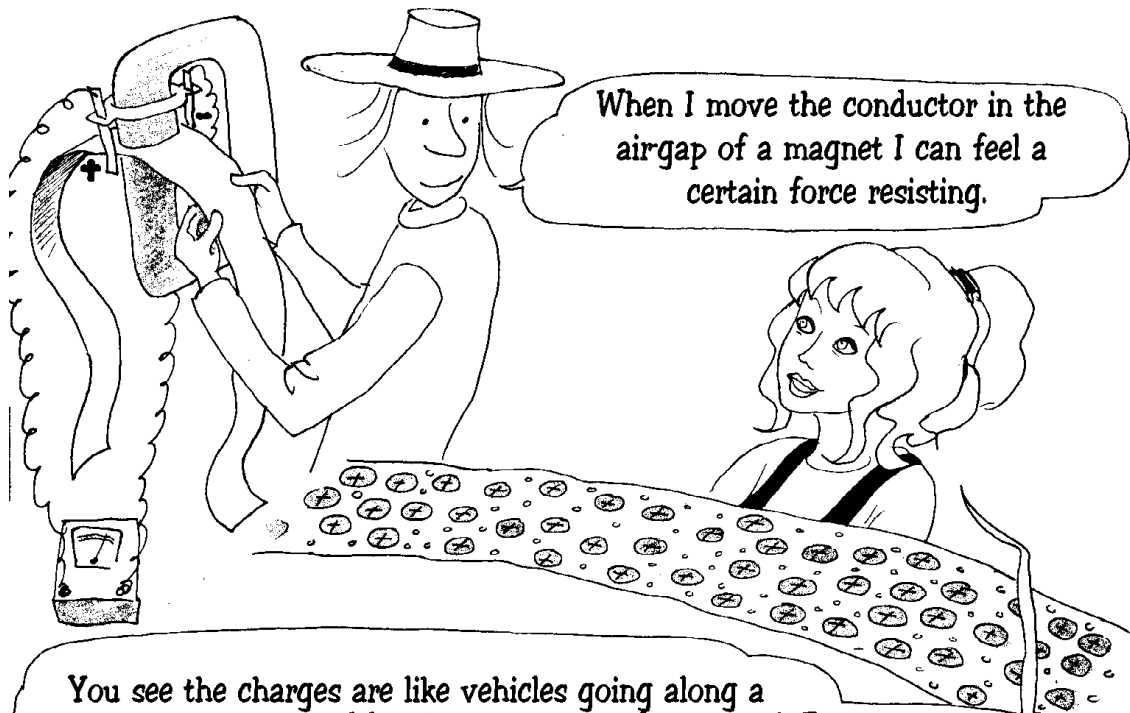
Sophie's right. If we turn a metal disk in the airgap of a magnet it brings about a migration of electric charges, electrons in this case, because the positive charges in the metal can't move within it.



So here is our first **ELECTRIC GENERATOR**

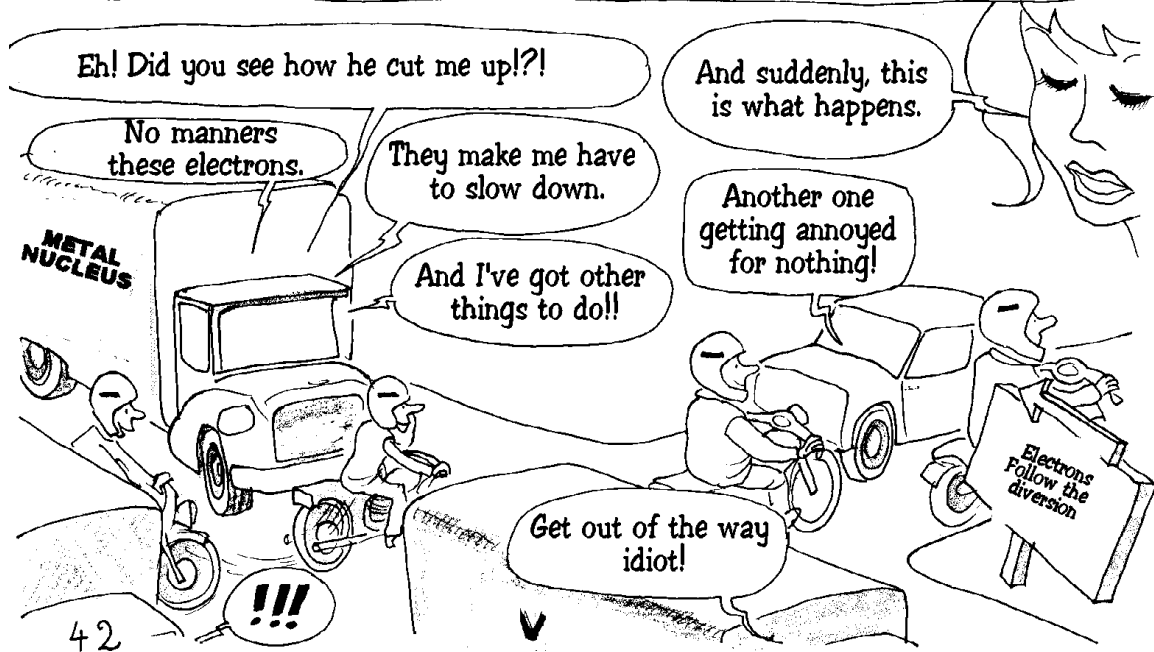


* The smallest magnet of a seamstress is about a hundred Gauss.



When I move the conductor in the airgap of a magnet I can feel a certain force resisting.

You see the charges are like vehicles going along a highway, represented by the movement of the metal. The positive charges are heavy lorries, incapable of turning right or left or changing speed. Their movement depends on the flow of all the other vehicles, each linked to the others. The electrons are like tiny motorbike riders who, at the beginning, also follow the flow.



Eh! Did you see how he cut me up!?!

And suddenly, this is what happens.

No manners these electrons.

They make me have to slow down.

Another one getting annoyed for nothing!

And I've got other things to do!!

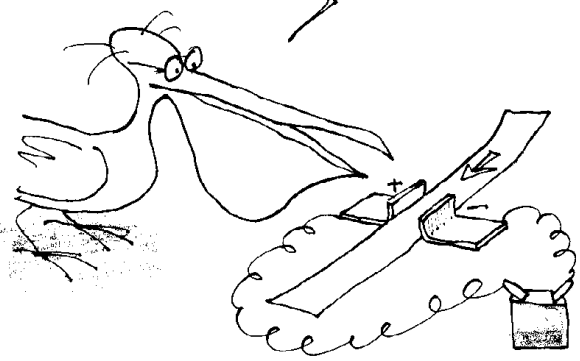
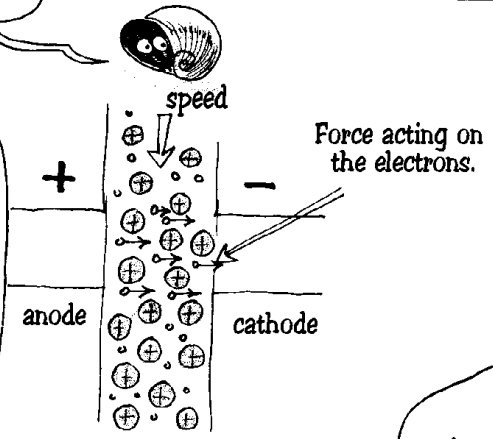
Get out of the way idiot!

METAL NUCLEUS

Electrons Follow the diversion

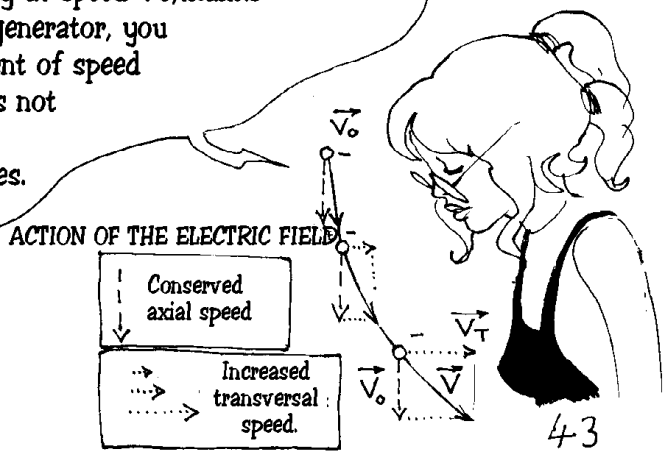
This is the explanation, on a microscopic level, of why a force needs to be exerted, to furnish WORK in order to produce electric energy.

