

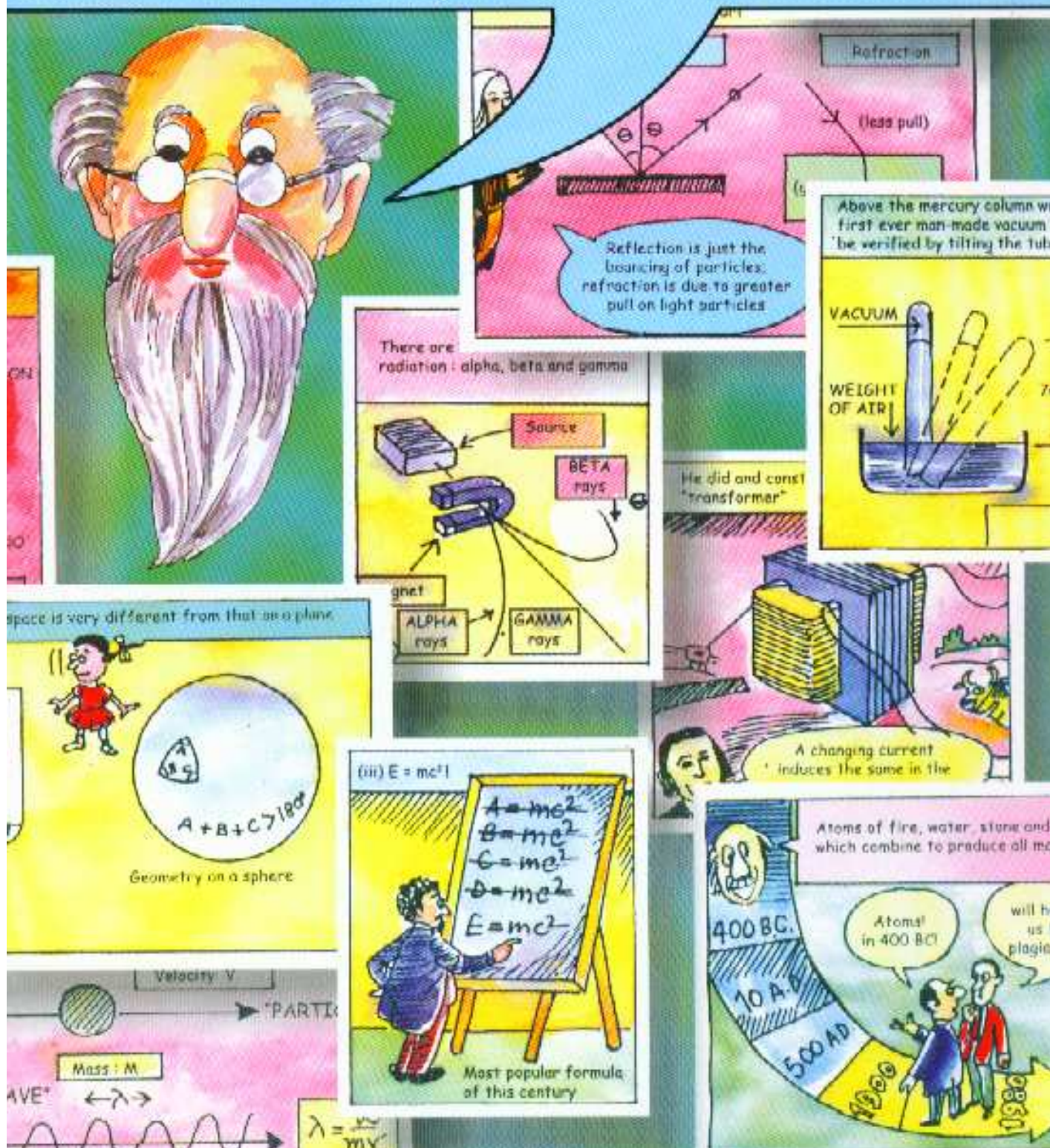
# THE STORY OF PHYSICS

Script by

**T. PADMANABHAN**

*Illustrations by*

**KEITH FRANCIS**


Redrawn by: **Avinash Deshpande**




# The STORY of PHYSICS

OH BOY! WHAT  
WILL THEY DO NEXT?


SCRIPT by  
T.PADMANABHAN  
ILLUSTRATIONS by  
KEITH FRANCIS  
Redrawn by  
Avinash Deshpande




A long time ago, about 10,000 BC,  
there was home science....



..... and even appropriate technology

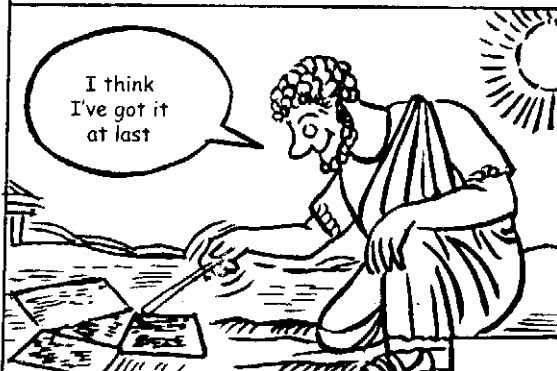


The earliest civilisations used many  
engineering concepts....




but physics - a  
scientific  
method that  
attempts to  
explain nature  
based on a set  
of laws -  
probably did  
not exist till  
the time of  
the Greeks.

Greece produced many thinkers and scholars:  
like Pythagoras (582 - 497 BC)




....who conducted experiments in harmony by  
plucking strings. When there was a simple ratio  
like 2:3 and 1:2 between the lengths a and b,  
the tune was pleasant




With more complicated ratios, the results were  
not harmonious

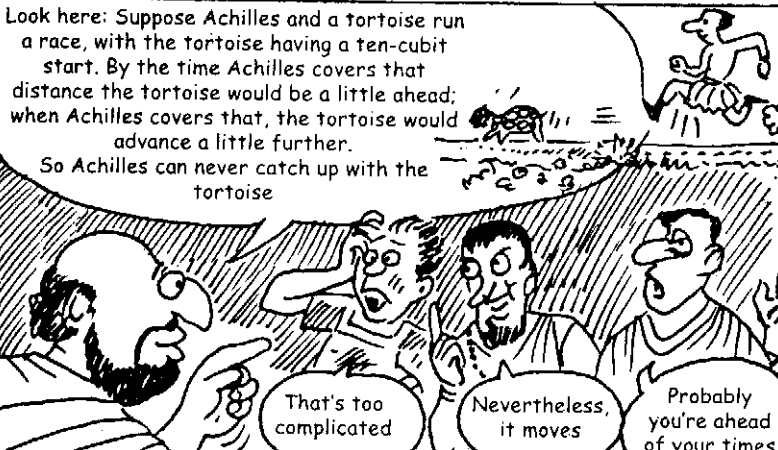
By Zeus! Pytho  
must be trying  
419:420




Zeno, a contemporary  
of Pythagoras,  
nearly proved  
that motion is  
impossible  
(Zeno's paradox)

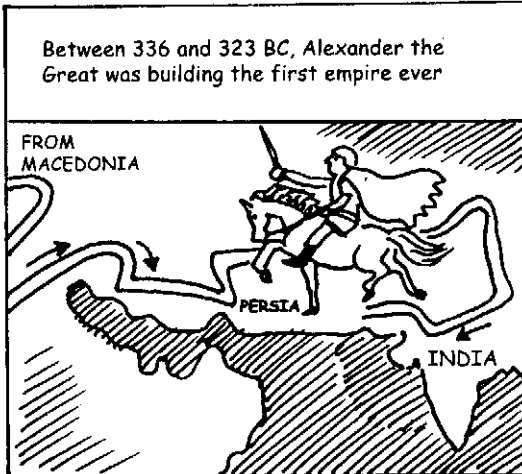
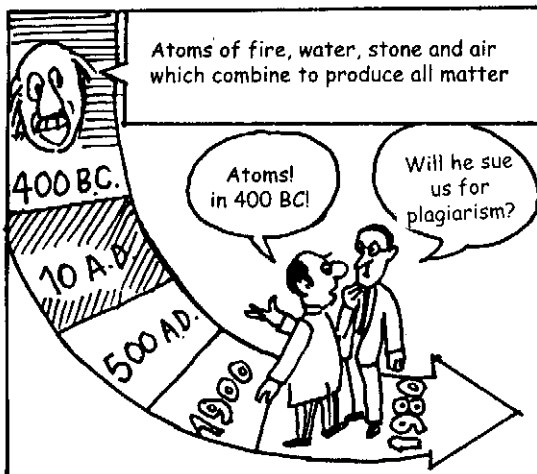


Look here: Suppose Achilles and a tortoise run  
a race, with the tortoise having a ten-cubit  
start. By the time Achilles covers that  
distance the tortoise would be a little ahead;  
when Achilles covers that, the tortoise would  
advance a little further.  
So Achilles can never catch up with the  
tortoise

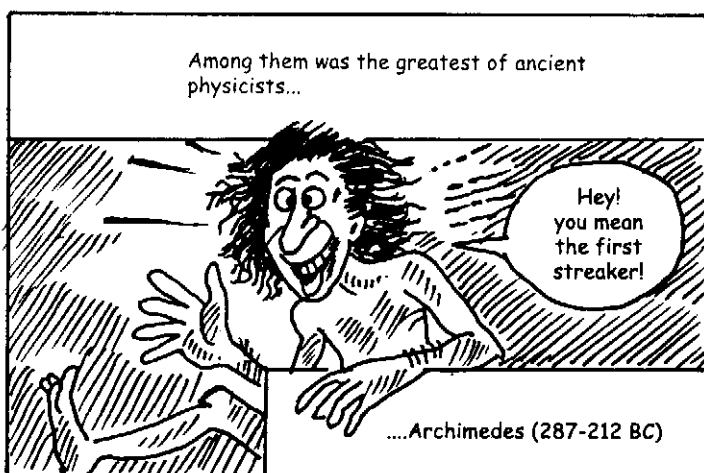
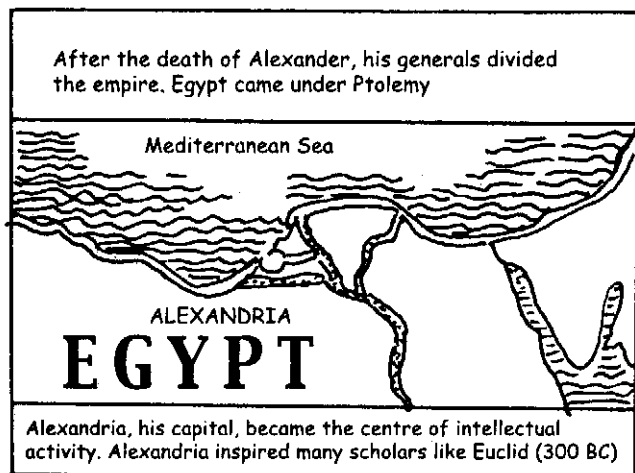
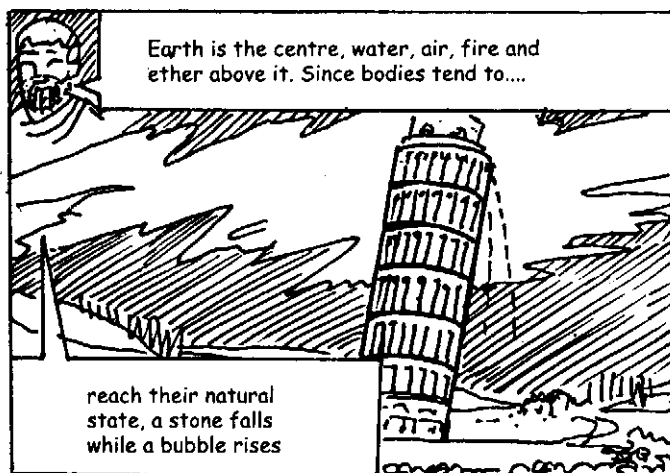
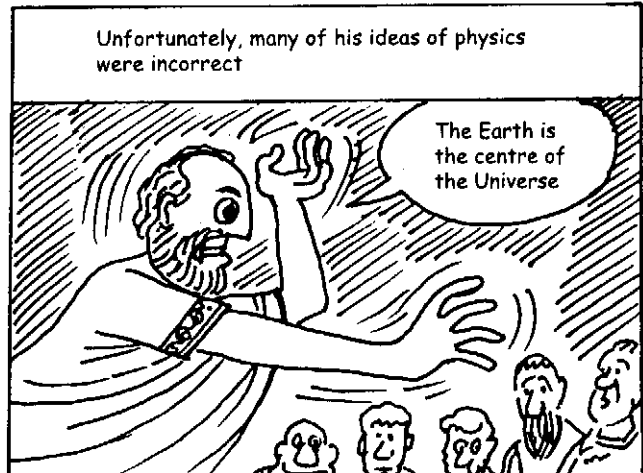
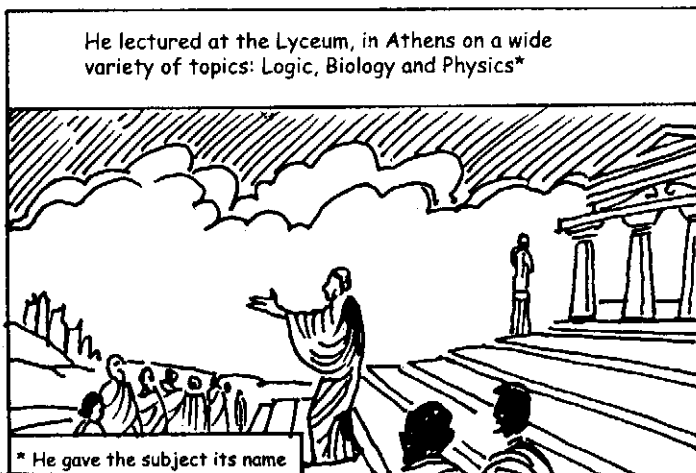


Democritus (~ 400 BC) tried to resolve Zeno's  
paradox by suggesting that matter is not  
infinitely divisible

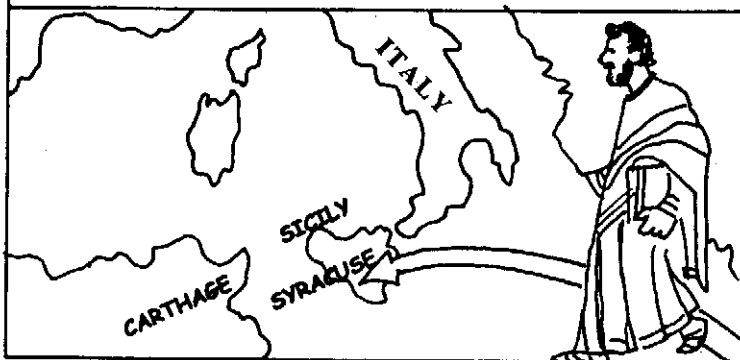




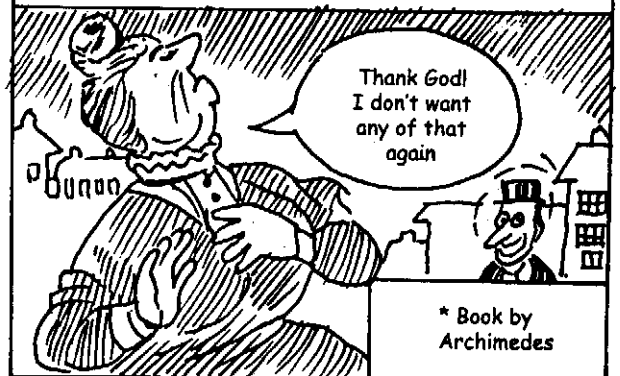
Around the same time his tutor Aristotle (384-322 BC) was attempting to build an empire of knowledge



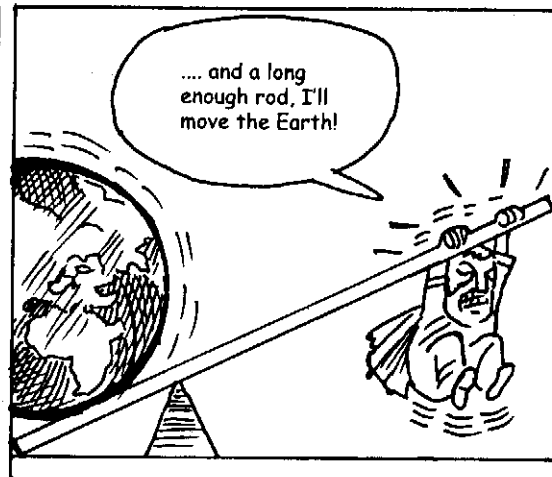
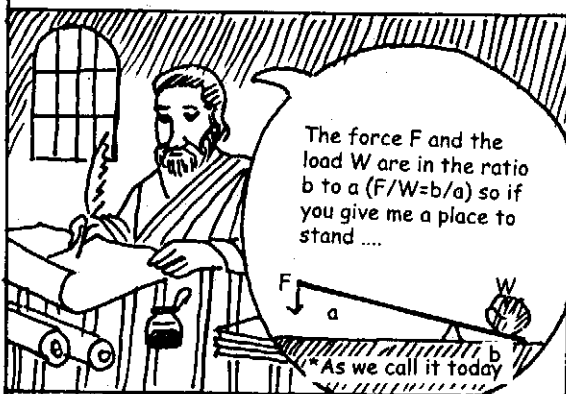
After his education in Alexandria, Archimedes returned to Syracuse, his native place, and enjoyed the royal patronage of Hieron



His law of "Floating Bodies"\* and the story of "Eureka" are too famous to be retold

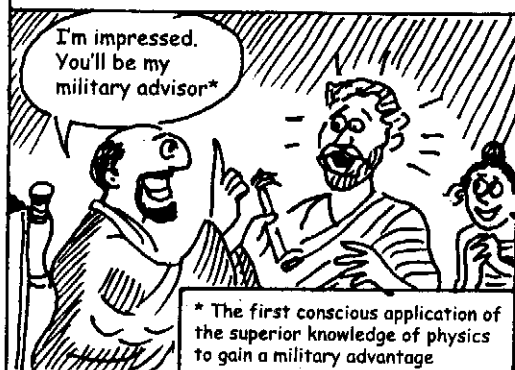


He was the first to develop the principle of statics in his book on the equilibrium of planes\*



Ha! that's a lot of words! What about moving a ship?

The story goes that Archimedes actually pulled a sheep ashore with pulleys and levers

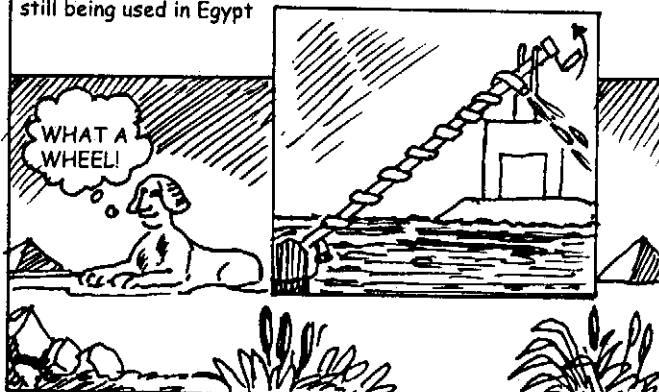


After Hieron, his grandson Hieronymus became the king. During the 2nd Punic war (218 BC), seeing the success of the troops of Carthage, led by Hannibal, Hieronymus broke his treaty with Rome and sided with Carthage. This led the Romans to lay siege on Syracuse

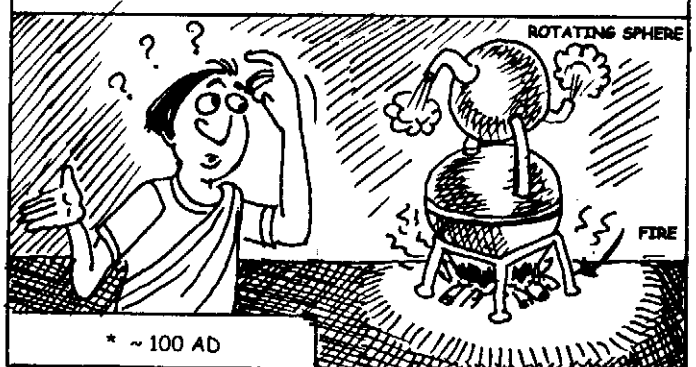
It is said that the war machines made by Archimedes kept the Roman General Marcellus at bay for more than two years



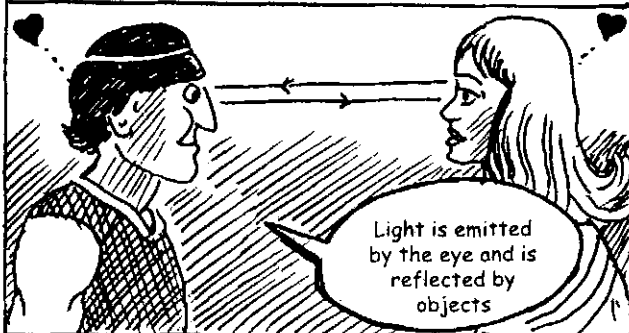
When the Romans finally took the city, Archimedes was killed by a Roman soldier. One of his inventions the water wheel is still being used in Egypt



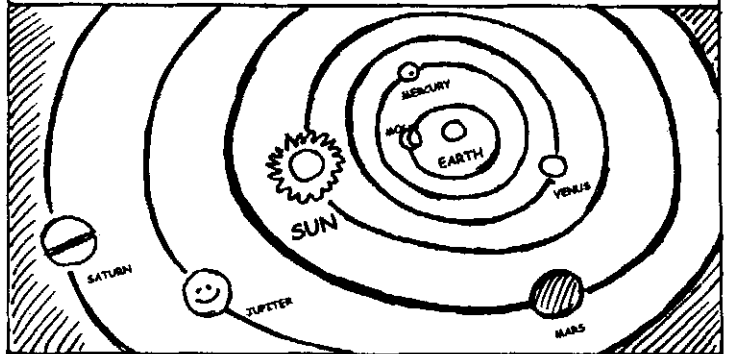
By 30 BC, Egypt was a Roman province having lost much of its glory. Among the few more geniuses it produced was Hero\* who made the first steam engine\*



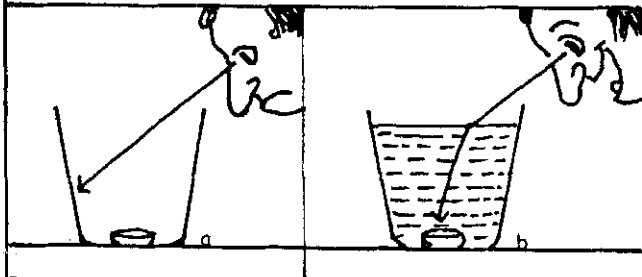
He also constructed the siphon and wrote books on mechanics and catoptrics. His views on vision reflected the thinking of those days



Another great Alexandrian was Ptolemy (127-151 AD) who believed the Universe was concentric with the Earth at its centre. We now know he was wrong

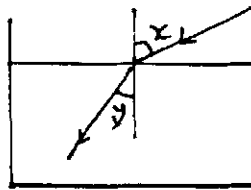


He also studied optics, especially the process of refraction



Refraction helps you to see the coin in (b) because light bends on crossing the boundary of water

Ptolemy conducted an experiment and carefully noted the angles  $x$  and  $y$ ....



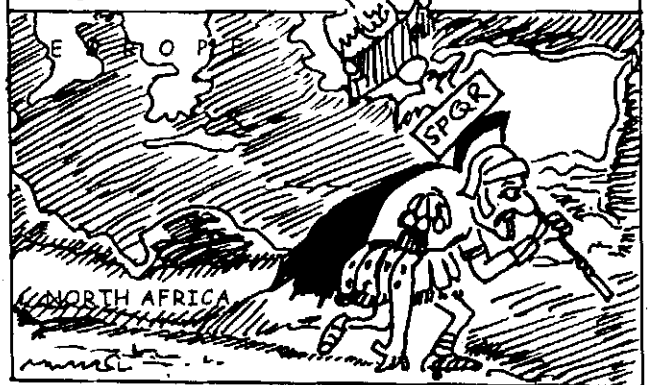
$x$	$y$
$10^\circ$	$8^\circ$
$40^\circ$	$29^\circ$
$50^\circ$	$35^\circ$
$80^\circ$	$50^\circ$

.... but failed to arrive at the formula connecting  $x$  and  $y$

The law  $\sin x$  and  $\sin y$  is a constant. It's now called as Snell's Law



After Ptolemy, Europe was in turmoil. The Roman empire fell, leaving mutilated kingdoms...



Hey! What's happening?



Shh! the dark ages are here.

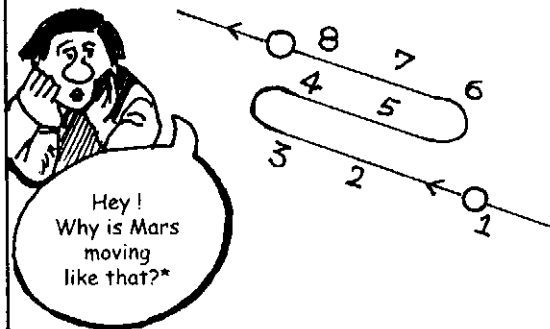


Arabian tribes swept through the Byzantine Empire and occupied Egypt in 640 AD. They preserved and transmitted Greek science to Renaissance Europe

The Renaissance was not really a rebirth for science. Europe was dominated by religious zealots



The religious faith of the post renaissance era did not encourage curiosity ....



Why don't we ever see Venus overhead?\*



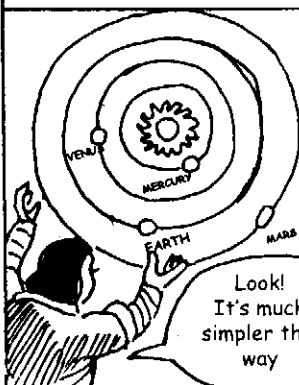
\*These questions have no simple answers in Ptolemy's system of the universe

Then came a man....

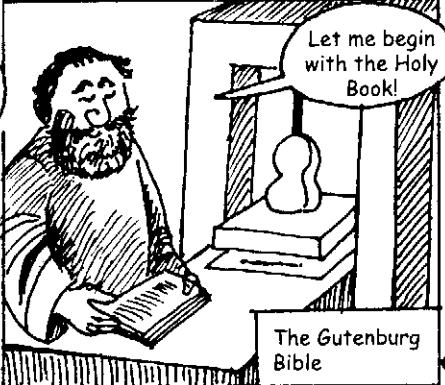


.... Nicolaus Copernicus (1473 - 1543)

.... Who stopped the sun and set the Earth in motion!



Gutenberg had invented printing nearly 100 years before this ....



The "unholy" tenets of Copernicus were printed in 1543....



But didn't Nicolai say in his book that "it does not represent reality"

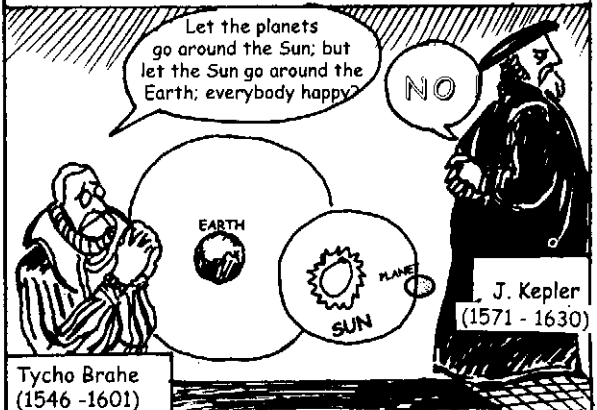


All the same, some accepted the Copernican model at once...

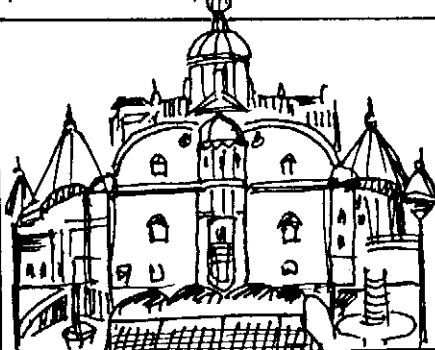


Reinhold (1511-53) published the "Prussian table of planetary positions" in 1551.

.... and some tried to bargain a bit

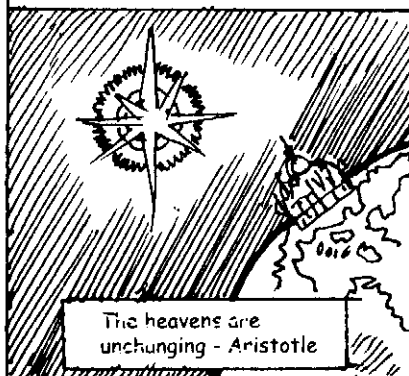


Ironically Tycho's observations made in his private observatory Uraniborg, Denmark....

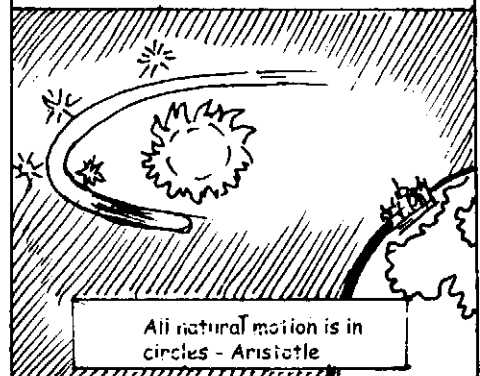


....had enough in them to support the Copernican model

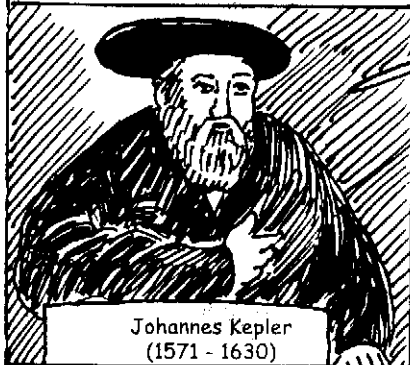
Tycho observed the flaring up of a new star ("supernova") (1572 AD)



and a comet with an elongated orbit....

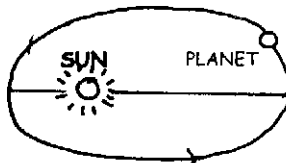


But the coup de grace to "Greek Physics" came from Tycho's student



Painstaking analysis of Tycho's data led Kepler to his three laws of planetary motion

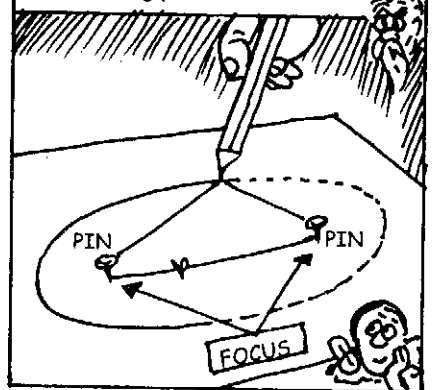
Planetary orbits are ellipses with the Sun at the focus



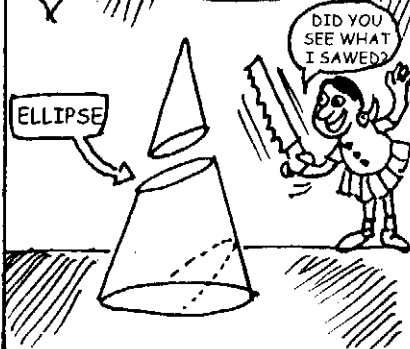
First law (1609 AD)

Hey, hold it! What's an ellipse? What's focus?

An ellipse, can easily be drawn with a pencil, string and 2 drawing pins: focii



It's one of the sections you get by slicing a cone at an angle. Besides an ellipse.



DID YOU SEE WHAT I SAWED?

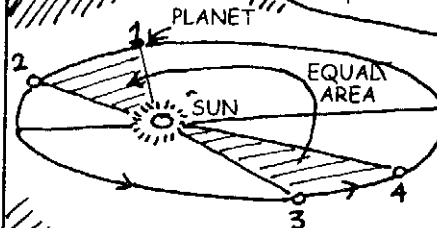
.... it is given by the equation....

No! No equation in a picture story!

Ok, Ok, Let's get back to Kepler

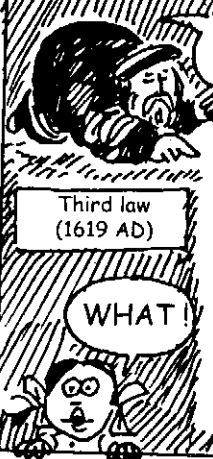
Second law (1609 AD)

The planet - Sun line sweeps out equal areas in equal intervals of time.



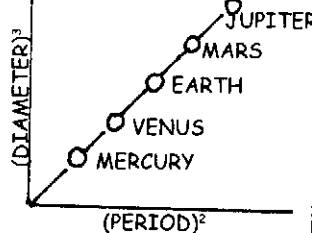
Thus it takes equal time to go from 1 to 2 as from 3 to 4. A planet moves faster when it is near the sun!

Kepler published these two laws in his "Astronomia Nova". The third law was given in his book "Harmony of the World" (1619) - A book full of mysticism!

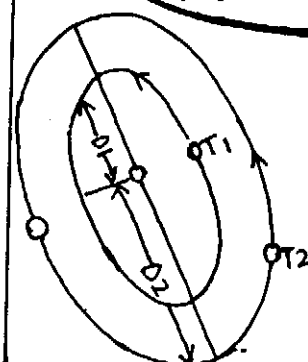


The squares of orbital periods are proportional to cubes of orbital semi diameter

Third law (1619 AD)

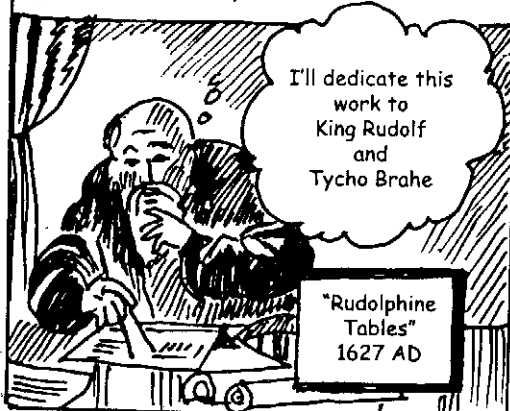


Kepler can never say it simply. Look if two planets have periods  $T_1$ ,  $T_2$  and distance  $D_1$ ,  $D_2$ , then....



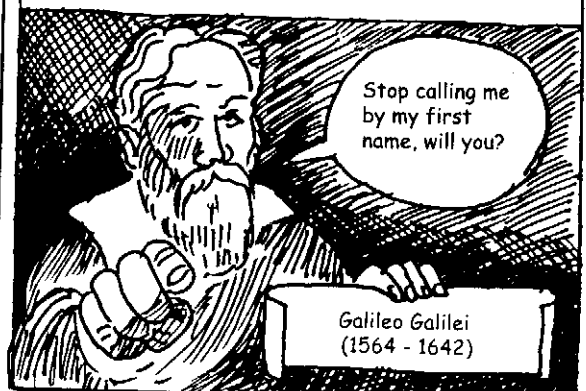
$$\frac{D_1^3}{D_2^3} = \frac{T_1^2}{T_2^2}$$

The planetary positions can now be predicted accurately



We have come a long way since the time of the Greeks. The heavens are in order. We know how they move. But why do they move?

