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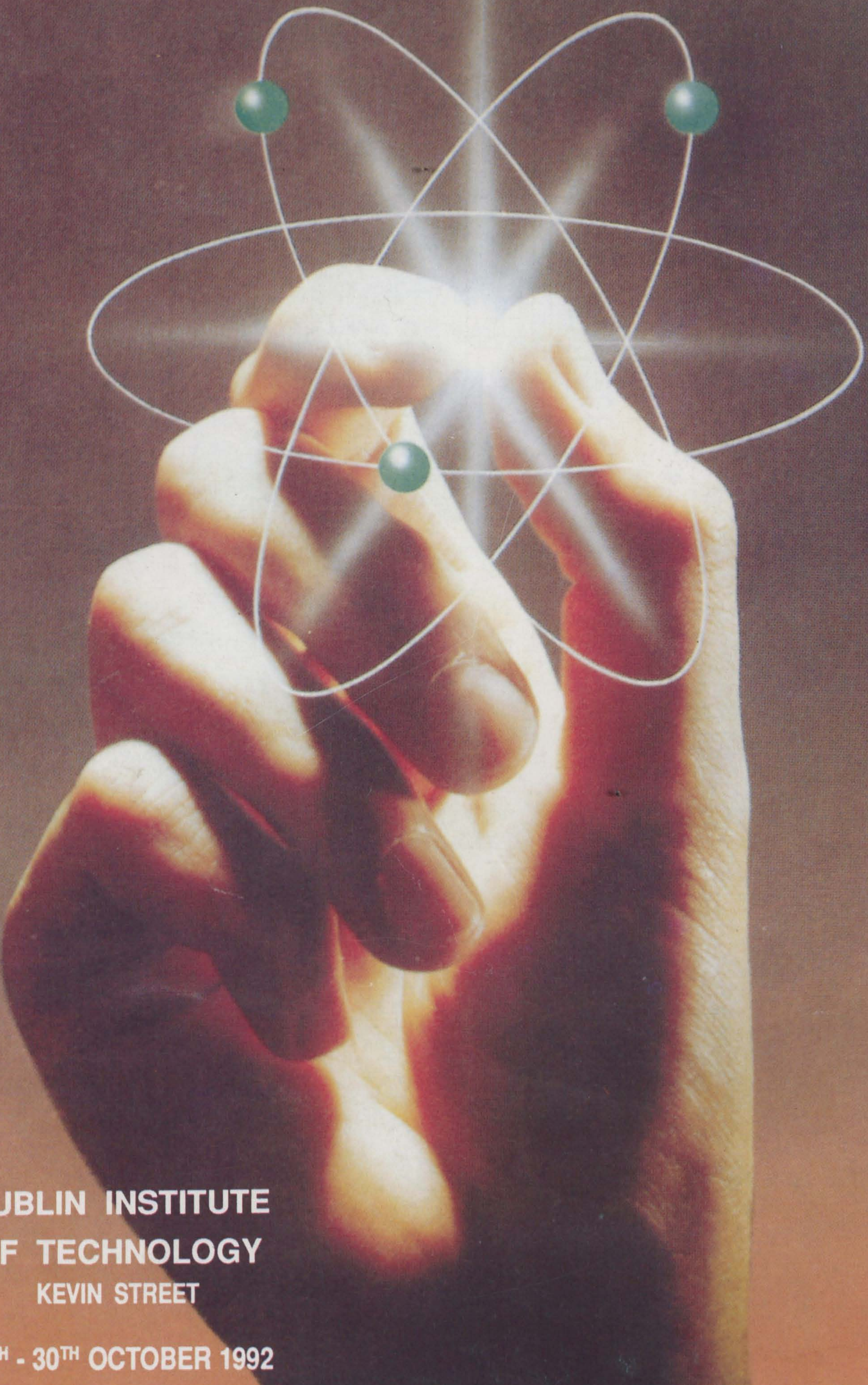
The Centenary of the Electron, A European Exhibition : The Irish Dimension

Dublin Institute of Technology

THE CENTENARY OF THE ELECTRON

A EUROPEAN EXHIBITION: THE IRISH DIMENSION



DUBLIN INSTITUTE OF TECHNOLOGY

KEVIN STREET

13TH - 30TH OCTOBER 1992

The European Exhibition
of
The Centenary of the Electron

under

the patronage of

L'Académie des Sciences **The Royal Irish Academy**

The Royal Dublin Society

and

The National Committees of

Ingénieurs et Scientifiques de France

Société Française de Chimie

Société des Electriciens et Electroniciens

Club D'histoire de Chimie

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Kevin Street
Dublin 8

Institiúid Teicneolaíochta
Bhaile Átha Cliath
Sráid Caoimhín
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FOREWORD

In May 1991, The Mayor of the French Town of Alençon, M. Alain Lambert, opened the exhibition - ***The Centenary of The Electron****. It commemorated the naming of the electron in 1891 by George Johnston Stoney , an Irishman from Cloreen, Co. Offaly.*

It was my privilege to visit this exhibition at Alençon. I recognised that this was one of the few exhibitions to acknowledge the place of Irish scientists in the development of electro-technology. I am greatly indebted to Electricité de France for allowing this exhibition to come to Dublin and honoured to host such a major exhibition at The Dublin Institute of Technology, Kevin Street.

Your visit to this exhibition will be a worthwhile experience and this booklet will help to remind you of our scientific heritage.

Francis M Brennan

Francis M. Brennan
Principal

Front cover by kind permission of Imperial Chemical Industries plc.

THE GREEK HERITAGE

ELECTRA'S TEARS

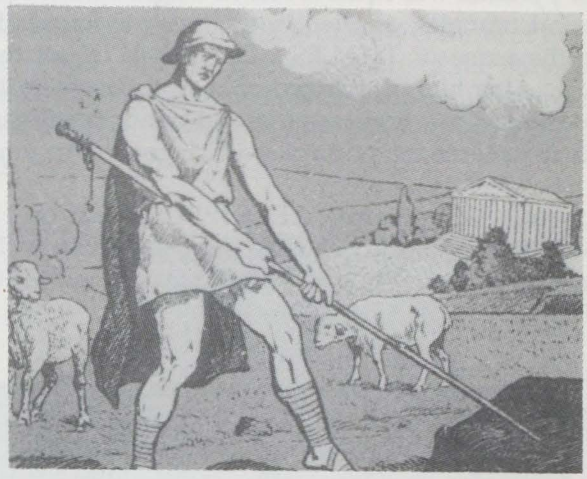
ZEUS, King of Olympus, used to fling lightening flashes and terrifying thunderbolts at those who dared to oppose him.

ZEUS, Master of the thunderbolt.

He considered that the tears of ELECTRA, daughter of OCEAN and THETIS, were too valuable to be lost and so he allowed them to change into AMBER (ELECTRUM in Greek) as soon as they touched the ground.

AMBER, which is a fossil tree resin, found along the shores of the Baltic Sea, was used for jewellery and for currency in ancient times. Its use led to the first transeuropean trade route. In Lydia, the country of King CRESUS, Amber was used as a monetary standard. If for a moment we examine ancient mythologies and religions, we will find the phenomenon of lighting constantly referred to as a weapon used by the supreme God in polytheism or by the single God in monotheism. JEHOVAH used it throughout the Old Testament.

The discovery of magnetism was also described in Greek mythological tales. Indeed the name magnetism itself recalls the unfortunate adventure of the shepherd MAGNES, whose staff, with its iron point, was attracted by a rock probably containing iron. Since then it has been known as magnetite.



The shepherd MAGNES

THALES, THE FIRST SCIENTIST

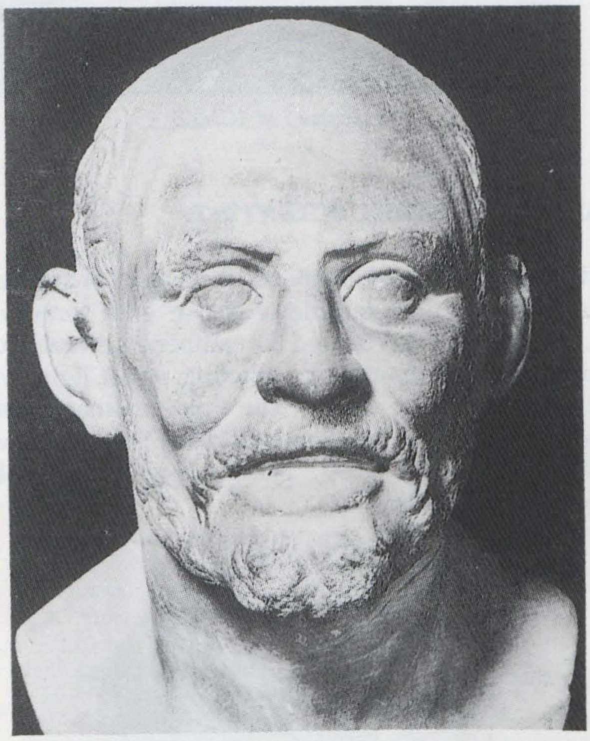
The history of electricity and hence the history of the Electron began in Ionia in the middle of the seventh century B.C. THALES de MILETUS related that amber when rubbed had the mysterious property of attracting small light weight objects like blades of straw. The first explanation of this phenomenon, which was given by THALES himself, is worth retelling. "Amber," he said, "has a soul and attracts objects as if it were breathing."

THALES de MILETUS

THALES also referred to the properties possessed by some "stones of magnesia", named after the city of Magnesia in Lydia, of attracting small pieces of iron. It is beyond all question that THALES was the first scientist in history. He was a geometer, a philosopher and an astronomer. The chronicles which have reached us reveal a highly colourful character who was renowned for falling into holes at night because he could not stop gazing at the moon and the stars.

THALES surprised the world with his ability to apply his knowledge to practical problems. Thus, one day, at the foot of the pyramid of Cheops, an Egyptian priest asked him what was, in his opinion, the height of the monument. THALES stuck his stick into the ground and explained to the priest that if the shadow of the stick corresponded to half its height, this meant that at the same moment, the shadow of the pyramid was equal to half its height. The theorem of identical triangles, applied in this way, is forever linked with the name of THALES. Thus THALES set the ball rolling. After him the thinkers of ancient Greece continued to go beyond practical concerns and minor peculiarities in order to research the principles which govern the universe.

Two men of science, LEUCIPPUS and his pupil DEMOCRITUS, both born in Abdera, a harbour in Thrace near the present Mount Athos, created the ATOMIC THEORY.



DEMOCRITUS, Father of the Atomic Theory

DEMOCRITUS' ATOMS

LEUCIPPUS was born in Abdera around 480 B.C. and founded a School in this city which DEMOCRITUS, born around 460 B.C., subsequently made famous. His fellow citizens called him the Laughing Philosopher. He was a contemporary of HIPPOCRATES, the Father of Medicine who, it must be added, came to Abdera to examine DEMOCRITUS on the request of his fellow citizens who thought that DEMOCRITUS was mad. DEMOCRITUS postulated that any given material can be cut in half and each half cut in half again and so on until a point is reached where the material becomes too small a particle to be subdivided again. DEMOCRITUS named this partical the ATOM from the Greek word meaning indivisible. He further postulated that all materials consist of various atoms each separated by space from one another. More or less simultaneously, around the middle of the 6th century B.C., PYTHAGORAS, the Father of Mathematics, arrived at the conclusion that the profound harmony of the world lay in numbers. He concluded this from his analysis of music based on vibrating strings.

The theories of PYTHAGORAS and DEMOCRITUS were complementary to one another. The notion of a discontinuous structure of matter was central to both theories. All was fine until the Pythagoreans discovered that the diagonal of a square could not be related to the side of the same square by rational numbers. The first irrational number which we express as $\sqrt{2}$ had just been discovered. HIPPASOS who revealed this secret by playing on his lyre, died by drowning. Was it an accident or an execution? Obviously his disappearance did not eliminate the problem. Scientists came to the conclusion that rational numbers and the discontinuous structure did not convey the reality. DEMOCRITUS atomic theory, with its indivisible particles, was therefore directly threatened.

Pythagoras' disciples believed that they had the answer. They assumed points of limited dimensions, so infinitely small that there would always be an infinite number of points in any segment of straight line. The concept of discontinuity, as we can see, was beginning to fade away. ZENO of Elea finished it off.

He presented a series of paradoxes proving that if one accepted this theory one could come to deny motion. Thus, ACHILLES, however fast he ran, could not catch up with the tortoise nor could the arrow ever reach its target.

PARMENIDES made a last attempt to save the theory of discontinuity pointing out that the discontinuous structure of matter appeared in measurement and therefore was found to be subjective since it is closely linked to the observer. But humanity was not ready to accept this new and extremely valuable idea which was only granted its due recognition some 2500 years later.

ARISTOTLE'S REJECTION OF THE EXISTENCE OF A VACUUM

The idea of the discontinuous structure of matter and the atomic theory then disappeared and made way for Aristotle's new theory. ARISTOTLE (384-322 B.C.) placed the notion of the continuous nature of matter at the centre of his theory and in that way denied the existence of a vacuum. There were four mutable elements: earth, air, fire and water which could change into one or another and in time transform into a fifth immutable element: ether. This made motion possible and answered ZENO's objections.