Remove a last doubt. Forget the magnetic field. Couldn't I obtain an equivalent braking force by provoking the lateral diversion of the electron flow towards the electrodes but, this time, in an electric field created by a generator?

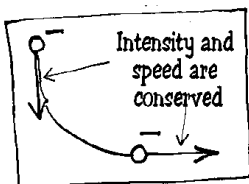


No Leon, that would be completely different.

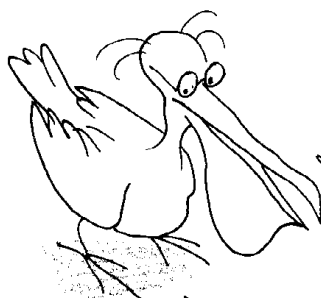
When you act on an electric charge, buried in the heart of an atom flow and moving at speed \vec{V}_0 , thanks to an electric force created by a generator, you are adding a transversal component of speed \vec{V}_t . But the axial component \vec{V}_0 is not modified. Therefore a generator transfers energy to electric charges.



ACTION OF THE MAGNETIC FIELD



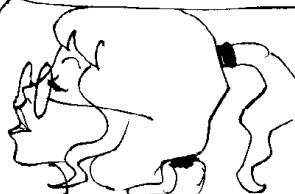
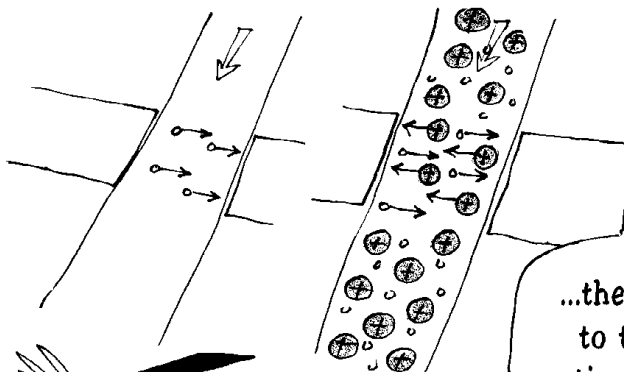
However a transversal magnetic field does not modify the kinetic energy $\frac{1}{2}mV$ of the charged particle. The direction of the speed changes but not its intensity. So the axial component of this speed, parallel to the general flow, diminishes and so a braking of the conductor results.



Yes but in both cases, I'm transversally calling on my population of free electrons...

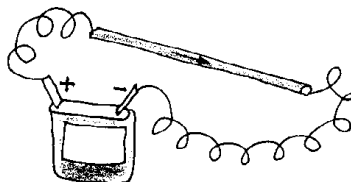
...so I should observe a transversal force.

Leon, you're forgetting that the LAPLACE FORCE is acting on the positive charges and that the forces balance themselves out...

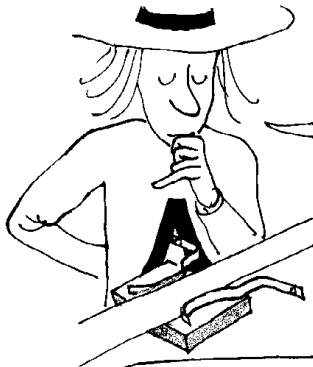


...the electric charges, strongly attached to the conductor transmit this force continually, so the free charges periodically retransmit this force through collisions.

That's why when electricity flows in the wire, it doesn't pull it.

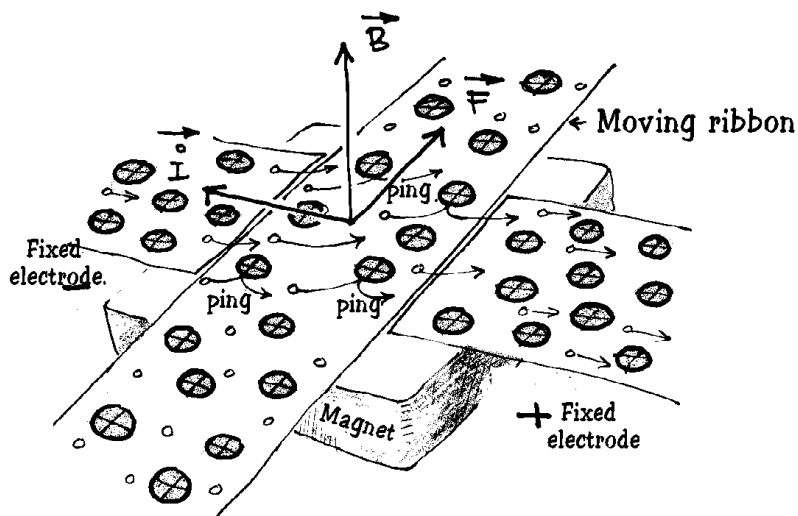


THE ELECTRIC MOTOR



That's given me an idea. By sending a current transversally through the ribbon conductor I am not creating a force. OK, that's been shown, but what happens if I combine the two effects: current flowing from the generator and the rotation of the speed vector because of the effect of a magnetic field perpendicular to the speed of the charges?

The generator will start to move electrons which will tend to cross the ribbon, passing from the cathode to the anode. But the magnetic field, by curving their trajectory inwards, will transmit part of the acquired impulsion along the axis of the ribbon, which will thus be subjected to a force.



An analysis of microscopic behaviour, at atomic scale, allows us to work out the macroscopic behaviour, at the level of our experiment.

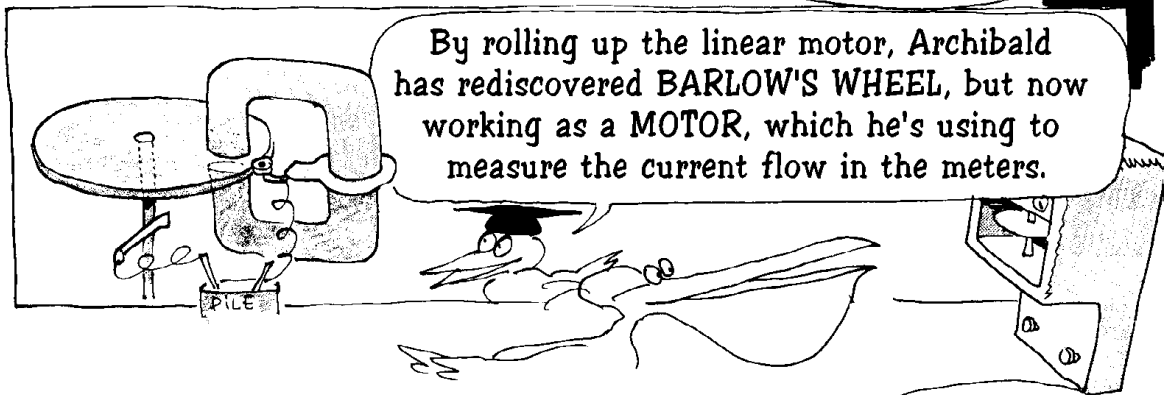


It works!

Sophie, can we pull a liquid, or even a gas, in the same way, a sort of LINEAR MOTOR?



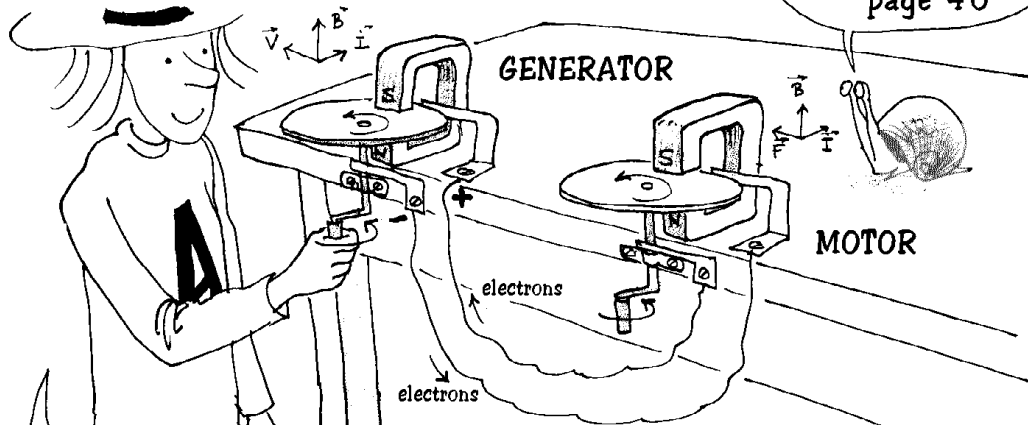
of course...(*)



By rolling up the linear motor, Archibald has rediscovered BARLOW'S WHEEL, but now working as a MOTOR, which he's using to measure the current flow in the meters.