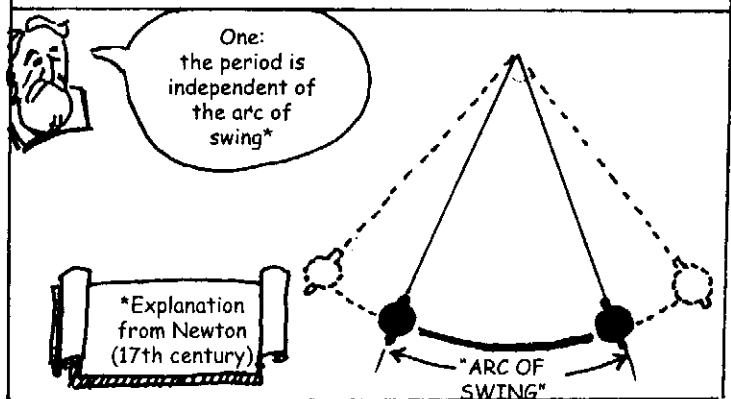
The first step towards the laws of motion was taken by Galileo Galilei



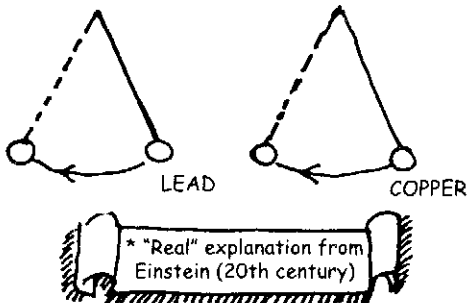
Galilei, Kepler's contemporary, was never very religious. One day, while at church, a swinging chandelier caught his attention



That let him to make two important observations about the pendulum:



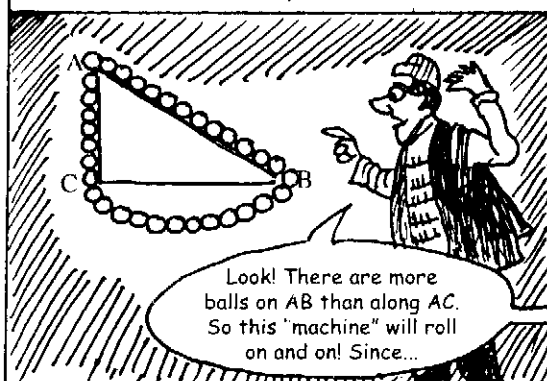
Two: the period is independent of the mass of the bob\*



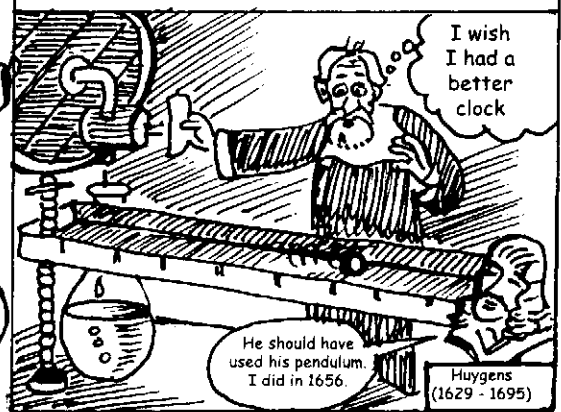
He also knew that bodies of different weights when dropped from a height will hit the ground together



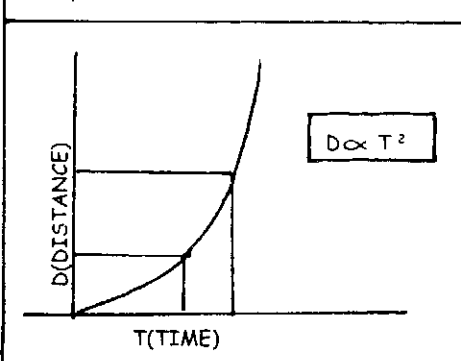
Simon Stevinus, another contemporary, has showed that the pull of the Earth is weaker on an inclined plane



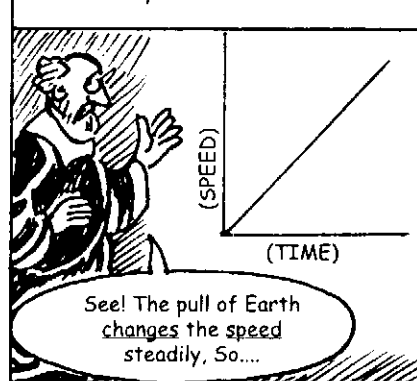
Galilei used the inclined plane to study the motion of objects



Galilei found that the distance covered by the rolling ball increased as the square of time interval....



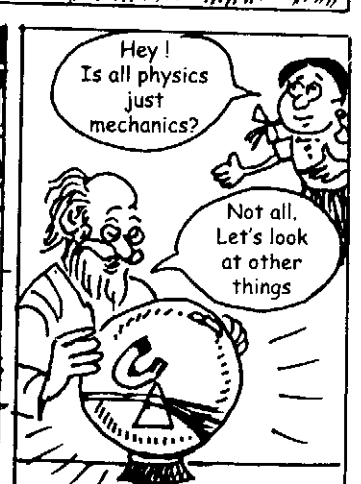
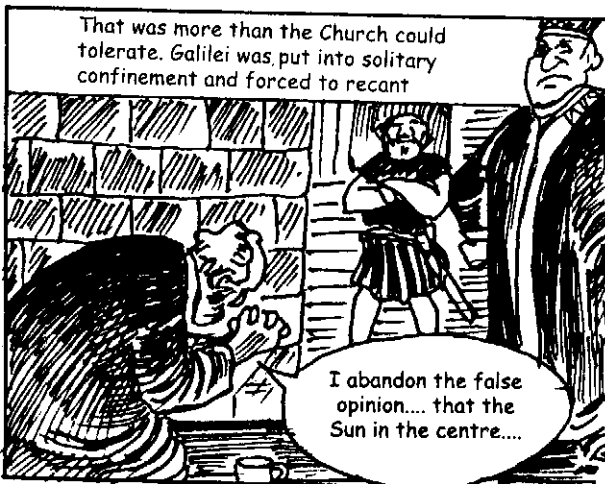
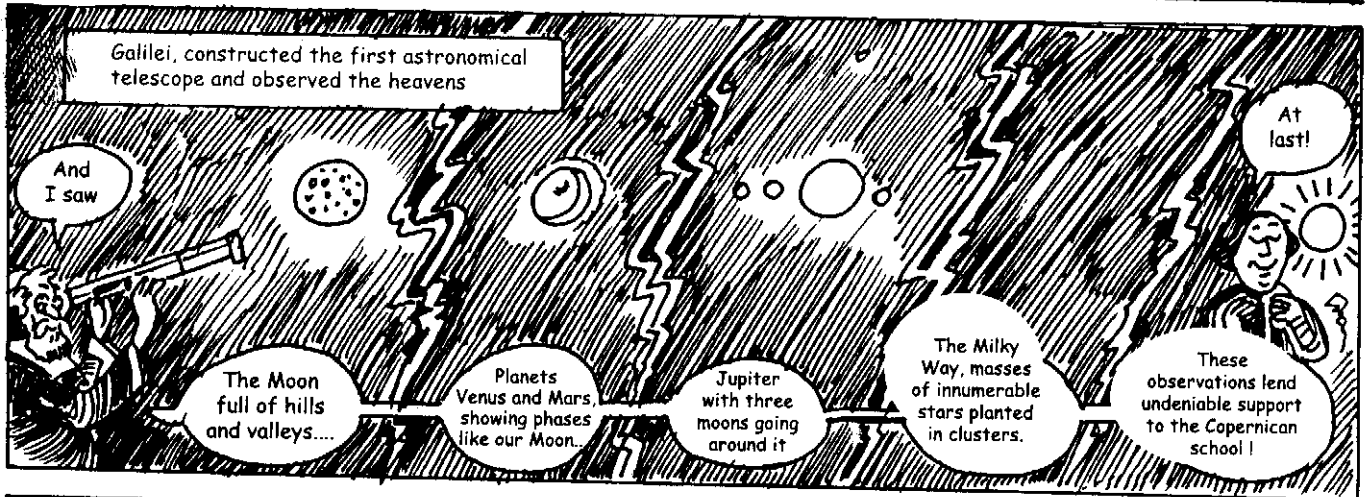
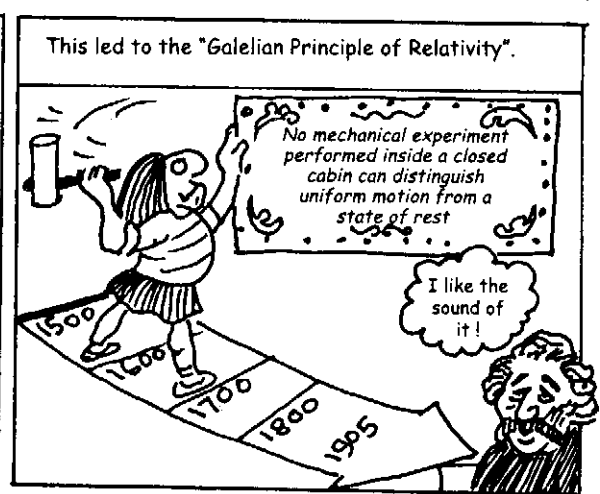
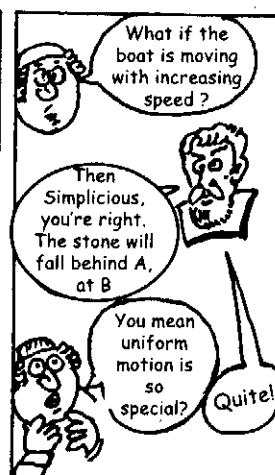
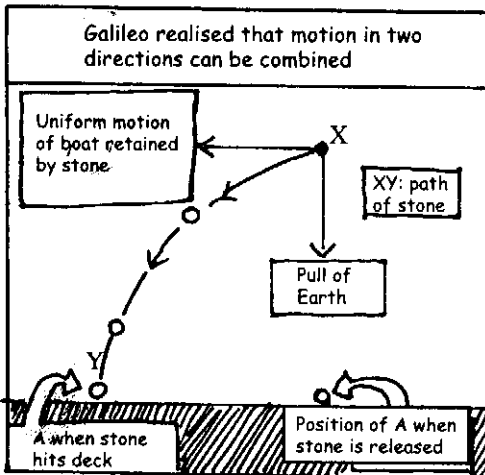
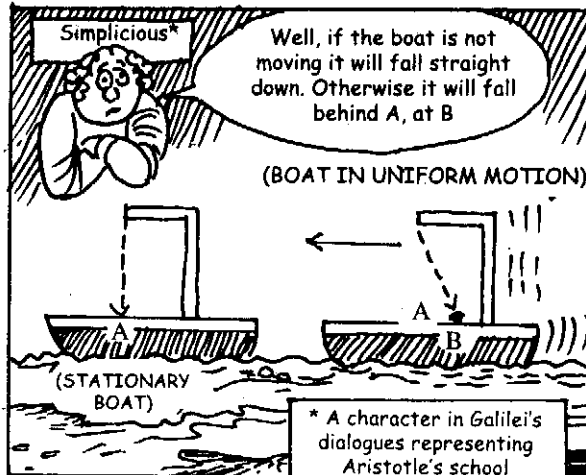
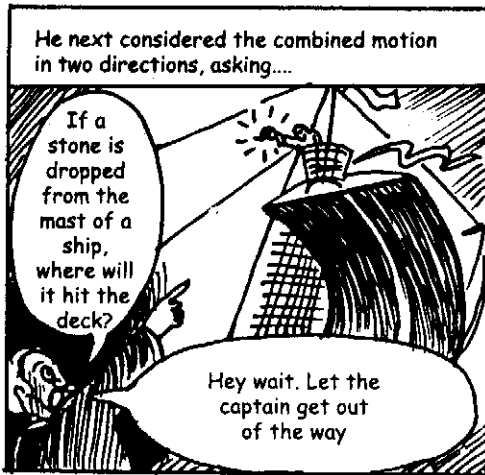
....while the speed increased linearly with time



....motion with unchanging speed needs no pull!





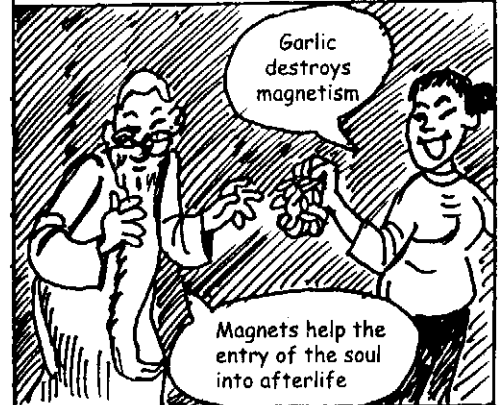


While the science of mechanics was racing ahead, magnetism and optics were crawling along....

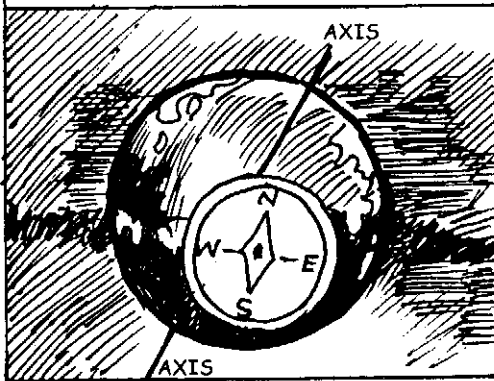
Lode stones (natural magnets) were known to Chinese miners from ancient times (2500 BC)



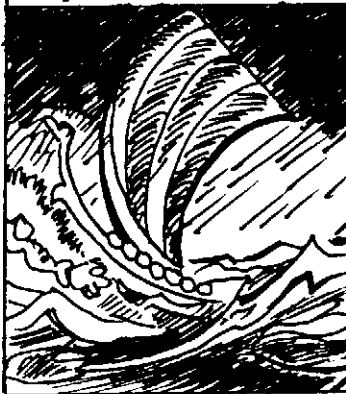
Magnetism was always associated with the occult



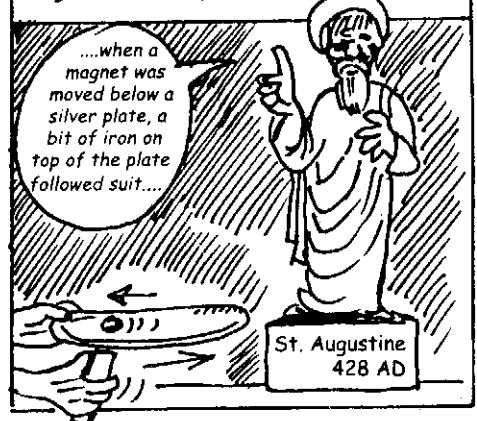
It is not known who discovered the "north seeking" property of magnets



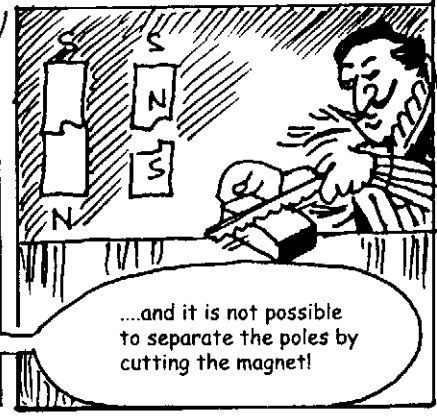
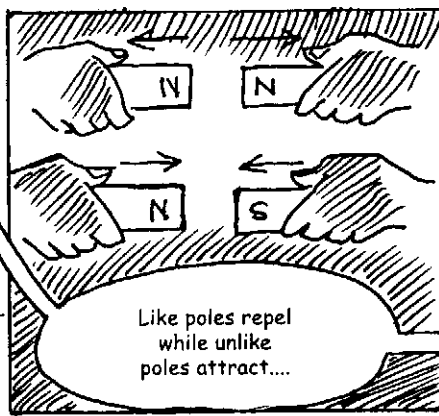
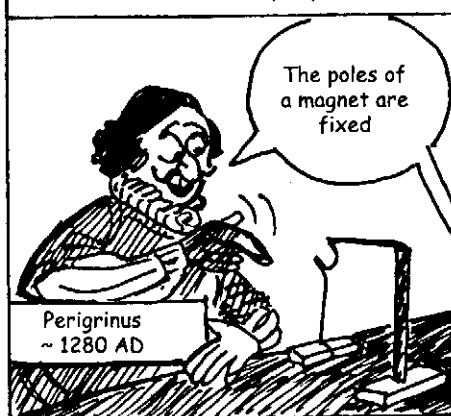
But even as early as 900 BC, magnetic needles were used as a navigational aid in stormy seas



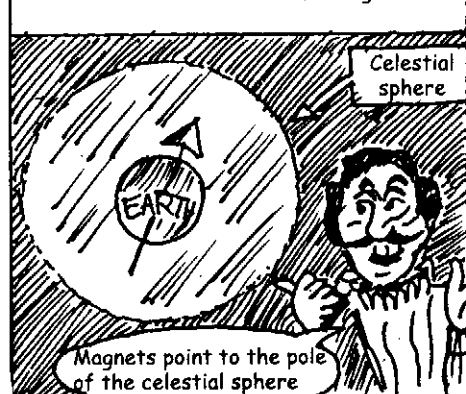
Many found the action of magnetic force mysterious....



Perigrinus, the French engineer, probably conducted the first set of experiments with magnets. He noted many important features:



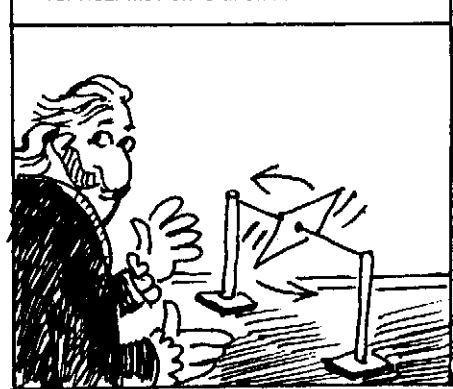
His explanation for "north seeking" behaviour was, however, wrong!



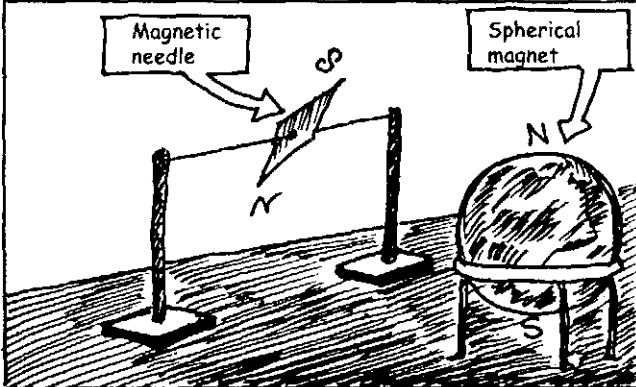
That is where the matter rested until the time of .... William Gilbert (1544 - 1603)



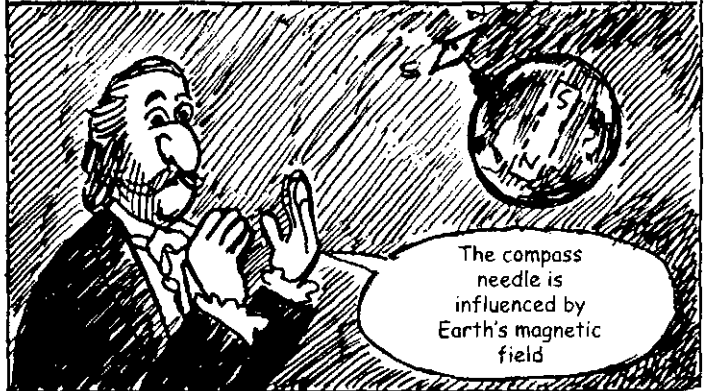
He noticed that a magnetic needle shows a "dip" towards Earth when vertical motion is allowed



Keeping a magnetic needle near a spherical magnet produced a similar "dip"



This made Gilbert suggest that Earth is a huge magnet!



It was known, since the days of the Greeks, that rubbed amber could attract pieces of straw....

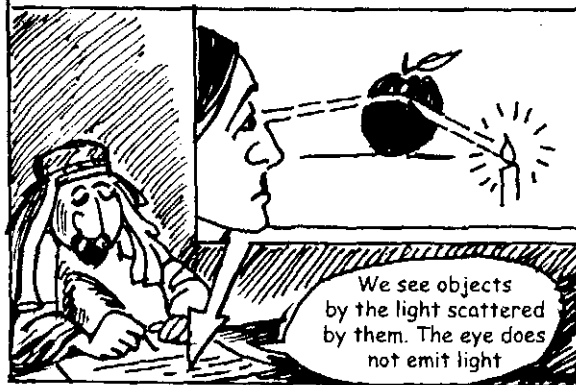


...Gilbert discovered this effect in many other materials and called them "electrics"

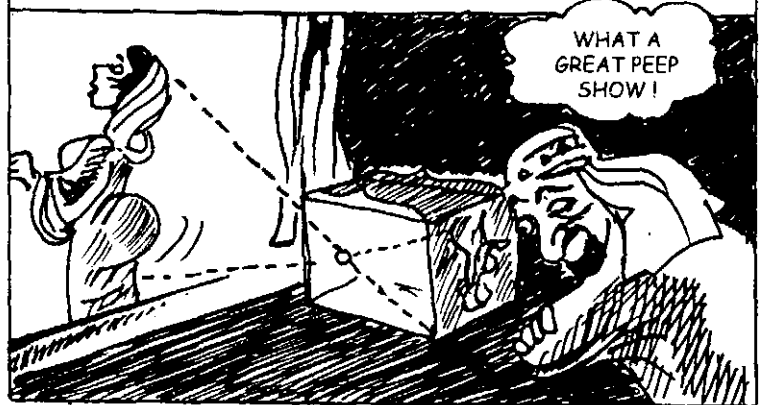
Another branch of physics wherein some development took place was Optics. Al Hazen (965 -1039AD) led an eventful life....



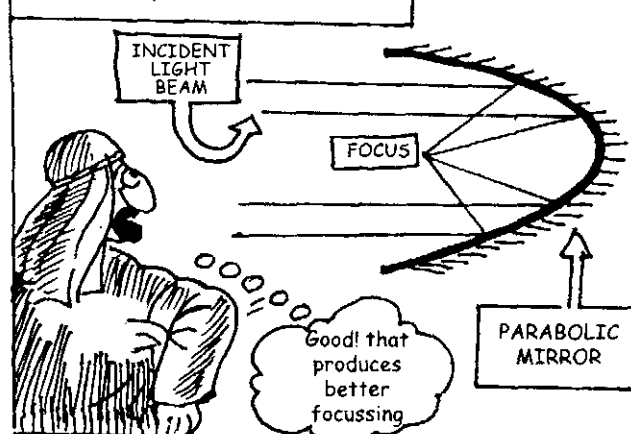
Al Hazen pretended insanity and conducted his experiments secretly!



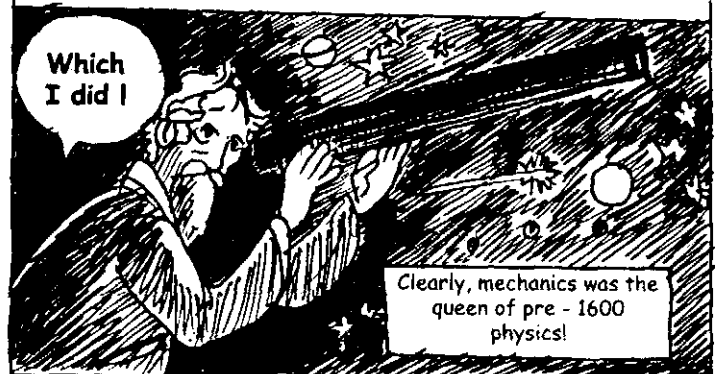
He also constructed the pin-hole camera....



.... and parabolic mirrors!



Al Hazen studied lenses and the phenomenon of refraction and reflection but failed to invent the telescope!



During his last days, Galilei had an able secretary....



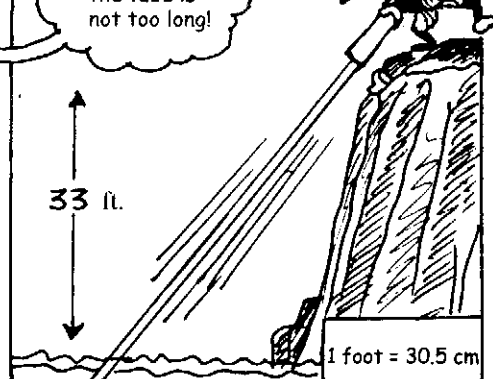
E. Torricelli (1608 - 1647)

Torricelli was intrigued by the action of a piston



As I pull the piston, the water flows in....

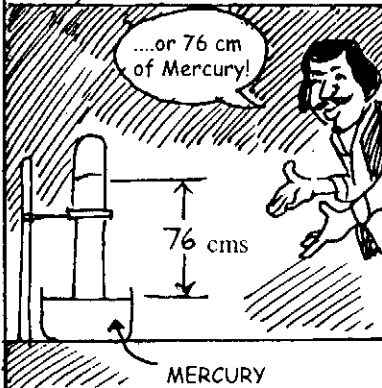
....provided the tube is not too long!



33 ft.

1 foot = 30.5 cm

He concluded that it is the weight of air that supports the 33 foot column of water

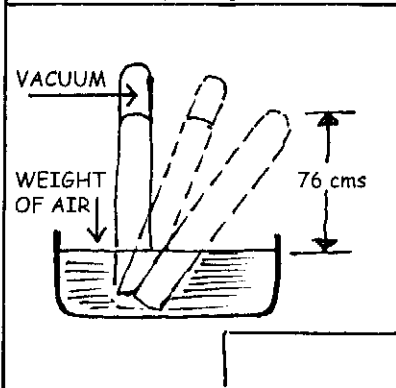


....or 76 cm of Mercury!

76 cms

MERCURY

Above the mercury column was the first ever man-made vacuum (as can be verified by tilting the tube)

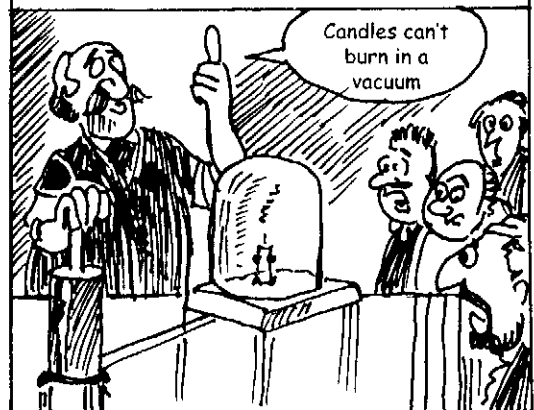


VACUUM

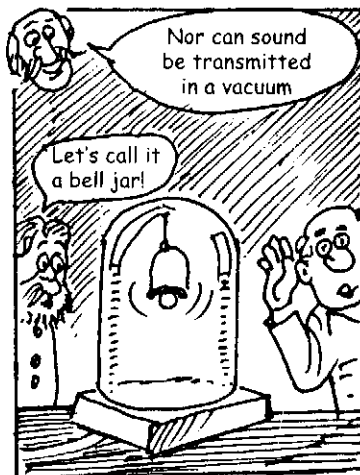
WEIGHT OF AIR

76 cms

Otto von Guericke (1602 - 1686), a contemporary constructed the first air pump



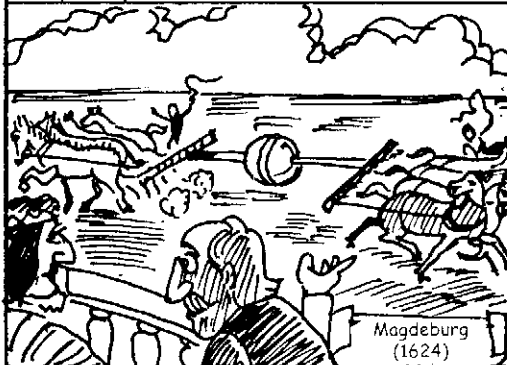
Candles can't burn in a vacuum



Nor can sound be transmitted in a vacuum

Let's call it a bell jar!

His famous experiment demonstrated the power of the vacuum in which 2 hemispheres held together by vacuum couldn't be pulled apart by teams of horses



Magdeburg (1624)

These ideas were taken further by Blaise Pascal (1623 - 1662), an infant prodigy



Don't look now, but there goes the crazy Pascal kid

Oh dear! He's so.... cute!

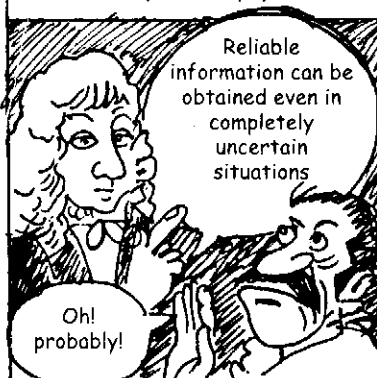
Pascal wrote a treatise on conic sections when he was 16, and made the first ever calculating machine at 19



Look papa, this can add and subtract

He isn't normal but he's useful

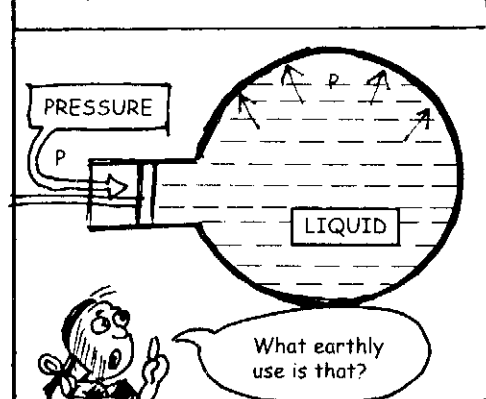
Pascal also founded the modern Theory of Probability which was extensively used in physics later



Reliable information can be obtained even in completely uncertain situations

Oh! probably!

He realised that pressure applied on a liquid is transmitted undiminished



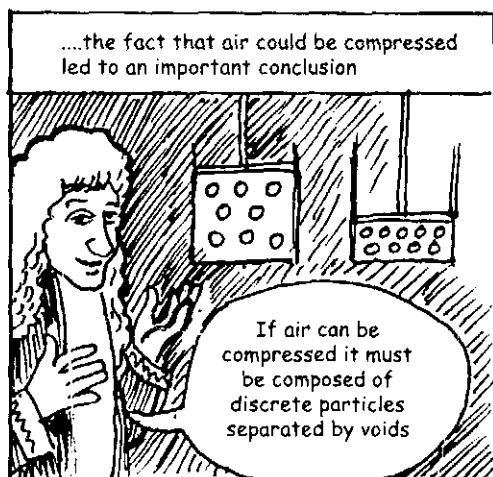
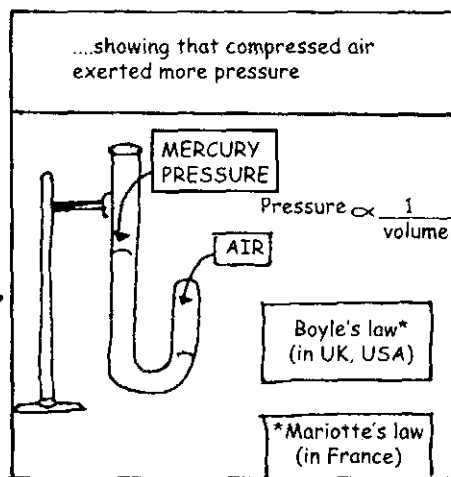
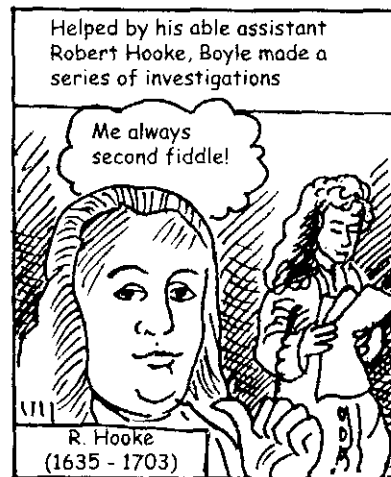
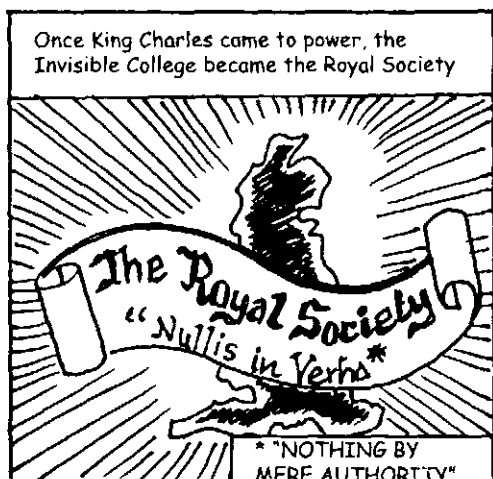
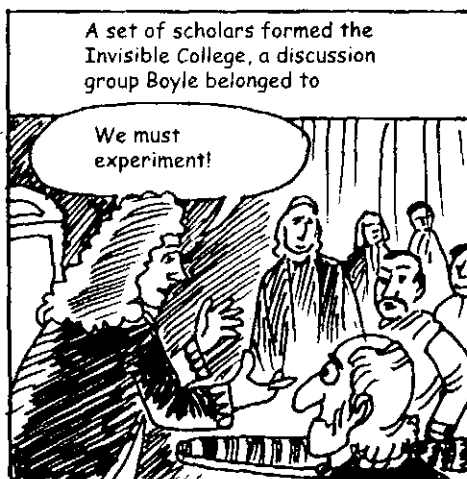
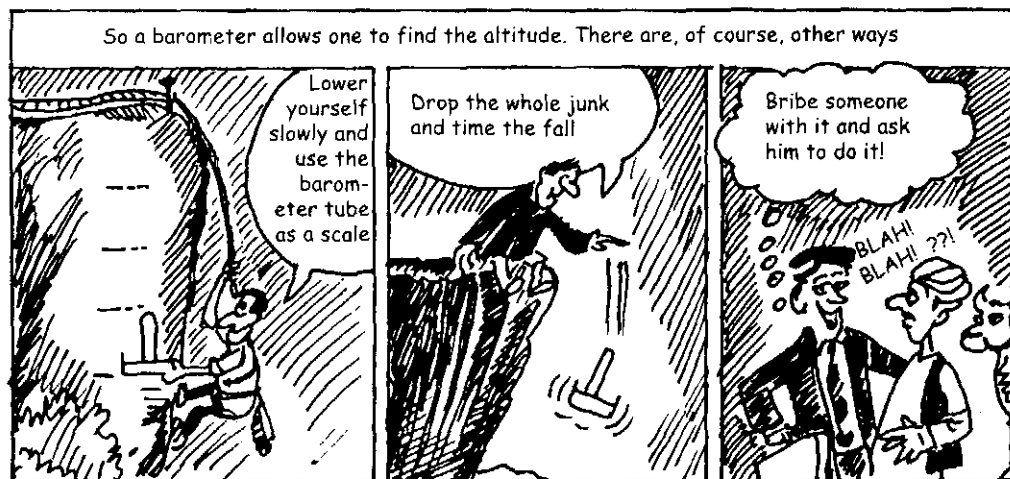
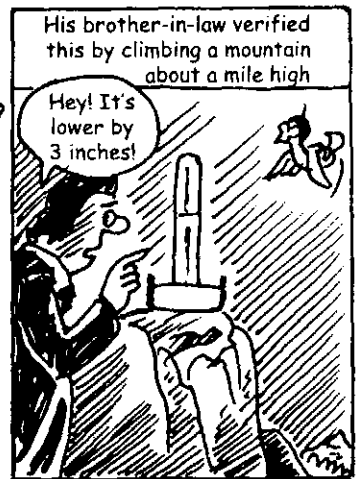
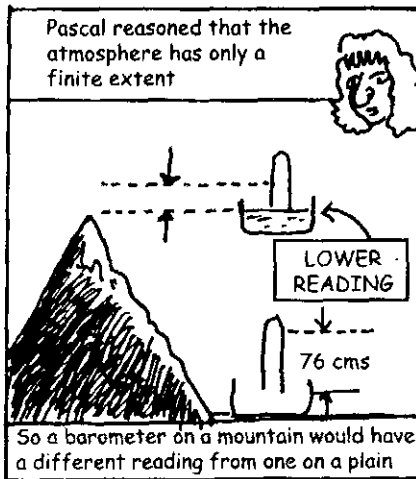
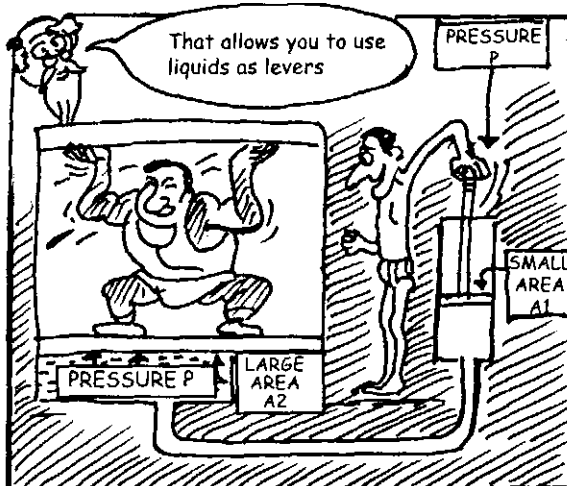
PRESSURE

P

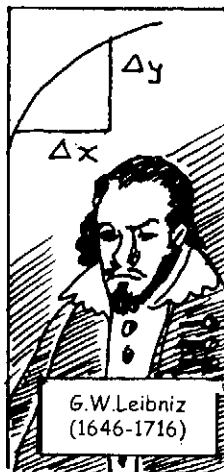
LIQUID

What earthly use is that?

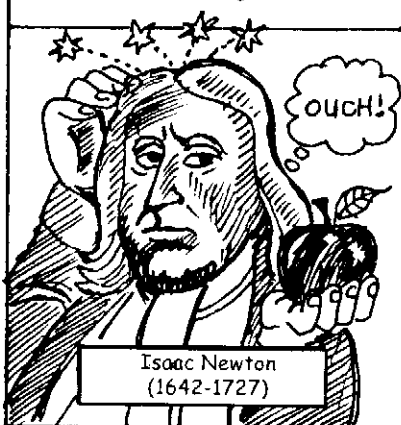




The latter half of the 17th century had an impressive starcast in European science...



...but the king among them was...