Over the next 2000 years, very few scientists rejected Aristotle's theory and returned to the theory of atomism to try to develop it further. Among those living in ancient times, one must mention EPICURUS (341-270 B.C.). EPICURUS in his "garden" maintained that different types of atoms were rather limited in number and that the large diversity of visible forms was the result of a change in combination of the atoms in terms of type and number. EPICURUS had just, in fact, described a molecule.

FROM THE END OF THE MIDDLE AGES TO THE 17TH CENTURY - FROM GILBERT TO COULOMB

THE COMPASS

The only scientific discovery of any significance from ancient times to the 14th century was: **the compass**. But what an invention! Literally it brought about the exploration of the entire world.

The property of a magnet, suspended by a string from a fixed point, always to point in the same direction, was first discovered in China in the 4th century A.D. But it was only towards 1100 A.D. that the magnet was mounted on a float and used for navigation.

This compass arrived in Europe around 1300. A century later, Flavio d'AMALFI developed the modern pivoted assembly.

GILBERT

In 1600 William GILBERT who was Queen Elizabeth I's doctor undertook the first serious research on magnetism. In his book **"DE ARTE MAGNETICA"**, he was the first to formulate the hypothesis that the earth itself acts as a gigantic magnet. In order to prove his hypothesis, he made "terrelae" or miniatures of the earth in magnetic iron oxide.

GILBERT discovered that when iron was brought to the stage of being red hot, it lost its magnetic properties but that it regained its magnetic properties when it was allowed to cool while pointing in the correct direction.

After his research on magnets, GILBERT developed the first electrical detector along the same lines as the pivoted compass. With this detector, he proved that many substances had the same electrical property as amber.

GALILEO AND THE INVENTION OF THE BAROMETER

After his famous court case in 1633, GALILEO was banished to live in his house at Arceti near Florence. This was where the "Master of the Fountains" of the Duke of Florence came to ask his opinion on an irritating practical problem: the water being extracted by suction pumps refused to rise above 10m30 or 33 ft. Nature abhors a vacuum but should this principle stop at 10m30.

With his disciple TORRICELLI, GALILEO started to study the phenomenon by measuring the amount of force that can be applied to the piston in a cylinder filled with water. He died in 1638 without succeeding in solving the problem. In 1643 TORRICELLI conceived the idea of replacing the water with mercury (density: 13,6) in order to make the observation easier. The top of the mercury stubbornly refused to rise higher than about 76 cm height. TORRICELLI then formulated the hypothesis that the column of mercury was in equilibrium due to the pressure of the atmosphere and consequently he named his instrument a **"barometer"**. But his death in 1647 prevented him from verifying his theory.

TORRICELLI and his barometer

THE DECISIVE EXPERIMENT OF PASCAL

At the beginning of 1648, the news of Torricelli's barometer arrived in Rouen where a young prodigy called Blaise PASCAL was living. If atmospheric pressure was responsible for the rise of the mercury, he thought a difference in height must exist between two measurements, one carried out at the bottom of a mountain and the other at the summit. PASCAL asked his brother-in-law Etienne PERRIER who was living in Clermont-Ferrand, to climb the Puy de Dome, 1,645m high whilst holding a barometer in his hand. The experiment took place on the 22nd of September 1648. The result of 71.2 cm at the bottom and 62.7 cm at the top was conclusive. As far as the scientists were concerned, the abhorrence of a vacuum had had its day. Beyond the atmosphere and above the mercury a vacuum existed!

MAGDEBURG HEMISPHERES

The Lord Mayor of Magdeburg, Otto von GUERICKE "publicly buried" the idea that nature abhorred a vacuum. He used a vacuum pump of his own device. The apparatus consisted of the pump body activated by a long lever and intermediate ranks under vacuum. He invented a whole series of particularly spectacular experiments. The most famous of these is called the Magdeburg spheres and took place in Ratisbon before the Emperor FERDINAND III and the German Diet.

OTTO VON GUERICKE: AN EXTRAORDINARY SHOW MAN

Otto von GUERICKE took a pair of hemispherical cups having broad, mating edges. After pressing the two hemispheres together to form a sphere from which the air was then pumped, he harnessed 4 horses then 5, 6, 7 horses to each side. Finally it took 16 horses to pull the hemispheres apart. Atmosphere pressure on its own had been enough to hold the two hemispheres together.

Robert BOYLE

THE FIRST ELECTRICAL GENERATOR

Simultaneously, around 1650, Otto von GUERICKE conceived the idea of mechanising the process of electrification by friction. He poured globes of sulphur around rods which he then used as axles. Rubbing the globes he put them into motion and this process produced the first electrical sparks in history. He also discovered a second phenomenon. Tiny particles brought towards his globes were violently repelled as soon as they came in contact with them. The phenomenon of repulsion had just been discovered.

DESCARTES AND HIS "DISCOURS DE LA METHODE"

In Holland Rene DESCARTES was writing a study on the universe when the sentencing of GALILEO led him to be more careful and to write a long explanatory preface which became known as the "Discours de la Methode" (1637). DESCARTES invited researches to examine all natural phenomena through scientific analysis rather than allow themselves to be influenced by the teachings of the early philosophers.

DESCARTES AND HIS VORTEX

In 1664 DESCARTES believed that neither vacuum nor atom existed and that "action at a distance" was inconceivable.

Matter and space created a continuous substance. For space to be always full, longitudinal motion was deflected into a circular motion. Hence the vortex.

THE RETURN OF THE ATOMIC THEORY

Robert BOYLE (1627-1691) was born in Lismore, Co. Cavan. He was the first chemist of modern times (he introduced the word chemistry) and thought that substances are composed of atoms constantly moving in a vacuum. He derived this idea from observing the flight of tiny midges in the air.

ISAAC NEWTON

Meanwhile, in 1687, Isaac NEWTON revolutionised physics with his universal law of gravitation:

$$F = k \frac{M_1 \; M_2}{d^2}$$

Two objects exert equal and opposite forces on each other, without being in contact. This concept was particularly difficult to accept. Later on, Newton's research on light led him to say that light had a corpuscular structure.

A SNEAK PREVIEW OF THE ELECTRON

Pascal's experiment at the Puy de Dome started a fashion in France for owning barometers. There was no scientist without one and it was considered quite "a la mode" to carry one while out walking. One evening in 1675, while the Abbè PICARD was carrying his barometer from the Observatory to the Place St Michel through the badly lit streets of Paris he noted a strange phenomenon. At times the tube of the barometer in which the mercury was being shaken began to glow.

Immediately of course the same experiment was carried out with other barometers but the phenomenon did not occur systematically. It was however sufficiently well established for the Academy of Sciences to take it into consideration and it became known as "Barometric phosphorescence".

During the following century this was found not to occur each time the experiment was carried out. It was only in 1723 that Du FAY showed that the success of the experiment depended on the cleanliness of the mercury. HAWKSBEE, who was then in charge of experiments for the Royal Society in London, finally produced the explanation which was that the phenomenon was due to an electrical discharge caused by the rubbing of the mercury against the glass in a rarefied gas. This experiment was then repeated in all the important physics laboratories of the time.

THE DUAL NATURE OF ELECTRICITY

The French botanist Du FAY carried out many experiments from which he concluded that only two types of electricity existed, one named resinous, the other vitreous also that identical types of electricity repel each other and, finally, that opposite types of electricity attract each other.

ELECTRICAL CONDUCTION

In 1729, Stephen GRAY noted that some substances, mainly minerals, have the property of conducting electricity instantly over a long distance. On this basis and by using his young assistant as a conductor, he was the first to classify materials through experiments, as being good conductors or poor conductors or insulators.

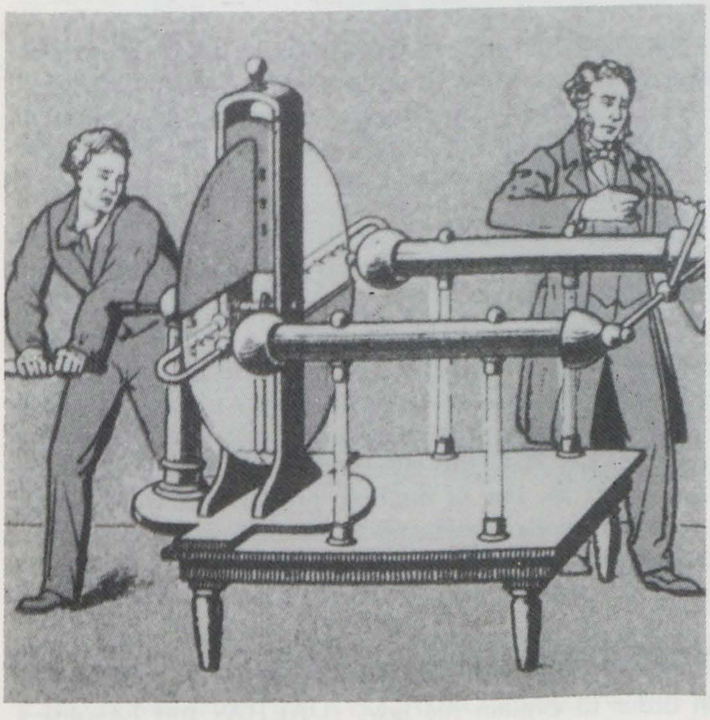
FRANKLIN HARNESSES THE THUNDERBOLT

In 1750, the famous American scientist, Benjamin FRANKLIN (1706-1790) was the first to suggest that lightning was electrical in origin. His work led him to the invention of lightning conductors. Finally FRANKLIN formulated the present day mathematical notation of electricity as being positive or negative, + or -.

A CENTURY OF PROGRESS

Otto von Guericke's generator was greatly improved during the century which followed its invention. The improvements were to:
- the mechanics of the rotation;
- the use of point action to improve the effect of the collected charge.

From the middle of the 18th century, generators like the RAMSDEN machine shown below, were able to produce a continuous flow of electricity and to create larger and larger sparks.



THE LEYDEN JAR

In 1745, Petrus MUSSCHENBROECK, lecturer at the University of Leyden, attempted to electrify water, using a glass filled with water into which he plunged a large rail. The experiment was unsuccessful, but as he was taking away the rail with one hand and holding the glass with the other, he got a violent shock which he described as a death shudder. All the practitioners of electricity in the world hurried to repeat his experiment. They noticed that the greatest effect was obtained when two thin sheets of tin were placed against the sides of the glass. The Leyden jar was born.

ELECTRICITY BECOMES FASHIONABLE

With the machines electricity became all the rage. Physics laboratories, where aristocrats enjoyed carrying out experiments, were full of these machines. Fair-haired women of noble lineage were happy to turn the starting handles. One zealous practitioner even electrified her parrot and young gallants created the electrical kiss: two participants, each standing on an insulated stool, caused a spark to jump between their lips.

NOLLET, THE APOSTLE OF WORLDLY PHYSICS

Everybody in Paris wanted to be "turned on"! The dedicated Abbè NOLLET, the apostle of worldly physics, did not know how to cope. It reached a stage of delirium when in Versailles, before the King, NOLLET made a whole company of 240 guards with arms linked jump into the air.

CHARLES COULOMB

Civil engineering officer Charles COULOMB (1736-1806) established that the forces produced by electrical charges were similar to those described in Newton's law of gravitation. For this purpose, he used a torsion balance of his own design and of extraordinary sensitivity (1 millionth of a gramme).

For the first time ever, it became possible to measure electrical charge and it was named the COULOMB in his honour. COULOMB transposed to magnetism his law concerning the attraction of electrical charges and introduced the notion of "Magnetic mass".

LAVOISIER, DALTON, VOLTA

LAVOISIER AND THE CHEMICAL REVOLUTION

Antoine Laurent LAVOISIER became passionately interested in chemistry when he attended a series of lectures, given by ROUELLE, which laid great emphasis on experiments and their results. His early work gained him entry to the French Academy of Sciences in 1768. He also engaged in farming to support himself financially.

LAVOISIER then began to develop the idea of a chemical element. He carried out experiments meticulously, introducing systematical usage of the weighing balance. On the 24th of June 1783, LAVOISIER and LAPLACE achieved the first experimental synthesis of water from two newly identified gaseous elements, namely hydrogen and oxygen. He repeated the experiment some weeks later and added an experiment perfected by MONGE where electric lightning produced the chemical reaction. By conducting a reverse experiment in 1784, he proved his famous law of conservation of matter. This law states that matter can be neither created nor destroyed, but can only be changed from one form to another.

Lavoisier's tests led him to establish the present day system of chemical nomenclature and to write a treatise on the Elements of Chemistry (1788). The chemical revolution occurred at a time when a second revolution was beginning, a revolution which tragically lead to Lavoisier's death.

LAVOISIER, LAPLACE, VOLTA

It was quite clear that electricity is present in all matter and this fact brought LAVOISIER closer to Laplace's ideas and led him to write the first mathematical equations for electrostatics.