REVERSIBILITY

Using only the law defined on page 40

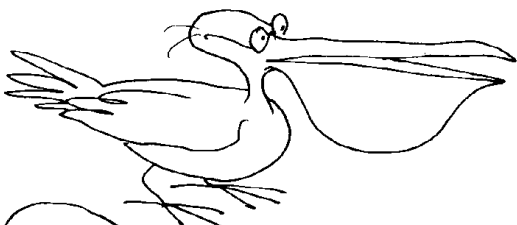
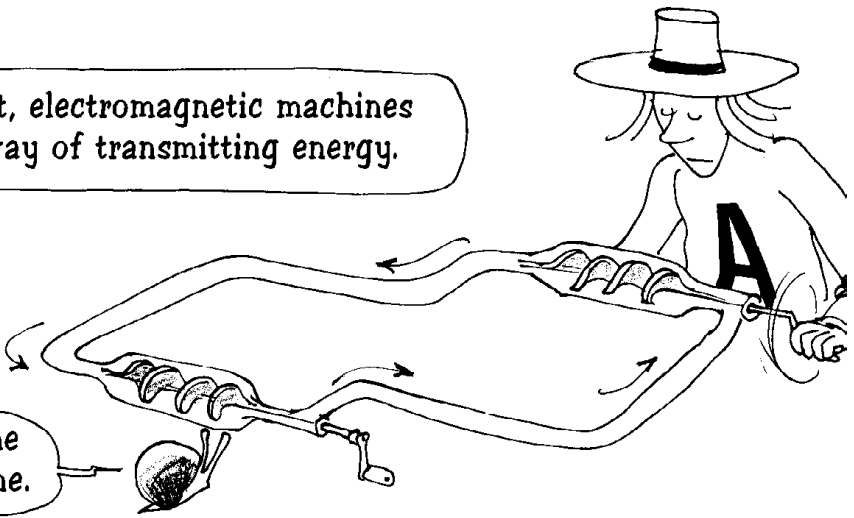


It's strange isn't it? The same machine can be used both as a generator and as a motor.

Looked at like that, electromagnetic machines are a practical way of transmitting energy.



We can do the same thing with a turbine.



By linking the handles you should be able to create PERPETUAL MOTION.



Leon, you know quite well that energy is dissipated in conductors through friction.

In electrical conductors, stationary or moving, electric charges are accompanied by numerous collisions with non-charged particles.

Move along there!

Even when we're parked we get into trouble.

I'll show you with your nice new atom!

Did you see the way he cut across?

Darling, stay calm.

Look at that, just look at that!

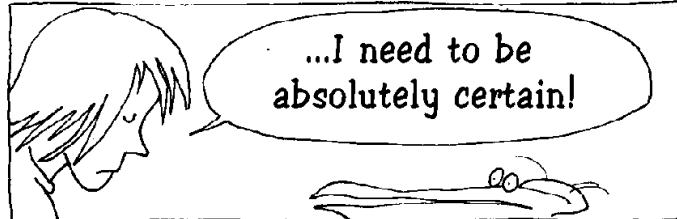
They cross any old how!

RELATIVITY

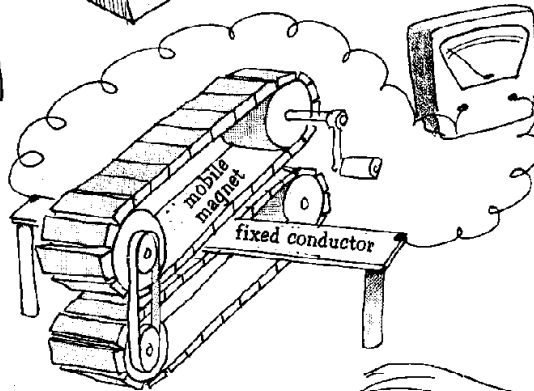
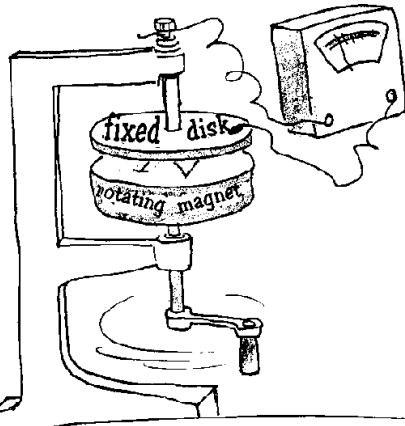
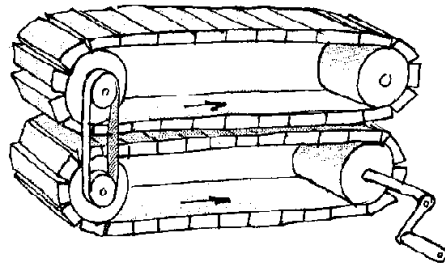
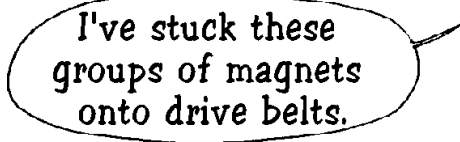
Tiresias, I've just had a good idea...



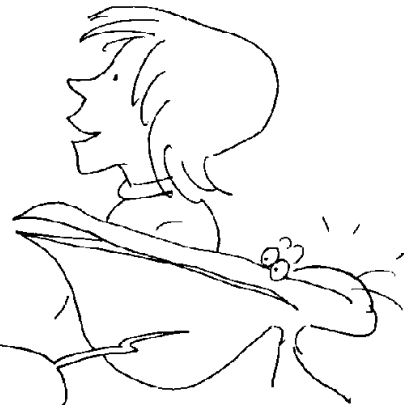
...I need to be absolutely certain!



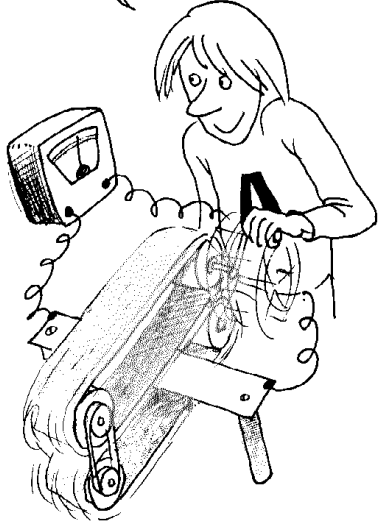
I've stuck these groups of magnets onto drive belts.



Instead of moving the conductor along the force lines of a magnetic field (constant in the interaction region), I immobilise the conductor and... I turn the field!



Look, I'm producing a current, that's certain.

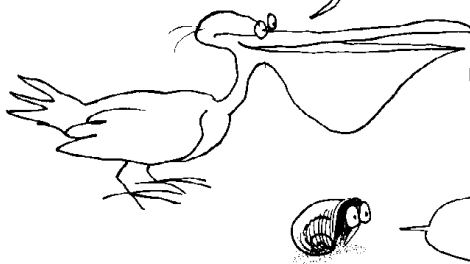


That just means that in the LAPLACE FORCE, what counts is the speed of the charges and the magnet IN RELATION TO EACH OTHER



MAGNETS

Sophie, what's a MAGNETIC FIELD.

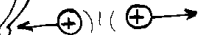


A better question would be : WHAT USE IS IT?

What do you mean, what use is it?