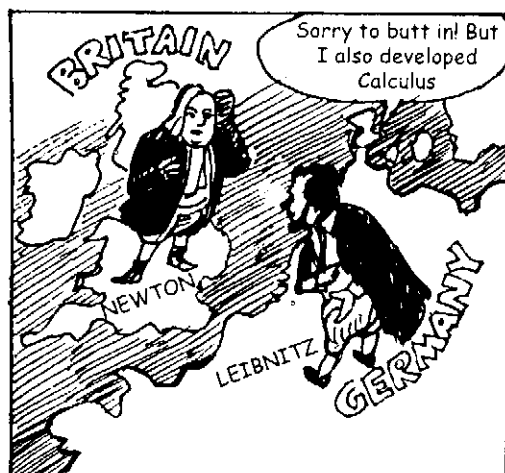
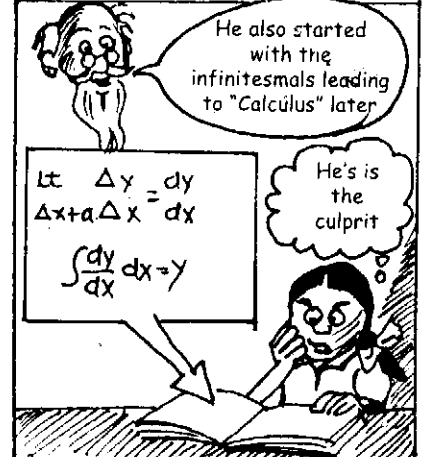
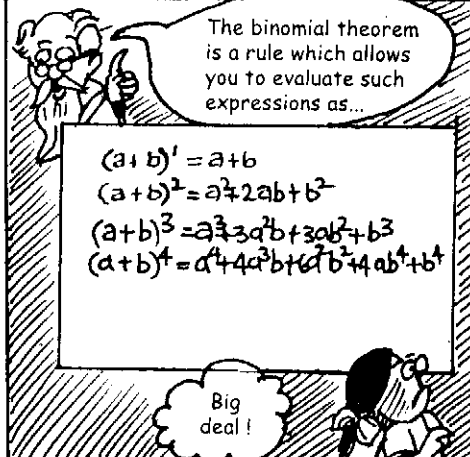
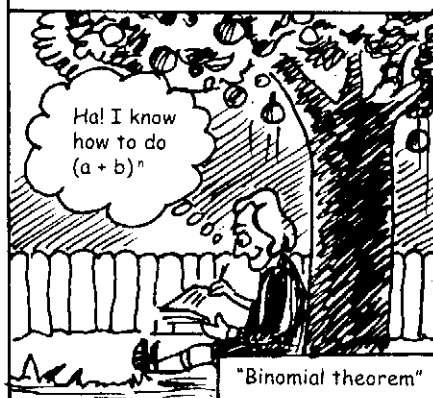
Newton, a christmas baby, was cared for by grandparents in his early years...



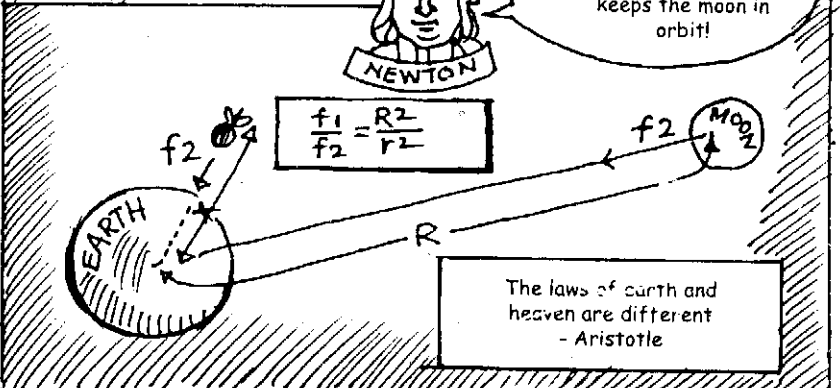
He graduated from Trinity College, Cambridge (1665), and survived the plague years (1666 - 67) on his mother's farm

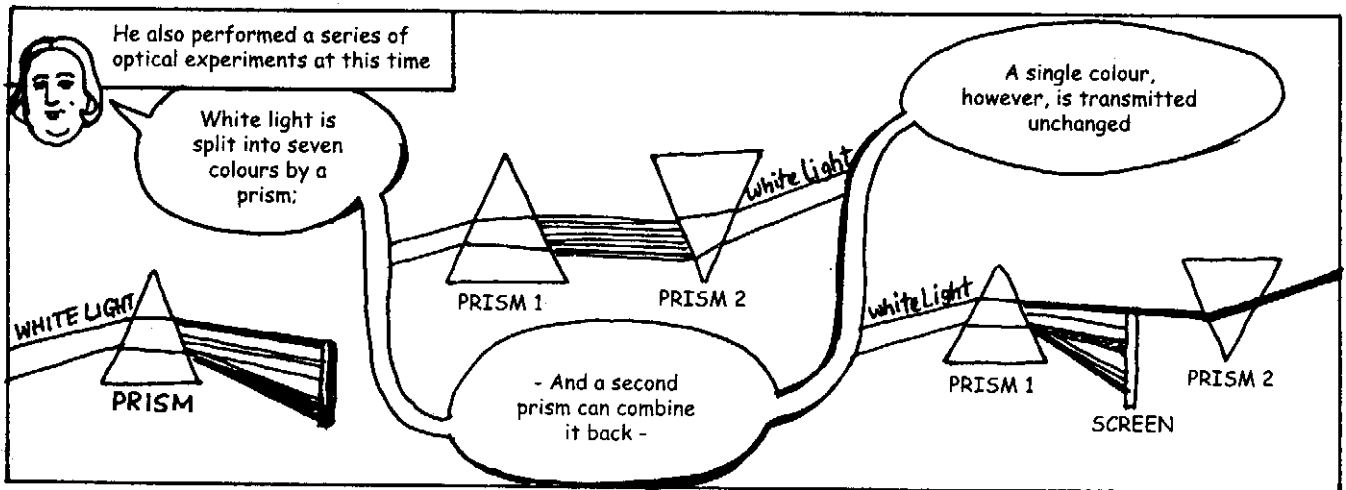


Once out of Academic Institutions, his genius flourished

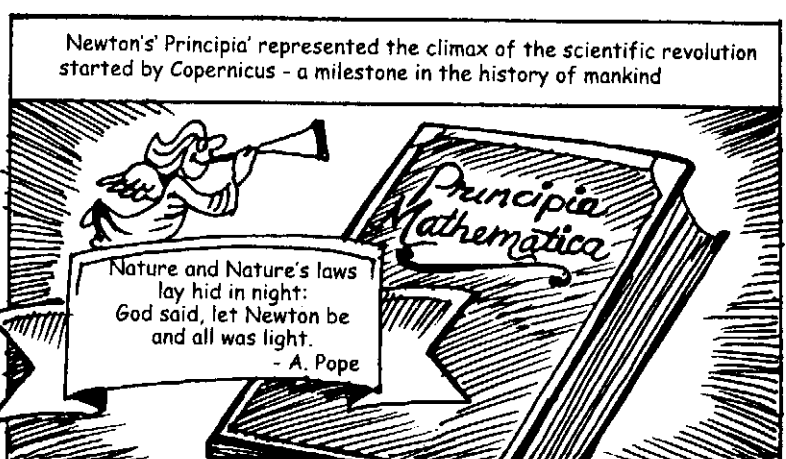
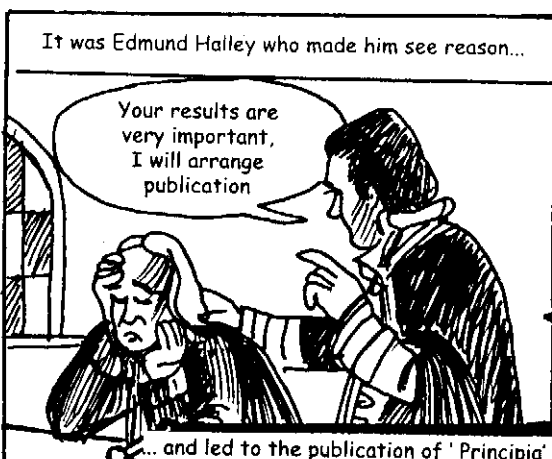
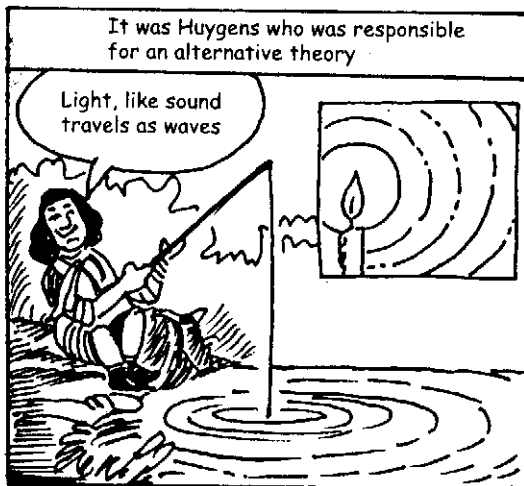
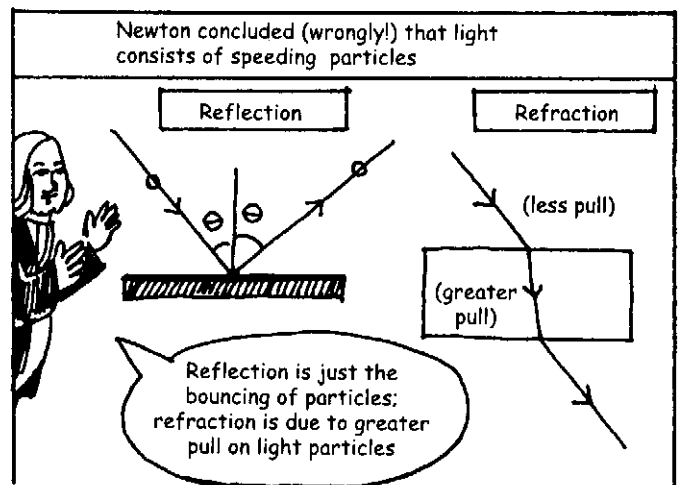


Also in the plague year was discovered the law of gravitation (published 15 years later)



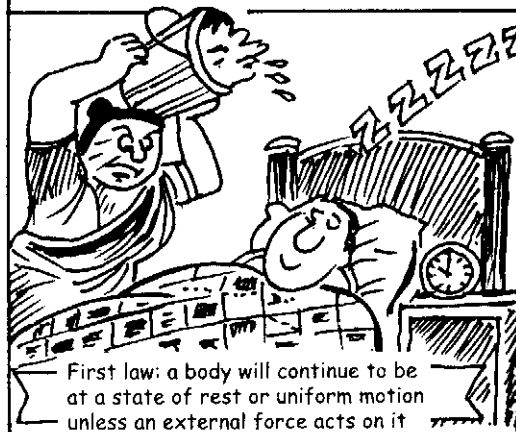


These experiments brought Newton fame and honour (Cambridge professorship in 1669, FRS in 1672) and also life long enmities, for example with Hooke



In his "Mathematical Principles of Natural Philosophy," Newton developed a comprehensive scheme for the mechanical universe

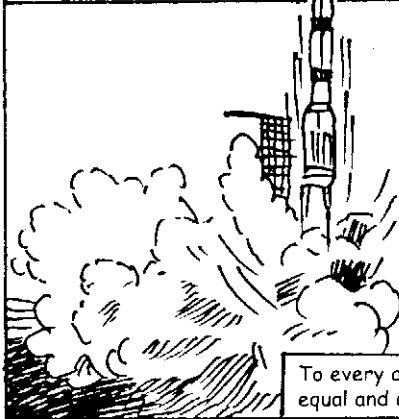
He codified the laws of motion, conceived by Galilei



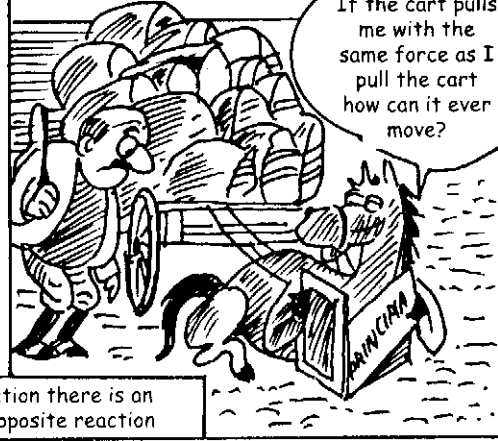
Second law:  
Acceleration = Force / Mass



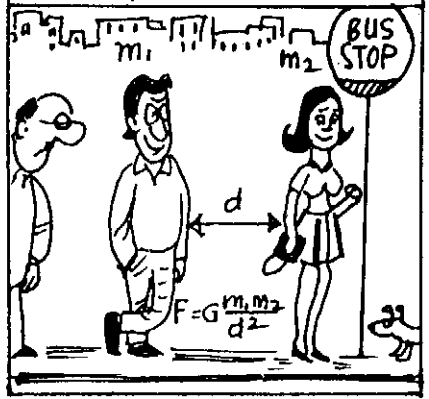
And the famous third law with its ups...



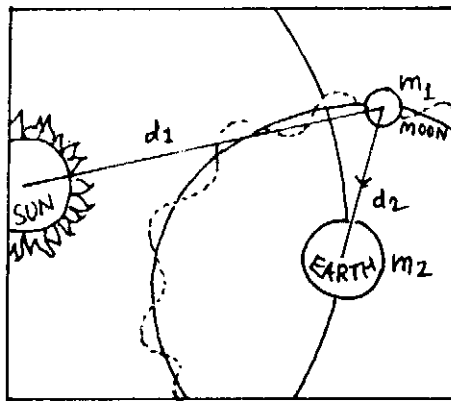
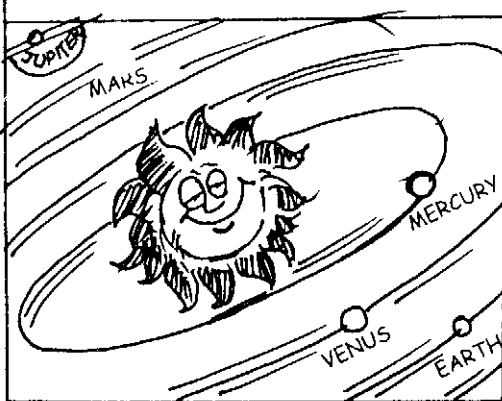
and downs....



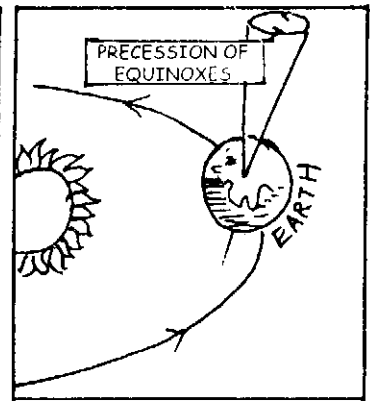
With tremendous intuition, Newton postulated gravitational attraction between any two bodies in the universe



Newton could now derive Kepler's laws of planetary motion, setting the heavens in order.

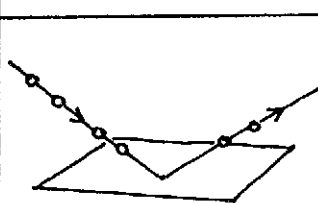


He could explain the irregular motion of the Moon....



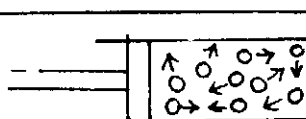
.... and the "wobbling" in the Earth's motion

In optics....



Light particles obey laws of motion

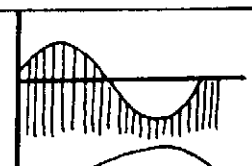
In thermodynamics....



Heat is a kind of motion

K.L. BOLTZMAN  
(1844 - 1906)

In electromagnetism...



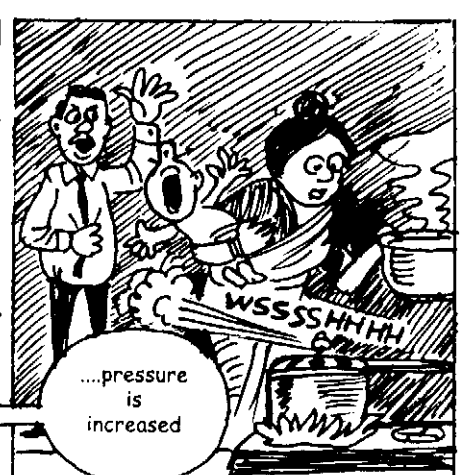
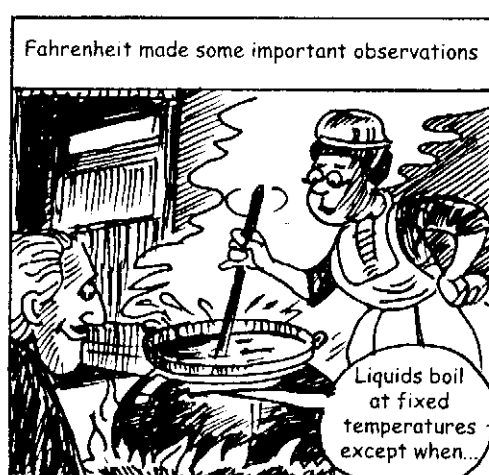
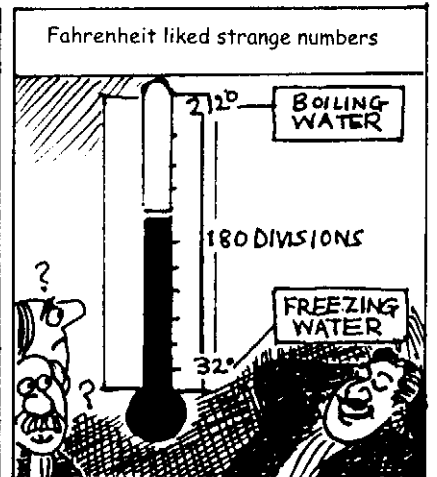
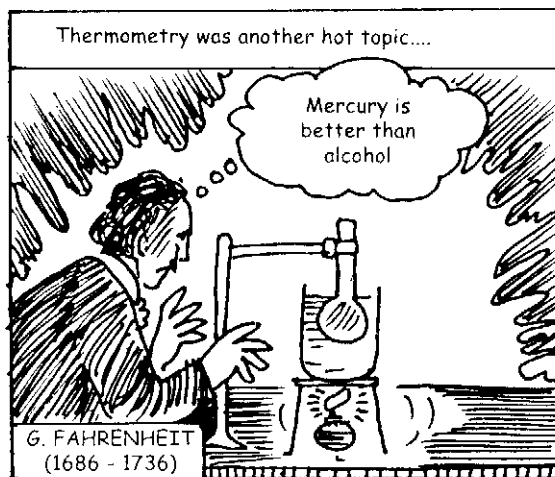
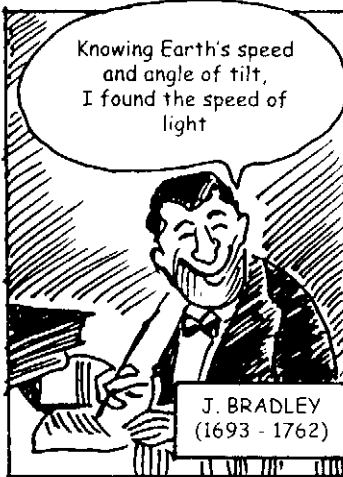
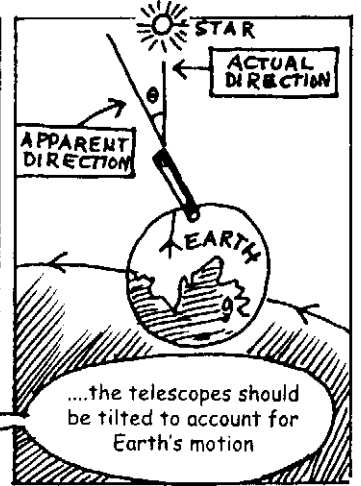
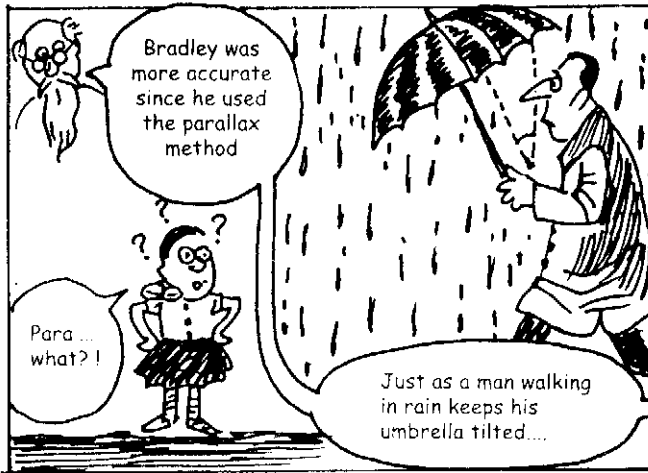
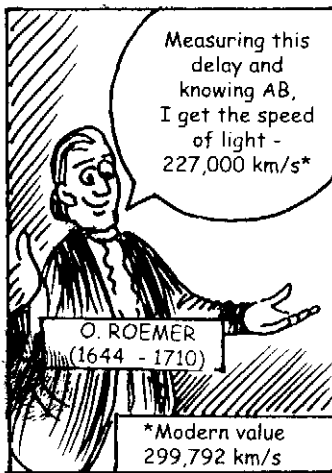
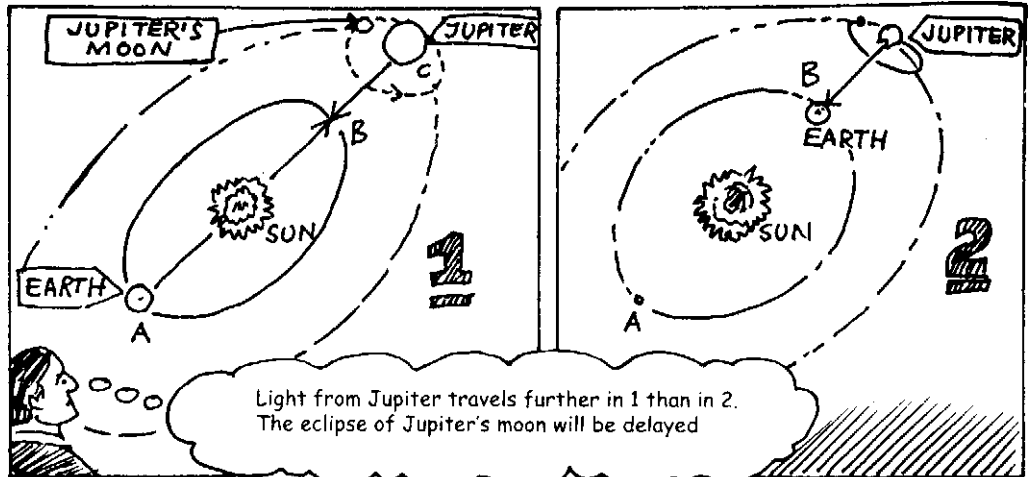
Electric waves are mechanical vibration of aether

J. C. MAXWELL  
(1831 - 1879)

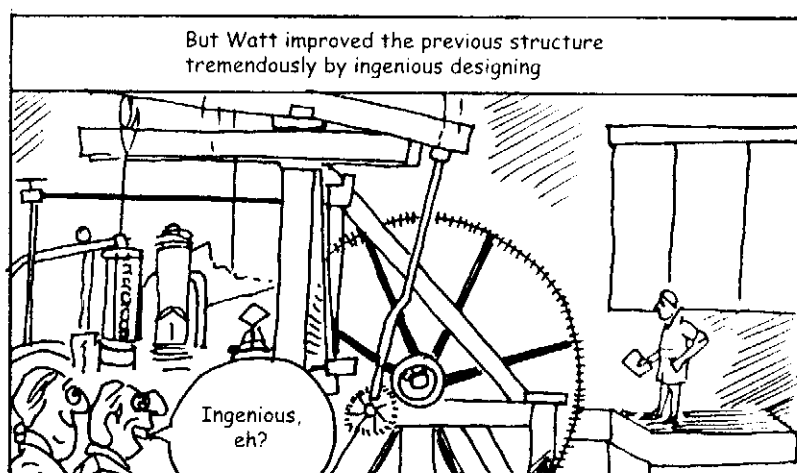
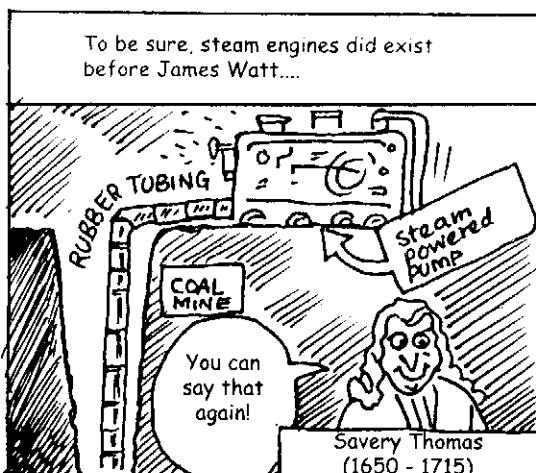
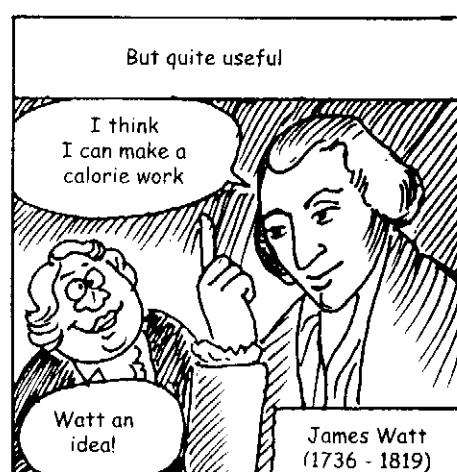
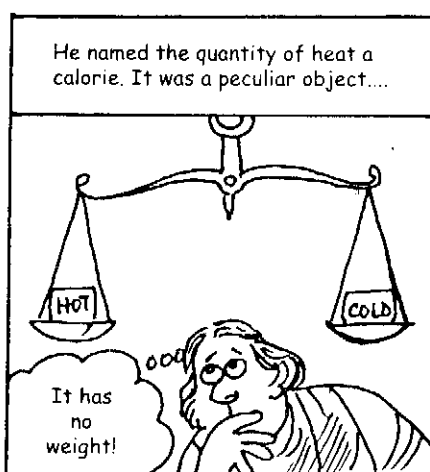
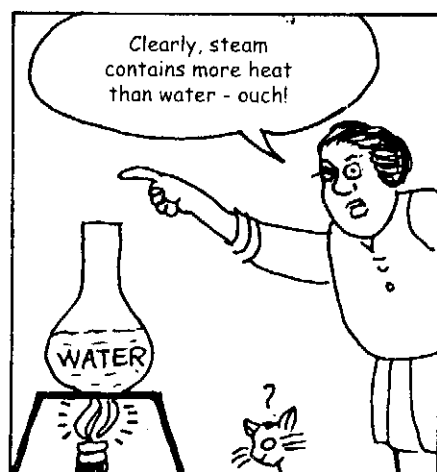
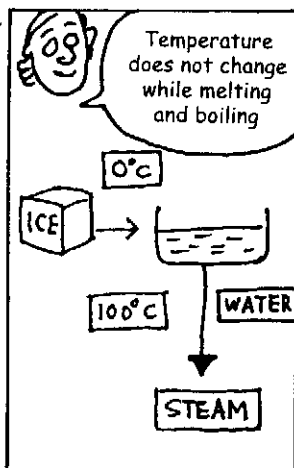
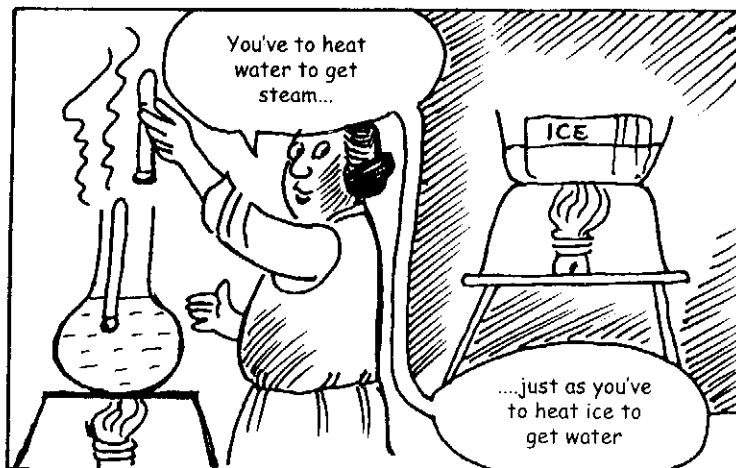
As we shall see, Newton's mechanistic view of nature influenced physicists for a long time to come



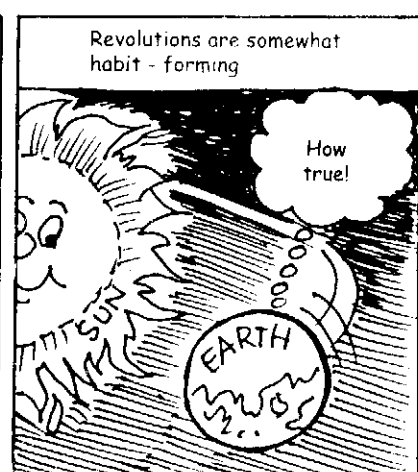
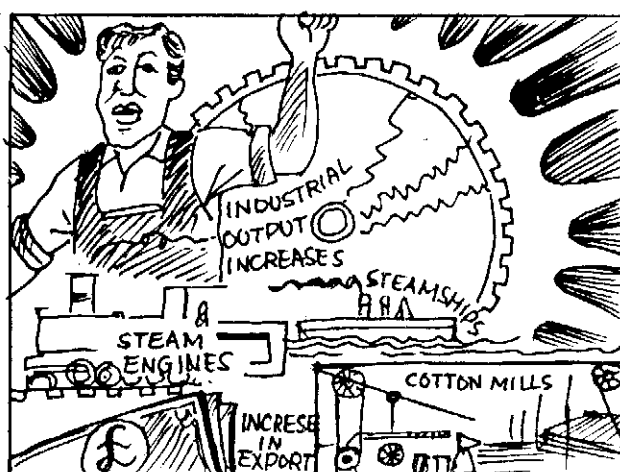
The post - Newtonian years witnessed a series of simple but important developments. Roemer measured the speed of light



That there is more to heat than just temperature was first recognized by Joseph Black (1728 - 1799)



By the 1780's steam power was being used a lot, heralding the era of the Industrial Revolution....



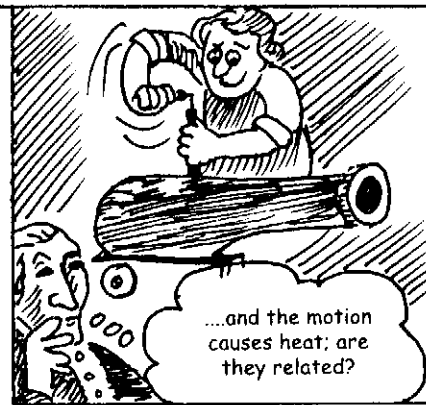
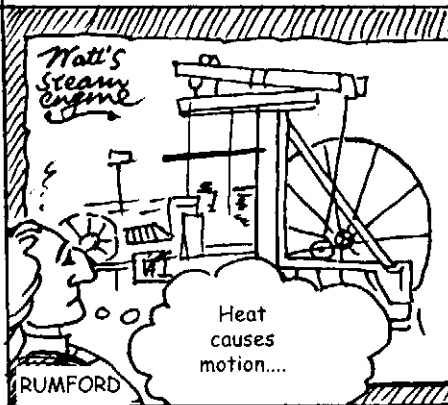
There were others to follow: in America



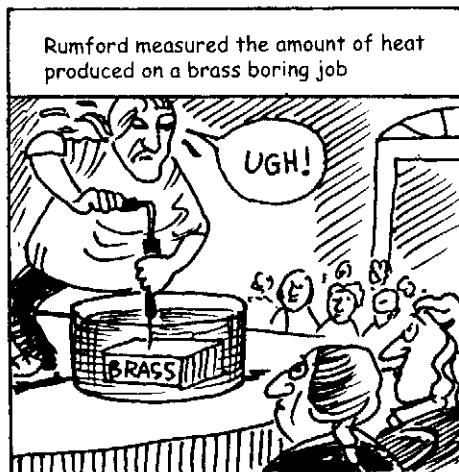
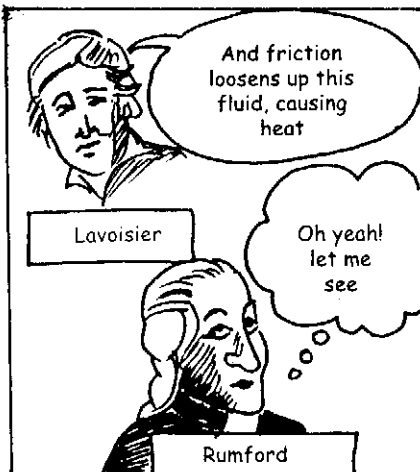
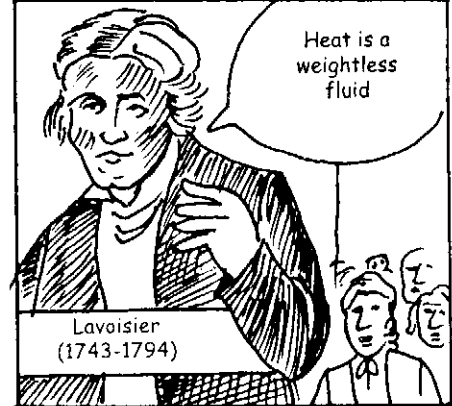
And in France...



Amidst all this, Count Rumford worried about the real nature of heat



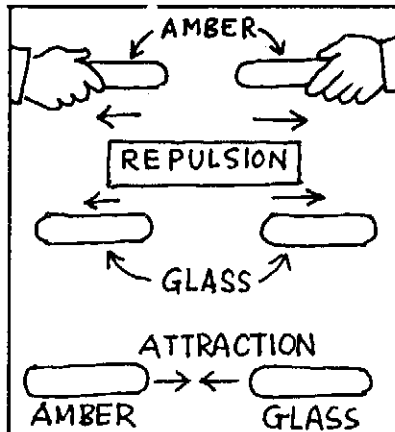
The popular view was against Rumford



Having disproved Lavoisier, Rumford proceeded to marry his widow. The marriage broke up soon with bitter words



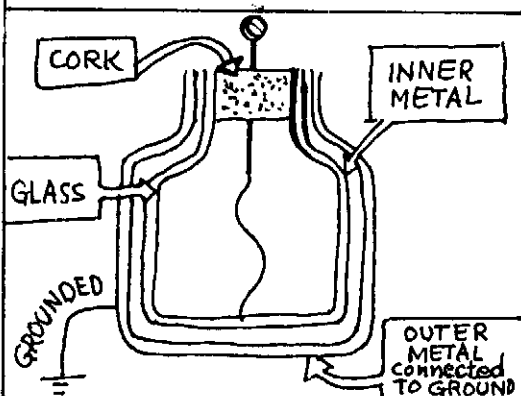
It was known by the 18th century that there are two kinds of electricity



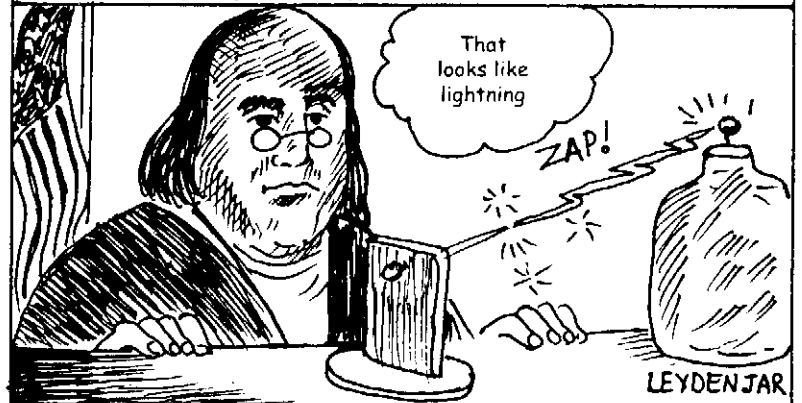
People knew how to store electricity



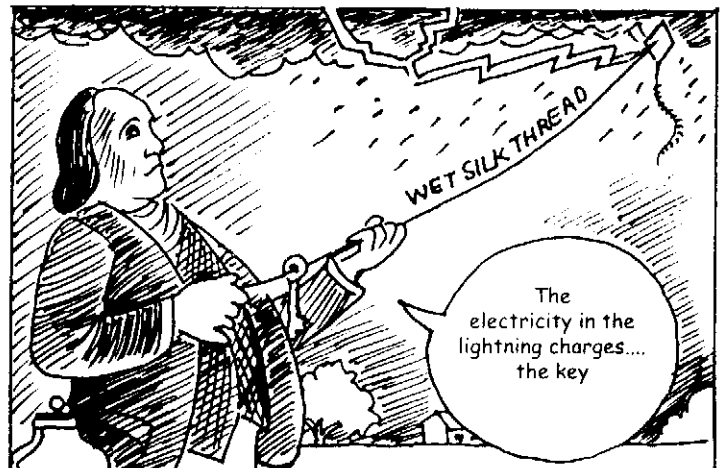
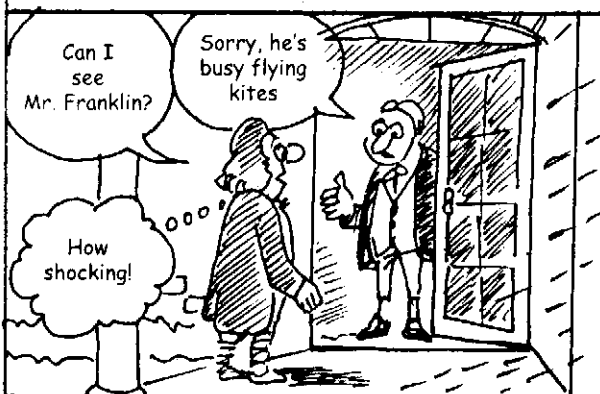
A Leyden jar consists of two metals separated by glass. The inner metal holds the charge



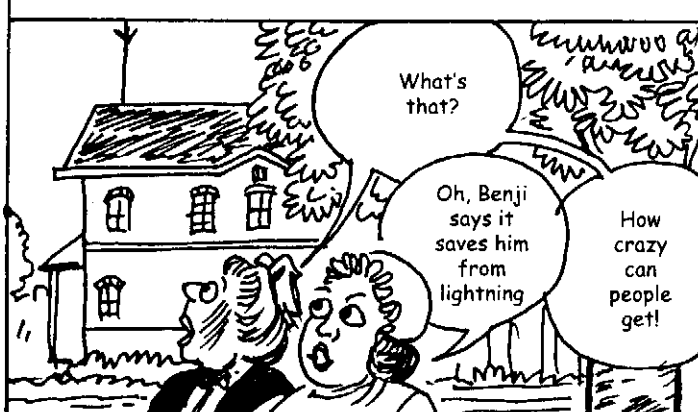
Among the many scientists experimenting with the Leyden jar was Benjamin Franklin (1706 -1790)



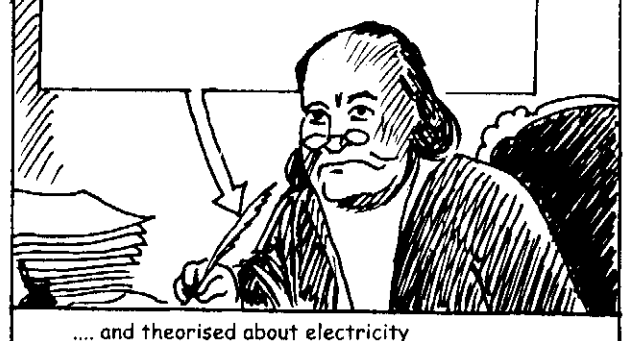
Franklin proceeded to check whether lightning was really an electrical phenomenon



Franklin devised the first lightning arrester....