Alessandro VOLTA

In 1771 a relatively unknown Italian scientist, Alessandro VOLTA, came to Paris. LAVOISIER and LAPLACE gave him a warm welcome and the three formed a research group.

Preparatory work for their experiments took considerable time and VOLTA had already returned to Italy by the time they were carried out by the two French scientists.

LAPLACE and LAVOISIER demonstrated that sparks can be produced by chemical reaction.

John DALTON

In 1801 PROUST proved Lavoisier's theories by experiment. That is, a chemical compound always contains the same elements which remain constant. And so it was that John DALTON, a professor from Manchester, set himself the following problem:

Given that two elements combine to form a compound of constant composition, what happens when two elements combine to form several different compounds? How can these facts be reconciled with the law of defined proportions? Having studied the composition of carbon dioxide and carbon monoxide, he observed that for a given quantity of carbon, monoxide contained precisely 50% less oxygen than dioxide. From this observation and several others, he formulated the law of multiple proportions which states that when two elements combine to form several compounds, the weight of one being a constant, the weight of the second element varies according to simple ratios, e.g. 1:2, 1:3, 2:3.

MODERN THEORY OF AN ATOM

In order to explain his law, DALTON put forward a hypothesis which was startling in its simplicity. By giving a new and more accurate meaning to Democritus' theory, he supposed that a substance is made up of tiny indivisible particles called atoms. All the atoms of a given element are identical and have a fixed mass which remains constant. A compound is a specific combination of atoms of more than one element. These ideas were presented publicly by DALTON in Manchester in 1803.

GAY-LUSSAC'S LAW

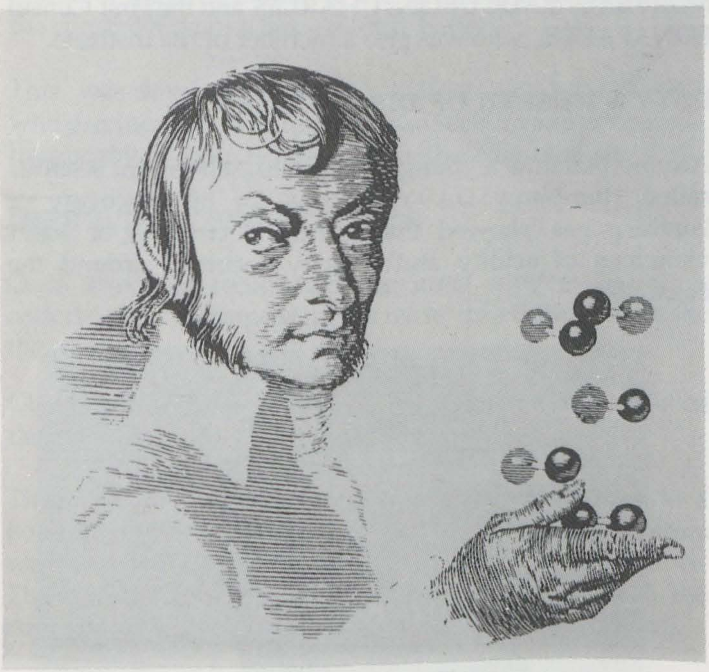
In France, GAY-LUSSAC, known for his precise measurement of gases, was initially surprised to find that the expansion coefficients of all known gases were identical, that is 1/273.

In 1805 he continued the water synthesis experiment. He was surprised once again, to find the exact combination of two parts hydrogen to one part oxygen.

Struck by the simplicity of this ratio, GAY-LUSSAC extended his research to other substances. In 1908, after three years of research, he determined that these simple proportions were general.

AVOGADRO'S HYPOTHESIS

Based on the unicity of the expansion coefficient of gases, Amédéo AVOGADRO put forward the hypothesis, in 1814, that equal volumes of all gases at the same temperature and pressure contain the same number of atoms. At the same time, AMPERE, a young French scientist, put forward a similar hypothesis.



Armadéo AVOGADRO

According to Dalton's law, all matter is made up of atoms and in the case of gases, has a corresponding volume of 22.4l. It was named the AVOGADRO number N, but its value remained unknown.

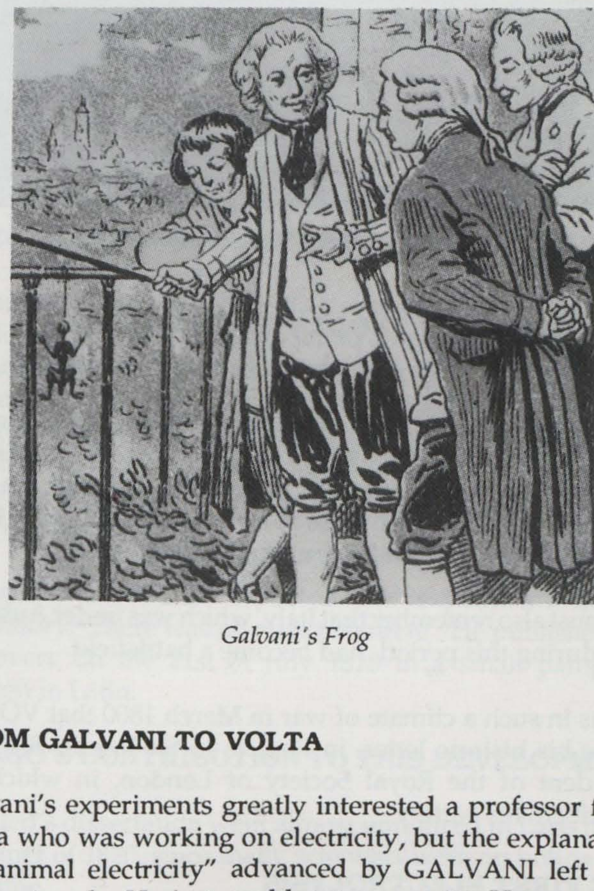
GROWTH OF INTEREST IN DISORDER

It all began in Bologna in 1780 and arose from the collection of ill-assorted equipment traditionally found in Science Laboratories. This usually ranged from such items as dissected frogs lying on a long table, to an electric machine close by. When an assistant touched the nerve of one of these frogs with a metal rod, its legs curled up instantly.

Madame GALVANI, who experimented with the electric machine, observed that these movements only took place when sparks occurred.

GALVANI'S FROGS

In order to examine the effects of atmosphere electricity, GALVANI prepared a large number of specimens and suspended them by copper hooks over an iron railing in her laboratory. She observed that a number of frogs which moved gently, due to a wind effect, went into convulsions when they came into direct contact with the iron bars of the railing.



Galvani's Frog

FROM GALVANI TO VOLTA

Galvani's experiments greatly interested a professor from Pavia who was working on electricity, but the explanation of "animal electricity" advanced by GALVANI left him unconvinced. He just could not accept it. However, he reconsidered Galvani's experiments paying particular attention to the metals involved. As far as he was concerned, the frogs were merely very sensitive current detectors.

THE INVENTION OF THE BATTERY

When VOLTA re-examined Galvani's initial experiments it led him to consider two types of conductors: Metal conductors, which he called conductors of the first type and Liquid conductors, which he called conductors of the second type.

By increasing the metal combinations, VOLTA was forced to admit that it was impossible to generate current with a sequence of conductors of the first type AB AB.

He then wondered if it might be necessary to have some contact between conductors from Type 1 and Type 2 in order to produce a significant effect. So he proposed arranging the conductors in a series of ABa ABa - "a" being a type 2 conductor.

A decisive step had been taken!

Volta's experiment with his battery

BACKGROUND TO VOLTA'S HISTORIC DISSERTATION

VOLTA, it would appear, had already brought together all the elements of his discovery in 1796. Why therefore did he delay the public presentation of discovery? Perhaps it was due to the birth of his three sons between 1795 and 1798, which led him to spend more time with his family.

We must also remember that Italy, which was under Austrian rule during this period, had become a battlefield.

It was in such a climate of war in March 1800 that VOLTA wrote his historic letter, in French, to Sir Joseph BANKS, President of the Royal Society of London, in which he described his battery.

THE FIRST ELECTROLYSIS

Volta's letter arrived a month later on Sir Joseph Banks' desk. At the conclusion of his dissertation VOLTA refuted Nicholson's recent work and so BANKS sent Volta's dissertation to NICHOLSON before presenting it to the public.

William NICHOLSON knew exactly how to take advantage of this private information. Together with a friend, called Anthony CARLISLE (1768-1840), he undertook the construction of a silver-zinc battery, adhering exactly to Volta's guidelines.

They began by repeating Volta's experiments and then conducted their own. One of their experiments, carried out on the 2nd of May 1800, involved water.

They observed a small current of tiny bubbles emerging from the point of the copper wire which was in contact with the silver extremity of the battery.

In the days to follow, NICHLOSON, working alone, continued to perfect his experimental device using platinum wires, double the amount of gas was released, 72 parts of oxygen to 143 of hydrogen, that being a ratio of 1:2.

VOLTA IN PARIS

After the victory at Marengo on the 14th of June 1800, Northern Italy once again came under French rule. One of Bonaparte's first decisions was to re-open the University of Pavia. VOLTA was to convey the thanks of the University to the First Consul. By this time Volta's letter to BANKS had been published and the chemical properties of the battery were made known, and so Volta's political mission became a triumphant one. Before arriving in Paris, VOLTA stopped in Arcueil where he was greeted by LAPLACE, and introduced to his colleagues at the Institute.

Before an elite group of French scientists, VOLTA spoke about his theory and conducted experiments during three historical lectures at the Institute which were held in November 1803.

There were many illustrious people in the audience, among them LAPLACE, MONGE, BERTHOLLET, FOURCROY, CHAPTAL, COULOMB, GUYTON-NORVEAU, VAUGUELIN, CHARLES and the First Consul BONAPARTE, who was also a member of the Institute.

DAVY'S WEALTH OF DISCOVERIES

Around this time a young 22 year old, self-taught scientist called Humphrey DAVY, famous for his discovery of laughing gas, showed that during electrolysis of water variations of acidity and basicity occurred around the electrodes.

Humphrey DAVY

The quality of his public presentations at the "Royal Institution" was such that he became Head of perhaps the best equipped laboratory in the world and received considerable financial support. In 1807 he electrolysed dissolved salts and for the first time isolated two new chemical elements, namely sodium and potassium.

DAVY became seriously ill within five days of the public presentation of his discoveries. On hearing this a huge crowd gathered around the Royal Institution and it was decided to post up a daily health bulletin on this true Prince of Science. Simultaneously, a fund was launched to build the most powerful battery of the time. When he recovered from his illness, DAVY, using other bases, carried out experiments which had worked so well on the alkalis.

The chemical elements which he named include Silicon, Strontium, Barium, Magnesium, Aluminium, Zirconium.

THE ELECTRIC ARC

In 1813, the Royal Institution's large battery produced a new type of electric spark between two carbon electrodes. This was extraordinarily bright and DAVY called it the electric arc, because of its shape.

This new discovery was universally admired.

THE CONSTRUCTION OF THE LARGE BATTERY BY THE ECOLE POLYTECHNIQUE

When he was informed of Davy's discoveries, NAPOLEON I invited DAVY to France even though France was at war with England. He contributed 20,000 Francs of his own money to the "Ecole Polytechnique" for the construction of a large electric battery.

This was developed by GAY-LUSSAC and THENARD, who produced it using quantities of sodium and potassium, thus enabling them to characterise these two metals.

IMPROVING THE BATTERIES

Once scientists recognised the great interest in Volta's battery, they attempted to increase its effects and make them last longer.

Chemical reactions occurring at the electrodes reduced their performance very rapidly.

They then devised a method of placing the battery in a horizontal position so that the electrodes and the separators were arranged alternately thanks to grooves in the container. This arrangement led to significant progress both in the strength of the current produced and also in its duration.

CHRISTIAN OERSTED

Christian OERSTED a Danish physicist, had a strange destiny. In 1800, the year that Volta's dissertation was published, OERSTED, a pharmaceutical chemist, received a research grant which allowed him to complete his education and become a lecturer in the University of Copenhagen in 1806.

OERSTED, Professor at the University of Copenhagen demonstrating to his audience the effect of electric current on a pivoted magnetised needle.

ELECTRICITY AND MAGNETISM COME TOGETHER

During the winter of 1819-1820 an amazing discovery was made which linked electricity and magnetism. OERSTED demonstrated to his students the thermal effect of electric current by heating a platinum wire to the point of incandescence. He discovered that the current flowing through the wire coincided with the deflection of a compass needle which was lying on a table having been used in a previous experiment.

Intrigued, OERSTED repeated the experiment in his laboratory. There was no doubt about it! He published his discovery on the 21st of July 1820 in a small pamphlet written in Latin.

ARAGO'S CONTRIBUTION TO THIS DEVELOPMENT

Oersted's dissertation went almost unnoticed in Paris in the Summer of 1820, since many scientists were on holidays at the time.

While spending some time in Geneva, ARAGO was invited to assist in a repetition of Oersted's experiment.

ARAGO fully realised the importance of this connection between current and magnetism. The experiment bothered him also, particularly as it revealed a force of a perpendicular nature in contrast to classical Newtonian motions. As soon as he returned to Paris, ARAGO presented the treatise and demonstrated the accompanying experiments in two lectures to the Science Academy. These took place on the 4th and 11th of September 1820.