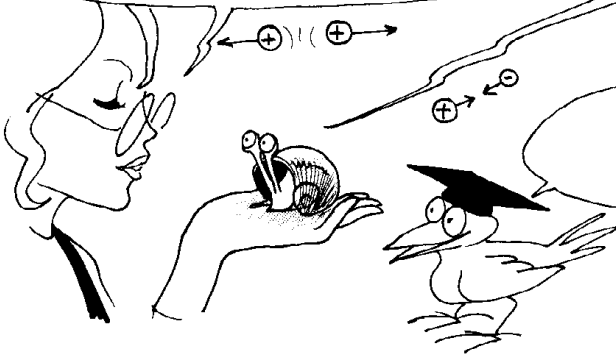


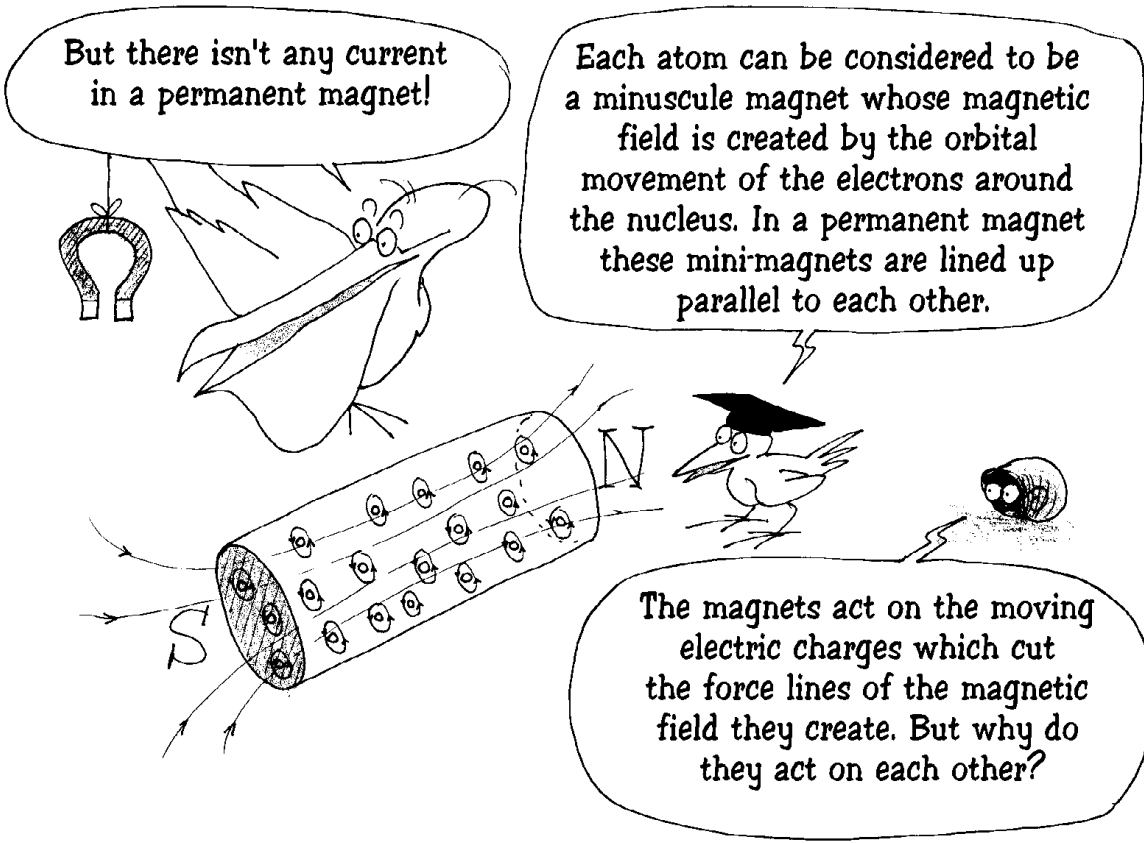
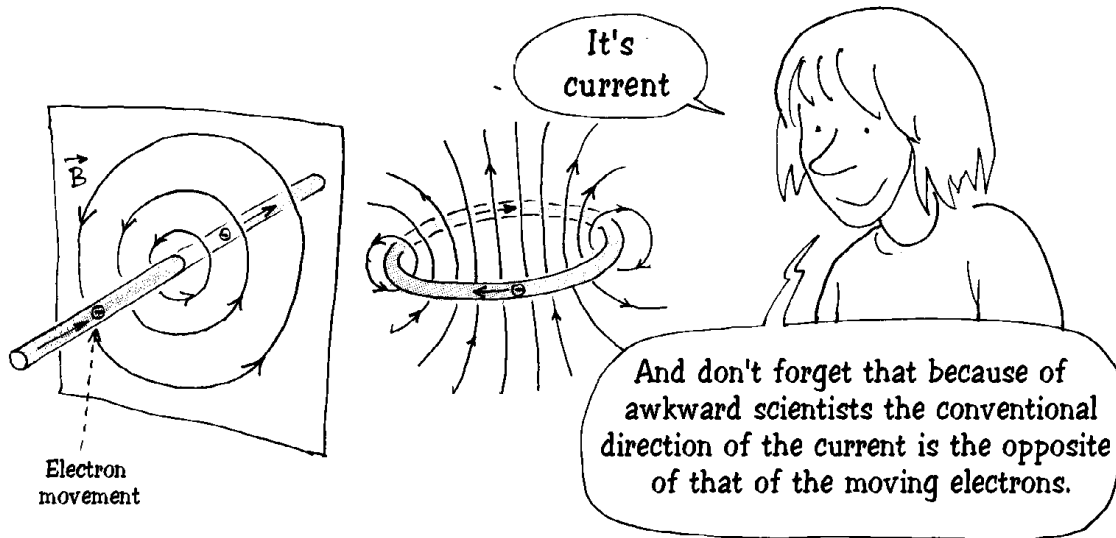
Two electric charges at rest attract or repel each other according to whether they have the same or different signs.

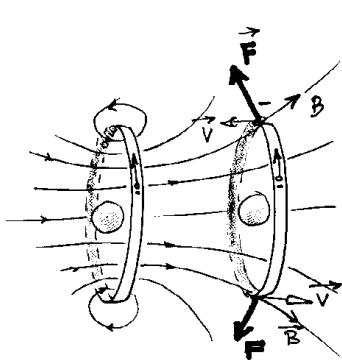


and they are also subject to a force when they move in relation to the lines of force in a magnetic field. ...

OK, but what creates these magnetic fields?

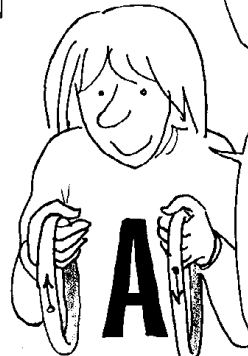
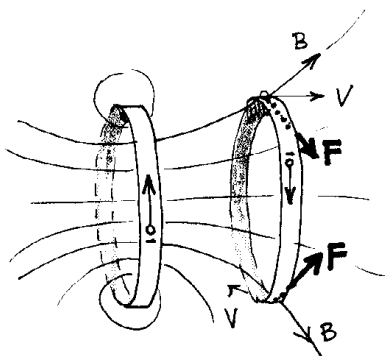






If I place two spires opposite each other, with currents running through them in the same direction, the electrons are submitted to a force tending to:

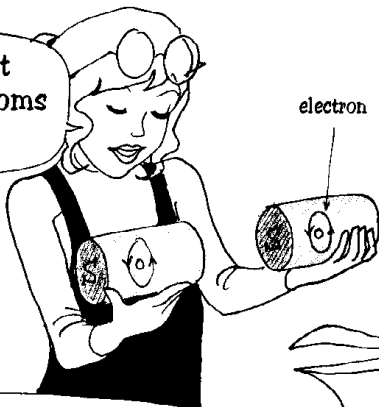
- dilate each spire
- bring the spires closer together.



But if I reverse the direction of flow of the electrons in the second spire, the Laplace force will tend to:

- Make each spire contract
- Push this spire away from the other one.

It's a bit like what happens with the atoms of two magnets.



electron

Yes but according to the diagram of earlier, a spire is not affected by a uniform magnetic field applied in the direction of its axis.

In the same way as a bar magnet is not affected by a uniform magnetic field applied in the direction of its axis.

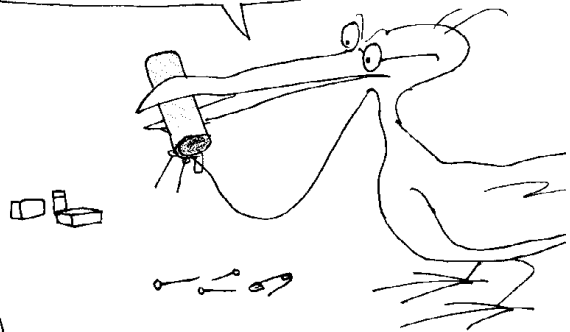
Logical, otherwise, to push itself forward it would just need to hold on to a good compass.



However a spire placed in a magnetic field tends to turn in such a way that its own field will line up with the first. This is the basis of the **MOBILE FRAME GALVANOMETER**. In fact a compass is nothing more than a collection of galvanometers of the same type.



So, can someone explain to me why a magnet attracts iron but not lead, or sugar?

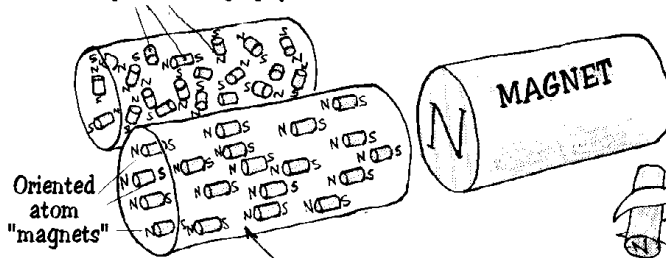


It's simple: iron atoms are also little magnets. They also have a certain mobility. When approached by a sufficiently powerful magnet the iron atoms turn and align, and the iron itself also becomes a magnet whose field is superimposed on that of the inductor magnet.