Electric fluid can be in excess (+) or in deficit (-). Excess attracts deficit





The exact law describing an electrical force between bodies was discovered by Charles Augustin Coulomb (1736 - 1806)

He devised a torsion balance to measure small forces

SCREW  
METAL  
Thin Wire  
METALLIC BALLS

The electric force is inversely proportional to square of the distance

Meanwhile, a shy, recluse, also discovered this balance\*and the law

Keep that tray over there and go away fast! I can't stand the sight of women

H. CAVENDISH (1731 - 1810)

He is crazy

He went further

I can find Newton's constant G

$$F = G \frac{m_1 m_2}{G^2}$$

But never published

$m/g = 981 \text{ cm sec}^{-2}$

$M = \frac{gd^2}{G}$

... and thus calculate the mass of Earth

At this time electricity was produced by rubbing some materials together. But some fish could be better

OUCH!

Electric eel

Galvani noticed that frog legs twitched when kept in touch with two metals

L. GALVANI (1737 - 1798)

Another example of animal electricity

Hm....m

A. Volta (1745 - 1827)

However, it was just chemical electricity, as Volta showed

No animal tissue is needed

COPPER

ZINC

SALT SOLUTION

The voltaic pile made life easy for experimentalists....

ELECTRIC CURRENT

ZINC

COPPER

cardboard dipped in salt solution

....and brought honours to Volta in the court of Napoleon!

KEEP UP THE GOOD WORK!

The Emperor likes him

Current favourite, eh?

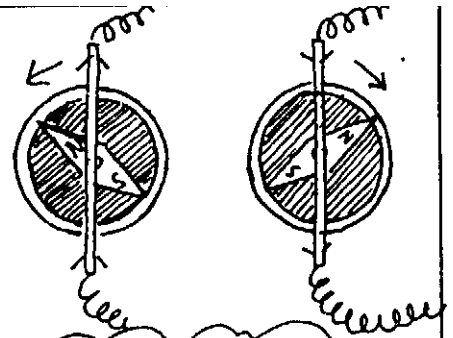
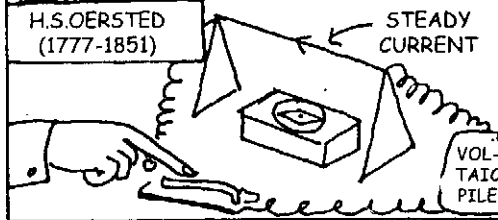
The voltaic pile made electrical experiments easy leading eventually to the unification...

... of electricity and magnetism



H.S. OERSTED  
(1777-1851)

Ha!  
an electric current  
does things  
to a magnetic needle



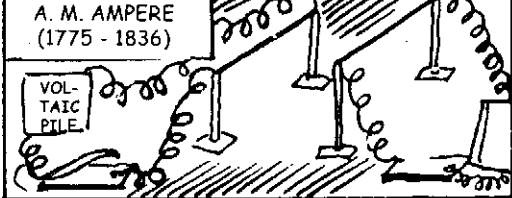
The needle is deflected  
depending on the direction of  
the current

The experiment was followed  
by many, especially Ampere



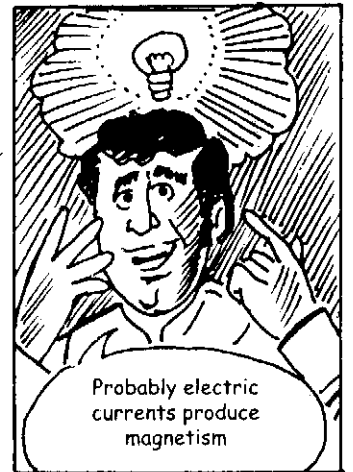
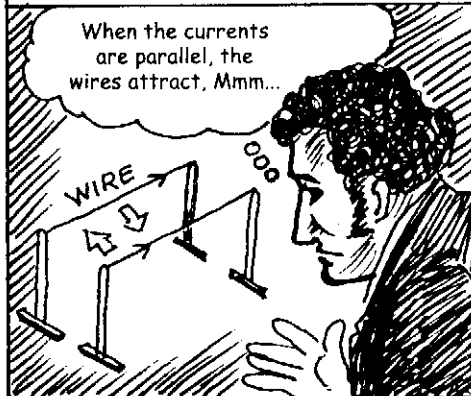
A. M. AMPERE  
(1775 - 1836)

Does one current  
affect another?



It did !

When the currents  
are parallel, the  
wires attract, Mmm...

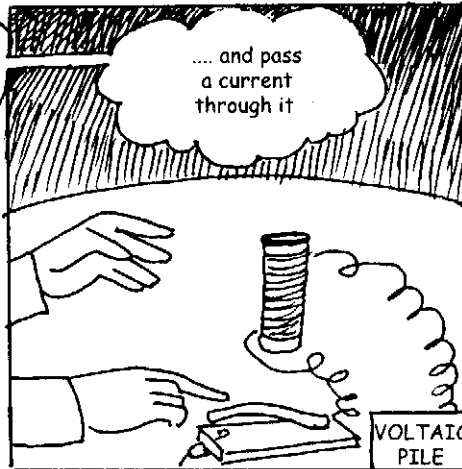


Probably electric  
currents produce  
magnetism

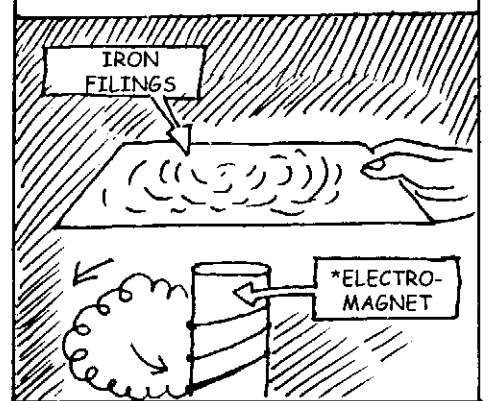
Let me wind around  
a tube many turns  
of wire....



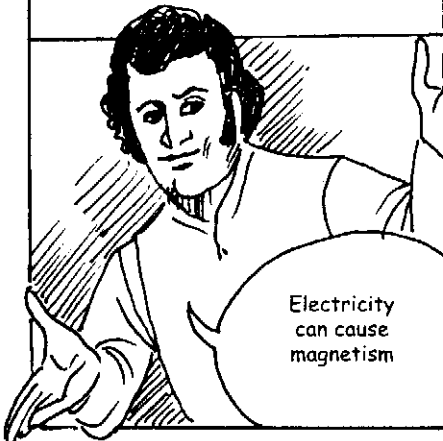
... and pass  
a current  
through it



Remarkably enough, the tube  
behaved like a bar magnet!

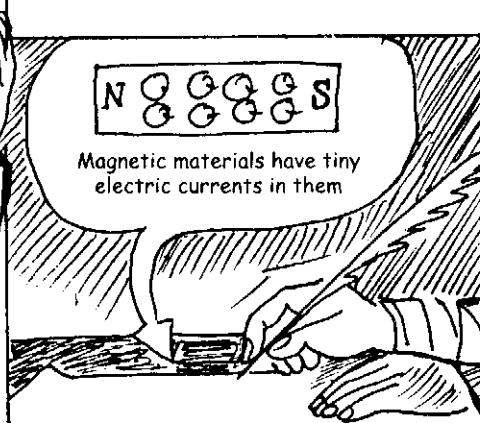


It was a great moment in history

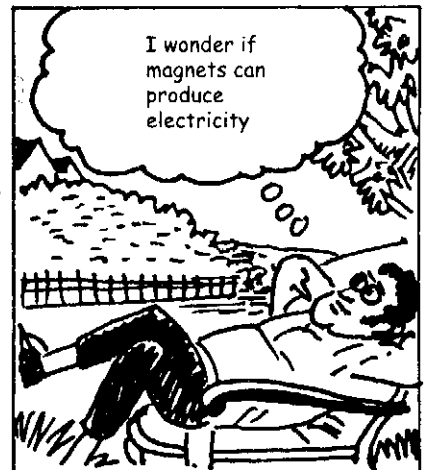


Electricity  
can cause  
magnetism

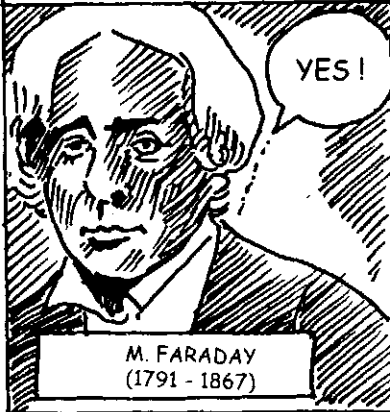
Ampere guessed right about magnetism



I wonder if  
magnets can  
produce  
electricity



The answer was...

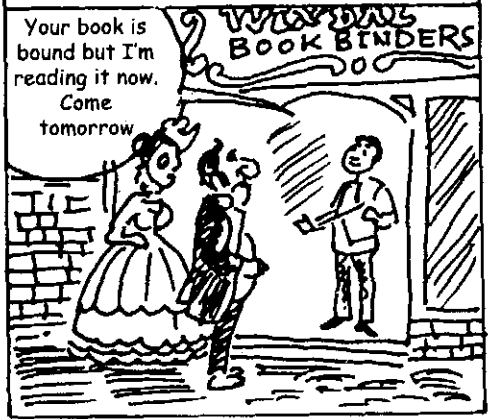


As one of ten children of a poor blacksmith, Faraday acquired an early advantage...

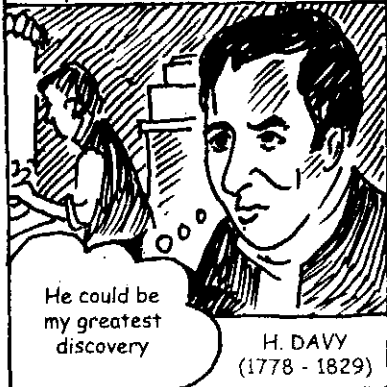


...and put it to good use

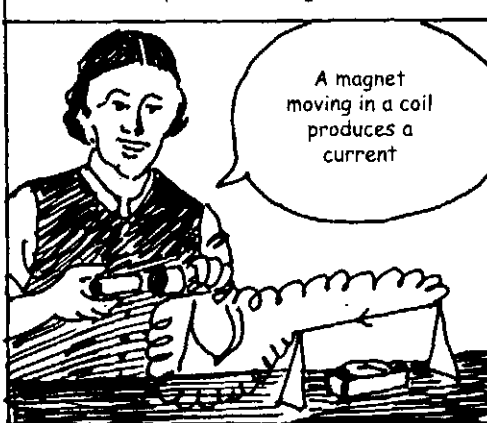
Your book is  
bound but I'm  
reading it now.  
Come  
tomorrow



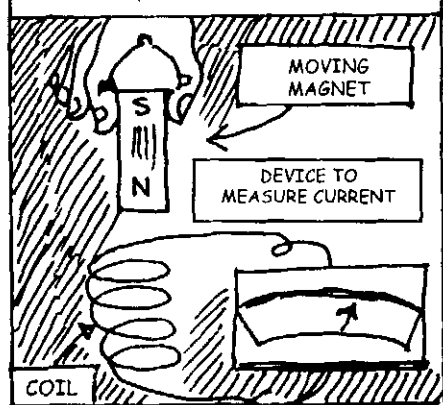
Having got a job with Humphrey Davy, he started electrical experiments



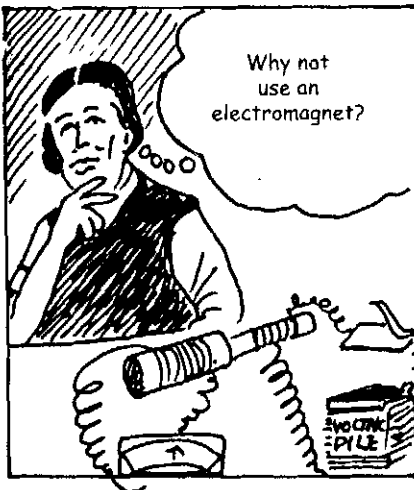
...and came up with startling results



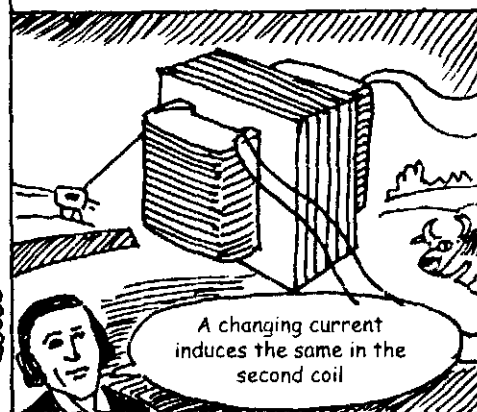
Clearly, magnetism caused  
electricity



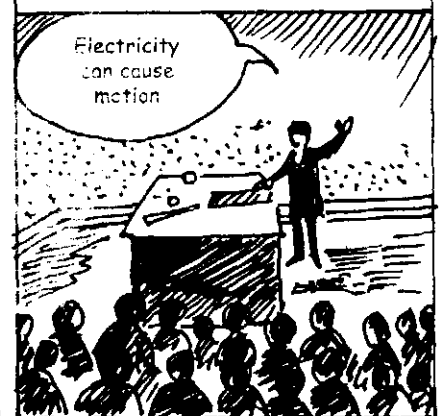
Why not  
use an  
electromagnet?



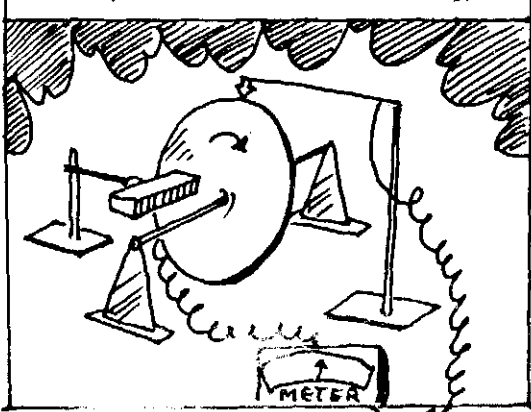
He did and constructed the first  
"transformer"



Faraday's lecture demonstrations  
attracted vast crowds

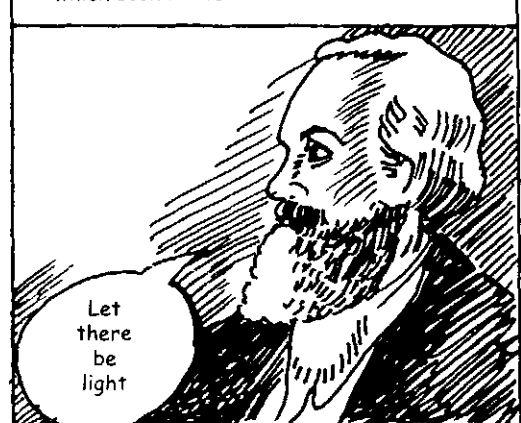


He designed the forerunners of the electric motor  
and the dynamo - two milestones in technology

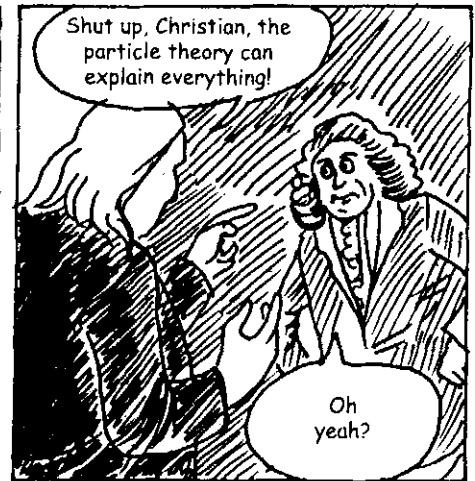
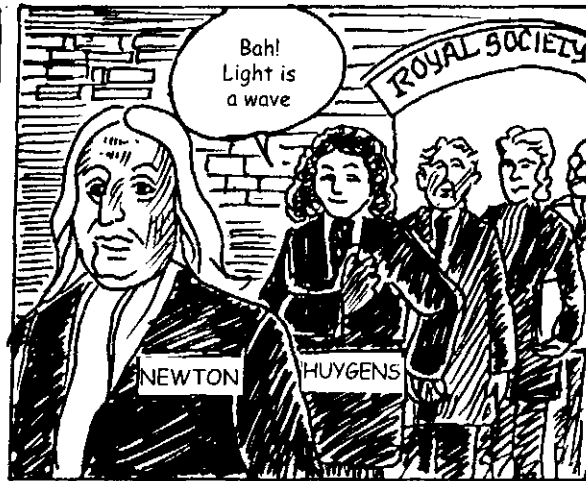


Probably  
more  
important,  
he  
completed  
the first  
unification  
of  
electricity  
and  
magnetism....

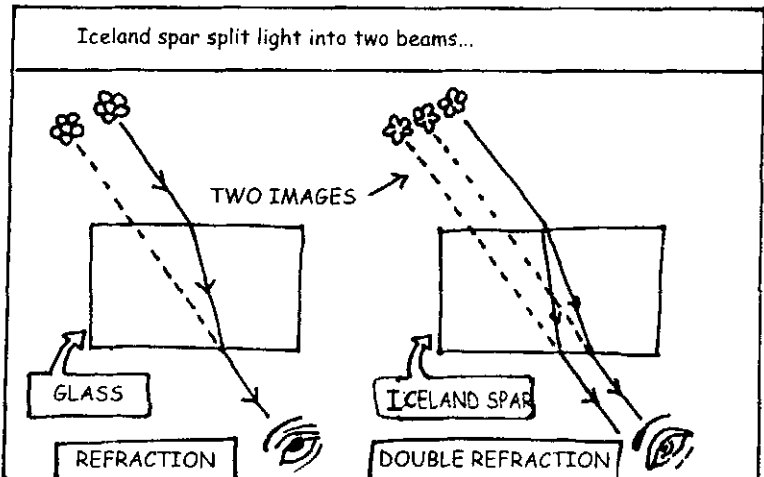
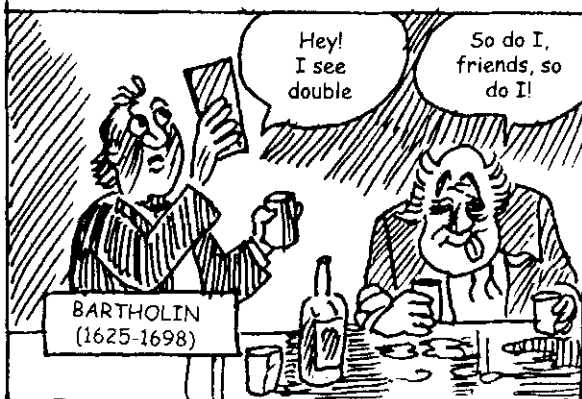
which soon led to the second unification



As we said before, Newton thought of light as particles, thereby casting sharp shadows



Everything? Not quite! There was this little trouble with a crystal called Iceland spar



...which Newton couldn't explain...



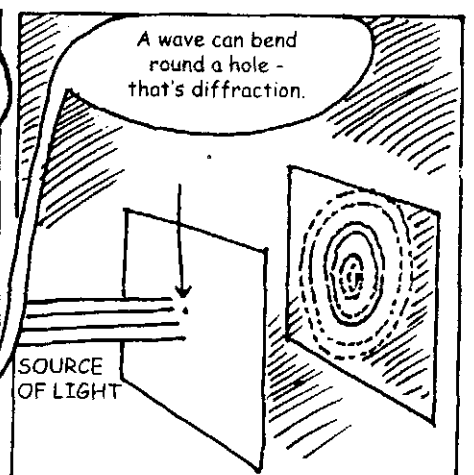
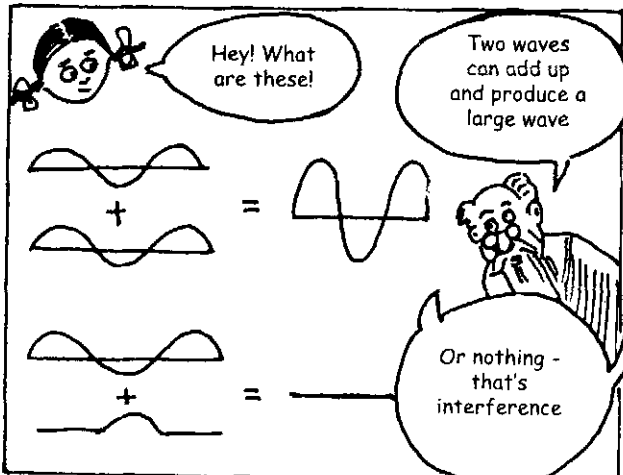
But then neither could Huygens!



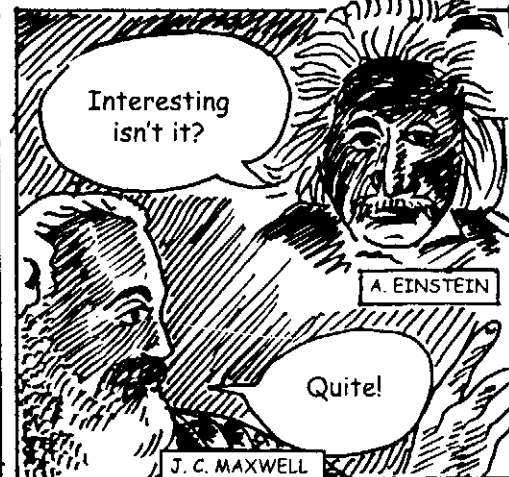
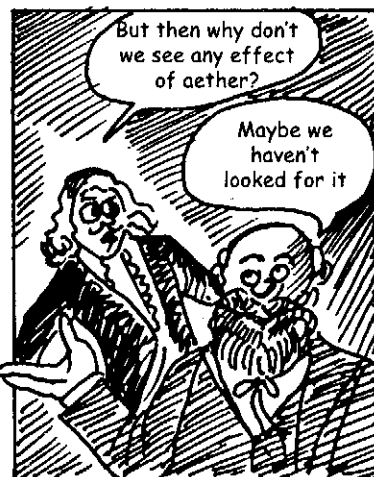
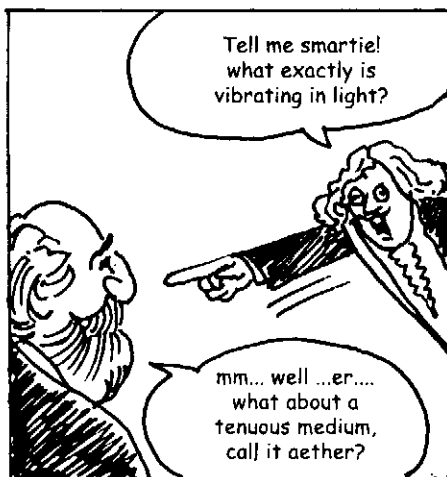
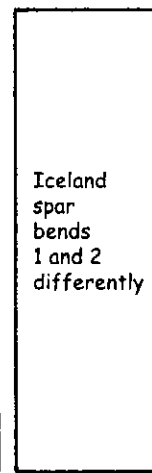
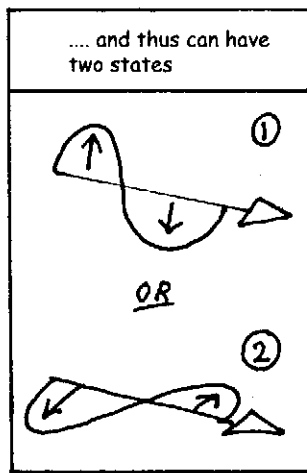
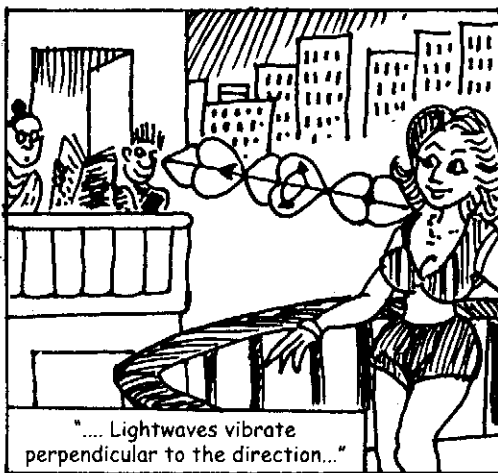
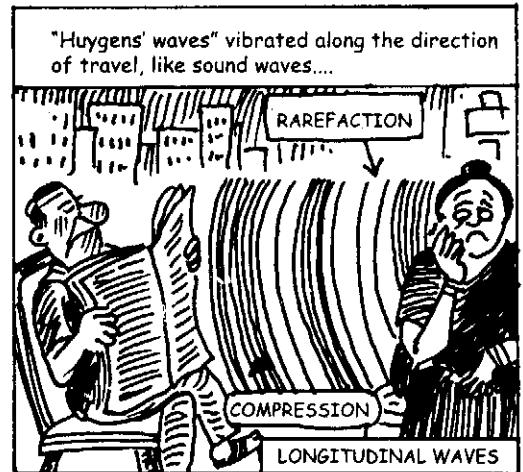
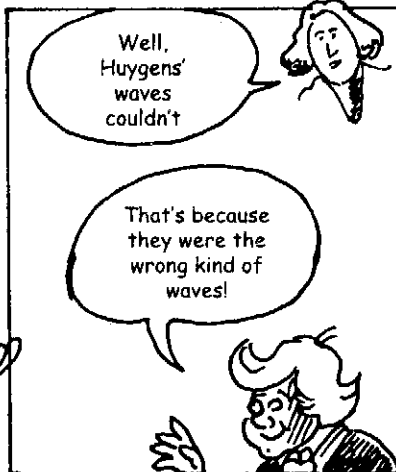
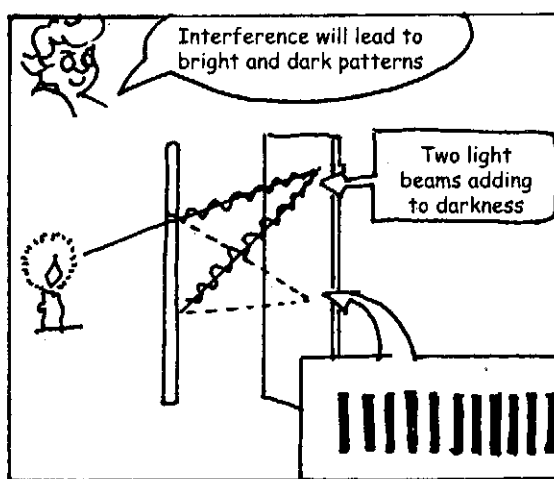
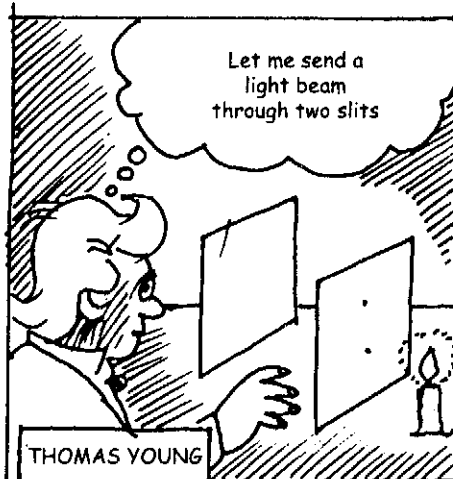
These matters rested until the time of Thomas Young - another child prodigy



Young showed that light undergoes interference and diffraction





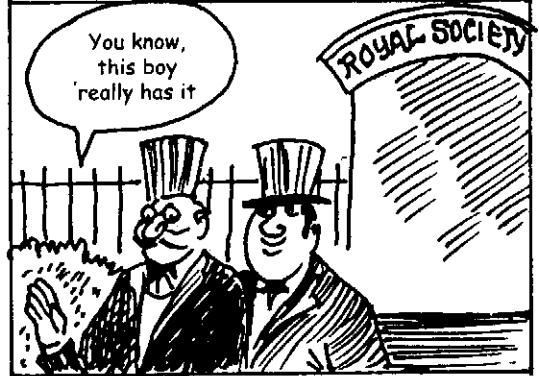


The nature of light was illuminated by another intellectual giant James Clerk Maxwell (1831 - 1879)

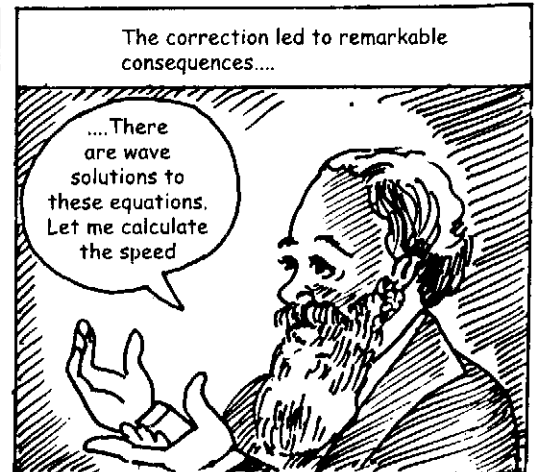
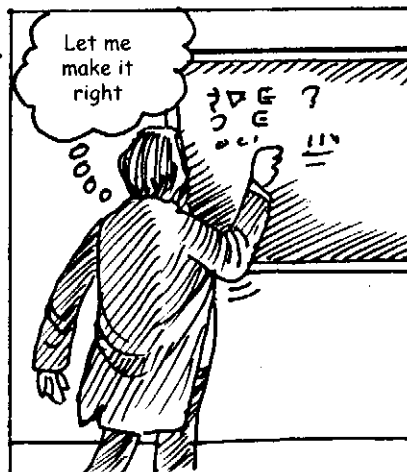
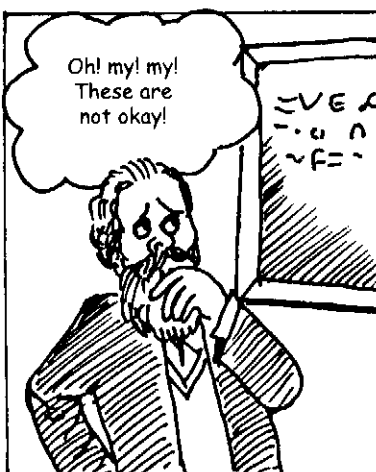
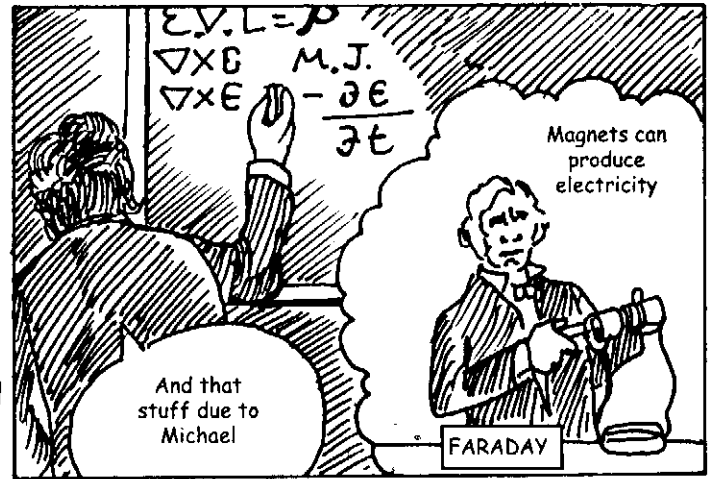
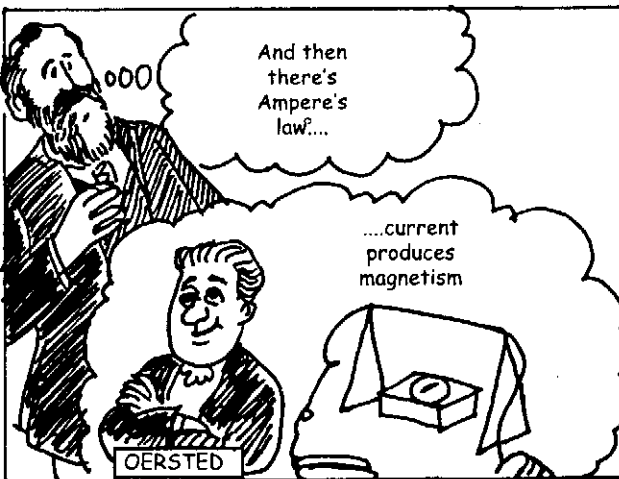
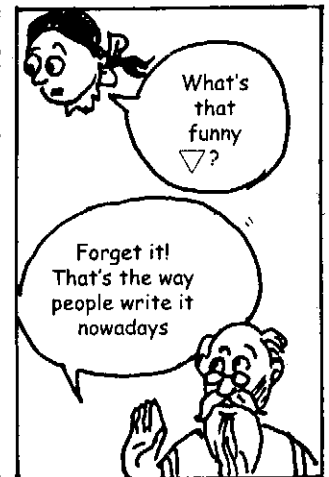
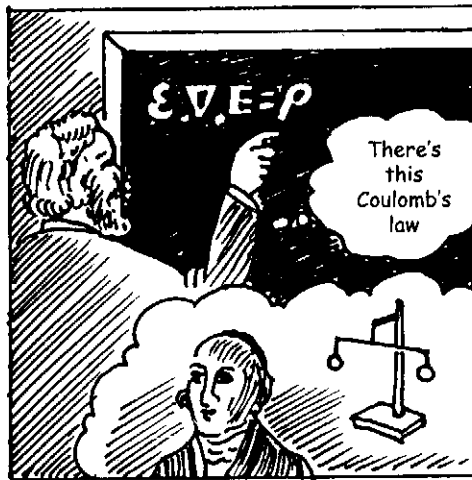
Yet another infant prodigy....