André-Marie AMPERE

AMPERE'S EARLY WORK

Born near Lyon in 1779 at the Domaine de Poleymieux, André-Marie AMPERE a self-taught scientist with a phenomenal memory, studied the encyclopedia from A to Z. At the age of 18 he was aware of the most recent scientific discoveries and the latest mathematics dissertations. He became a professor in Bourg in 1802 and his work in Mathematics gained him entry to the Science Academy in 1814.

AMPERE'S INTUITION

AMPERE attended the two lectures given by ARAGO. He too, was as intrigued as ARAGO, and he decided to devote his time exclusively to studying this new phenomenon. When current passes through a wire, he observed, it produces a reaction in the magnetised needle. Is this because the current magnetises the wire? Not at all. Its action on the wire is not due to a simple magnetic action since it does not conform to Coulomb's Law (the resulting forces are in fact tangential and not radial). Therefore if this effect is not provoked by magnetism it must stem from electricity.

In other words, currents should behave like magnets and interact with each other.

On the 18th of September, eight days after Arago's lecture, AMPERE announced his first discovery, that is, that when current is passed through two parallel wires, the wires attract each other when the current is moving in the same direction and repel each other if their directions are opposite.

He then noticed that if a piece of iron is placed near the current it became a magnet. This inspired him to wrap the wire around a coil containing an iron core and so the Solenoid was invented.

Finally, he established the intensity of the voltage of the current.

Within two weeks AMPERE had formulated his law of electrodynamics.

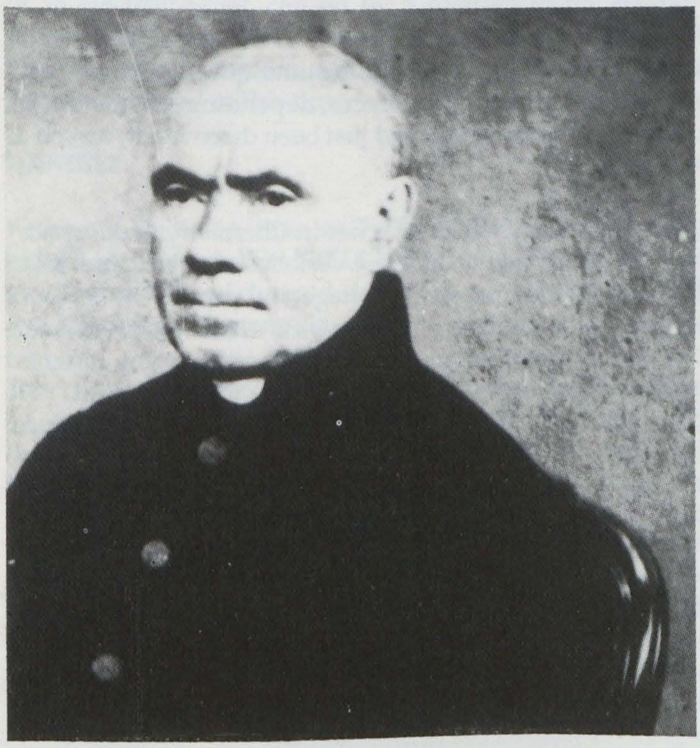
The visual method of presenting the results of the effect of currents according to Ampere's findings must be stressed.

Using the Solenoid, ARAGO developed the electromagnet which was to prove very useful in the future. He also discovered that by placing steel bars inside a coil they could be permanently magnetised.

CALLAN, FARADAY TO STONEY

CALLAN

Nicholas CALLAN (1799-1864) was an Irish Priest and scientist born in Darver, Co. Louth. He was Professor of Natural Philosophy of St. Patrick's College, Maynooth, where he constructed large batteries, electromagnets and electric motors. CALLAN invented the induction coil in 1836 and his great coil of 1837 was capable of producing a 38mm spark. Unfortunately his work has received scant international recognition and his discoveries and inventions are often credited to others, for example RUKMKORFF rather and not CALLAN was credited with the invention of the induction coil.



Nicholas CALLAN

DAVY AND FARADAY

In 1812, at the peak of his scientific career, DAVY decided to stop teaching in order to devote all his attention to research. His last series of lectures was followed with intense interest by the 21 year old Michael FARADAY, a book-binder's apprentice at the time.

Faraday's notes taken at these lectures filled a 386 page copybook.

FARADAY then wrote to DAVY asking to be allowed to demonstrate his laboratory skills; he included his notes as proof of his talents.

DAVY invited FARADAY to come and see him. He portrayed science as a "stern mistress" and joked a little about Faraday's illusions, but the latter stood his ground, whereupon DAVY took him on as his assistant.

Some months later, in spite of the country being on a war footing, DAVY decided to accept an invitation from the Emperor Napoleon, and left for France accompanied by his wife and FARADAY.

DAVY brought along a small portable chemistry laboratory in order to try out experiments en route. He found occasion to use his "travel kit" to spectacular effect with his analysis of a chemical sample sent to him by AMPERE. DAVY established that it was a chemical element with chemical properties similar to chlorine. He named it Iodine.

At that point DAVY decided to push on as far as Italy. On 17th June and in the company of FARADAY, he paid a visit to VOLTA. On that day the past and the present and the future of electricity intersected.

Upon his return to England, FARADAY made up his mind to concentrate definitively on scientific research and demonstrations under the aegis of the Royal Institution where he became a laboratory director in 1824.

THE FIRST ELECTROMAGNETIC MOTOR

Oersted's discovery in 1820 led FARADAY to attempt to determine the link between Electricity and Magnetism.

In 1821 he published a first paper on this subject. He demonstrated that a magnet, suitably mounted on a mercury contact, could revolve indefinitely around an electric current.

This apparatus of FARADAY was the first electromagnetic motor. Peter Barlow's famous wheel was in fact, to appear later in March 1822.

THE MAJOR DISCOVERY OF INDUCTION

After a series of nonproductive experiments in 1824, FARADAY discovered the phenomenon of induction on the 24th September 1831.

He took a ring of soft iron and wound two lengths of insulated wire around it. The extremities of one of the two wires were connected to a galvanometer which would measure any current. A battery allowed the current to flow into the second circuit. FARADAY observed that when the battery discharged into the second circuit nothing happened, but when the current was switched on or off, the galvanometer was deflected.

FARADAY understood that the advent of the current was linked to the magnetisation and demagnetisation of the soft iron core. The principle of electromagnetic induction had been found.

Michael FARADAY

FARADAY'S INDUCTION COIL

His explanation of this phenomenon led him right away to a second experiment, where magnetisation and demagnetisation in an electric circuit were created by the movement of magnetic needles in the vicinity of a solenoid. Thus was established the principle of the direct transformation of mechanical into electrical energy.

FARADAY AND THE IDEA OF A FIELD

Faced with the phenomenon of induction FARADAY endeavoured to understand it and provide an explanation. He performed many measurements relative to the lines of force created in surrounding space by magnetic needles and conductors through which the current was passed.

He came up with the following explanation: the presence of a magnet brings about the transformation of the medium surrounding it. Lines of force have a physical existence for FARADAY. To obtain a current by induction, the conducting element must cut through the lines of force.

Faraday's explanation was to find itself fundamentally at variance with scientific thinking focussed on what was inside the magnet and the wire. His interpretation became the object of much derision and caricature.

THE REVOLUTION IN OPTICS

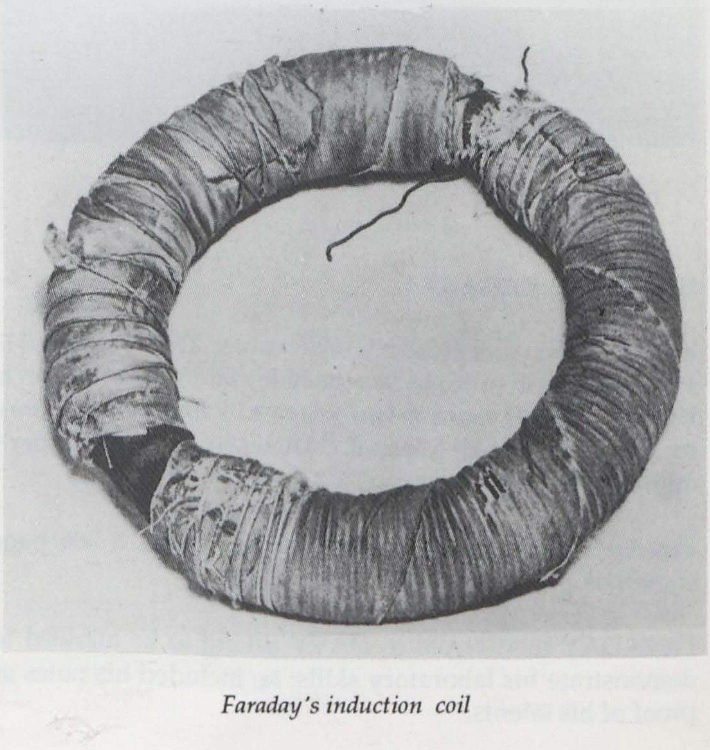
In 1807 the English physicist Thomas YOUNG took it upon himself to attack Newton's corpuscular theory of light, but it was Augustin FRESNEL, with the backing of ARAGO, who got the credit for establishing the wave theory of light. He did this by creating a great many new experiments, in particular those involving the interference of light waves, by incorporating the phenomenon of polarisation recently discovered by MALUS, by associating a wavelength with each colour, and finally, by providing this theory with a mathematical form in addition to a simple geometric method for resolving problems.

After FRESNEL the wave nature of light left no further room for doubt. As a consequence there were implications for its carrier medium, the ether, with its apparently contradictory properties of extreme subtlety in order to fill the universe without giving rise to friction, and of extreme rigidity in order to explain the very great propagation speed of light.

THE LAWS OF ELECTROLYSIS

From 1833 on, FARADAY began to compare the different known forms of electricity. At the time, questions were being asked about possible differences, depending on their origin. Light whose complexity had just been discovered, served as an analogy.

In his "Experimental Researches in Chemistry and Physics" he concluded that the different varieties of electricity were to be distinguished solely by voltage and power. In his work leading to the discovery of the laws of electrolysis he placed, one behind the other, electrolytic baths containing different chemicals through which the same current passed. He observed that the weights of the chemical compounds, liberated in a given period of time by precisely identical amounts of electricity, were proportionate to their atomic weights or simple fractions thereof.



Faraday's induction coil

Whereupon FARADAY established the electrochemical terminology: electrolyte, electrode, anode, cathode, ions, cations, anions.

FARADAY AND ATOMIC THEORY

Although he never openly adopted Dalton's atomic theory, he observed that it permitted a simple explanation of the laws that had been discovered.

The quantity of electricity associated with these equivalent atomic weights, called the FARADAY, and denoted by $\mathcal{F}$, was shown to have the value of 96,500 Coulomb.

A PUZZLING EXPERIMENT

In 1845, FARADAY mindful of the recent discoveries which were bringing about a revolution in optics decided to look into the possibility of interactions between light, electricity and magnetism.

He observed that the passage of a polarised light in the core of an electromagnet, caused by a rotation in the rotation plane of the light. This discovery, which established a link between the phenomena of light and magnetism was not fully understood at this time.

DANIELL

At about the same time as FARADAY was discovering induction, his friend DANIELL thought up the constant cell in which each metal electrode (copper or zinc) was immersed in a solution of its own salt.

This constant cell facilitated the industrial use of electricity e.g. the telegraph and electroplating.

THE WORK OF MAXWELL

In 1831, the year of Faraday's discovery of induction, James Clerk MAXWELL was born in Edinburgh. Very quickly the young MAXWELL proved himself to be a mathematical genius and a remarkable physicist. While still a student, he composed his first treatise on colour combinations. His reputation as a mathematician speedily won him a post as Professor in Aberdeen in 1856 and afterwards at King's College.

In 1859 MAXWELL brought about a revolution in physics making use of probabilistic mathematical theories to construct a kinetic theory of gases.