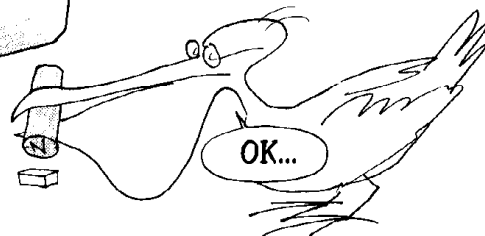
Nothing with sugar

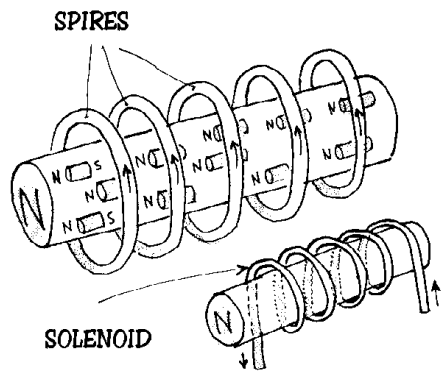
Atom "magnets" (varying orientation)



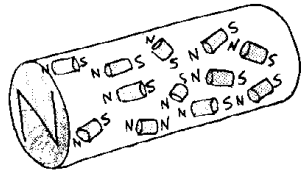
Oriented atom "magnets"

the piece of iron has become a magnet

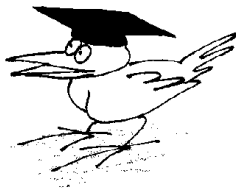




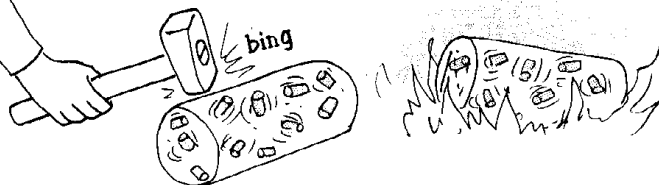
I understand now why we put an **IRON CORE** in **ELECTROMAGNETS**. It reinforces the fields created in the system by the spires.



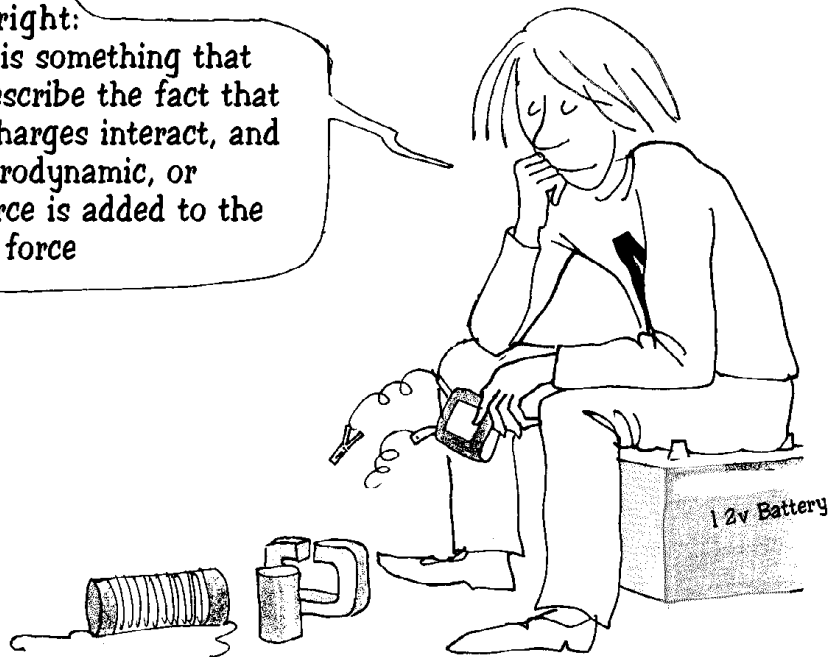
When we take away the magnetising magnet or the solenoid, the iron's atom-magnets will retain, up to a point, their orientation. A **RESIDUAL MAGNETISM** will subsist...



and that we can make disappear by giving mobility back to the atom-magnets either by heating the iron, hitting it, or putting it in a variable magnetic field, as I did with a small magnet on a pencil for the pigments of the television tube that had been accidentally magnetised.

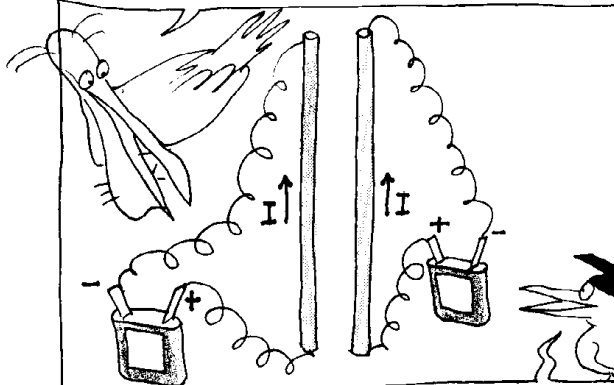


So if I've got it right:
 the magnetic field is something that
 was invented to describe the fact that
MOVING electric charges interact, and
 that this new electrodynamic, or
 electromagnetic force is added to the
 basic, electrostatic force



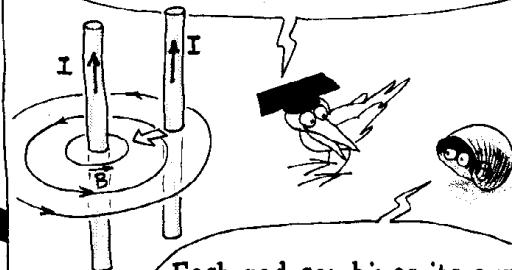
RELATIVITY AGAIN

How can we measure a magnetic field
 as objectively as possible?

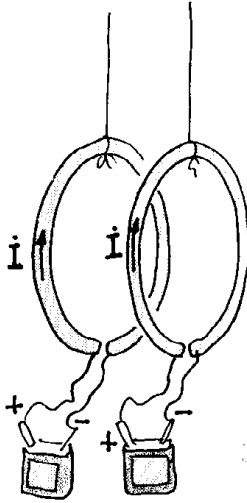


Well we can put deux rods parallels to
 each other and with an electric current
 of intensity I flowing through them

Under these conditions the two
 rods will be subject to a
 mutually equal force of attraction.



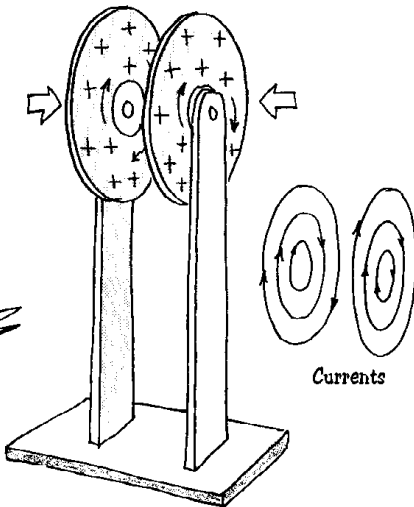
Each rod combines its own
 current with the magnetic
 field created by the other
 rod.