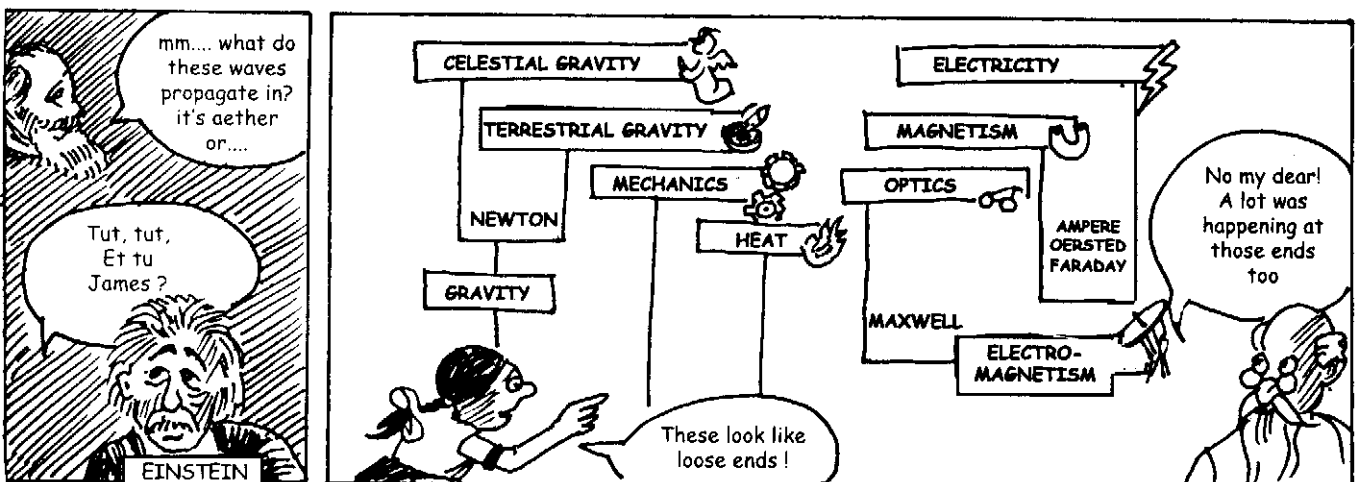
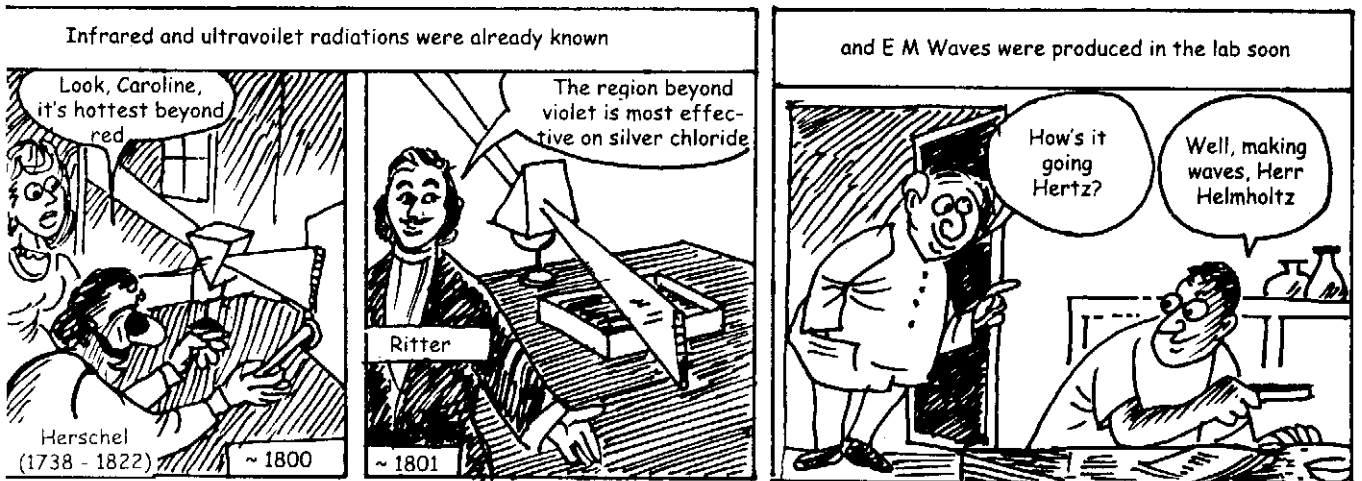
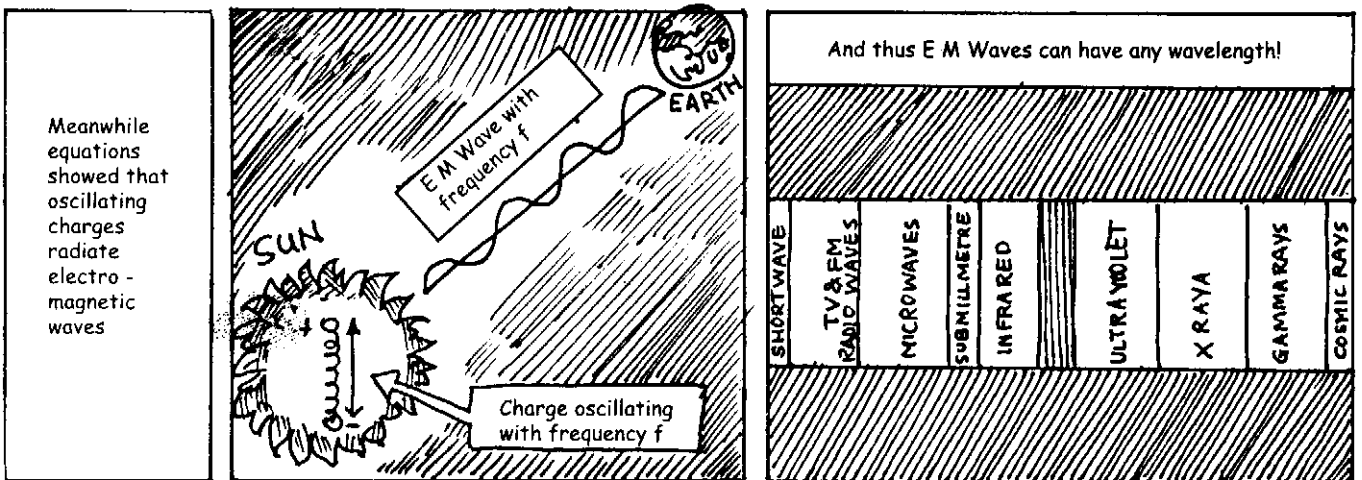


...whose first paper was read at Royal Society of Edinburg when he was 15

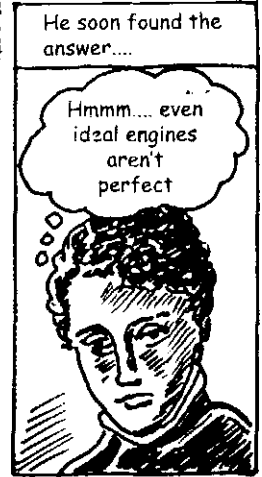
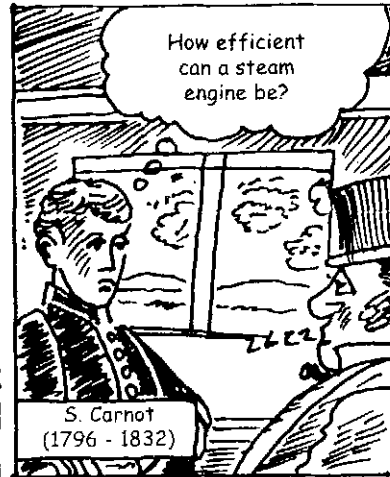


Later in his life he looked at electromagnetism....



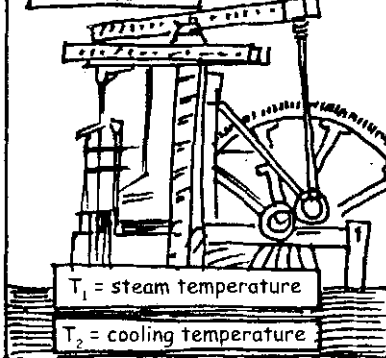


Joining heat and mechanics into "thermodynamics" was the work of many. To begin with there was Sadi Carnot

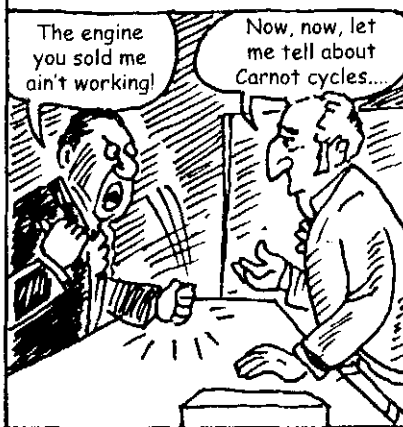


The efficiency of an ideal engine was less than one!

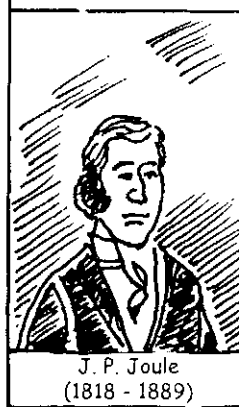
$$E = 1 - \left(\frac{T_c}{T_h}\right)$$



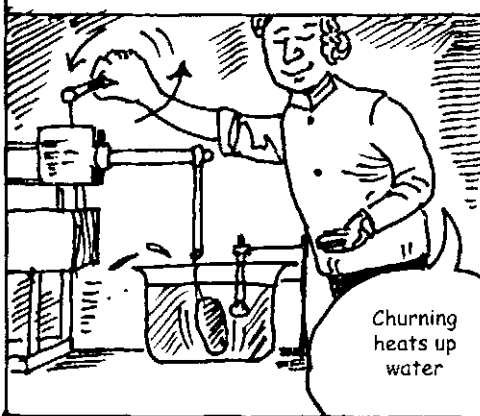
And most engines were far from ideal!



The connection between heat and motion was pursued by others



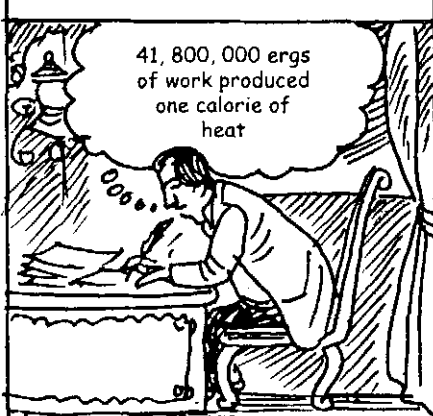
Joule made precise measurements of the heat produced by mechanical motion....



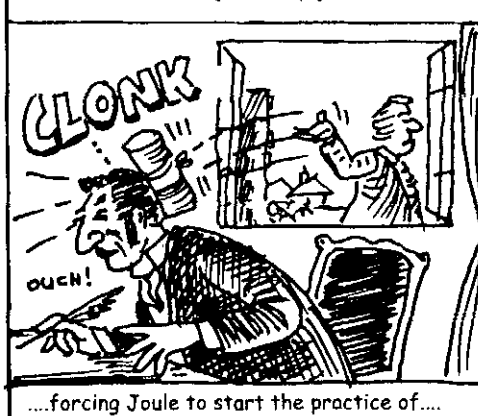
.... and had a scientific honeymoon



Finally he formulated the theory....

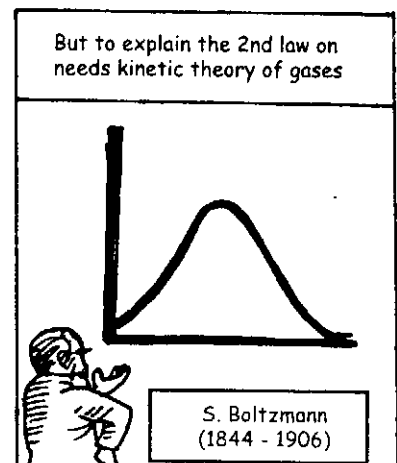
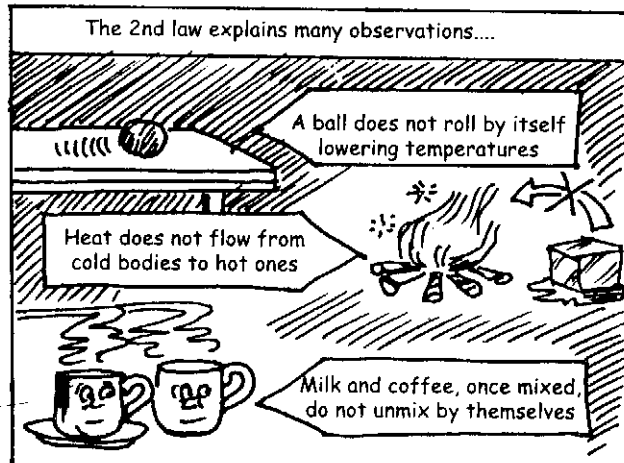
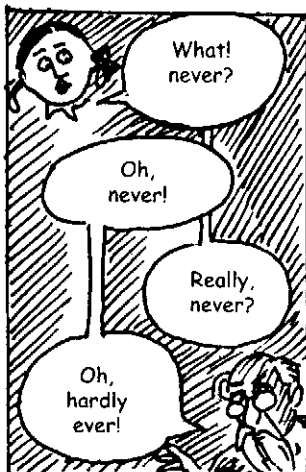
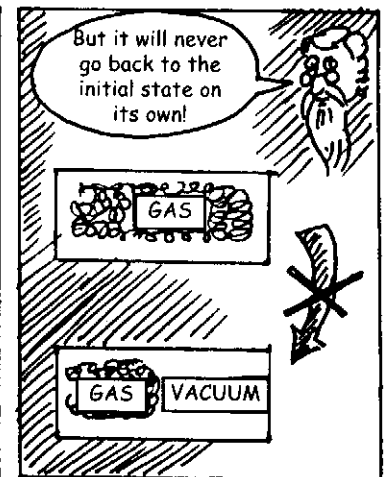
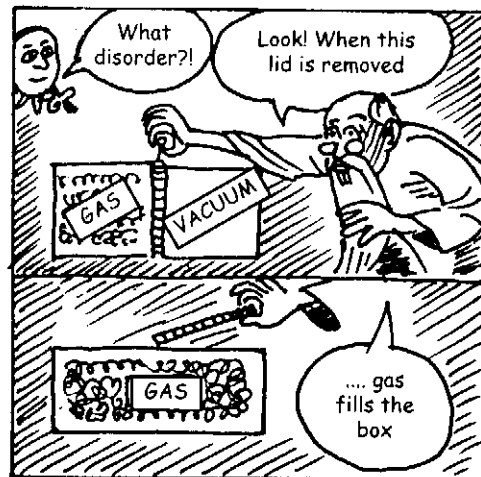
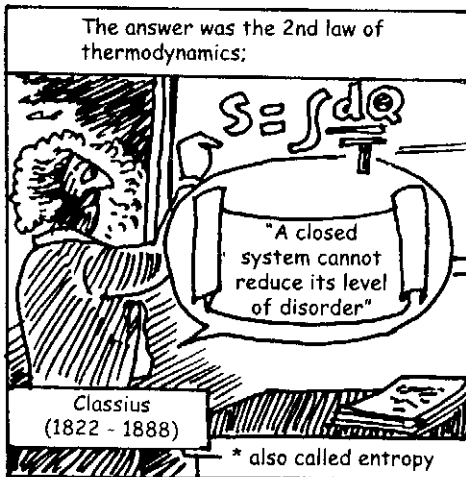
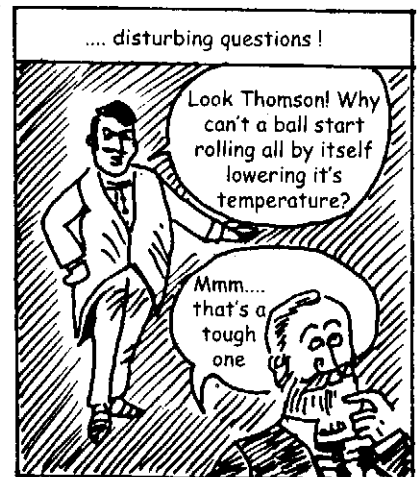
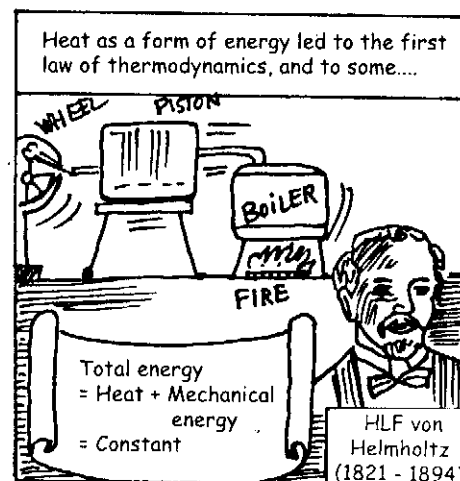
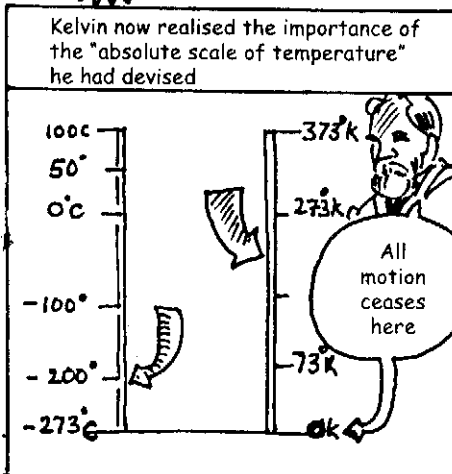
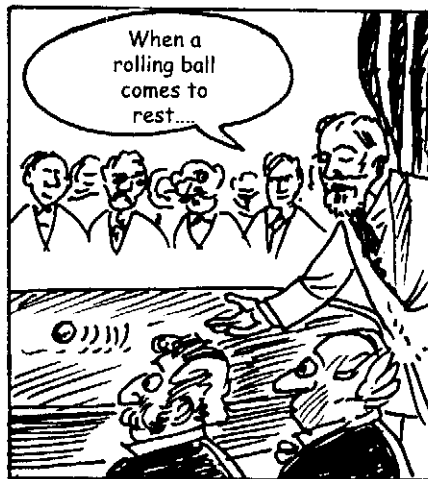


.... which was rejected by journals....



....doing science through\* newspaper

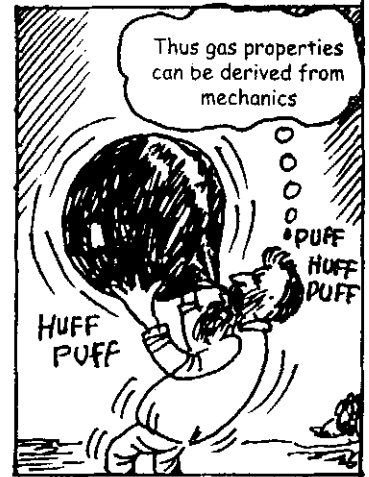
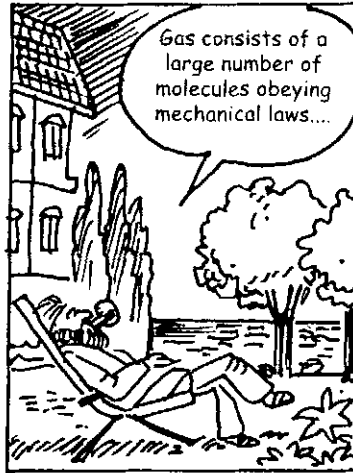
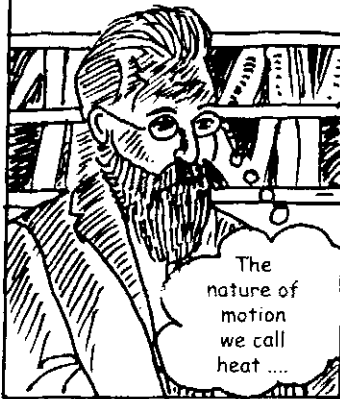




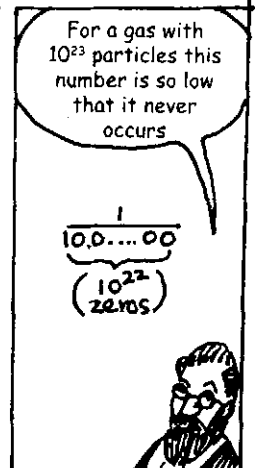
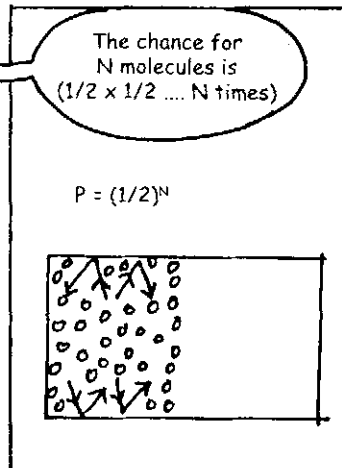
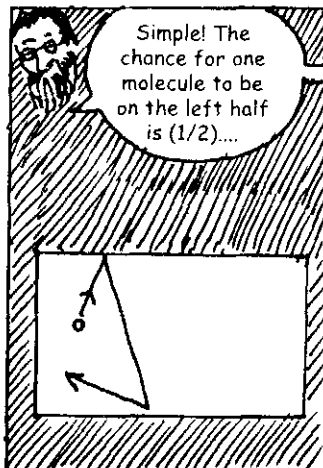
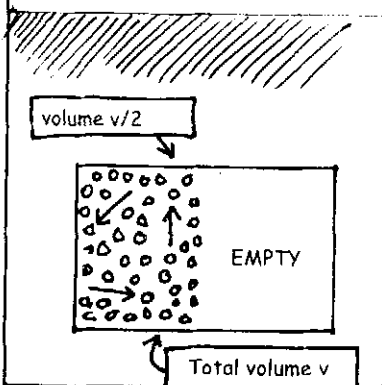


The complete connection between heat and mechanics was established by the works of Maxwell and ...

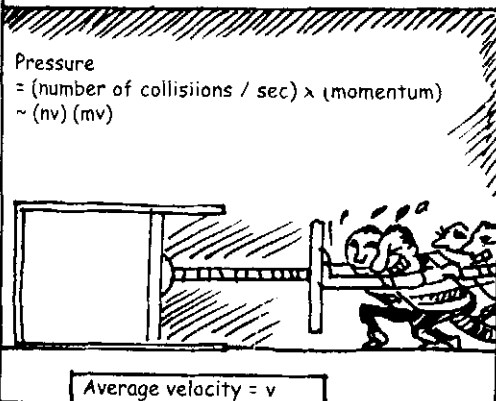
S. BOLTZMANN



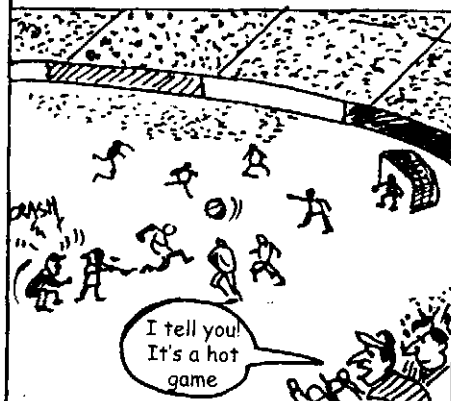
Why don't all the molecules of the gas stay like this?



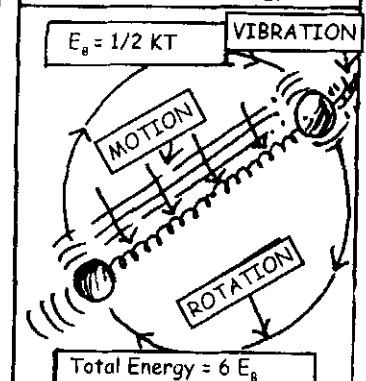
Boltzmann explained that pressure was due to molecular motion....



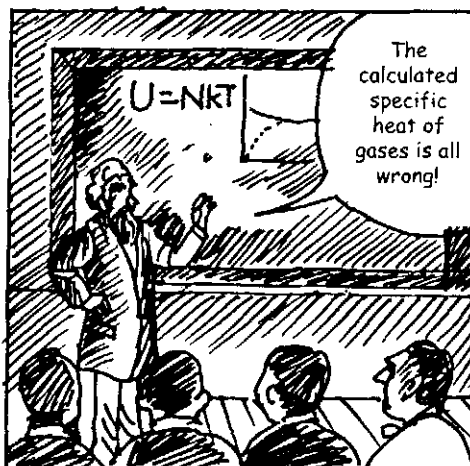
...So that temperature became just a measure of random motion



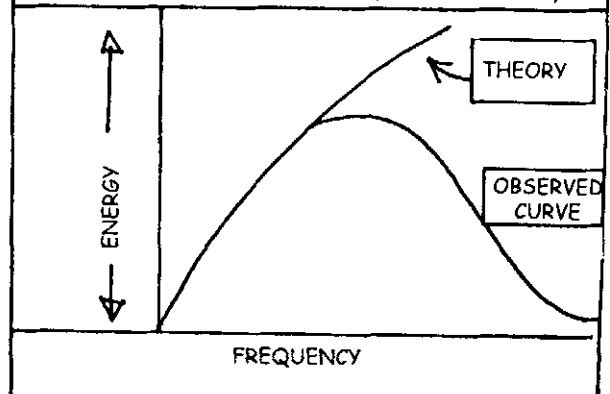
To every degree of freedom of motion Boltzmann associated fixed energy

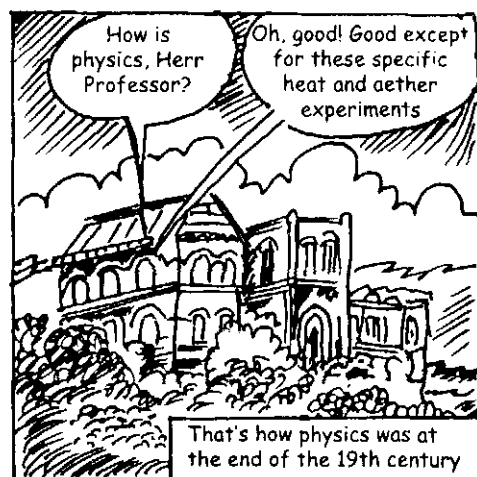
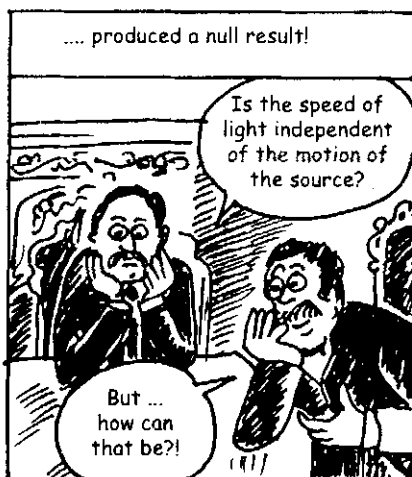
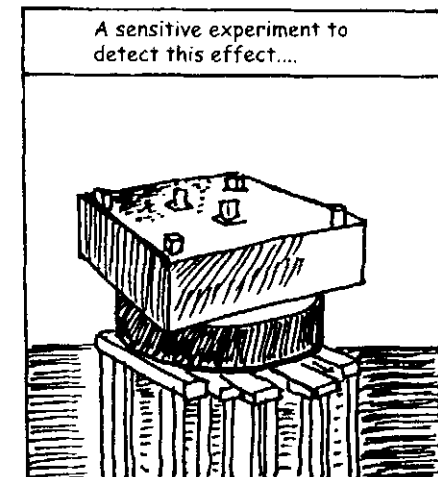
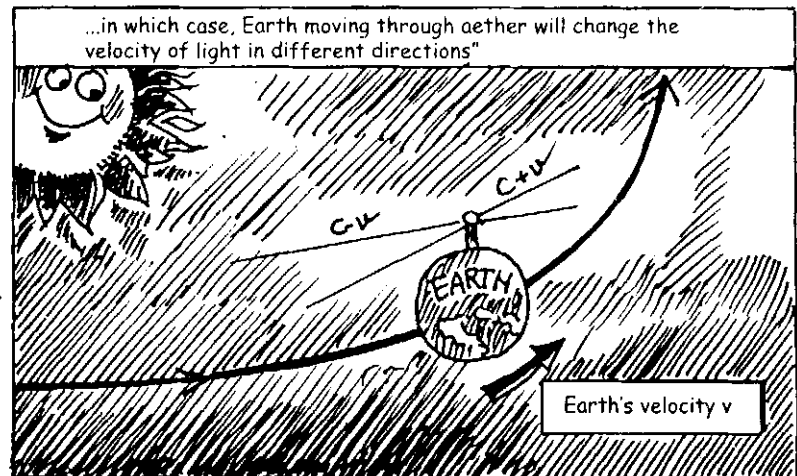
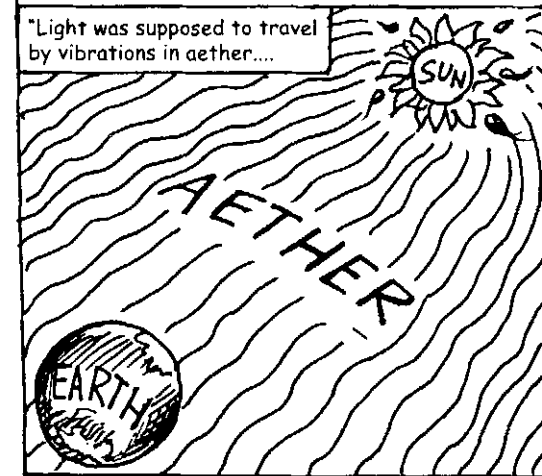
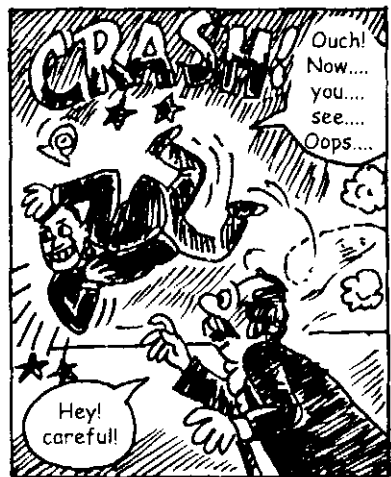
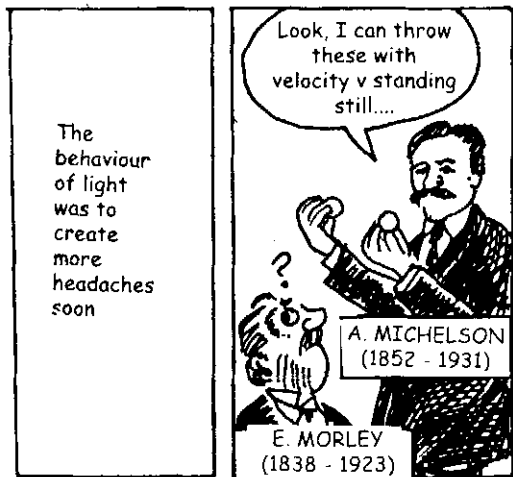
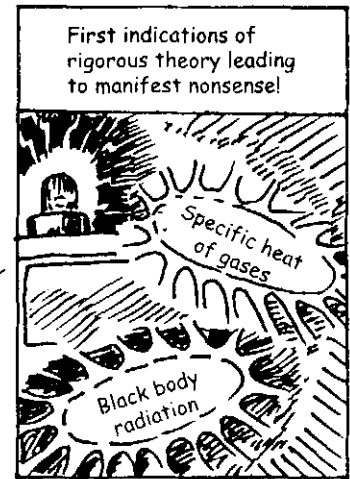
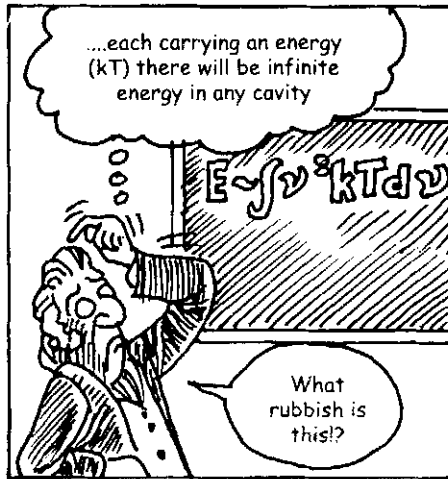
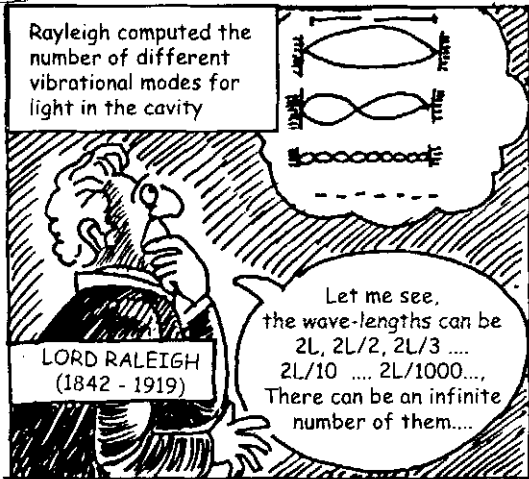


.... Which seemed to explain many observations but not all!



Similar difficulties occurred when Boltzmann's ideas were used to explain emission of light by a hot black cavity



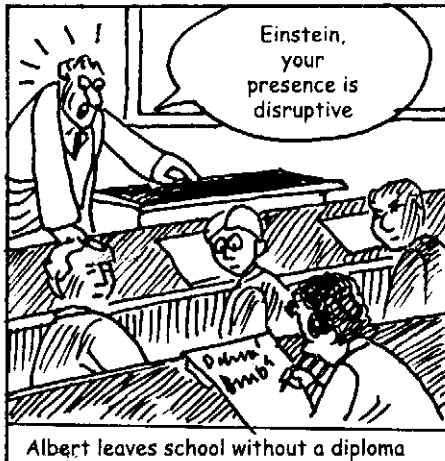


The problems of classical physics led to a drastic revision of basic concepts, via relativity and the quantum theory. Relativistic revolution was the work of...

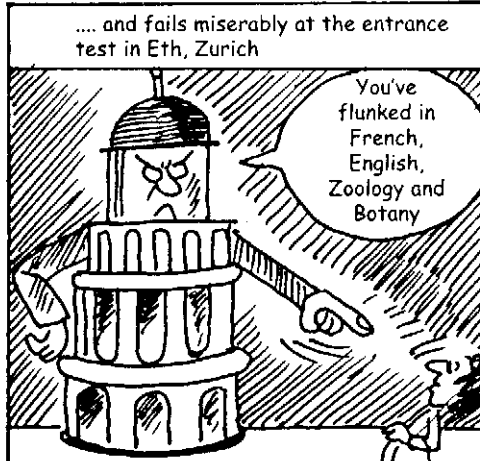
... a boy born in 1879, Albert Einstein



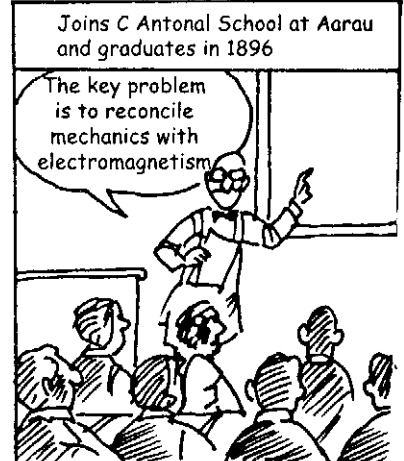
Albert's early life would give hope to every dumb nitwit....