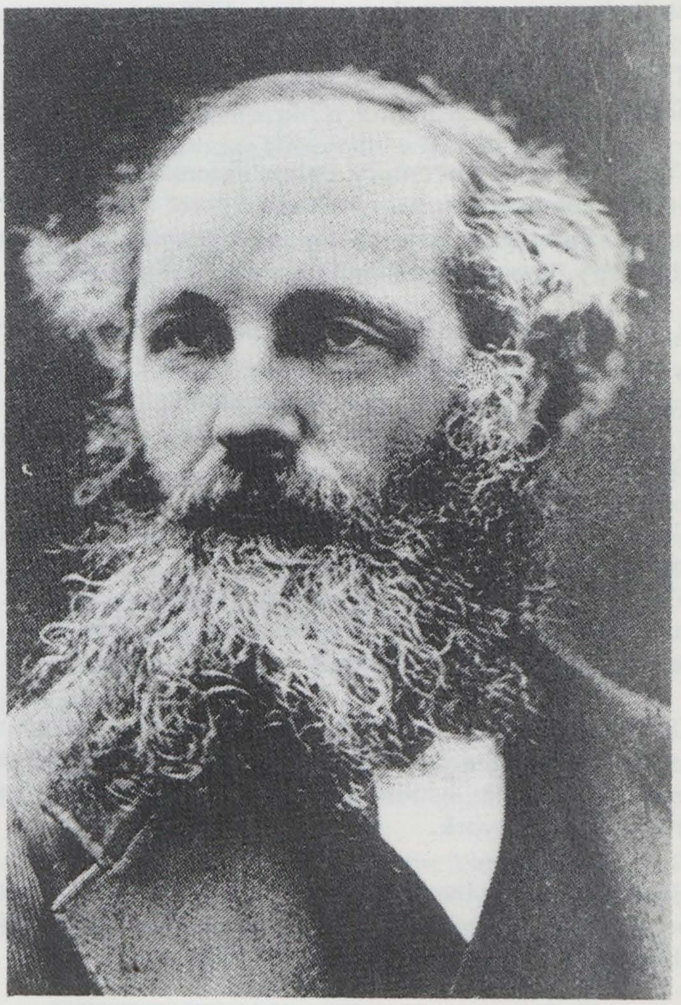
With Dalton's theory as a starting point and a very simple model of perfect gases, MAXWELL began by straightforwardly linking gas pressure to the average speed of gas molecules:

$$P = \frac{1}{3} MV^2$$

The resulting velocities were very high! For instance, for oxygen, one obtained 480m/s. However, Maxwell's mathematical genius was to lead him much further to the law of distribution of speeds, which would allow Avogadro's number to be calculated for the first time.

THE MEETING WITH FARADAY

Very early on, MAXWELL developed an interest in Faraday's hypothesis concerning the electric and magnetic field of force.



James Clerk MAXWELL

In 1860 he met FARADAY who presented him with his interpretation and his unexplained experiment involving the interaction between light and magnetism.

From 1862 to 1864, MAXWELL developed the idea of a "Displacement Current" a variable electrical field corresponding to a displacement in the vacuum or in the dielectric and engendering a magnetic field additional to the one produced by moving charges.

However this electromagnetic field (the term is Maxwell's) behaved like a wave, which implied speed of propagation. Now, the propagation speeds of electricity and of light had just been measured and found to be equal. MAXWELL saw in this more than a mere coincidence. The concordance of figures was so striking that *"We can scarcely avoid the inference of light consists in the transverse undulation of the same medium which is the cause of electric and magnetic phenomena"*.

We have a mathematical description, known as Maxwell's equations of these combined electric and magnetic variations. These electric waves, of the same nature as light but totally invisible, were treated as pure fantasy by the majority of scientists.

Unfortunately for MAXWELL, FARADAY who had died two years previously, was no longer there to defend his successor. Heartbroken by the lack of understanding in the scientific community, MAXWELL retreated to Scotland where he died prematurely and tragically in 1879.

THE CHEMISTS ARE WON OVER TO ATOMIC THEORY

Throughout the 19th century, Dalton's atomic theory gained little acceptance because experimental proof was lacking. It regained impetus through the development of carbon chemistry where it turned out to be especially useful.

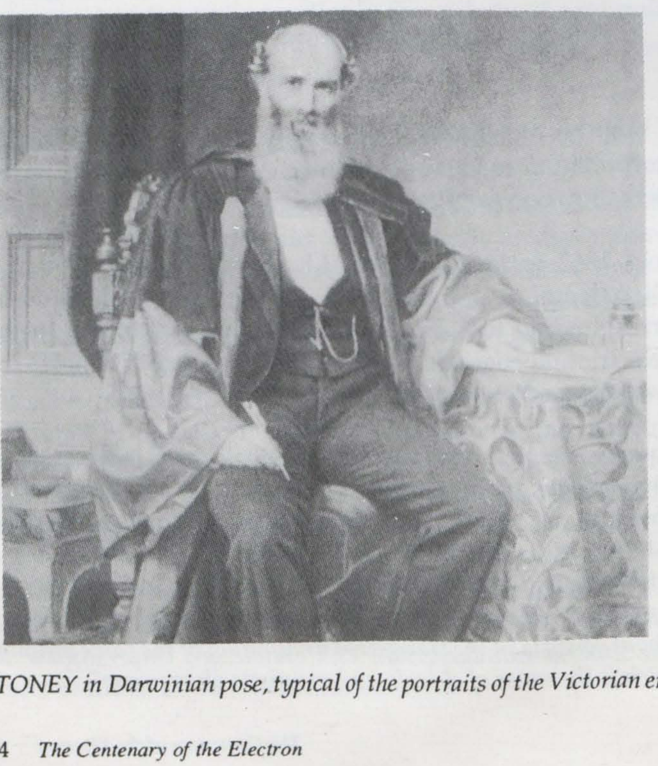
At the Karlsruhe Congress in 1860, the Italian CANNIZARO, with the support of the Frenchman WURTZ, achieved a general consensus with regard to the atomic theory.

GEORGE J. STONEY

George Johnstone STONEY was born on 15th February 1826 in Clareen, near Birr, Co. Offaly, in Ireland. At that time the STONEYS were big landowners, but the economic crises culminating in the terrible famine of 1845-48 forced them to sell their land and settle in Dublin.

Upon leaving Trinity College, STONEY became astronomical assistant at Birr Castle (Parsonstown). This first post was to mark him for life, astronomy was to remain a recurrent theme in all his work.

His professional career involved him in lecturing and in the organisation of teaching and he contributed a great deal to changes in his country's educational structure.



STONEY in Darwinian pose, typical of the portraits of the Victorian era.

LOOKING FOR FUNDAMENTAL CONSTANTS

Astronomy lead to his developing an interest from its creation in the kinetic theory of gases and first and foremost in the displacement speed of the molecules or the atoms of which they are composed. He connected these speeds with the escape velocities of stars. Thus he explained how the moon came to lose its atmosphere (1870).

Astronomy also induced him to investigate the profound unity of the universe and its fundamental constants, which for him lay in gravity, electricity and light.

THE ATOM OF ELECTRICITY

After Maxwell's presentation of the kinetic theory of gases in Aberdeen, STONEY took up the calculation of the number of atoms by the number of molecule grams, in other words Avogadro's number (1860). However, this first piece of work would not be published until 1868. It contained the totally novel idea that light, which is emitted or absorbed by atoms, is directly related to internal orbital movements of atoms.

For STONEY in 1874, Faraday's law relating to electrolysis implied the existence of an elementary quantity of electricity, an atom of electricity, so to speak.

This is how he calculated the value of this atom of electricity:

$$e = \frac{\mathcal{F}}{\mathcal{N}}$$

(The FARADAY unit divided by Avogadro's number), be obtained 10^{-20} Coulomb.

THE NAMING OF THE ELECTRON

In July 1891 he presented a revised and perfected version of all of his earlier ideas. Convinced of the existence of the elementary particle of electricity, he named it: **The Electron**.

To explain the emission of light by atoms, he introduced the idea of elliptical orbits of these electric particles within atoms and suggested that the fine structure of line spectra could be explained in terms of such orbits.

In 1893 the German physicist RICHARDZ returned to Stoney's method calculation and by introducing the latest measurements of constants relating to gases, he obtained for Avogadro's number a value which was very close to the current value of 6.023×10^{23}.

Recognition of Stoney's work and the definitive adoption of the nane Electron, was the achievement of LORENTZ who asked STONEY to write the preface to his work on electronic theory and he paid him a special tribute in Stockholm when he received the Nobel Prize in 1902.

STONEY died in London on 5th July 1911 after a long illness. His ashes rest in the little cemetery in Dundrum, Co. Dublin.

THE CAPTURE OF THE ELECTRON

THE DISCOVERY OF THE CATHODE RAY

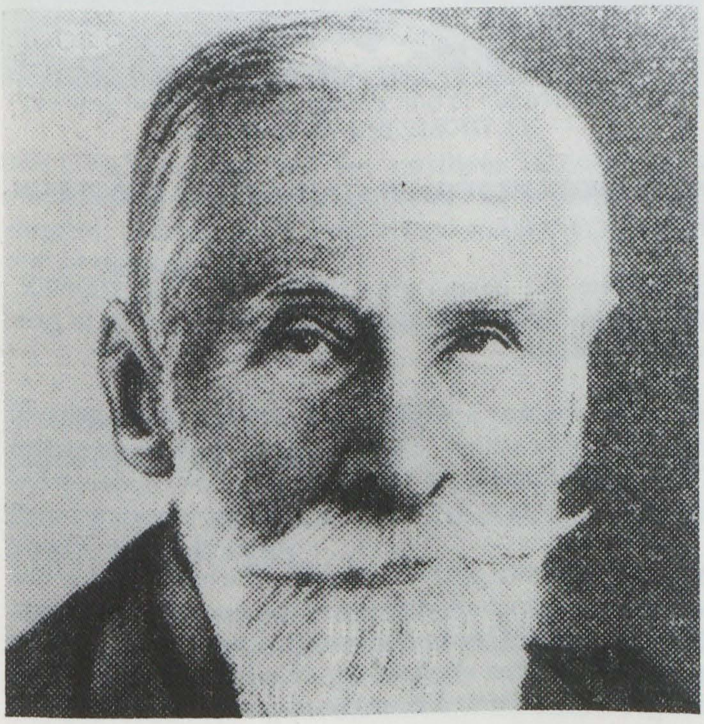
Around 1855, using Ruhmkorff's induction coil and a new mercury vacuum pump of their own design, PLUCKER and GEISSLER observed a glow on the glass of the tube when the gas in a bulb was progressively evacuated. The electric discharge changed appearances several times before becoming completely dark.

In 1867, HITTORF noticed that this glow seemed to come from the cathode.

In 1876, GOLDSTEIN confirmed it and called it cathode ray emission.

CROOKES' TUBE

Chemist and physicist, William CROOKES was already well known when he became interested in this mysterious glow. He put different objects in the path of the radiation, one of which was a Maltese cross, and observed their shadows, proving that the radiation propagated itself in a straight line from the cathode.



William CROOKES

In 1869, CROOKES made the major observation that radiation could be deflected by a magnetic field. In 1879, he postulated that the cathode ray was corpuscular in nature.

HERTZ and LENARD however supported a wave radiation, having shown that the cathode ray could go through a thin metal sheet and thus exit the tube.

J.J. THOMSON'S EARLY WORK

Joseph John THOMSON, born in 1856 was the son of a bookshop owner in the suburbs of Manchester. Initially interested by a career in engineering, he quickly switched to fundamental research in physics. In 1876, he got a scholarship to study in Cambridge University where he spent the rest of his life.

Extremely gifted, he rose quickly to the top of his field. In 1883, at the age of 27, he succeeded RAYLEIGH as the Head of the newly founded Cavendish Laboratory.

RAYLEIGH had already set the laboratory on the track of cathode rays. J.J. THOMSON followed that path. In 1894 to determine whether these rays were wave or corpuscular in nature, he measured the speed of the cathode ray using a rotating mirror. The result was 50,000 km/s. This value was so low compared to the speed of light and to the speed of Maxwell's recently confirmed electromagnetic waves that the wave nature of the ray became very doubtful.

The French scientist Jean PERRIN solved this mystery a few months later.

PERRIN PROVES THE EXISTENCE OF THE ELECTRON

Jean PERRIN was born in Lille, on the 30th September 1870. After studying there, he went to the Ecole Normale Superieure in Paris. Cathode radiation was the topic of his thesis.

Jean PERRIN

He thought that if the cathode ray was really formed of charged particles it should be possible to identify this charge. How? First of all by using an electroscope, an instrument which had always been used for that purpose. He simply had to put an electroscope into a Crookes' tube, something which was obviously easier said than done.

Jean PERRIN was successful in 1895. The cathode ray was, in fact, a bombardment of negatively charged particles.

And so, after receiving its name from STONEY, the electron was finally signed, sealed and delivered by PERRIN.

PERRIN AND AVOGADRO'S NUMBER

In order to check and determine precisely the value of the electron charge calculated by STONEY, it was necessary to determine experimentally and with great precision, Avogadro's number. This is what PERRIN did in the following years.

In the first decade of the 20th century, PERRIN conceived and implemented no less than 13 different methods of determination using Brownian motion.

PERRIN AND FRENCH RESEARCH

We must not fail to mention here the crucial role that PERRIN played in the promotion and popularisation of science, and in the organisation of French scientific research. He was the Chief State Secretary for Research and was responsible for the Palais de la Découverte, and much else including the present-day C.N.R.S. (Centre National de Recherche Scientifique).

LORENTZ AND HIS THEORY OF THE ELECTRON

PERRIN had hardly released his results when the Dutch physicist Hendrick LORENTZ, Professor Physics in Leyde applied them to the whole universe. He concluded that since electrons were to be found in solids as well as in air and gas, they were therefore present everywhere in matter and were one of the constituents of atoms. On that basis, LORENTZ undertook a reconstruction of Maxwell's theory based at this time on the electron.