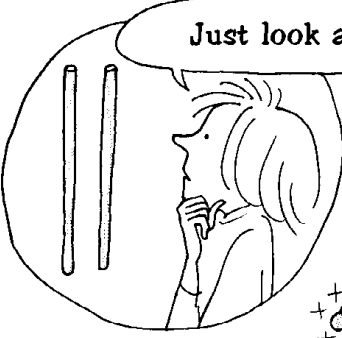
We could roll the rods so that they made two spires which, as they have parallel currents running through them, would move towards each other



As we saw already on page 51

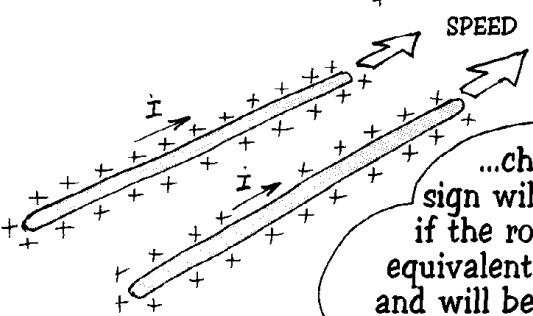
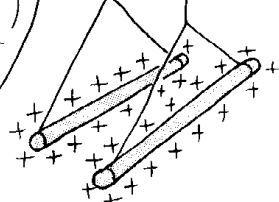
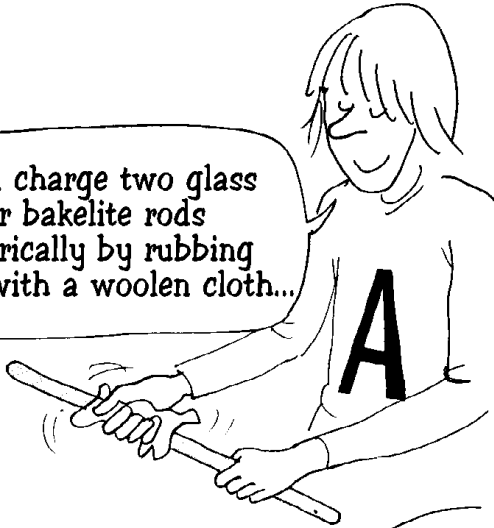


In the same way we can send electric currents with the same sign through disks facing each other and so make them turn. This is equivalent to current and is accompanied by an electromagnetic force.



Just look at that...

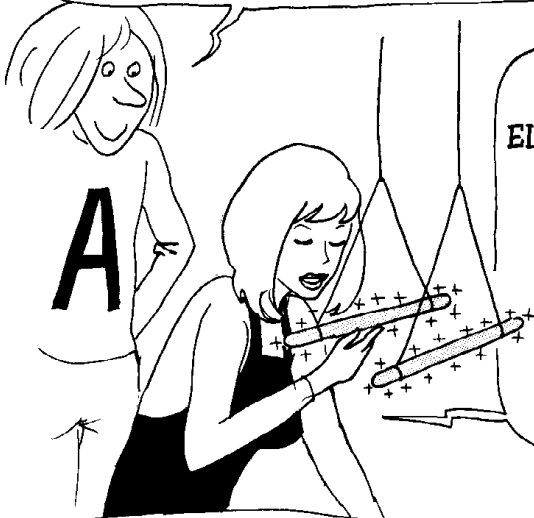
I can charge two glass or bakelite rods electrically by rubbing them with a woolen cloth...



...charges of the same sign will repel each other but if the rods move like this, it is equivalent to two parallel currents and will be accompanied by a slight attractive component.



The earth moves around the sun which itself orbits in our galaxy, the Milky Way, at 234 km/h. The galaxy may also be moving in relation to the universe. It's amazing Sophie: By pointing these two parallel, electrically charged rods to the sky in any direction and in measuring the force acting between them, we should be able to work out the direction of our movement in the Universe and our speed!



No, you won't measure anything. This **ELECTROMAGNETIC FORCE**, associated with **MOVEMENT**, is only perceptible by an observer who moves in relation to the charges. But whatever our movement, in relation to the sun, to the galaxy or the cosmos, we are moving at the same speed as the rods.

Electromagnetism is essentially relativist.

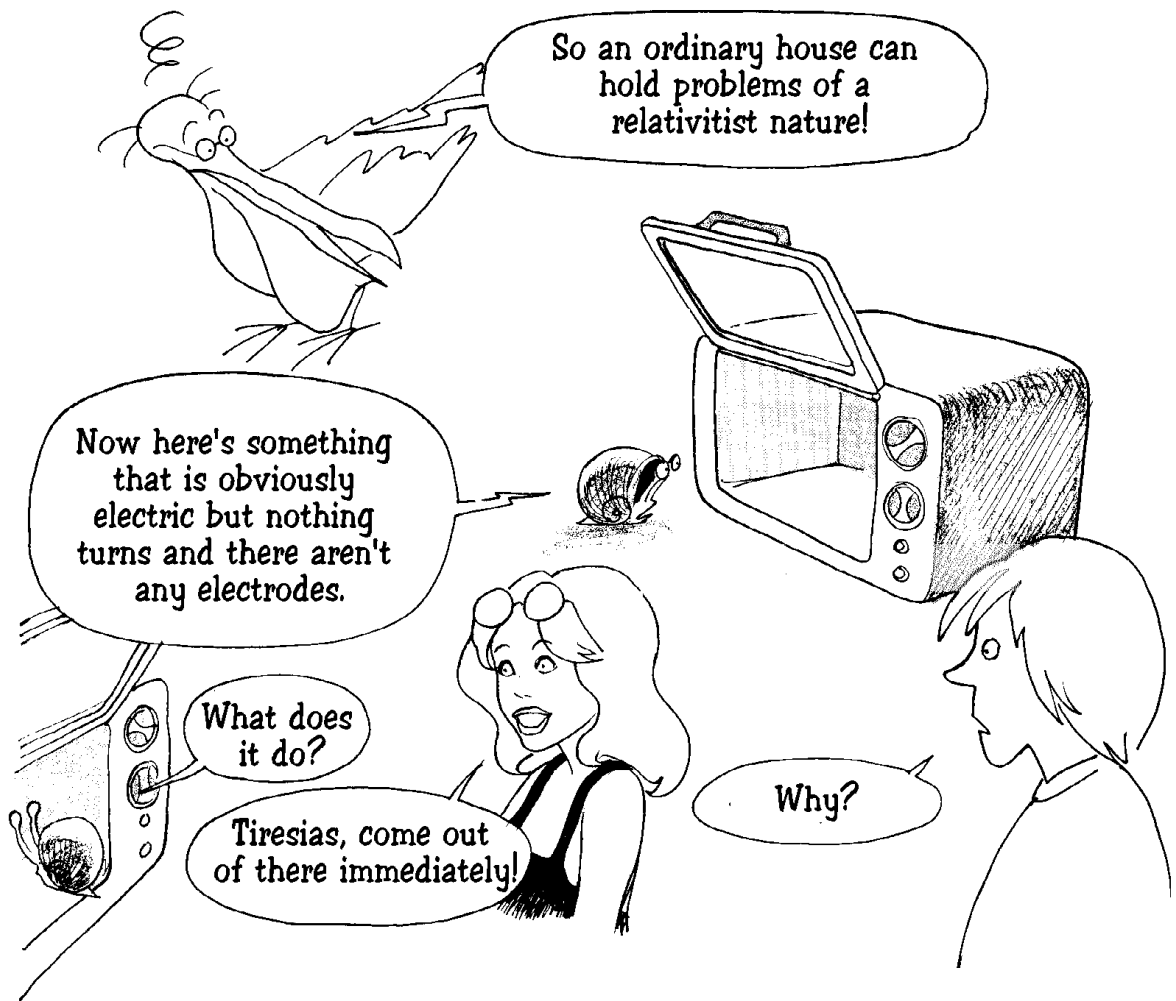


It's true that the experiment Achibald suggested recalls that of MICHELSON (*) at the beginning of the twentieth century. It consisted of measuring the speed of light in all directions in order to discover the absolute direction of the earth in the Universe.

I can't say I'm surprised because I was told that light was an electromagnetic wave.



(*) Michelson, Physician. Nobel prize 1907



So an ordinary house can hold problems of a relativist nature!

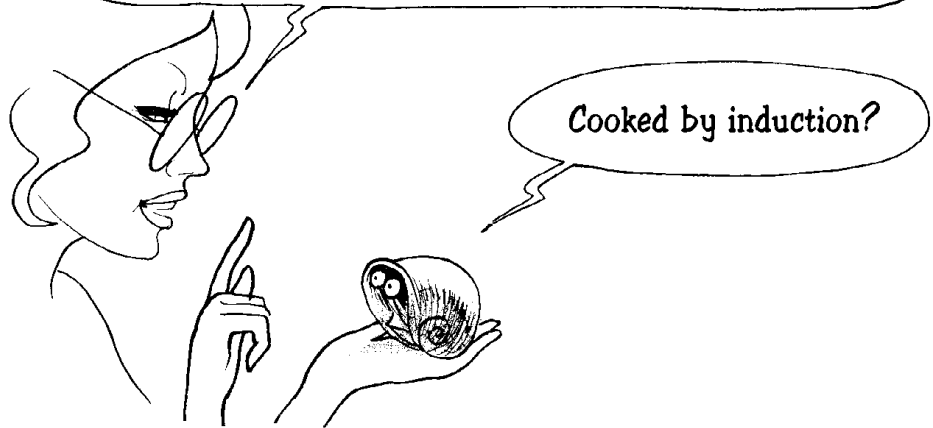
Now here's something that is obviously electric but nothing turns and there aren't any electrodes.