Albert leaves school without a diploma

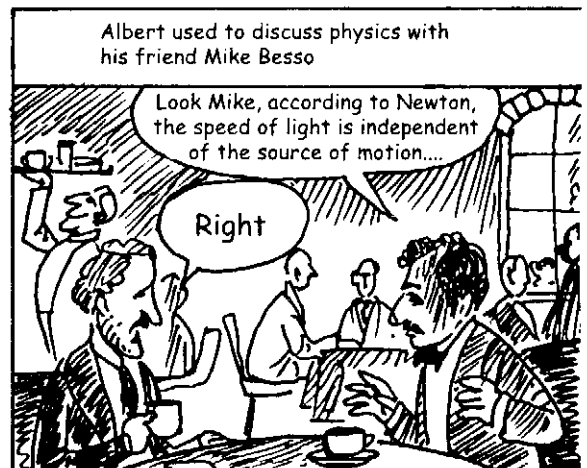
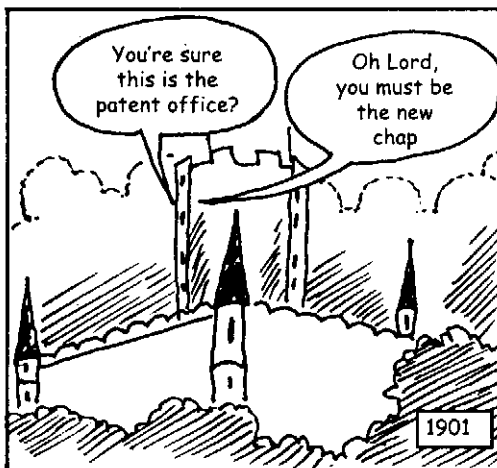


.... and fails miserably at the entrance test in Eth, Zurich

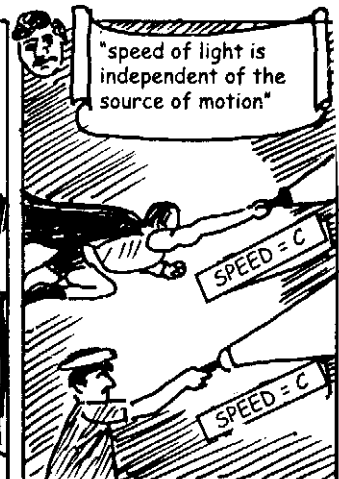
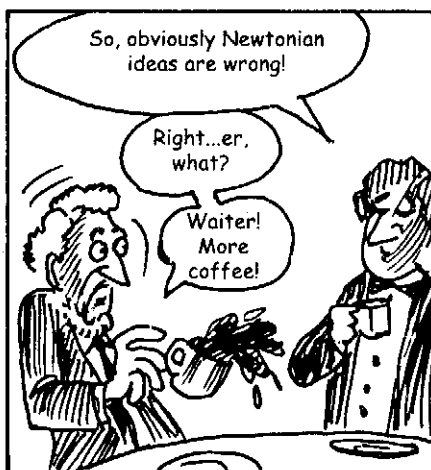


Joins C Antonal School at Aarau and graduates in 1896

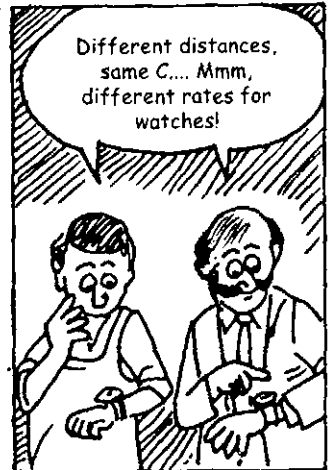
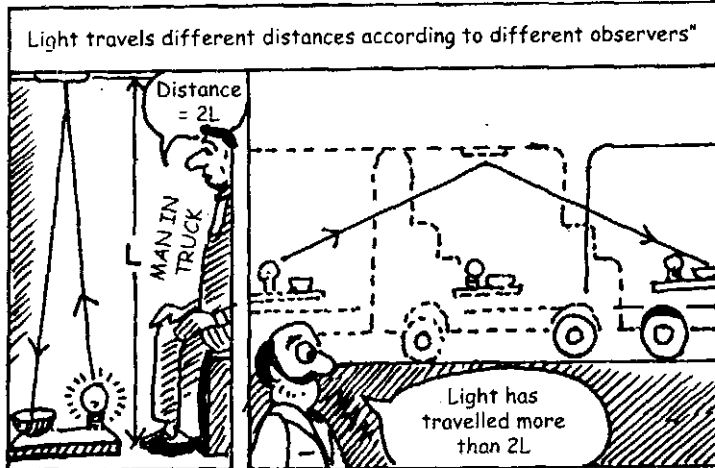
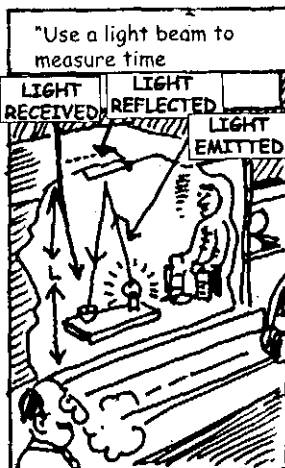
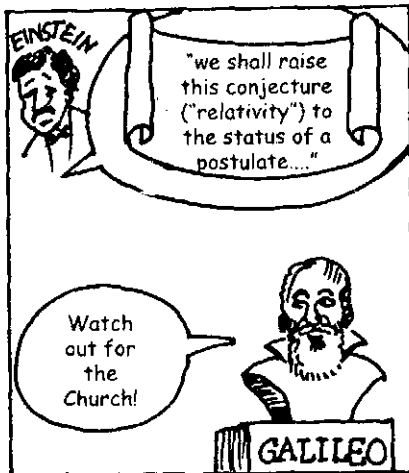
After five years in Zurich, he gets a job at Bern, only because of the influence of a friend Marcel Grossmann



Albert used to discuss physics with his friend Mike Besso



Albert also believed that the laws of physics should not distinguish between state of rest and state of uniform motion

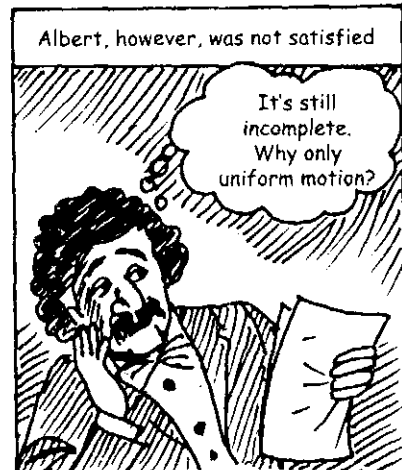
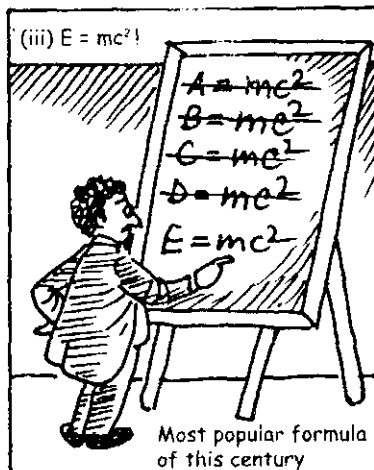
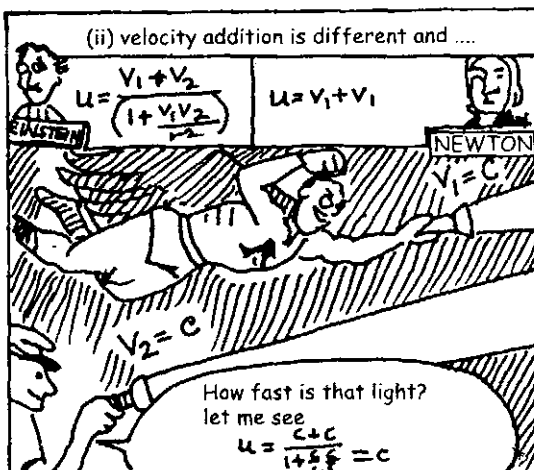
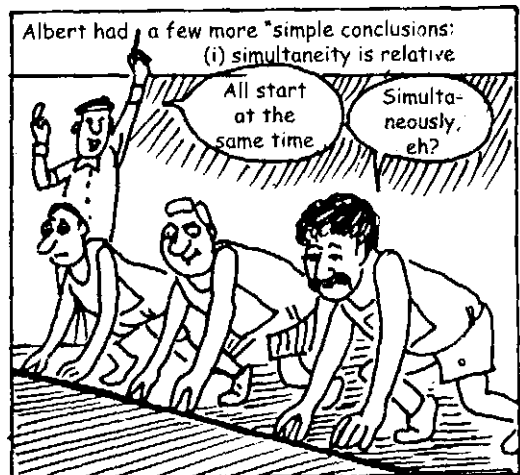


Calculation shows....

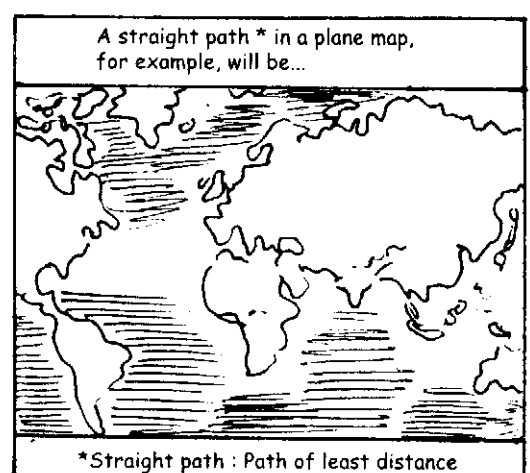
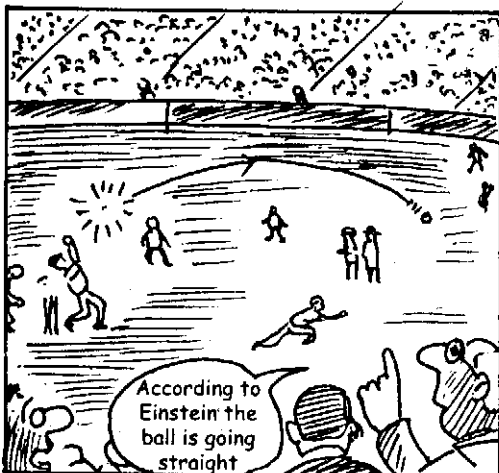
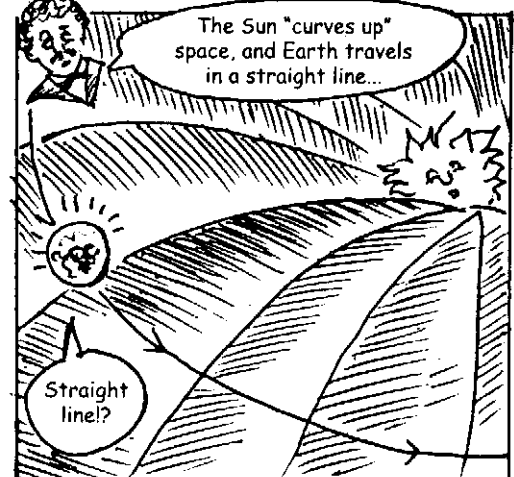
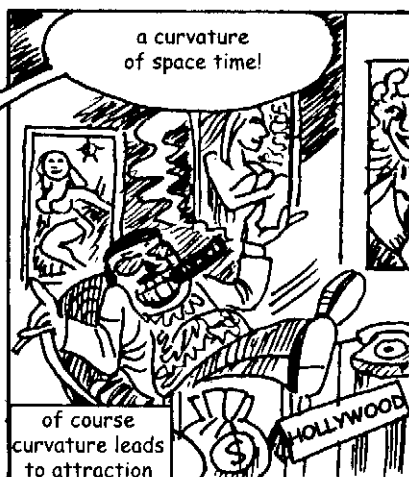
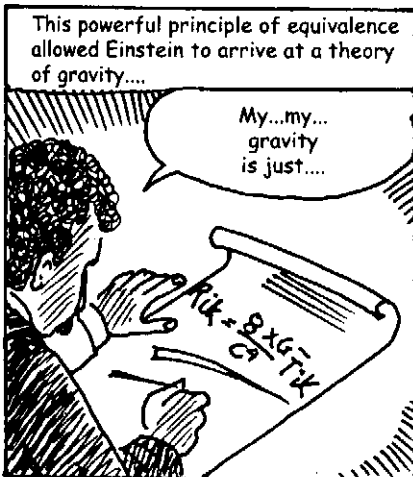
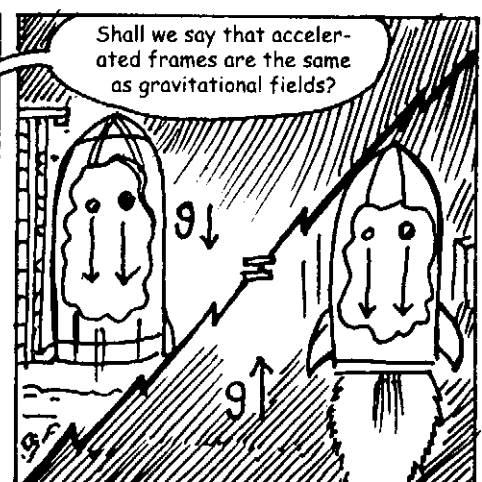
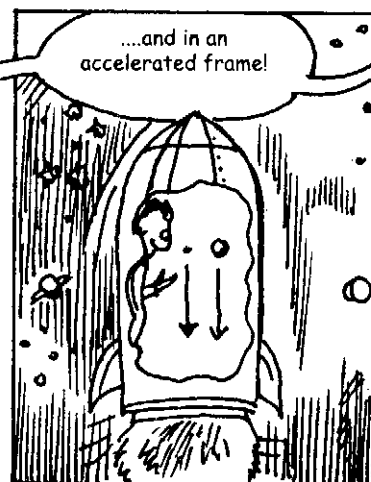
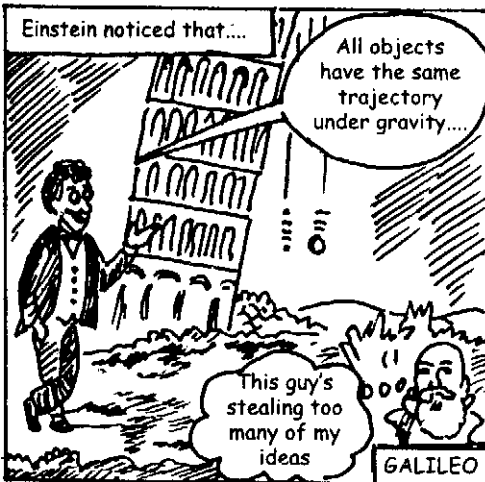
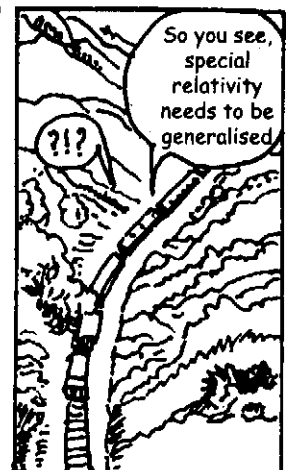
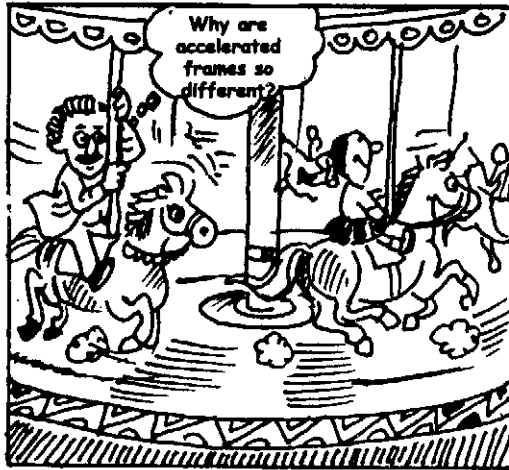
$$t = \frac{t'}{\sqrt{1-v^2/c^2}}$$

$t$  = time elapsed for man on road  
 $t'$  = time elapsed for man in truck  
 $v$  = speed of truck

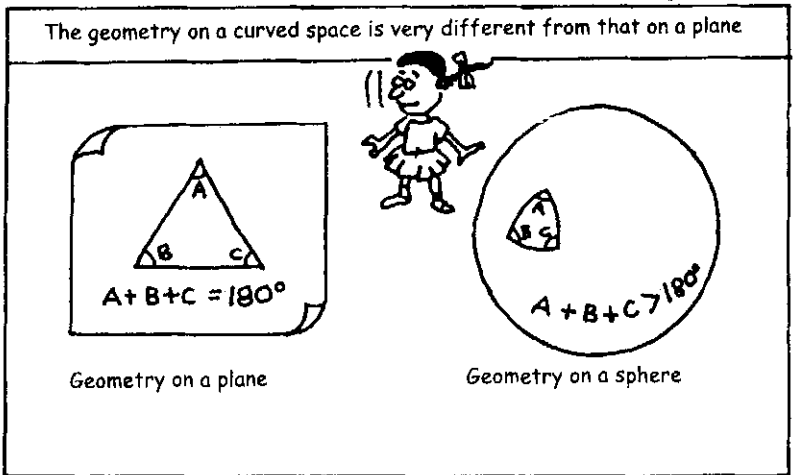
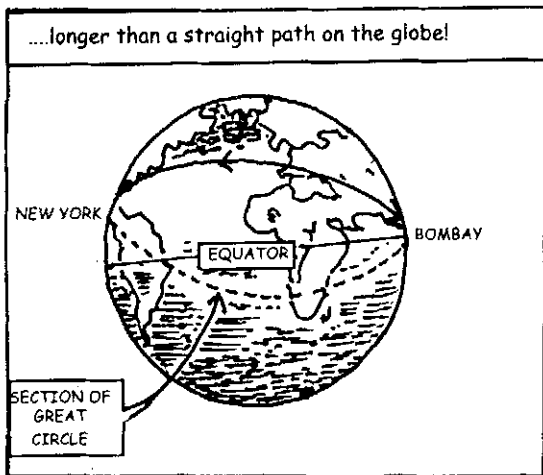
Absolute time flows equally without relation to anything - Newton



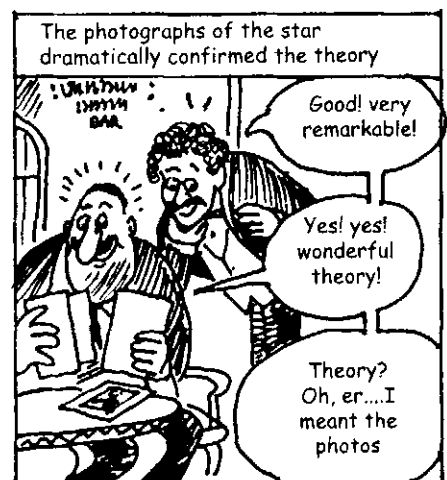
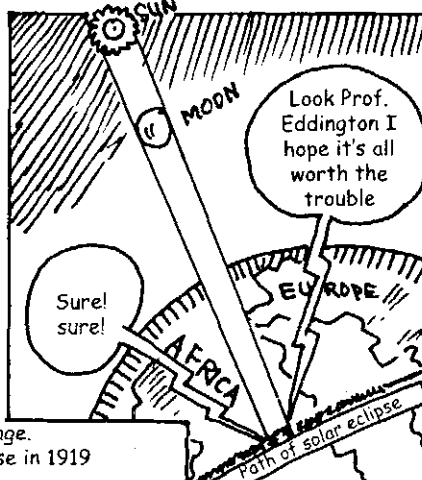
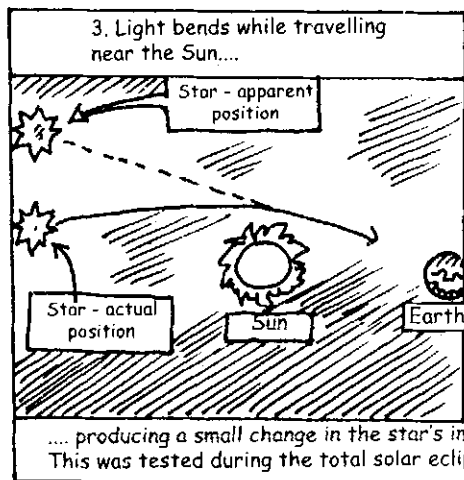
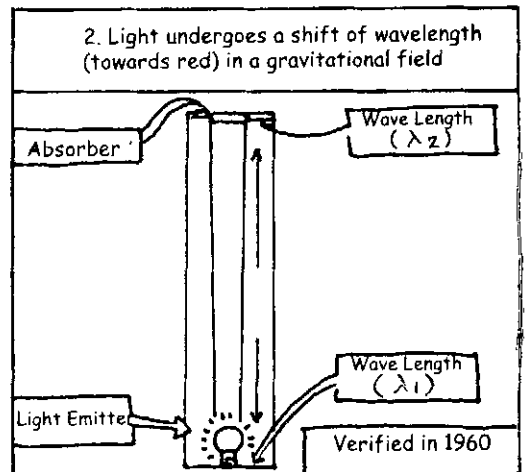
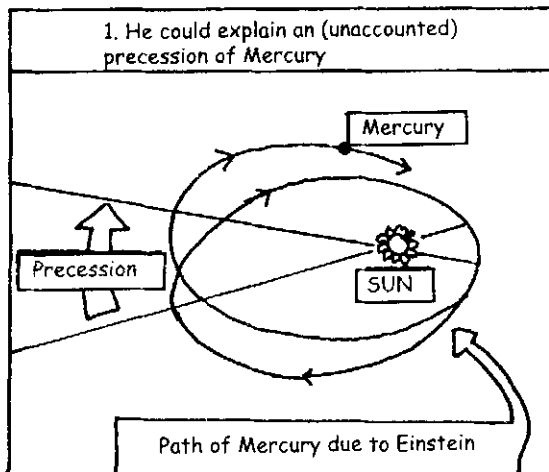
Dissatisfied with the role of motion Einstein generalised further, constructing the most beautiful theory devised so far



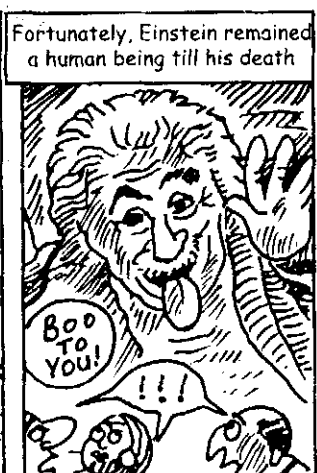
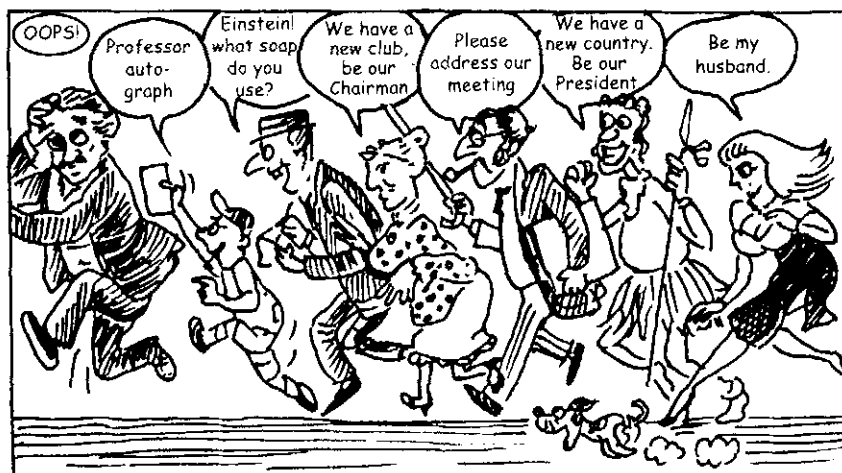




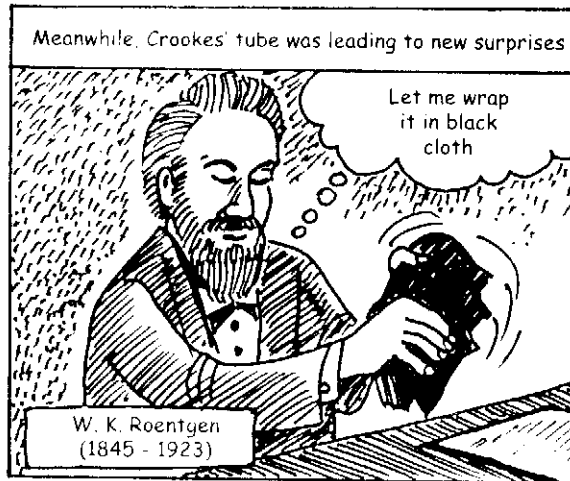
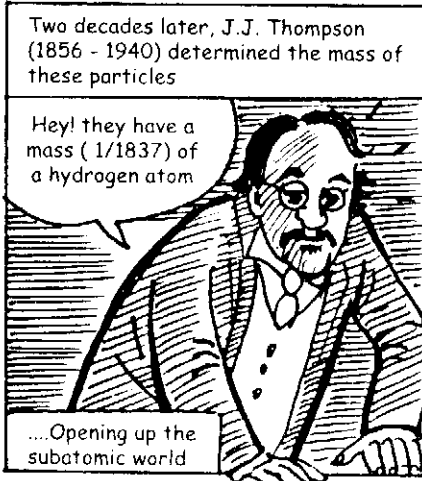
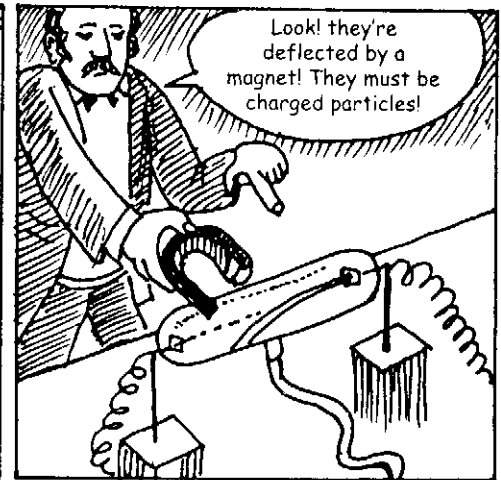
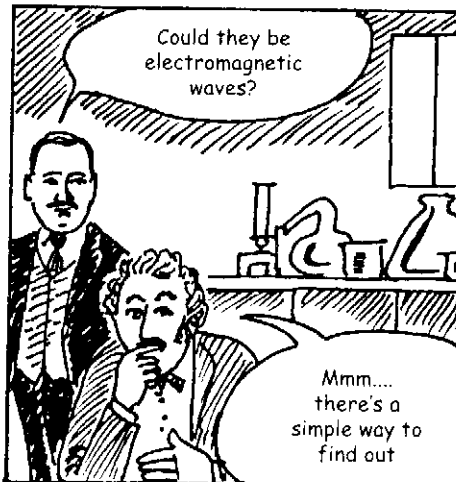
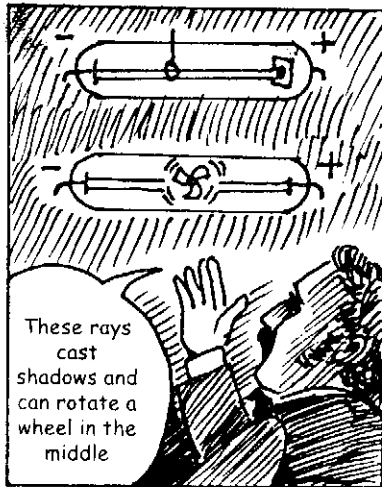
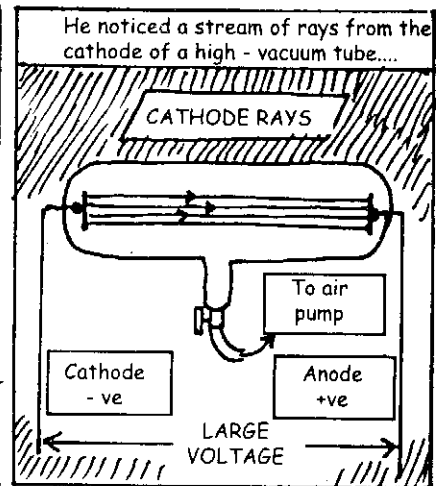
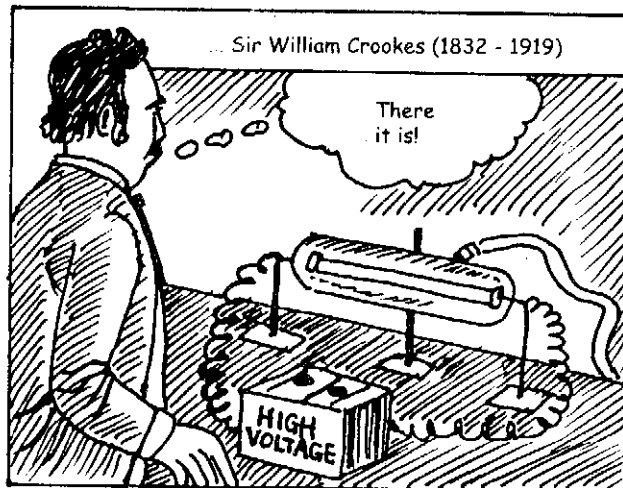
Using the correct geometry for curved space time Einstein worked out the consequences of his theory of gravity



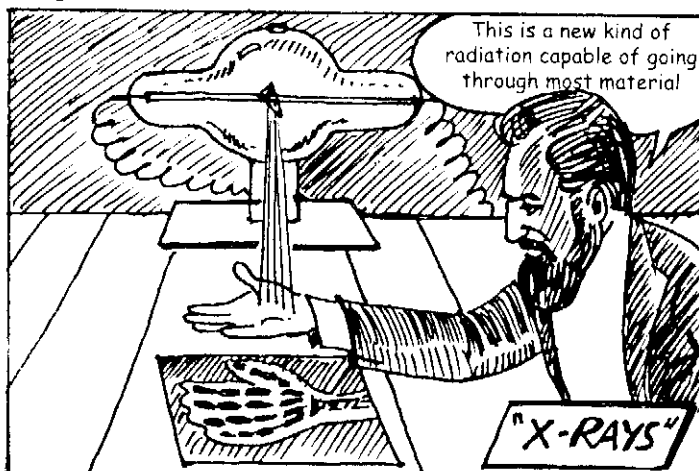
Never since Newton has a single man achieved so much or become so famous



While the relativistic revolution was in progress, an army of physicists was trying to understand the structure of matter. To begin with there was....

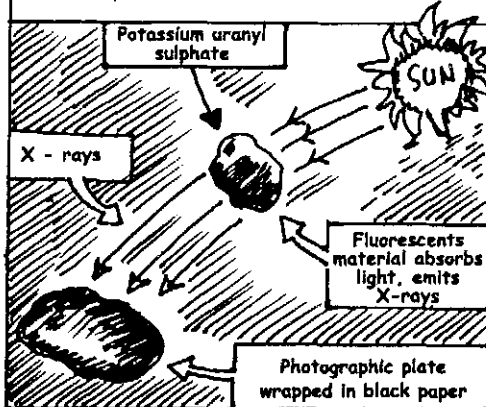


With systematic experimentation Roentgen could arrive at the correct solution



X - rays were investigated by A. H. Becquerel (1852 - 1908) the French physicist who was looking at the X - rays emitted by fluorescent material

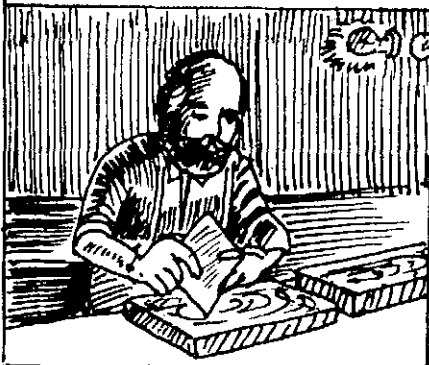
He proceeded as follows:



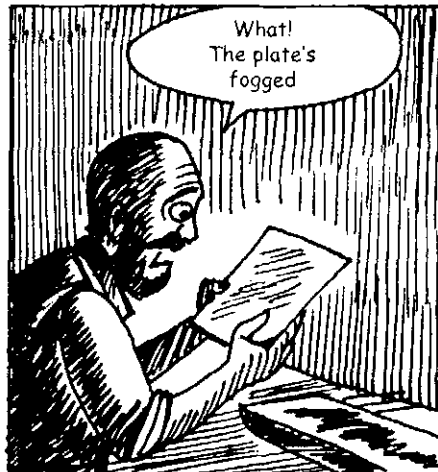
Then came a cloudy day....



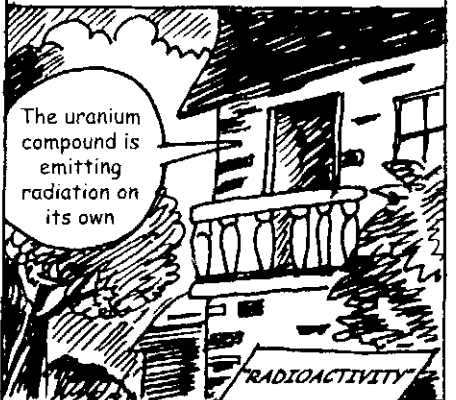
Something prompted him to develop the plate even though it wasn't exposed to sunlight!



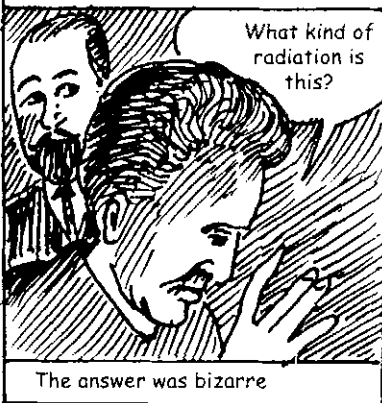
What! The plate's fogged



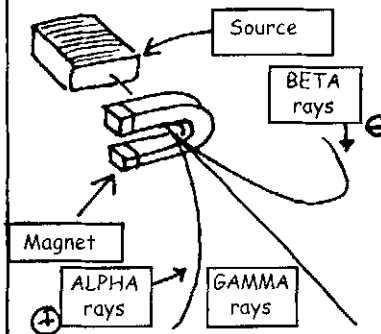
Becquerel was forced to the startling conclusion



This idea was actively pursued by the Curies

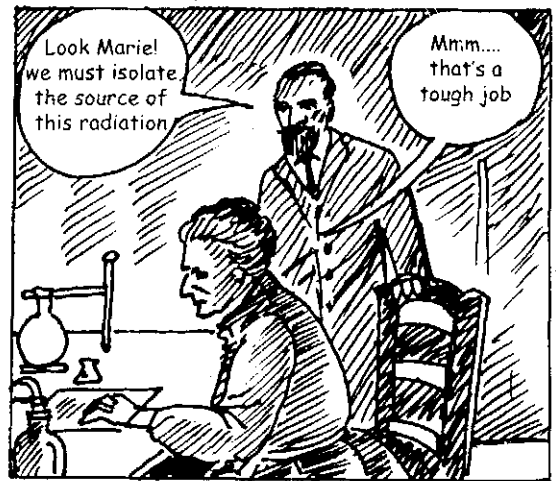


There are three kinds of radiation : alpha, beta and gamma



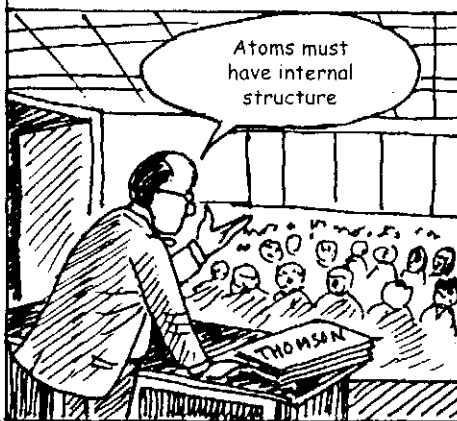
Look Marie! we must isolate the source of this radiation

Mmm... that's a tough job



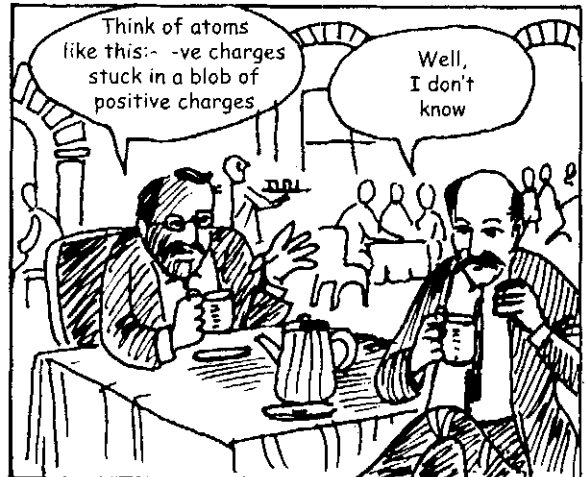
After years of toil they isolated of powerful radioactive source - "radium"