In appreciation then of Stoney's pioneer role, LORENTZ asked him to write the preface to the work which he published on the Theory on the Electron.

LORENTZ AND THE ZEEMAN EFFECT

In his adaptation of Maxwell's equations, LORENTZ had to add new terms, one of which conveyed the effect of the electric field and another, the effect of the magnetic field on the electron. However this had the following consequence. Interactions between light and matter must therefore occur!

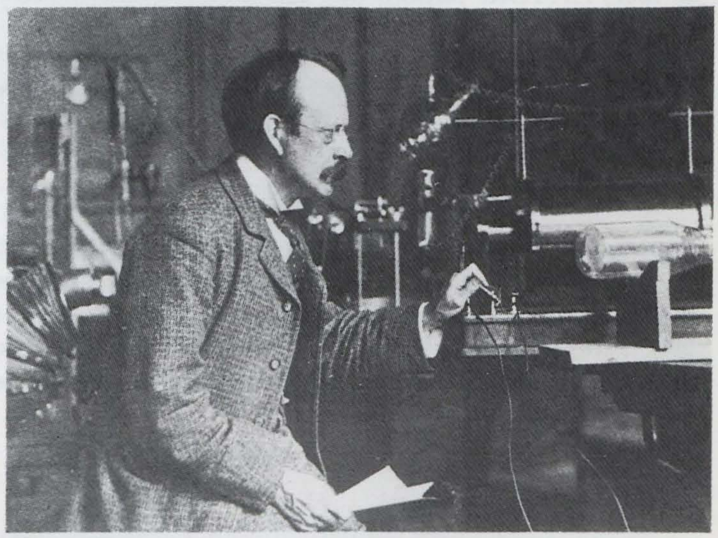
LORENTZ had advanced the hypothesis that the lines in the emission spectra of element like sodium would be split when placed in a magnetic field. This hypothesis was all the more daring since FARADAY had tried a similar experiment and had not observed anything. One of his students, Pieter ZEEMAN, succeeded in splitting the sodium line spectrum and so Lorentz's view on the universality of the electron received brilliant confirmation.

THE CHARACTERISATION OF THE ELECTRON BY J.J. THOMSON

The experiment of THOMSON and PERRIN escalated into a race that THOMSON won comfortably in 1897.

He compared the deflections created by an electric field, and a magnetic field, upon a very fine beam. The comparison of the two deflections allowed THOMSON to get: e/m, the charge to mass ratio for the electron.

After some hesitation, J.J. THOMSON himself accepted the name given by STONEY.



J.J. THOMSON in his laboratory

THE DIRECT DETERMINATION OF THE ELECTRON MASS

To confirm the charge already circulated by STONEY, Joseph John THOMSON used a method which was to gain wide acceptance.

It was known that a vapour would condense in droplets around condensation centres such as dust particles. THOMSON thought of using electrons as condensation centres.

Behind a very thin gold foil through which electrons could pass, he put a vapour chamber. The number of droplets then formed gave him the number of electrons corresponding to a given amount of electricity. Knowing the electronic charge he was able to deduce the mass:

$$m = 9.1 \times 10^{-31} \text{ kg}$$

The result amazed him since the mass was about 2000 times smaller than that of the hydrogen atom, believed at that time to be the lightest particle.

Mass of matter was therefore not directly connected to the electrons!

THOMSON was then forced to consider how the electrons were incorporated in matter. He visualised a structure now called "the plum pudding model". According to THOMSON the atom was like a plum pudding where the electrons were embedded in a mass of positive dough. However, he later became a supporter of Perrin's planet-type system based on Stoney's idea.

WILSON'S CLOUD CHAMBER

After that, all that remained was to see the electron. What initially appeared impossible soon became a reality. In 1902, taking up J.J. Thomson's idea of using electric particles as condensation centres, Charles WILSON, Cambridge Professor, managed to find a means of photographing electron trajectories. This was achieved by making the sudden reduction of pressure in a saturated vapour, coincide with the passage of the particles through the vapour.

This cloud chamber whose modern equivalent is the bubble chamber was to prove itself extremely valuable in the future research.

This experiment was then considered to be the most elegant in the world.

MILLIKAN AND THE DIRECT DETERMINATION OF THE CHARGE OF THE ELECTRON

They still had not directly determined the charge of the electron.

In 1909, Robert MILLIKAN thought of charging tiny droplets of oil so as to hold them in balance between two opposing forces, those of gravity and of electrical attraction.

MILLIKAN showed that the variations in this balance resulted from step-wise changes in the electric charge on the droplets, charges which were always multiples of a basic unit or elementary charge:

$$e = 1.591 \times 10^{-19} \text{ Coulomb.}$$

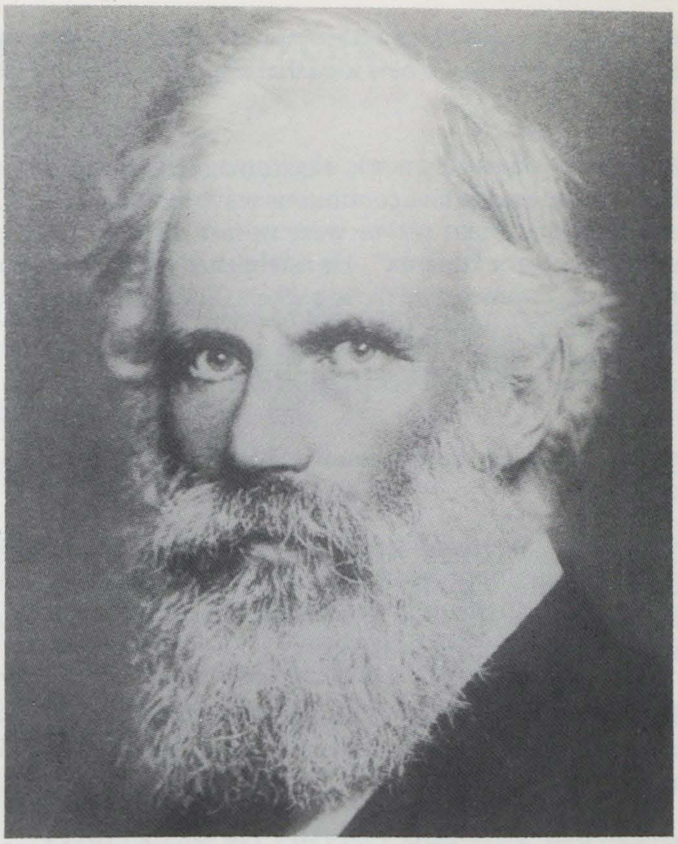
WAVE PARTICLE DUALITY: EINSTEIN, De BROGLIE

HERTZ AND THE DISCOVERY OF RADIO FREQUENCY WAVES

Through his theory of electromagnetic waves, MAXWELL established in 1859, a link between electricity and light. However, his ideas were so audacious that from the start they provoked nothing but derision and ridicule.

In 1883, HELMHOLTZ asked HERTZ, one of his students, to think about a device which could establish the existence of Maxwell's waves.

In 1888 HERTZ, with an oscillating discharge device in one room, managed to generate sparks in another room, that is, through a wall. Maxwell's waves did therefore exist. They were to be called Hertzian or radio waves.



George Francis FitzGERALD

HERTZ measured the speed of these waves. It was equal to the speed of light. He observed another secondary, disturbing phenomenon: the sparks of the receiver circuits were brighter when the circuit was illuminated.

Wireless Telegraphy now only required a simple efficient and useful receiver to appear. BRANLY brought it about with his filings tube or coherer.

THE ULTRA-VIOLET CATASTROPHE

By the end of the 19th century, scientists had reason to be proud of their work. The electron and electromagnetic wave had just been combined in Lorentz's electronic theory of matter. However, two events were about to cast a spanner in the works. The first was called the ultra-violet catastrophe.

Based on Lorentz's theory, the English astronomer JEANS calculated the special radiation which should emanate from very hot bodies like stars and electric filament lamps. He found that the calculated spectral distribution did not agree with the experimentally measured distribution. The calculations suggested a much higher emission of ultra-violet light than was actually measured.

How could Lorentz's electronic theory be reconciled with these experimental facts. In 1890 PLANCK found the solution.

PLANCK'S QUANTUM THEORY

Max PLANCK was born in Kiel, Germany, on the 23rd April 1858. He decided to make his career in scientific research, more precisely in theoretical physics, because of his exceptional aptitude for mathematics and physics. It was in his thesis, submitted on 14th December 1899 in Berlin, that PLANCK presented a new idea that astounded the scientific world.

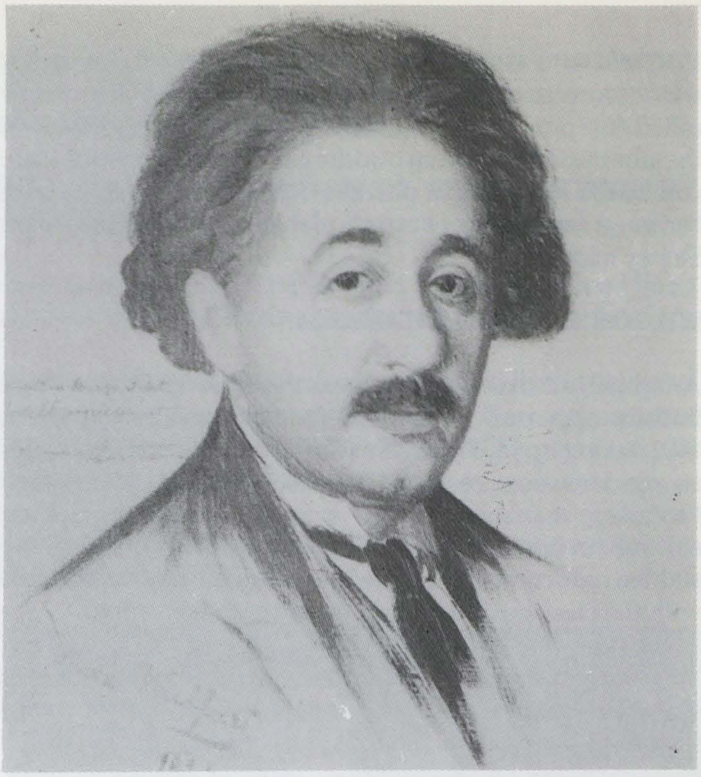
Ever since Maxwell's work, electromagnetic radiation had been considered to be a continuous wave motion. PLANCK assumed that these waves were in fact divided into very small packets or "quanta". He established a simple formula relating to the energy of those packets (E) to the frequency of corresponding waves (υ).

$$E = h\upsilon$$

where "h" is a constant known from then on as Planck's constant.

It was shown that, since the high frequency quanta corresponding to ultra violet light were proportionately more energetic, their emission was, in fact, less likely than classical theory had predicted.

Despite this agreement, the quantum theory was much disputed until a young scientist called Albert EINSTEIN appeared.



Portrait of EINSTEIN by Max Wulfort 1921

EINSTEIN AND THE THEORY OF RELATIVITY

EINSTEIN then intervened for the second time, since, for him, Michelson's experiment proved that the speed of light was constant in every direction.

He used Lorentz's mathematical formula and showed that it implied that the speed of light is a limiting speed which no moving object could reach. The reason? Simply that the mass of objects increased with their speed and would become infinite at the speed of light.

Einstein's theoretical developments made him predict a link between mass M and energy E, which depends on the speed of light C. Hence the now famous: $E = M C^2$

In the following years, EINSTEIN developed his ideas. He reached what was to be called the General Theory of Relativity.

The novelty was to be the introduction of a new dimension: Time as a matter of fact, when all bodies are in motion relative to one another, three dimensions are not enough to describe a given event. It was necessary to bring time into the relationship.

EINSTEIN'S EARLY WORK

Born in Ulm, Germany, on 14th March 1879, Albert EINSTEIN was by 1902 an engineer in the Patents Office in Bern.

After publishing a mathematical theory of the Brownian motion that was to be used by PERRIN, EINSTEIN studied the interaction between light and electro-magnetic waves already demonstrated by Hertz. In 1905, he showed the existence of the photo-electric effect. Radiation directed on to certain bodies led to the liberation of electrons. The existence of a threshold frequency in this effect could only be explained by the quantum theory.

Light was therefore corpuscular! EINSTEIN thus resurrected Newton's theory. The word photon was then coined to describe these quanta of light.

This caused a major uproar. Clearly, interference phenomena could only be explained if light was a wave motion. However, the photoelectric effect also implied that light must be corpuscular. A massive challenge was thus put before the entire scientific world of the time.

THE SECOND SPANNER IN THE WORKS: MICHELSON'S EXPERIMENT

In 1888, HERTZ experimentally confirmed Maxwell's theory. However, the whole theory was challenged by one of Maxwell's own ideas. He had indeed suggested measuring the speed of the earth's movement around the sun with an interference experiment. Light should travel faster when travelling parallel to the direction of motion of the earth than when travelling perpendicular to it.

In 1881, the American Albert MICHELSON, who had just left the Naval Academy for scientific research, undertook to set up this experiment which was considered pointless by most scientists of the time. He did not observe any effect! Light seemed to travel just as fast in both directions. Repeated many times, this experiment always gave the same negative result.