What does it do?

Tiresias, come out of there immediately!

Why?

This system allows the transmission of energy over a distance. If it turned itself on you would have been cooked by induction.

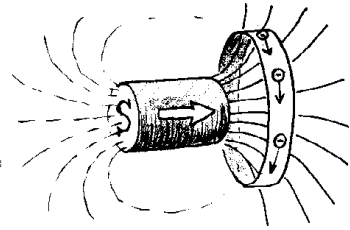
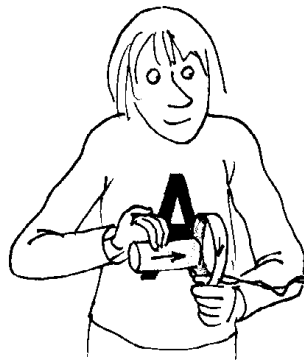
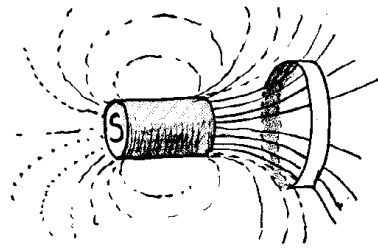


Cooked by induction?

INDUCTION

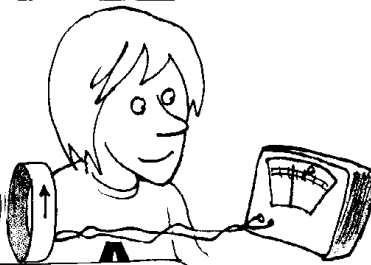


Look. Archibald has put a copper spire opposite a permanent magnet. A certain number of the force lines pass through the interior, the rest are outside.

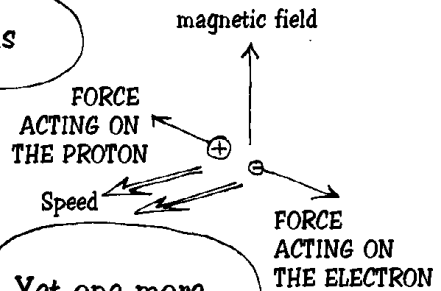


Now he's bringing the magnet closer to the spire, in other words he is moving the group of force lines as a block. As they cross the metal of the spire an electromagnetic force results which, acting on electrons, is an **INDUCED** current.

If the magnet and the spire are static in relation to each other, the current cancels itself out.



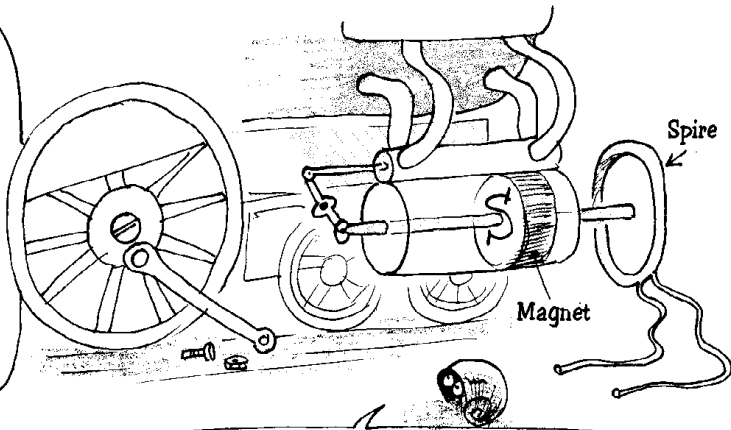
But if you pull the magnet, the current is reversed.



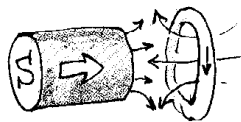
Yet one more application of **LAPLACE's** law.



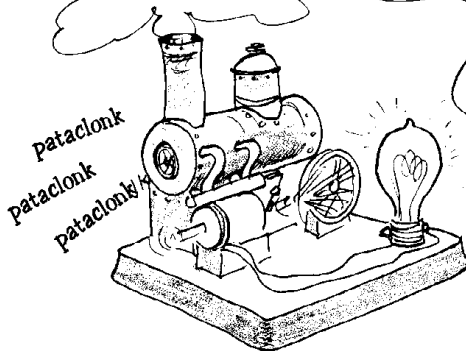
Look Tiresias,
I've modified this steam
engine by replacing the
piston with a magnet, so
you can make to-and-fro
movements and create an
ALTERNATING CURRENT
in the spire.



If the piston slides without friction we will
have found a way to produce free electric
energy, if we ignore, of course, a small loss
through the Joule effect in the spire.

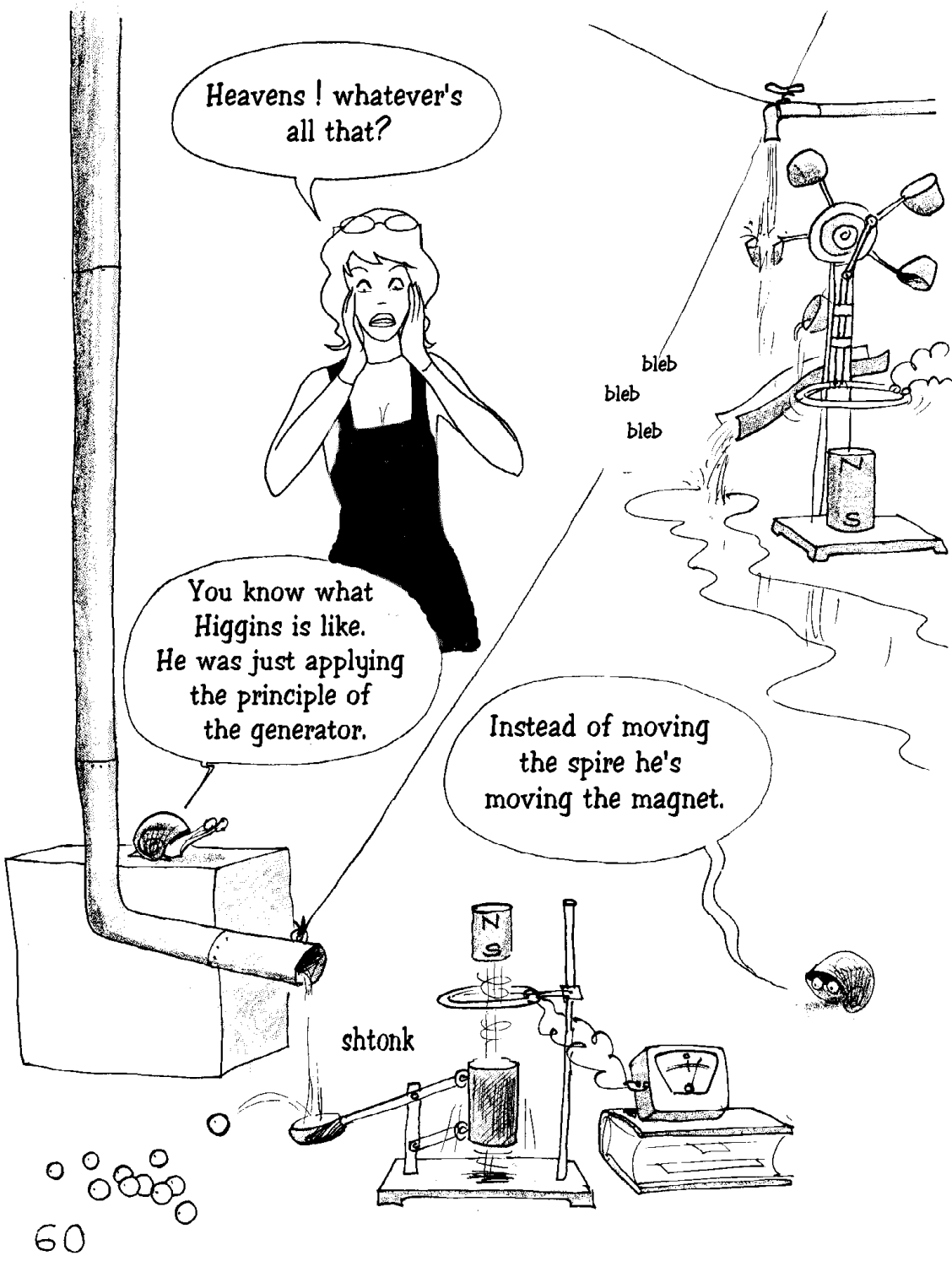


You're forgetting that the passage
of current will create its own
magnetic field which will oppose
the movement of the magnet-piston
(LENZ'S LAW). So **WORK** will have to
be applied to produce this energy.