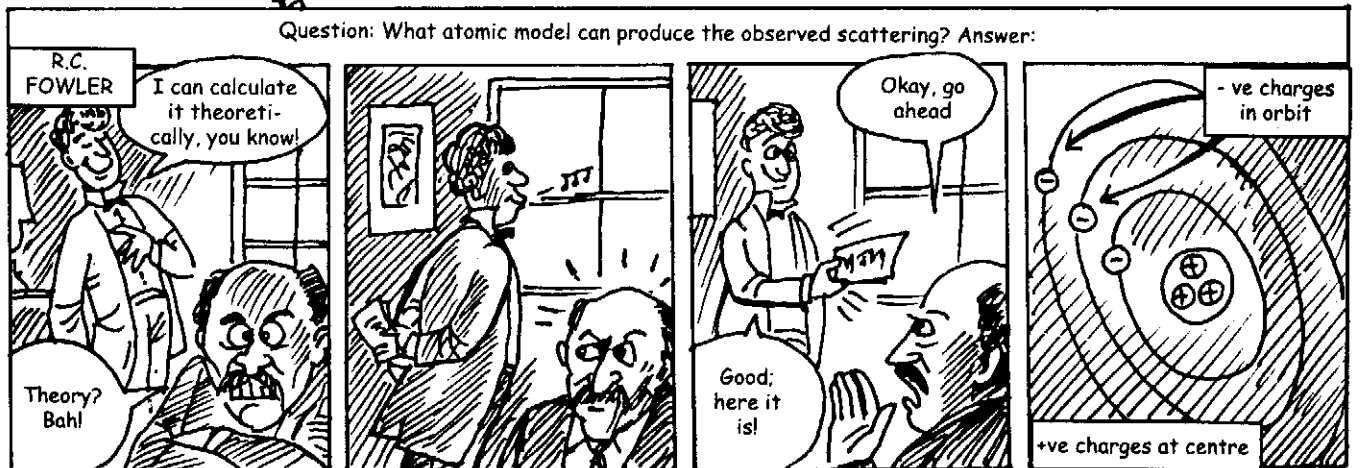
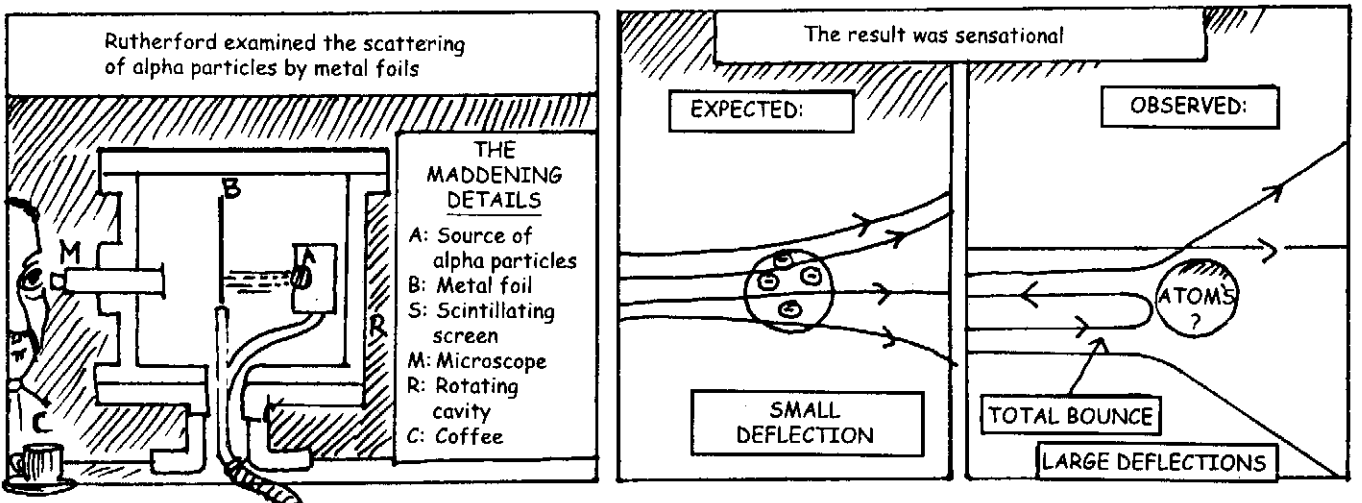
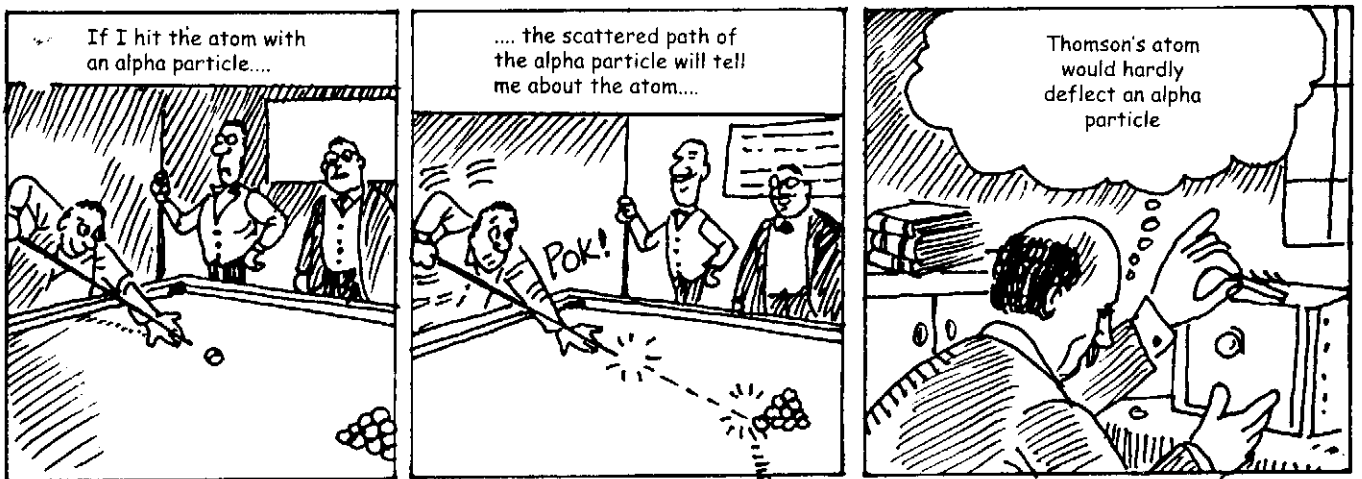
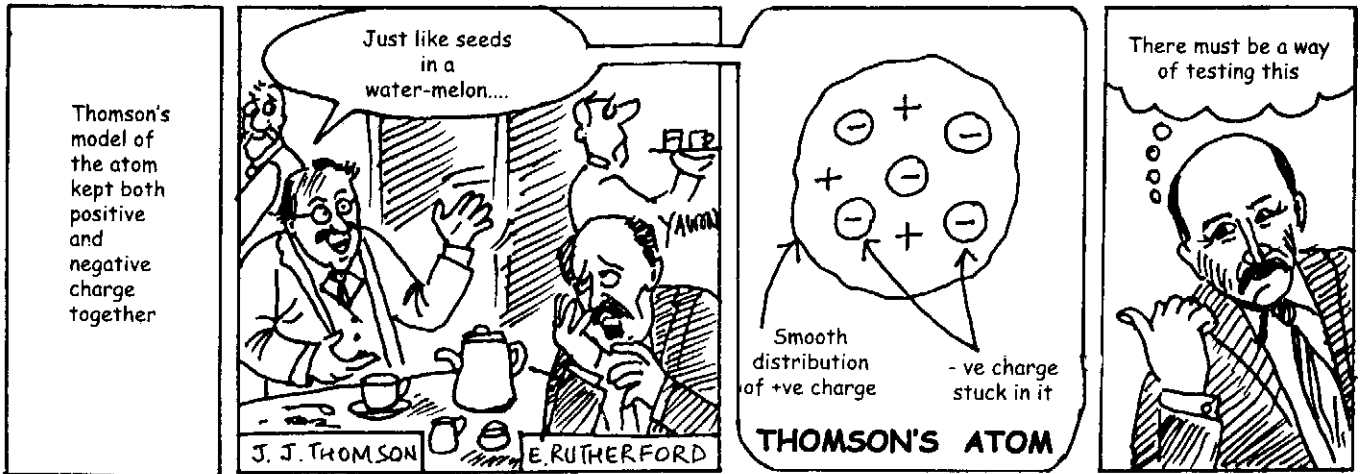
Radioactivity opened a new dimension to matter

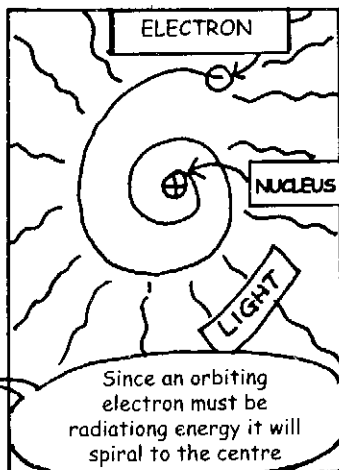
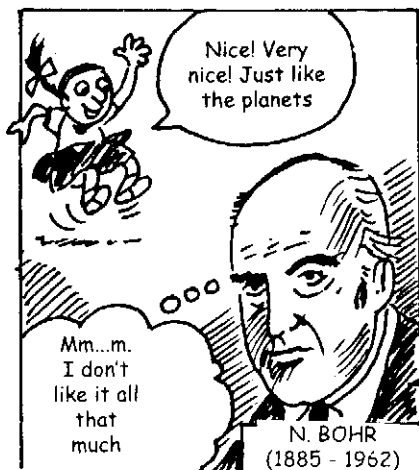


Think of atoms like this: - -ve charges stuck in a blob of positive charges

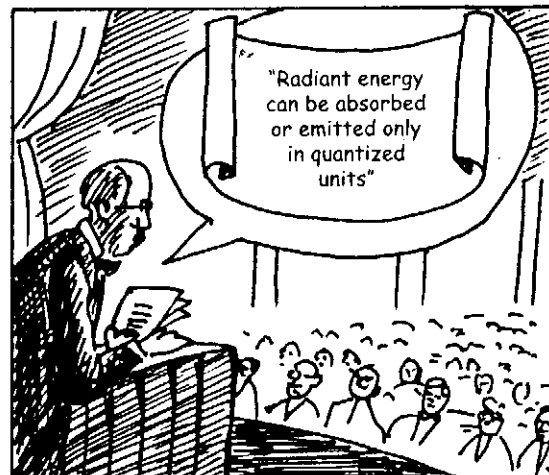
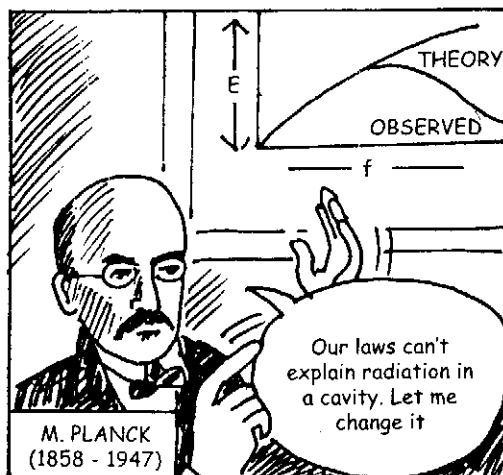
Well, I don't know







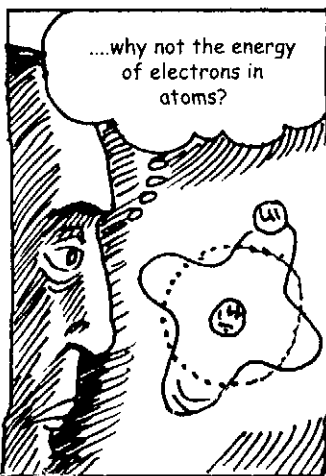
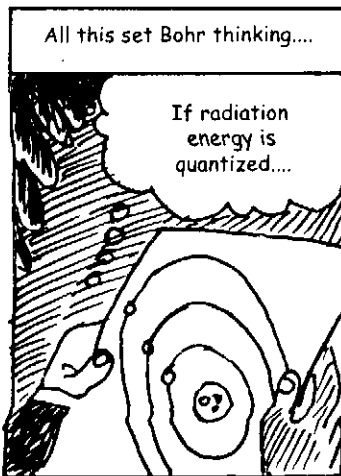
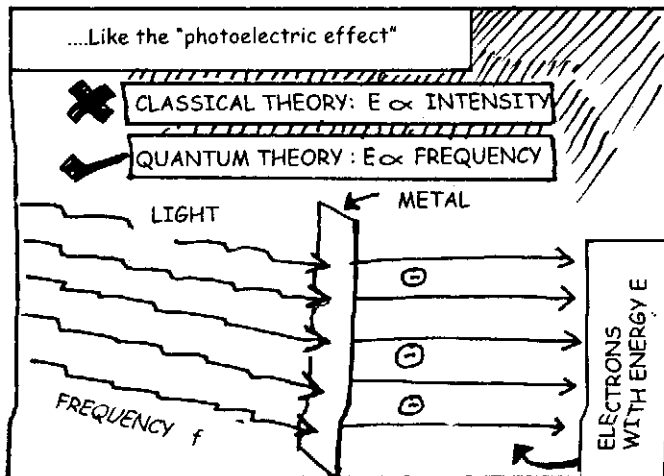
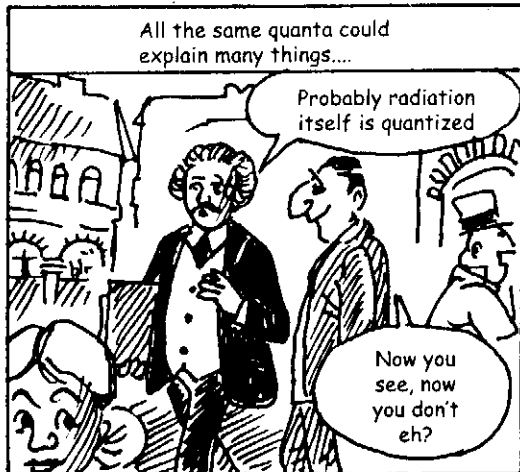
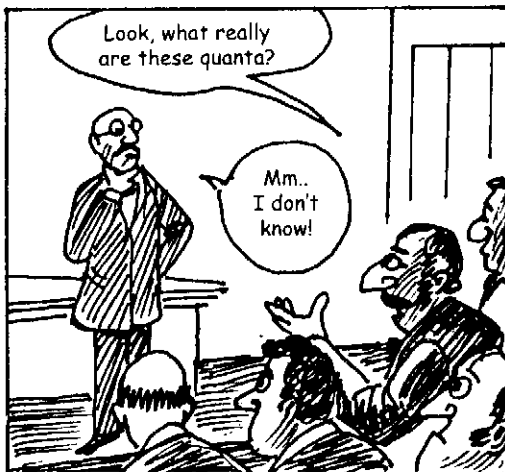
To understand how Bohr "changed the laws" we've to go back a few years. Someone was already tampering with the laws!



Planck introduced a new constant

Energy of a quantum =  $h \times \text{frequency}$

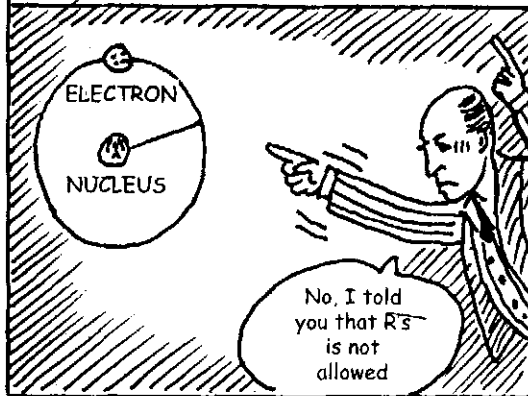
$h = 6.6 \times 10^{-27} \text{ ergs. sec}$



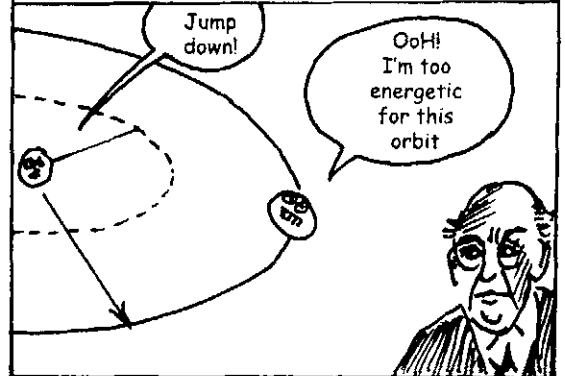


Niels Bohr had to give up many cherished principles to implement his idea

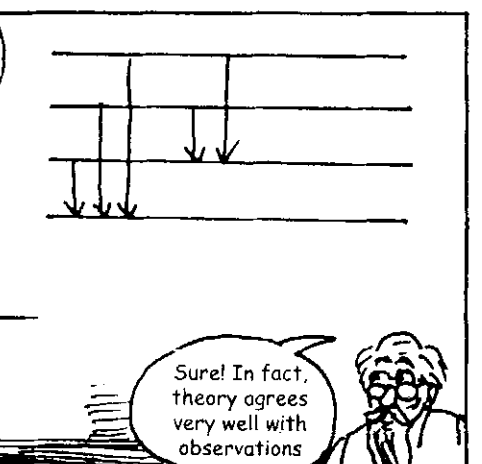
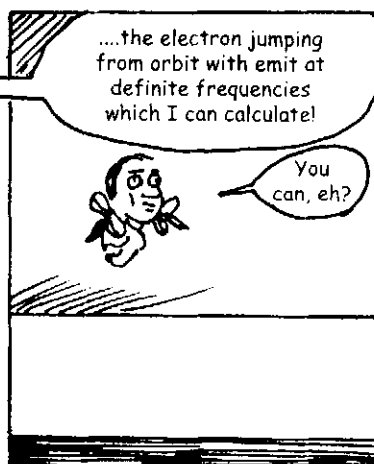
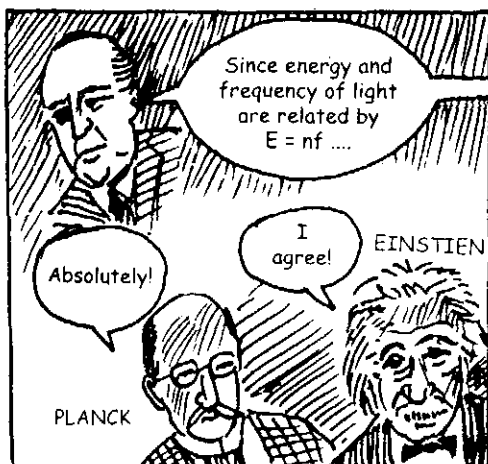
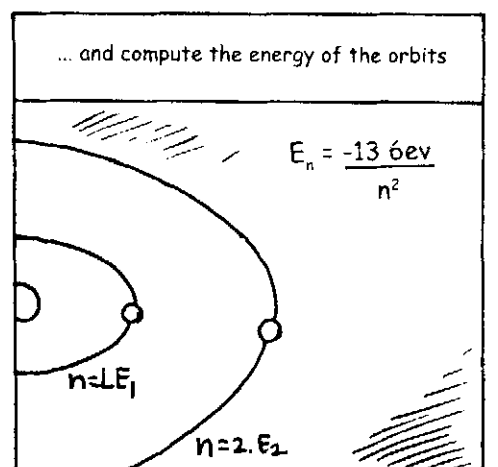
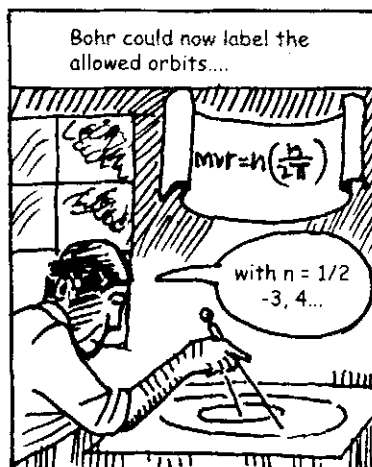
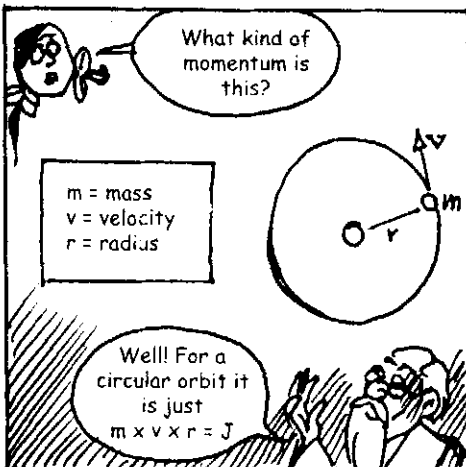
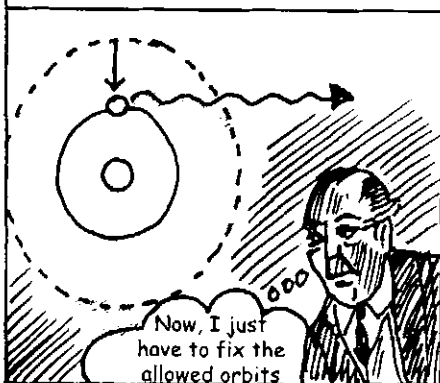
Electrons cannot orbit at all distances



Though accelerated, they can't radiate while in a definite orbit



Electrons emit radiation only when they jump from one orbit to another



Further complications led to better understanding. First, Sommerfeld introduced elliptical orbits

There can be both circular and elliptical orbits to the same energy

For  $n = 1$ , one circular orbit for  $n = 2$ , one circle and three ellipses....

Of course! I always told you so

KEPLER

Then came "Pauli's exclusion principle"

You can't put more than two electrons in each orbit

Why?

Because three is a crowd! Besides ....

....I can explain the periodic table with this rule!

Periodic Table of the Elements

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	

Indeed Pauli could!

But all these are ad hoc!

What are these orbits, anyway?

Yes, but why do they work?

It took sometime for more definite answers to emerge

Are waves and particles so different?

L. DeBroglie

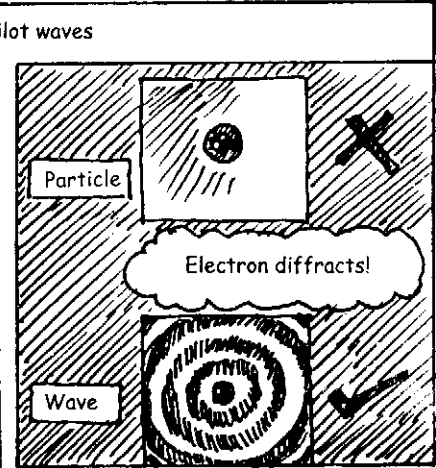
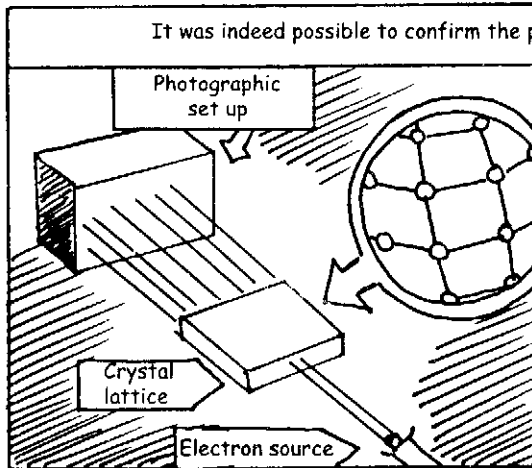
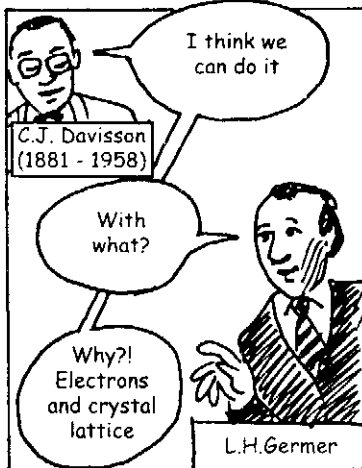
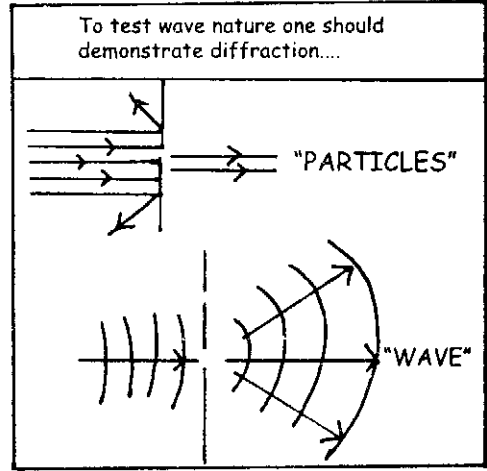
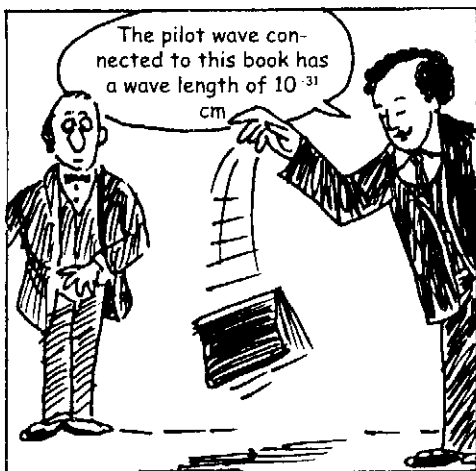
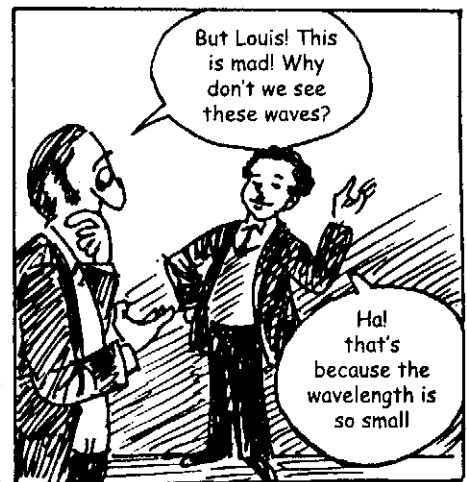
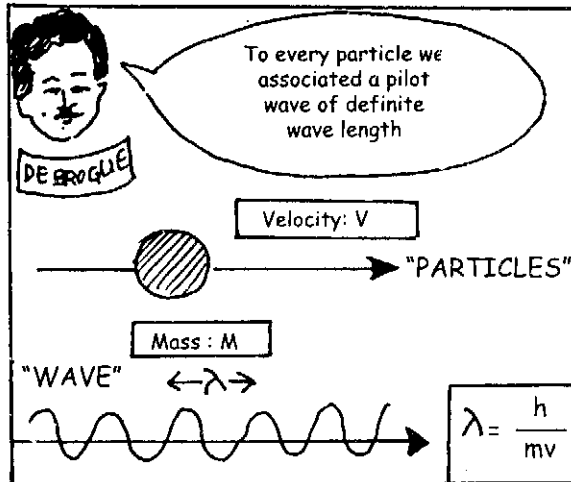
The electromagnetic wave has particle properties

Then why can't particles have wave properties?

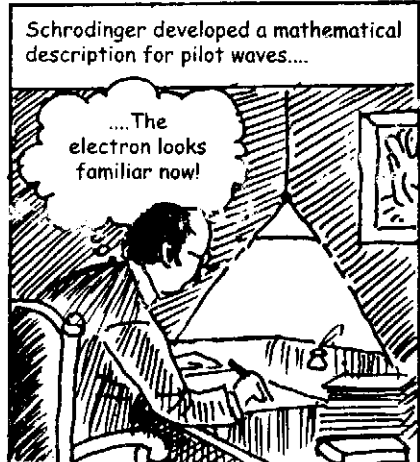
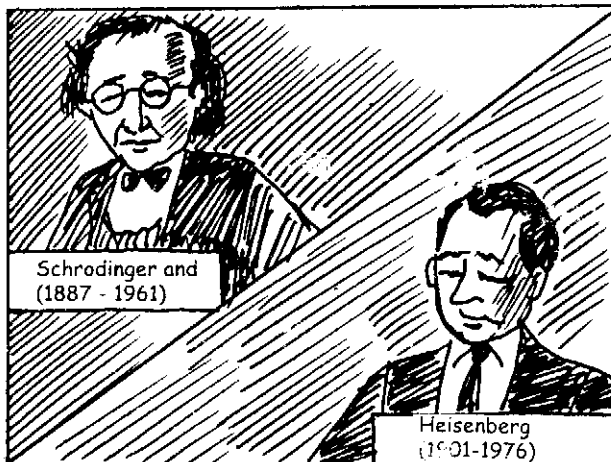
Associating a "pilot" wave with an electron can "explain" Bohr's idea

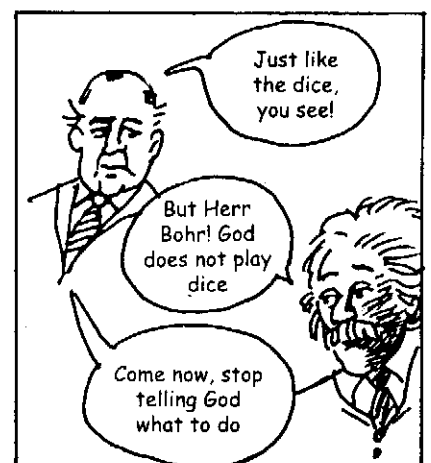
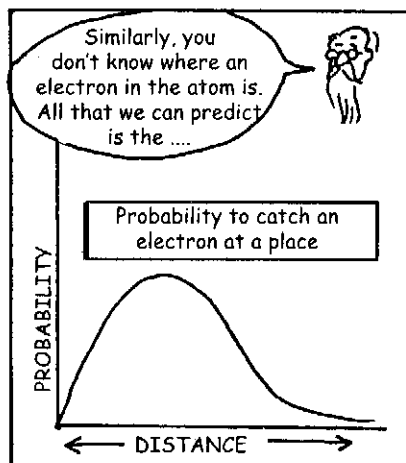
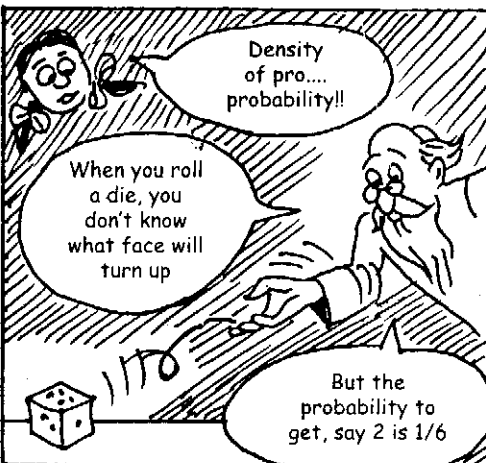
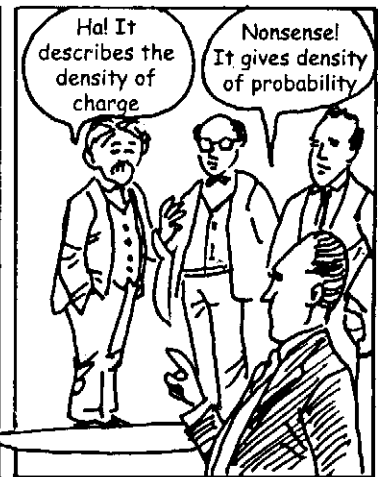
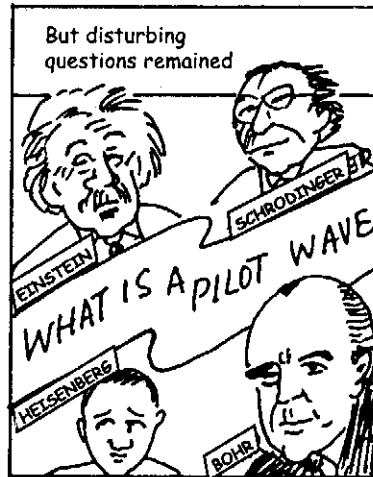
Pilot wave?

with one bold stroke DeBroglie eliminated the distance between wave and particle

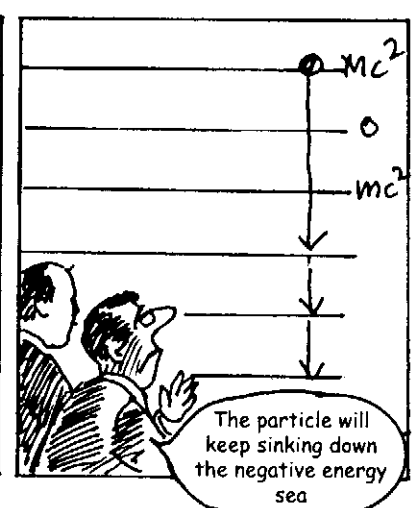
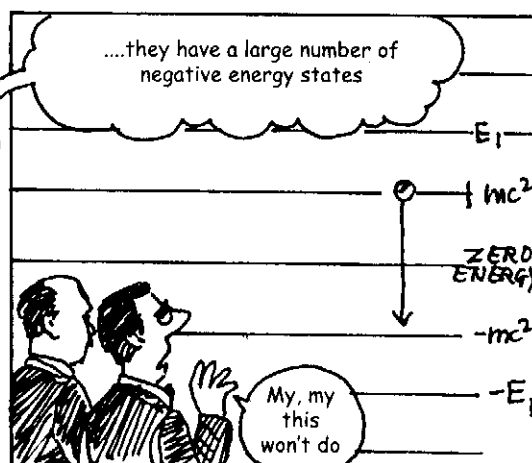
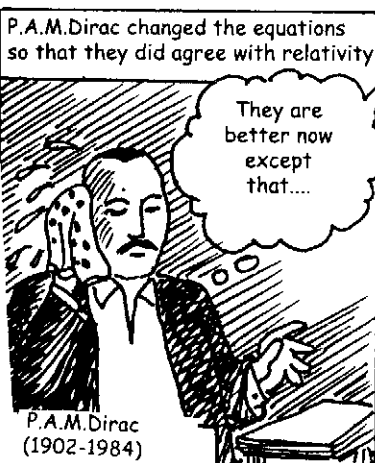
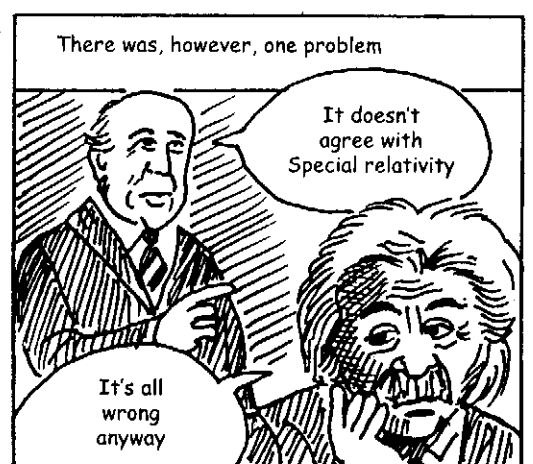
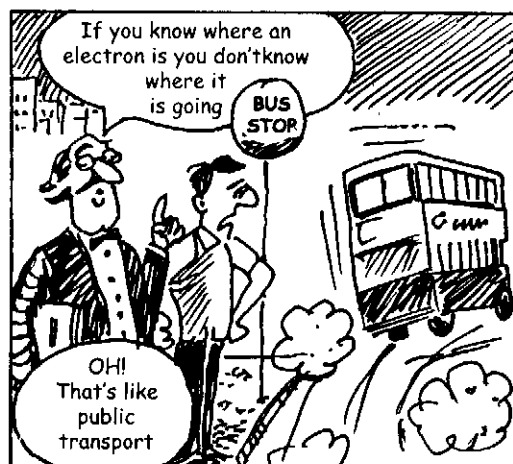


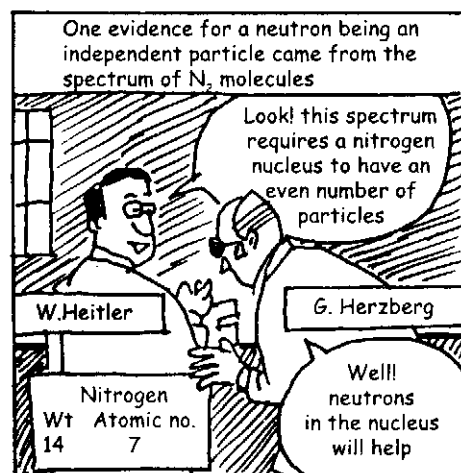
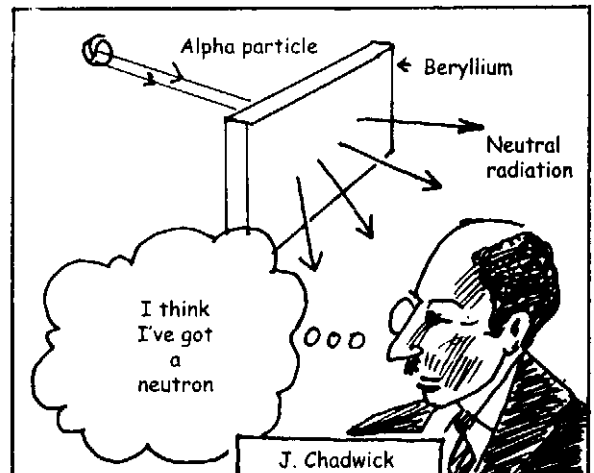
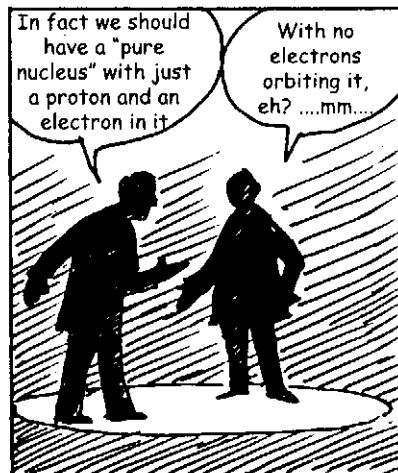
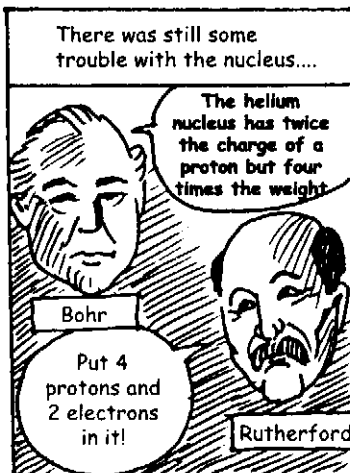
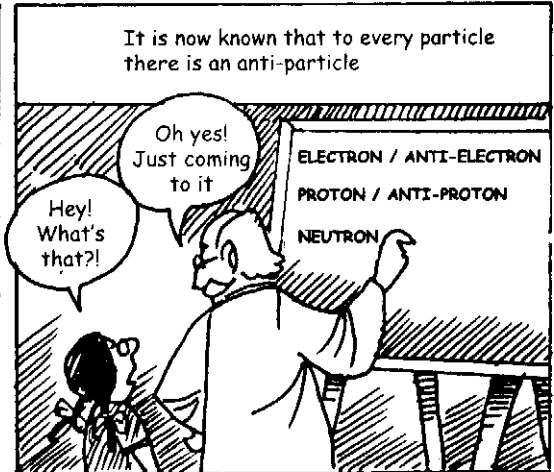
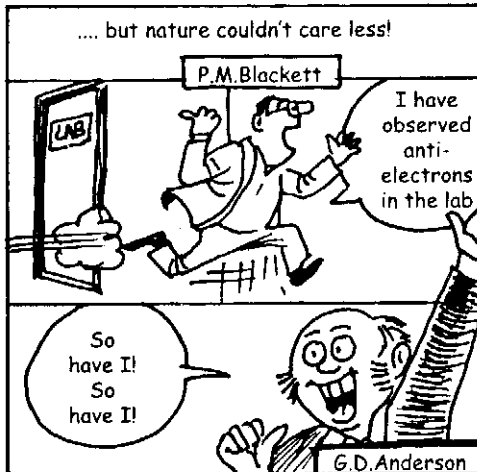
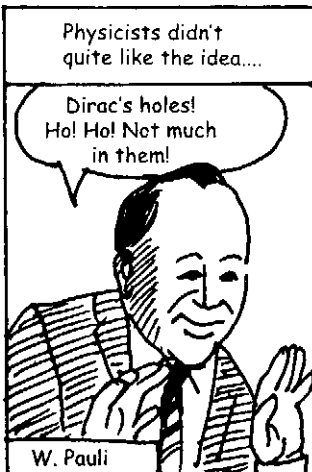
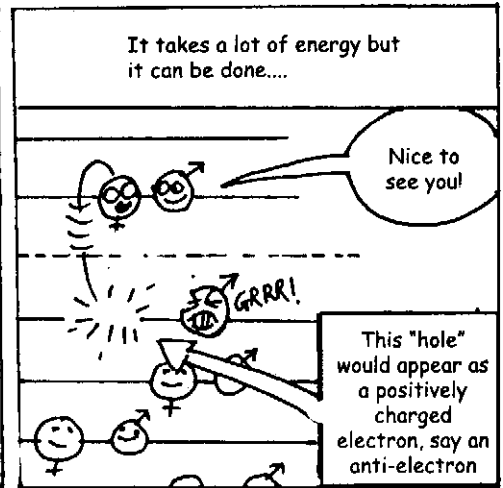
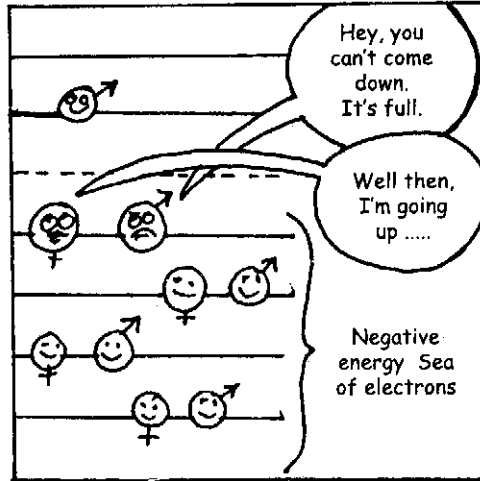
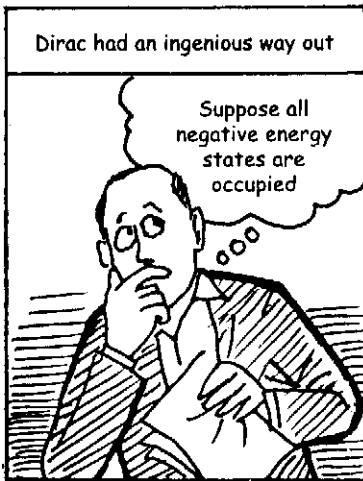
From the sketchy idea of pilot wave to a full fledged wave mechanics was a complex transition. The main contributors were