George Francis FitzGERALD (1851-1901) was born in Dublin. He submitted an audacious interpretation which was that one of the interferometer arms became shorter due to its movement in space. LORENTZ succeeded in 1903 in putting this hypothesis into a mathematical form and incorporating it into his existing theories. (Lorentz-FitzGerald Contraction).

PROPERTIES OF THE ELECTRON AND THE STRUCTURE OF MATTER

THE DISCOVERY OF THE PROTON

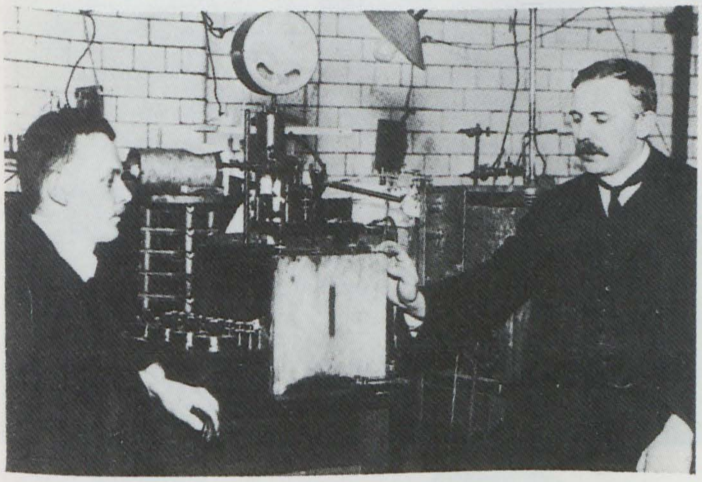
In 1886, GOLDSTEIN the German physicist, thought of using a cathode ray tube, incorporating a slit in the cathode. He observed a luminous spot on a screen placed behind the cathode. This ray, which moved in an opposite direction to the cathode ray was called the "canal ray".

The application of Perrin's experiment identified it as a corpuscular ray with a positive charge.

The application of Thomson's experiment carried out in 1897 by WIEN, showed an e/m ratio about 2000 times smaller than that of the electron for the canal rays. WIEN concluded that they were made up of atoms which had lost one or more electrons. Hydrogen, in particular corresponded to the elementary particle which RUTHERFORD later named "proton" in 1913.

RUTHERFORD'S ATOM

At the beginning of the 20th century, the latest theory about matter was propounded by J.J. THOMSON in his famous "plum pudding".



RUTHERFORD, (on the right) in his laboratory with GEIGER

This concept was further developed by RUTHERFORD, one of Thomson's own students at the Cavendish Laboratory who was later to succeed him as head of this establishment.

In 1909 this New Zealander Ernest RUTHERFORD, born in 1871 proved that the alpha ray of the radioactivity phenomenon, discovered by BECQUEREL is made up of helium atoms which have lost both their electrons. In 1911 he used this ray to bombard a very thin metal foil. Most of the rays traversed the foil undeflected, but some were highly deflected and some even recoiled in the opposite direction.

RUTHERFORD demonstrated with this experiment that matter is concentrated in nuclei. In 1913 returning to ideas of PERRIN and STONEY, RUTHERFORD presented the planetary model of the atom.

CUL DE SAC

However, very soon, a major objection was raised against Rutherford's model. In its original motion the electron is equivalent to a circulating current. It ought therefore to emit electromagnetic radiation. This emission corresponds to a loss of energy forcing the electron to draw even closer to the atomic nucleus. The proposed system cannot therefore be stable.

BOHR AND THE INTRODUCTION OF QUANTA

In 1885, the young Dane, Niels BOHR, who was studying at Cambridge, embarked on the application of Planck's theory of quanta to the atom. Instead of emitting energy in a constant stream, in approaching the nucleus, the electron would emit energy in packets of quanta. This implies that it passes abruptly from one orbit to another emitting light.

What are these orbits? BOHR began by taking hydrogen, the simplest atom, and also the simplest model for the movement of the electron, a circular orbit. Reasoning inductively as the result was already known (Balmer's law named after the Swiss scientist who demonstrated that the lines of hydrogen formed a geometric series), BOHR arrived at the definition of stable orbits i.e. the angular momentum of the electron on these orbits must be an integer multiple of Planck's constant divided by 2π.

Why on earth should this be the case? The answer to come some time later was that stable orbits are in resonance with the wave lengths associated with the electron by de Broglie's theory of wave mechanics.

Louis de BROGLIE

WAVE OR PARTICLE

We have seen how Fresnel's wave theory of light conflicted with Einstein's interpretation of the photo-electric effect, which implied that light had a corpuscular nature. But the phenomenon of interference implied just as inevitably a wave nature.

WAVE MECHANICS: WAVE AND PARTICLE

The solution to the problem was found by a very young man, bearer of an illustrious name, Louis Victor de BROGLIE descended from a long line of high-ranking officers in the French army.

Born in Dieppe in 1892, de BROGLIE set his sights at first at history but the scientific problems which puzzled his brother Maurice led him to opt for scientific research.

After the 1914-18 war, which interrupted his studies, he presented in his thesis the idea of associating a wave to a particle, not only for light but for all particles.

The fundamental relations of EINSTEIN and PLANCK gave the frequency and hence a wave length associated with each particle:

$$W = h \qquad \upsilon = MC^2 \qquad \upsilon = \frac{MC^2}{h}$$

DIFFRACTION OF ELECTRONS

In 1927, DAVISSON and GERMER observed an interference effect for electrons. Thus the wave particle duality was established.

It was to lead to a practical application of major importance i.e. the electronic microscope, first produced in Canada in 1937 by HILLIER and PREBUS. The short wavelength associated with electrons permitted huge magnification.

THE NEUTRON

In 1932 James CHADWICK discovered a new particle which was electrically neutral with a mass approximately equal to that of the proton. He named it the neutron. His discovery enabled him to throw light on the structure of all elements, by defining the notion of isotopes which possess the same number of protons and thus of electrons, differing only in their number of neutrons. This served to explain MENDELEIVE's periodic table, based on the physical and chemical properties of elements.

The number of protons in each nucleus corresponds to the number of its place in the table. Essentially, the masses of the elements are attributed to their atomic nucleus.

THE ELECTRON BECOMES NEBULOUS

The developments which followed the mathematical formulation of wave mechanics led HEISENBERG, the German physicist to the use of the mathematics of matrices. However, in this type of mathematics the result of multiplication depends on the order of the factors.

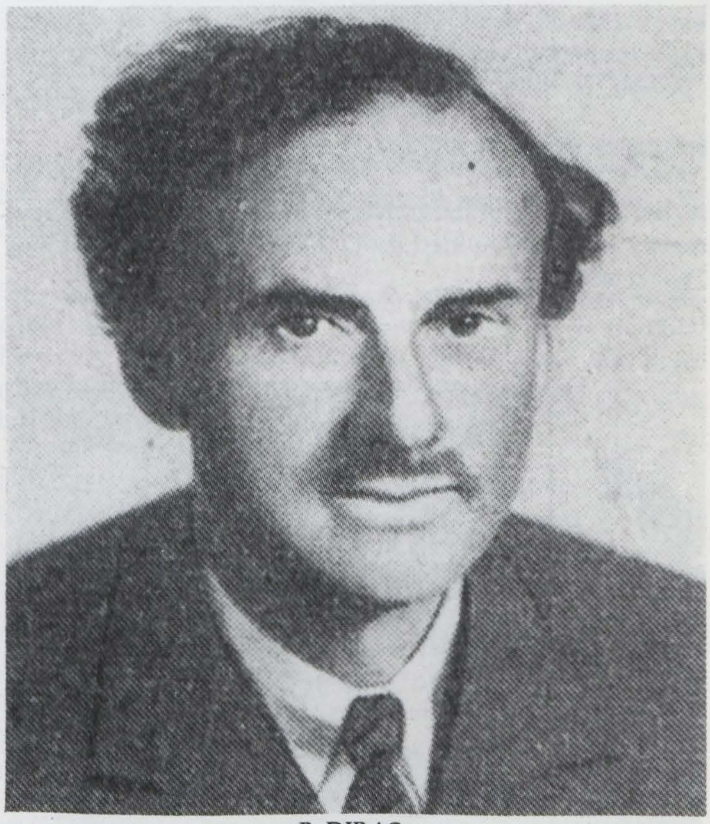
This property has had a major consequence: were one to measure precisely the position of the electron one would have to settle for a very approximate measurement of its velocity. Therefore were one to calculate precisely the position of the electron, one had to settle for an approximate speed and vice versa. Thus originated Heisenberg's famous principle of uncertainty.

Furthermore, in wave mechanics, electronic orbits become less well-defined. They turn into waves of probability very abstract and mathematical. They indicate that there is more likelihood of finding an electron in one region rather than in another. When applied to molecules this concept led to the familiar chemical orbitals.

So it could be said that PARAMENIDES had been right 2500 years previously.

DIRAC'S OPERATOR

In 1933 the English physicist DIRAC was to go further. He applied the equations of general relatively to wave mechanics.



P. DIRAC

Dirac's formulation brought him to the notion of the operator, which when applied to the wave function gives the result of a measurement.

The mathematical formulation of DIRAC had a second consequence i.e. his equations admit two solutions of opposite signs. This heralded the theory of antimatter.

The electron had to have a twin particle of opposite, therefore positive charge. Observations of cosmic radiation carried out in Wilson's cloud chamber proved soon thereafter the existence of this positive electron.

On the basis of Davy's experiment on the electric arc, Leon FOUCAULT, of subsequent pendulum fame, built the first arc lamp in 1844 using gas-carbon electrodes.

The first public lighting system was installed in the Place de la Concorde in Paris in 1850.

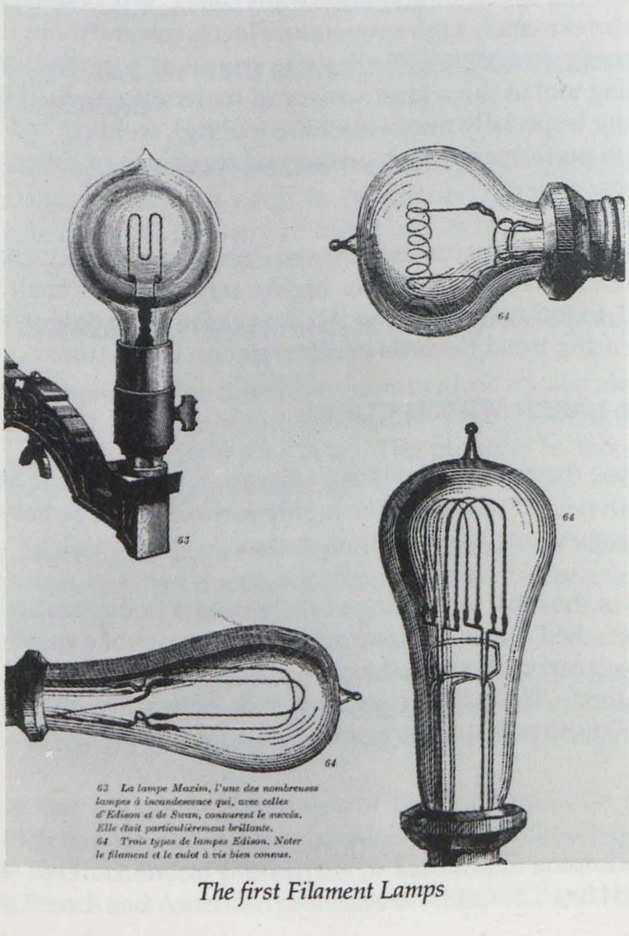
In 1875, the Russian JABLOCHROFF made electric arc lighting a practical proposition but only for public lighting purposes. Household lighting was still dominated by gas.

THE CARBON FILAMENT LAMP

In 1845, the American J.W. STARR had the idea of using carbon filaments, made incandescent by passing an electric current through them, inside glass bulbs containing a vacuum.

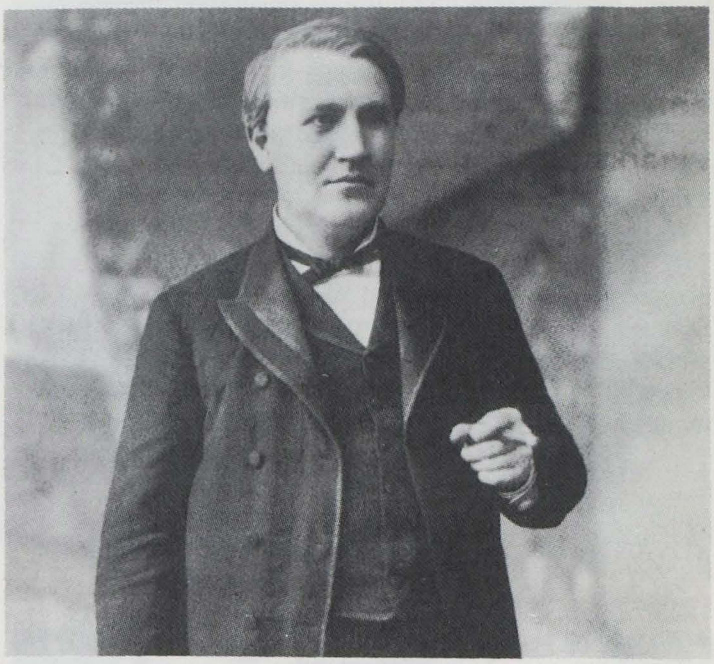
There were, however, certain technological problems associated with the carbon filament and the vacuum which delayed its implementation. The Englishman SWAN presented his first bulb in 1878.