So here is our first
alternating current generator.





Heavens ! whatever's all that?

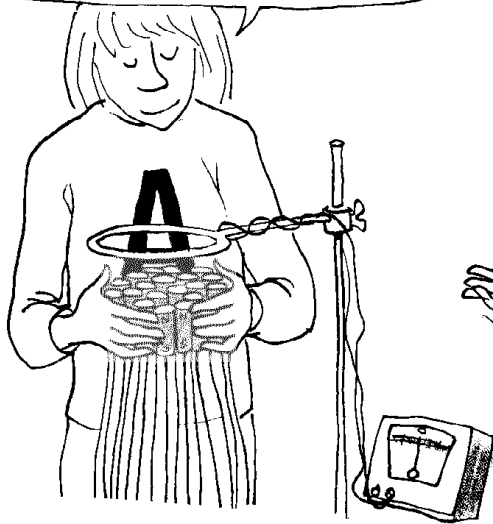
You know what Higgins is like. He was just applying the principle of the generator.

Instead of moving the spire he's moving the magnet.

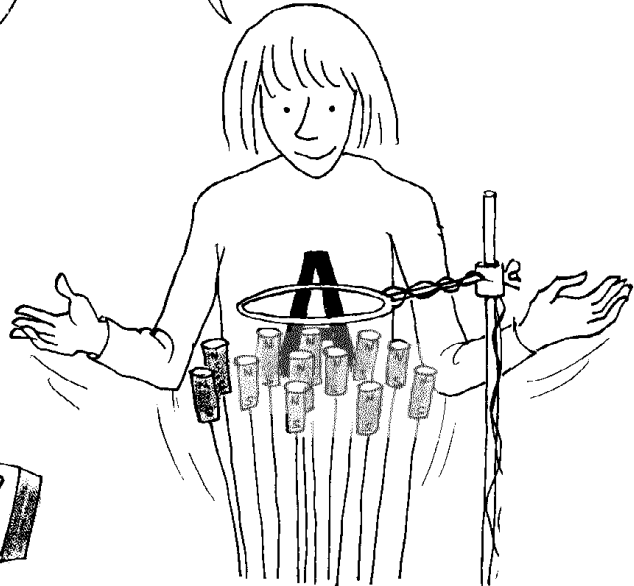
bleb
bleb
bleb

shtonk

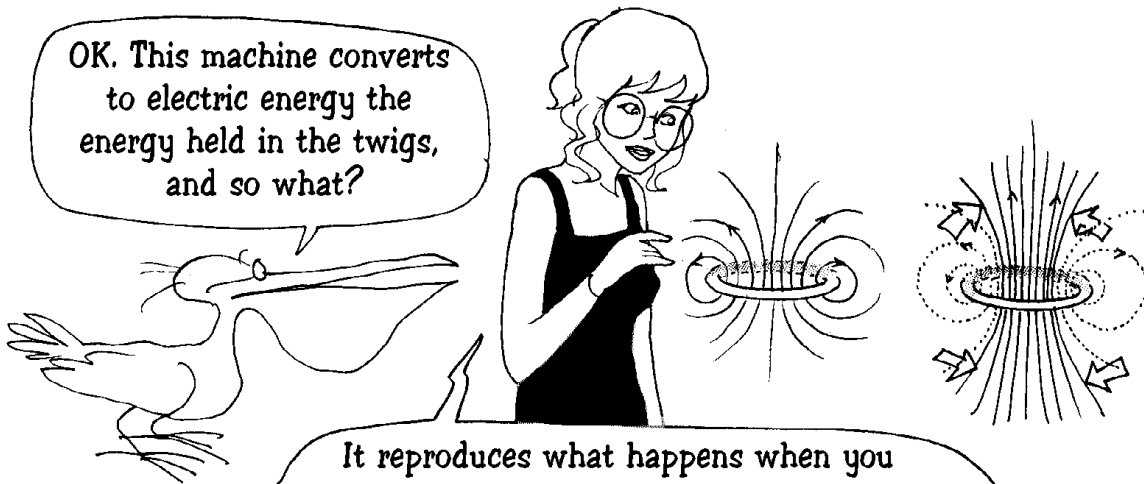
As we're producing alternating current by moving one or several magnets in front of a spire, I've invented this TWIGGO-GENERATOR. I've attached the magnets to flexible rods, twigs...



...when I let them go they separate and come back together alternately and produce an alternating current in the spire.

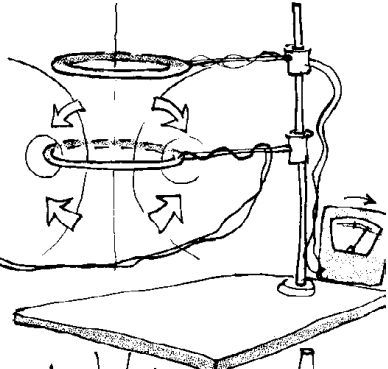


OK. This machine converts to electric energy the energy held in the twigs, and so what?



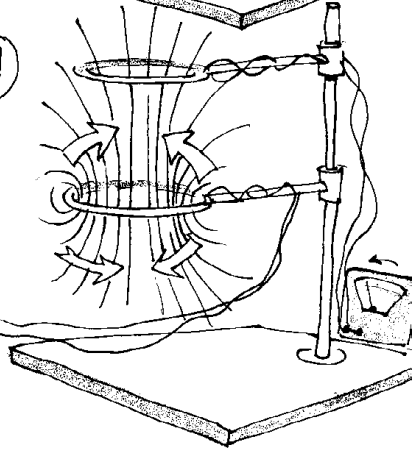
It reproduces what happens when you increase the current passing through the spire. It's as if new force lines are created on its surface which "compress" the old ones, like in a bundle of twigs.

And vice-versa. When we reduce the current the spire "swallows" the lines of the field one after the other and the bundle comes loose.

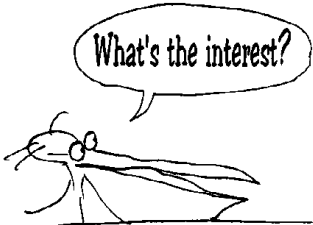


hop!

This explains why a spire transversed by an alternating current can transmit energy at a distance to another spire.



HF HEATING



What's the interest?

It's a very efficient heating system. We could completely cook a finger with a ring on it if it was put into a space surrounded by a variable magnetic field

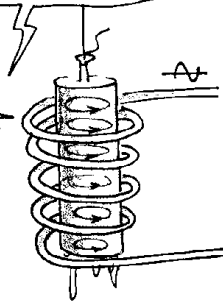


We can melt gold bars.

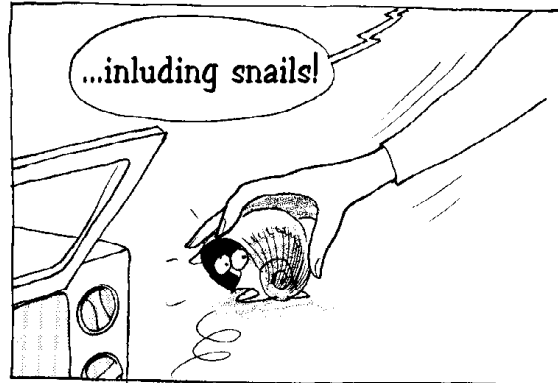
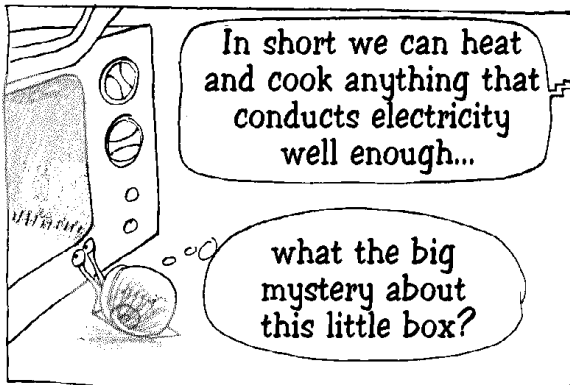
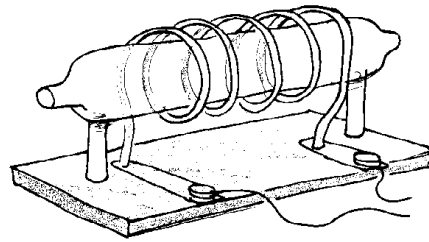
Solenoid



We can also heat up conductor blocks and create an infinity of current loops.



We can also heat a gas by sending a high frequency current through a coil.



EPILOGUE