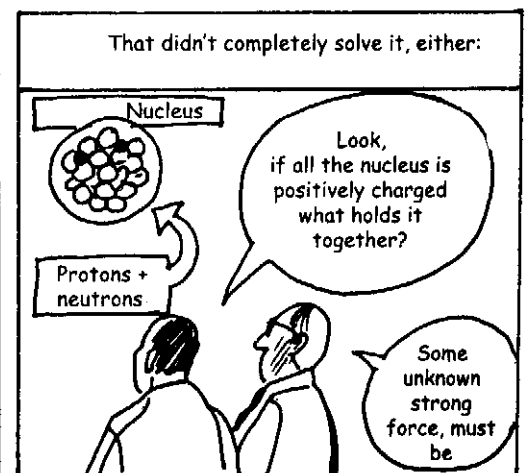


The concepts of quantum theory are bizarre and slowly evolved into a working sets of rules. A central concept was the uncertainty principle

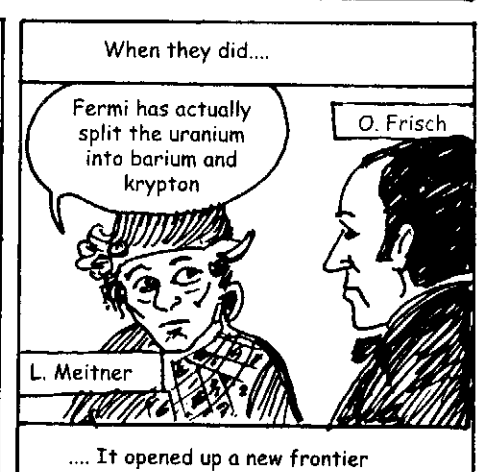
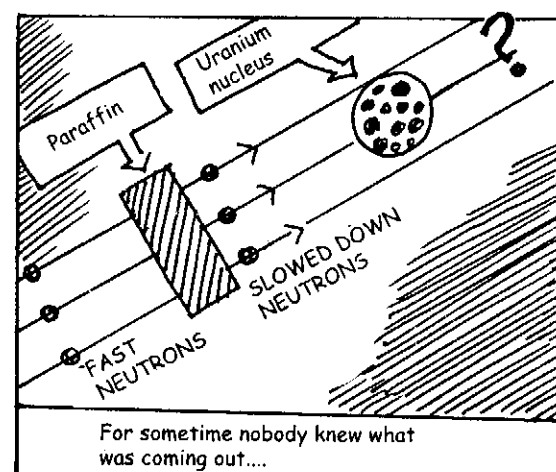
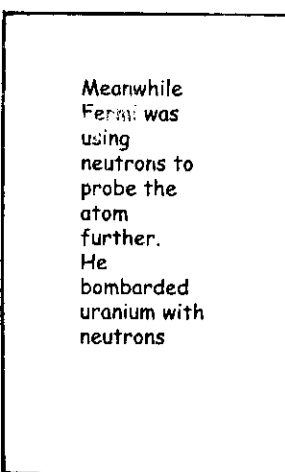
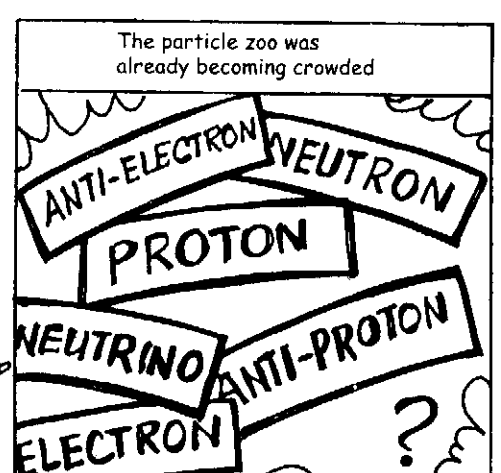
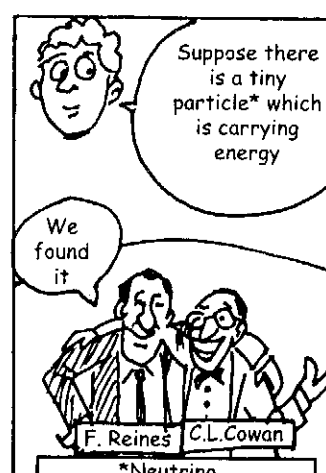
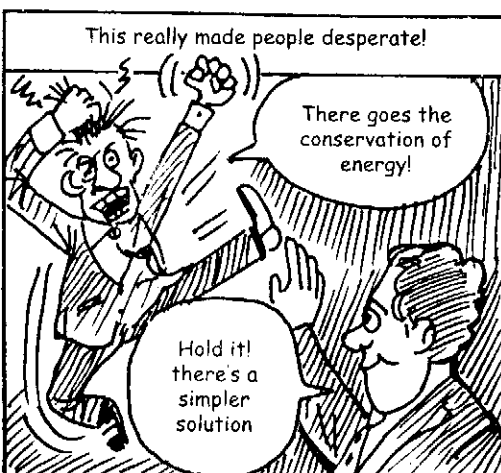
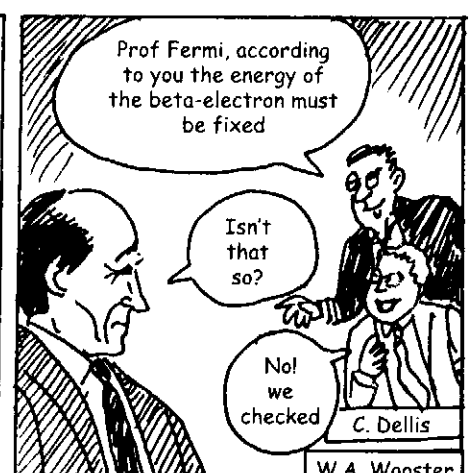
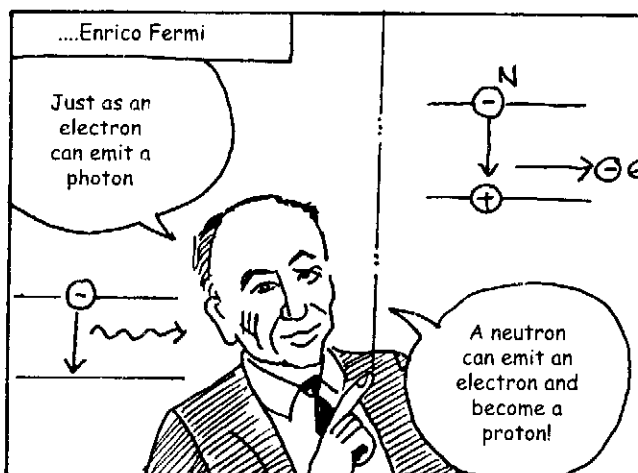
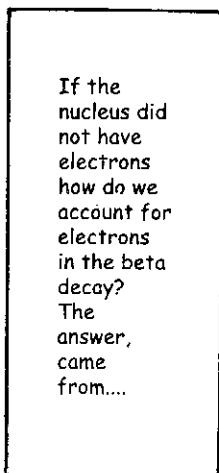
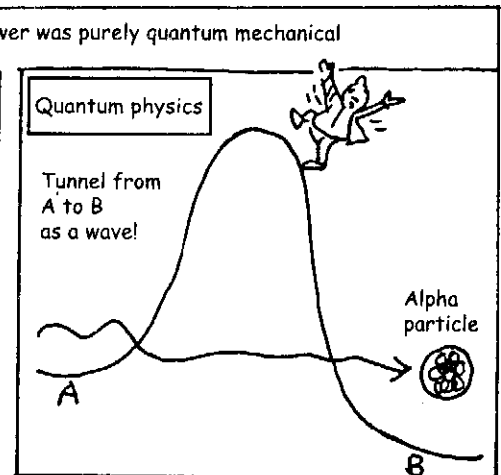
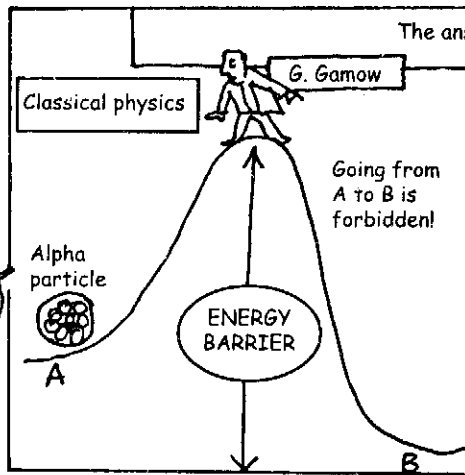
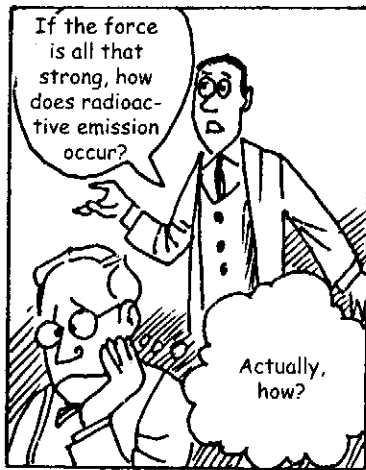


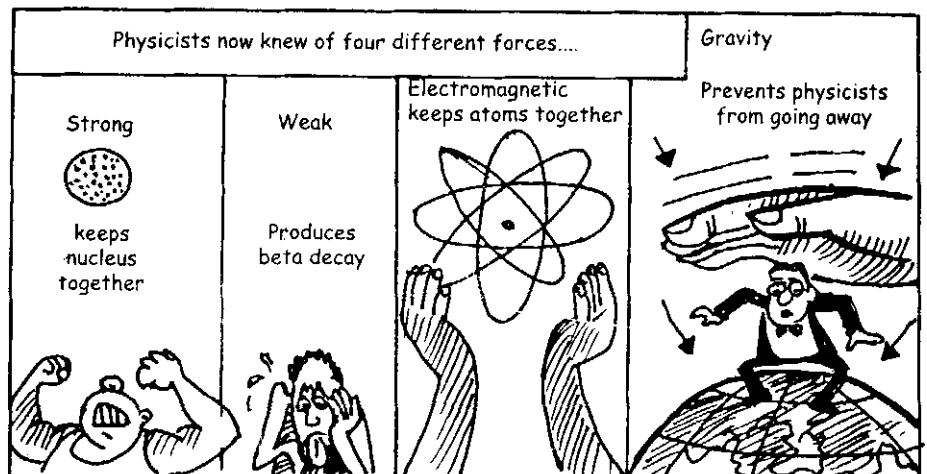
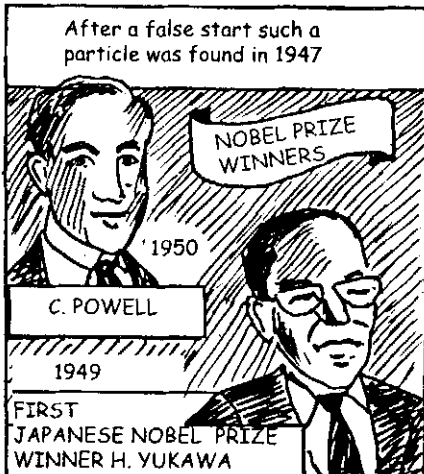
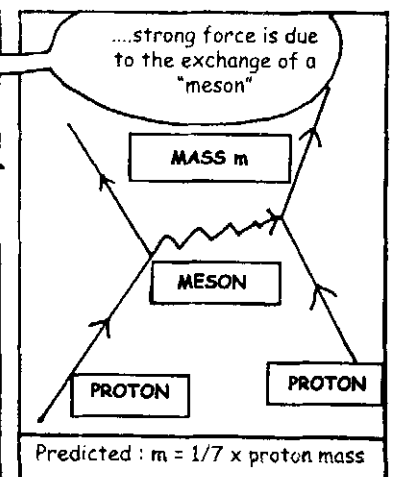
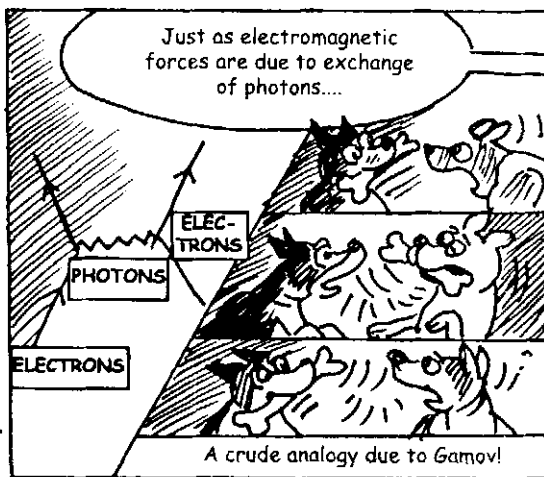
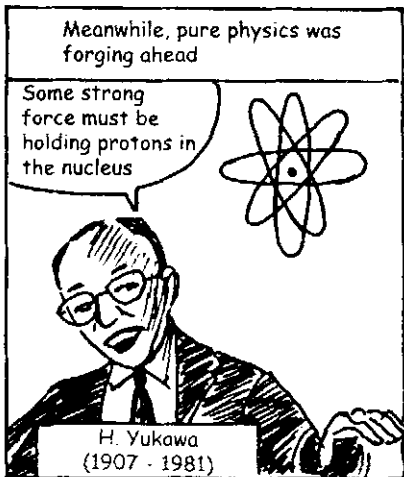
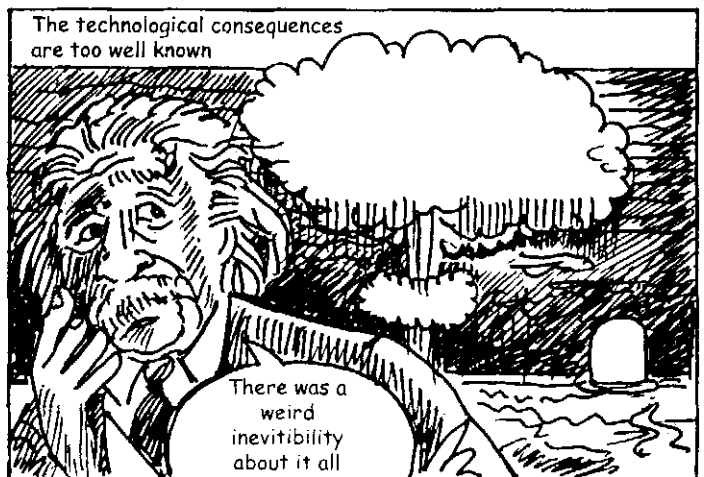
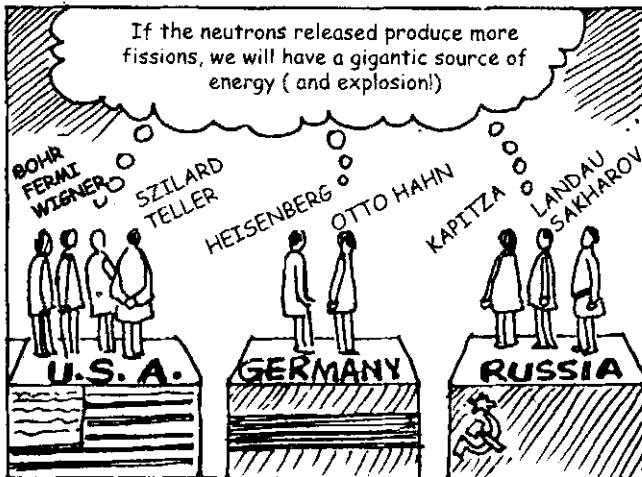
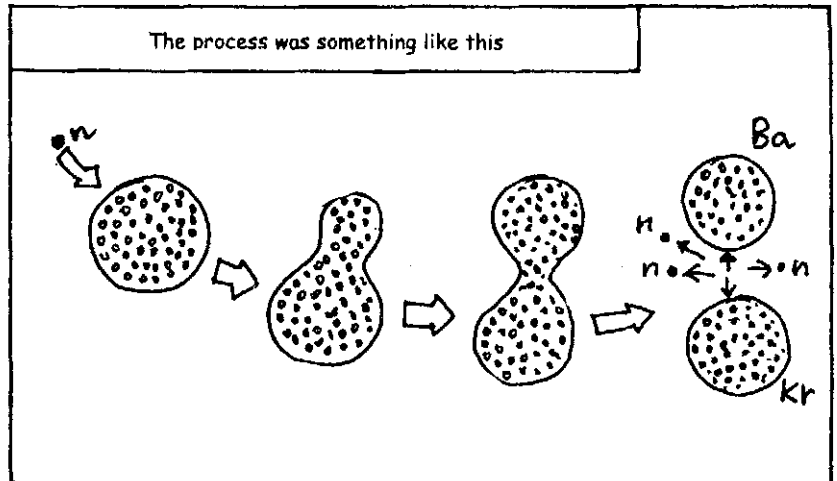
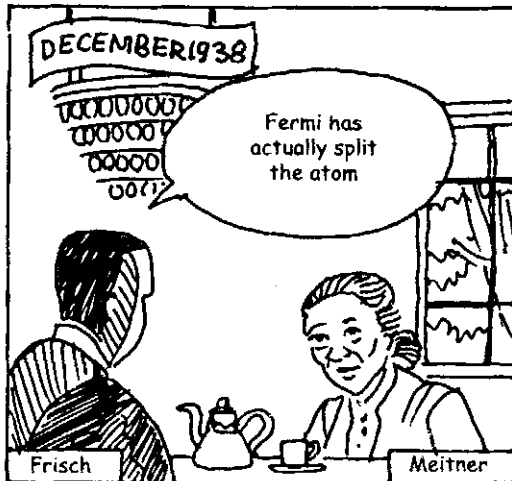


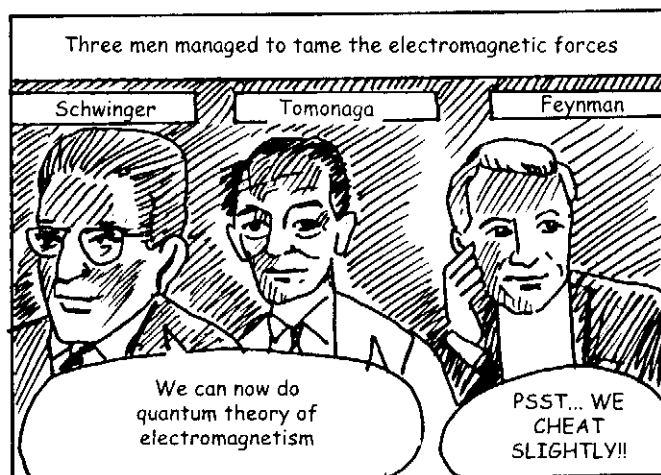
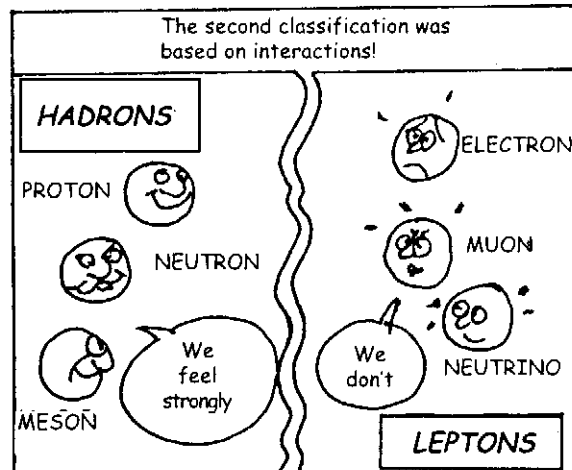
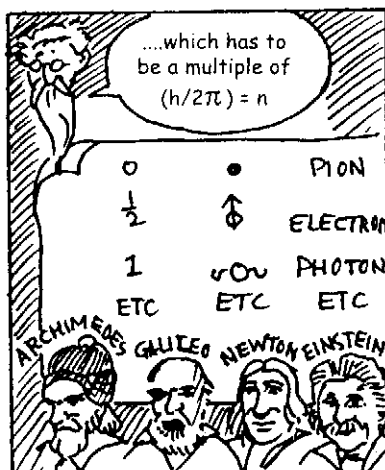
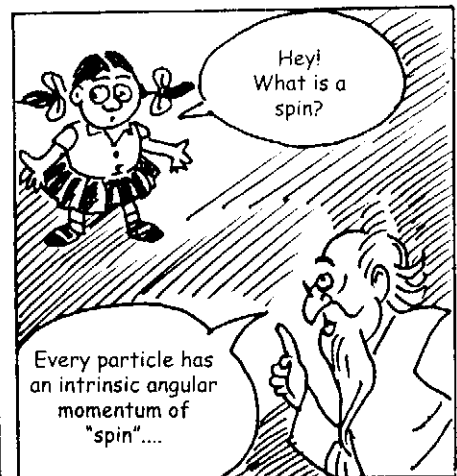
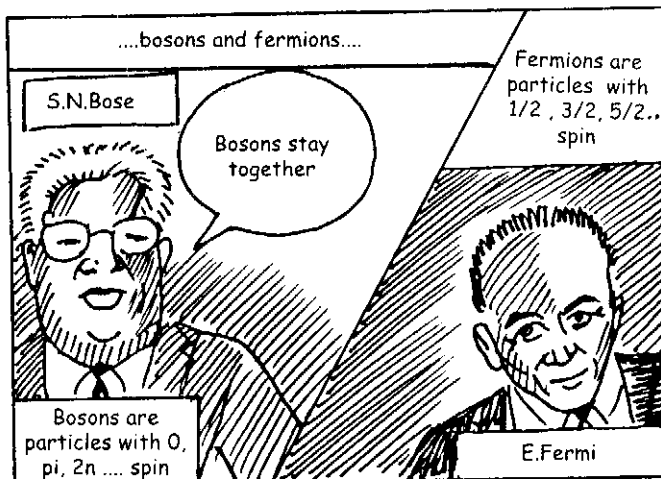
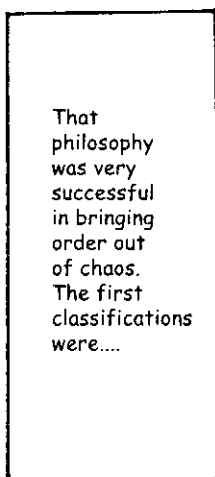
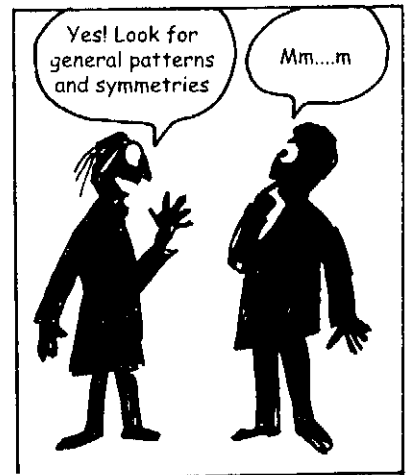
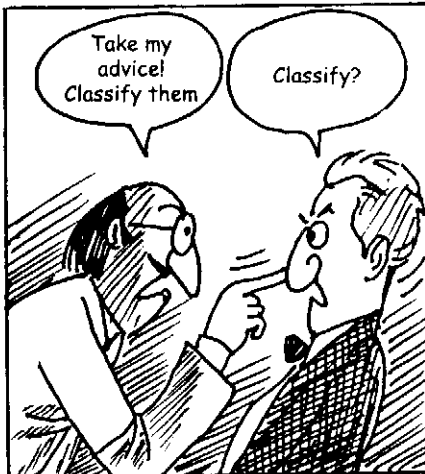
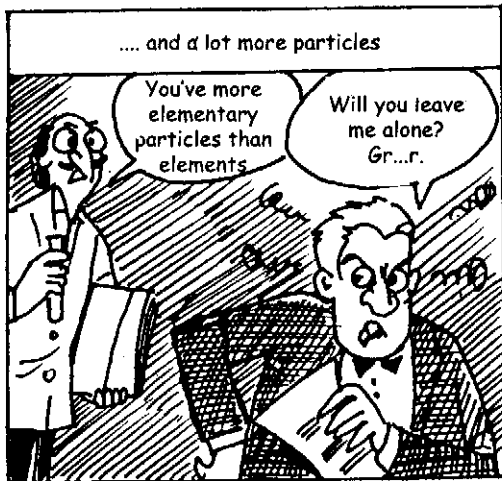
Nitrogen nucleus		
14	Protons	
7	Electrons	
21	Particles	
7	Protons	
7	Neutrons	
14	Particles	



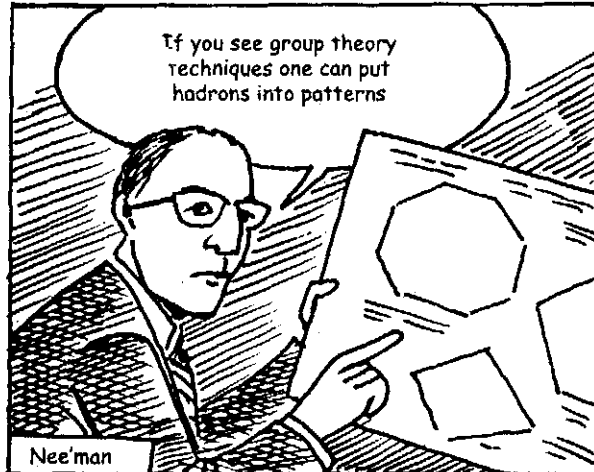




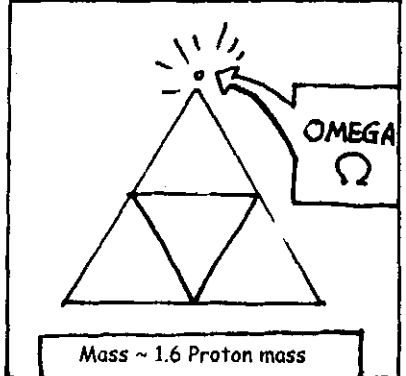




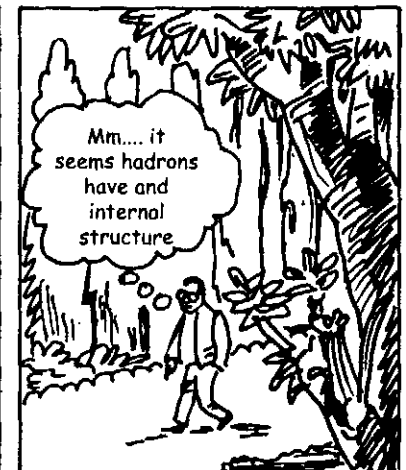
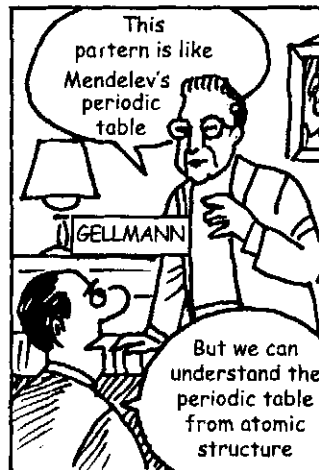
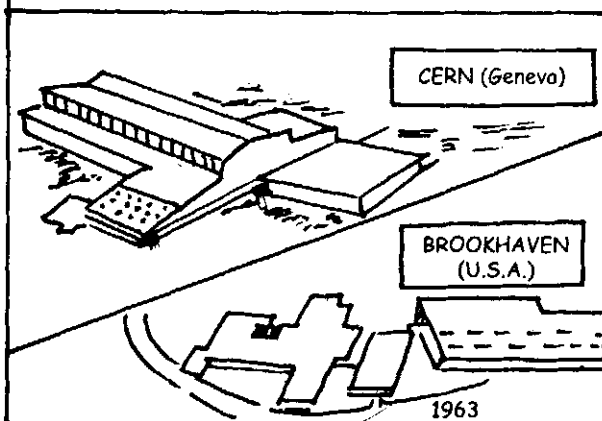
The first step in ordering hadrons were taken by M. Gellmann and Y. Nee'man



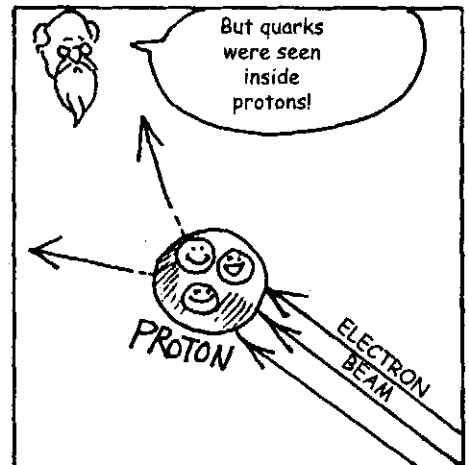
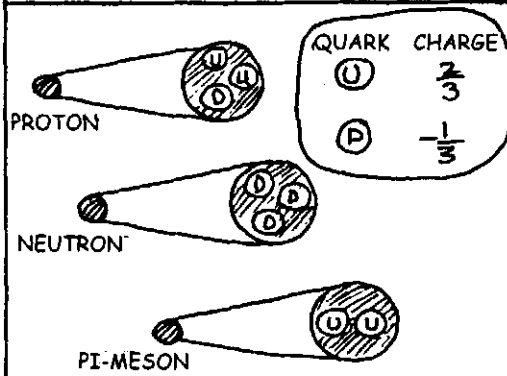
These patterns demanded the existence of yet another particle



....which was soon discovered at



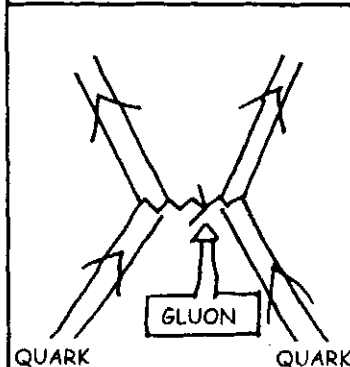
Gellmann and G. Zweig suggested that hadrons are made of quarks - "up" quarks and "down" quarks



The problem was reduced to studying QUARKS and LEPTONS. It was soon discovered that there are more of them

QUARKS	LEPTONS
1. UP	ELECTRONS 1
2. DOWN	MUON 2
3. STRANGE	TAU-ON 3
4. CHARM	

The strong force between quarks was due to the exchange of gluons



What about weak and gravitational forces?



After years of toil there was a breakthrough



A. Salam

S. Weinberg

Electric and weak forces can be unified as one electro-weak force

The electro-weak model predicted new "exchange" particles, which were soon discovered

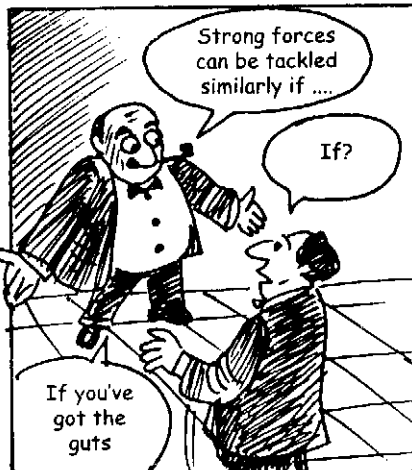


Do you think they have struggled enough?



Yes. Let's give them the W and Z bosons now!

That was the last definitive progress in this story of physics. Several new attempts were made to extend our understanding further



Strong forces can be tackled similarly if ....

If?

If you've got the guts

Gutsy physicists made a definite prediction

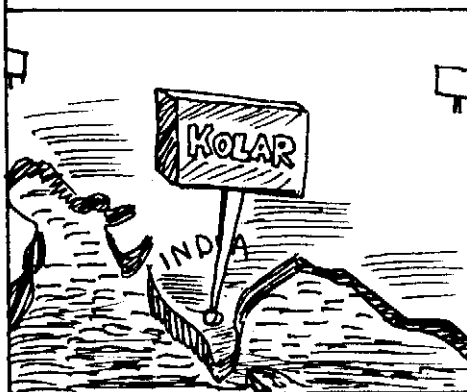


Protons are unstable

What do you mean. Dad isn't there?

Dad is made of nucleons isn't he?

Experiments all over the world are yet to confirm the prediction



Yet another headache is always there



What about gravity?

I wish it wasn't there

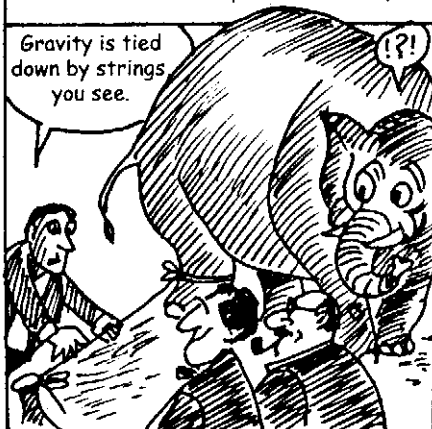
The "taming of gravity" is an on-going tale of ups and downs



Supersymmetry describes gravity very well

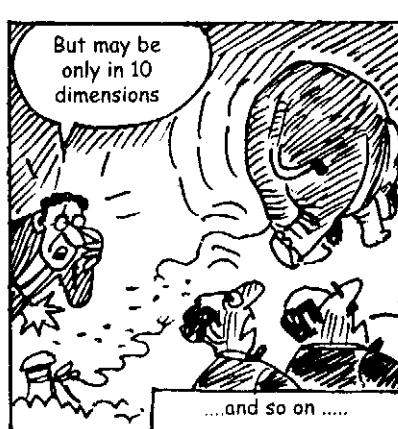
1980 - 83

The most fashionable pastime nowadays is based on a formalism called "superstrings"



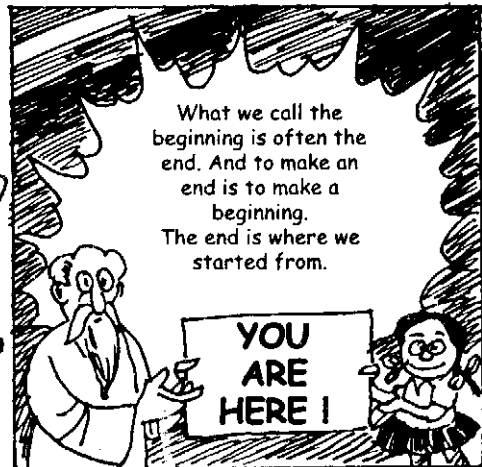
Gravity is tied down by strings you see.

(?!)



But may be only in 10 dimensions

....and so on .....



What we call the beginning is often the end. And to make an end is to make a beginning. The end is where we started from.

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