On the 27th October 1879, EDISON succeeded in keeping a bulb lit for 13.5 hours. The following year saw the start of Edison's first factory at Menlo Park.



The first Filament Lamps

Although the legal claim taken by EDISON against SWAN came to nothing, it did bring the two together in work of world-sharing importance.



Thomas EDISON, Businessman

FLUORESCENT LIGHTING

In 1910, Georges CLAUDE discovered that a red light could be obtained by passing an electric current through the inert gas called neon. The advertising industry was quick to seize on the applications of this discovery. The fluorescent tube appeared in 1939.

Under the same conditions, mercury omits a bluish light, rich in ultra-violet. If the inner walls of the tube are coated with a fluorescent substance sensitive to ultra-violet, a light is emitted whose colour depends on the composition of the substance used.

EINSTEIN AND STIMULATED LIGHT EMISSION

In 1917, EINSTEIN drew a remarkable conclusion from Bohr's theory: instead of occurring naturally, the passage of an electron from an excited orbit to a fundamental stable free orbit may be brought about by stimulation. It emits radiation that is in phase with the wave that stimulated it. The new emission augments or amplifies the passing wave. If this phenomenon can be multiplied sufficiently, the resulting beam made up of wholly coherent light will be extremely powerful.

This is the principle of the Laser invented by EINSTEIN.

(**LASER**: Light Amplification Stimulated Emission Radiation)

THE LASER

This new discovery by EINSTEIN in 1917 was of no interest to anyone until 1950 when TOWNES in the USA and BASOV and PROKHOROW in the USSR had the idea of using it to amplify hyper-frequencies for radar purposes (Maser). In 1953, TOWNES used a ruby rod for the same purposes.

Then in 1958, TOWNES transposed his ruby maser to the area of optics. Thus, in 1960 he obtained the first Maiman Laser. In 1960, Bell Laboratories developed the gas laser which was less powerful but functioned continuously. Since then the practical applications of the laser have widened considerably in areas such as machine-tooling, surveying, communications, medicine, holography.

PHOTOVOLTAIC CELLS

The first photovoltaic cells converting light directly into electricity were produced in the Bell Laboratories in the USA in 1954. They were composed of a thin sheet of silicon placed over another thinner sheet, impregnated with boron. When light struck the outside layer, it sent electrons into the inner layer thus creating a potential difference.

ADVANTAGES	DISADVANTAGES	USES
• No moving parts • Durability • Min. Maintenance • No need for back-up	• Max. output in theory 25% • Real output 16%	• Space • Automatic Weather Stations

LASERS

In contrast with ordinary light sources, lasers produce a highly-focussed intense ray of light (up to one billion megawatts/cm^2) which is coherent and monochromatic. These diverse qualities justify their numerous uses.

LASER READ MEDIA

The compact disc is well-known nowadays as a means of reproduction of music, instead of the good old "78". This technology is not, however, confined to the area of high fidelity. Pictures, sound, digital data can all be recorded and restored on a laser player. Thus, filing, distribution of catalogues and directories, video-chips, data-banks, mapping, education and training are all applications of this technology. They are in direct competition with similar paper-based methods.

LASER AND FIBRE-OPTICS

Imagine a video camera, a microphone or even a telephone. The sounds and pictures which they record are transformed into electrical signals, modulated and then transported to our receivers through copper cables, by telephone cable or coaxial for T.V. With a laser diode, however the electrical signals can be transformed into high signals which are then dispatched through a fibre-optic cable to a photo-receiver. The bright signal is thus transformed into an electrical signal allowing sounds, images, computerised data to be displayed on a VDU, a loud-speaker or a computer. Thus fibre-optics can replace the tried and trusted copper cable.

HOLOGRAPHY

The idea for this is attributed to Dennis GABOR (British Physicist, Nobel Prize 1971) who in 1947, thought of recording on to a photosensitive plate, all information relating to the light waves emitted by an object. This included not only its intensity as in photography, but also its phase (which would convey the object in relief).

He named this "hologram" (from the Greek "holos" meaning all, and "graphein" meaning to write).

THE LASER WITH MEASURES

The ray emitted by a helium-neon laser can be used to check the verticability of a tower, to correct the flatness of a road surface, to find the axis of a tunnel to be constructed. It is also used to achieve perfect alignment of the different elements of a particular accelerator in nuclear physics. Armies use it to guide short-range ground-to-ground missiles.

THE LASER WHICH TRANSPORTS ENERGY

One of the laser's most important characteristics is the very high level of energy which can be concentrated on a tiny surface (up to one billion megawatts/cm^2). It is possible to achieve extremely high temperature levels (several thousand degrees). In industry the laser is in use as a cutting and drilling tool in the widest variety of materials, in machine-tooling (especially micro machine-tooling), welding and as a high performance tool for thermal treatment of different metals.

This development comes at the same time as the introduction of new materials which are highly refractory, difficult to weld, to tool and to cut and it comes at the same time as the increasing trend towards miniaturisation in electronics.

THE LASER WHICH CURES

In 1962 the laser made its appearance in bio-medicine and health related sciences. The highly focussed laser radiation can achieve wonders on living tissue.

One of the most interesting of these uses is in the treatment of detached retina. By concentrating the beam of a ruby (on ionised argon) laser on the back of an eye, a perfect weld is obtained. The whole operation lasts only a few minutes. There is no pain and no need for an anaesthetic.

CHEMISTRY

THE FIRST INDUSTRIAL USE OF ELECTRICITY

This came about, first of all, in the electrochemical industry and, more especially in the electro-plating process discovered by the Russian JACOBI.

France played a prominent role in this area through the activities of CHRISTOFLE, the first company (founded in 1840) to use these processes.

Because of its high standard of gold and silver electroplating, it quickly became the major supplier of tableware to European and even Asian rulers and royalty. It was the official supplier to Louis-Philippe and was actively supported by Napoleon III.

When the factory in the Rue de Bondy in Paris grew too small, the workshops were transferred to their present location in Saint-Denis. This is where the huge copper-plated statues which grace the Paris Opéra were made, as well as the statue of the Blessed Virgin which stands on top of the Notre Dame de la Garde Cathedral in Marseille.

CHRISTOFLE gave back more than it owed to electricity. The time he spent in CHRISTOFLE's workshops decided ZENOBE GRAMME to research a means of producing electricity without the use of batteries.

THE START OF THE MAJOR ELECTROCHEMICAL PROCESSES

Following the replacement of the battery with the dynamo and the consequent drop in production costs, the major electrochemical industry of today had its beginnings at the start of this century.

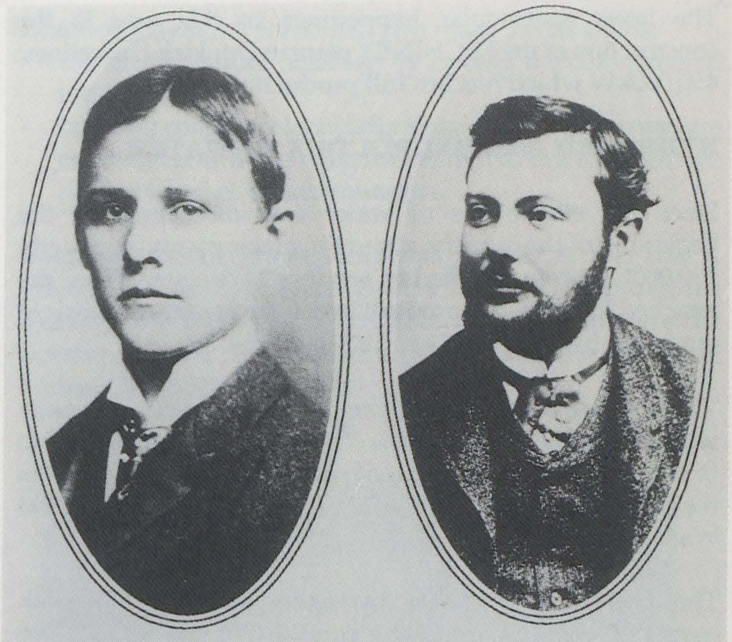
At first there was calcium carbide for acetylene lighting.

Then, there was the direct synthesis of nitric acid by electric arc, based on water, which relieved the problem of fertiliser imports to Europe from Chile. The pioneers in this area were the Norwegians BIRKELAND and EYDE.

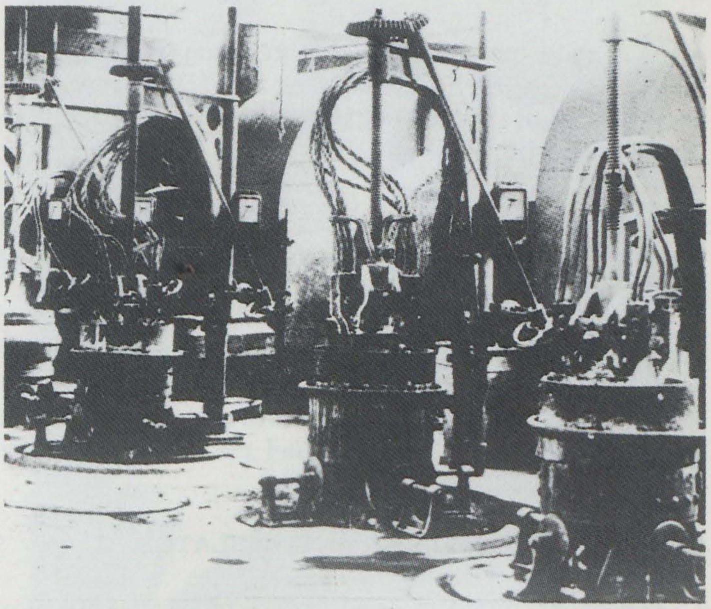
In France, the Father of hydro-electric power, BERGES, developed the production of chlorate for the manufacture of explosives.

At the same time, electrolysis of sodium chloride, initially for the production of metallic sodium, began its battle against the two existing processes of LEBLANC and SOLVAY.

The last important development is a joint one of a kind which happens very rarely in the history of technology, i.e. the electrochemical production of aluminium according to the French and American processes of HEROULT and HALL.



Hall Héroult



Heroult's first aluminium production unit in Froges at the end of the 19th century

Finally, ozone from its very beginnings, plays an important role in environmental chemistry.

TWO MAJOR ELECTROLYSIS PROCESSES

The 1914-18 war gave an extraordinary stimulus to the electrochemical industry. For each year of the war, investment in this area was greater than all the investments made during the preceding thirty years.

The reasons were, firstly, the demand for chlorine for use in chemical warfare and, secondly, the demand for aluminium in the aircraft industry.

At the present time, chlorine and aluminium are still the major electrolysis processes representing about 800-900kW each in France alone.

The latest spectacular happenings in this area is the construction of the PECHINEY plant in Dunkirk-Gravelines: 450,000kW which reaches full production in 1992.

HYDROGEN AND HYDROLYSIS OF WATER

Since the electrolysis of water was discovered at the beginning of the century, about ten major plants of capacity 200,000kW were installed to produce hydrogen. These are attached to dams and produce hydrogen for the synthesis of ammonia (used in fertiliser manufacture).

The best-known of these plants is in RYUKAN in Norway with a capacity of 400,000kW. The production of deuterium (a heavy isotope of hydrogen) on this site was involved in the battle to produce "heavy water" during the 2nd World War.

The possibilities offered by using seasonal low-peak electricity and the need for a combustible gas which does not give off CO_2, has brought together Electricité de France and Gaz de France in an effort to develop high-pressure water electrolysis systems.

After installing a 2,400kW prototype on the RHONE-POULENC site at Pont-de-Claix, an ALSTHOM prototype has now been in service since,1989 on the Air Liquide site at Waziers, near Douai.

Hydrogen has major implications for the future since it is the only completely non-polluting fuel, its combustion simply produces water.

At the present time, hydrogen is proving extremely useful in space. In its liquid form it fuels the engines on the Russian and American Space Shuttles and also the rocket stages of Ariane. It will also fuel the future European shuttle HERMES.

PLANTE AND THE LEAD ACCUMULATOR

Gaston PLANTE (1834-1889) was a physicist who also studied art under ISABEY and music under BIZET. He carried out independent scientific research in various fields in his own research laboratory.

In 1860 he discovered that it was possible to transform inactive couples into an electric current. During the next 20 years he worked tirelessly and perfected a couple consisting of two lead electrodes dipped into diluted sulphuric acid, and from this he managed to produce 18 Ah/Kg of charge capacity and to obtain 90% recovery of charge. This was the forerunner of today's lead acid battery. At the time of Plante's invention, there was very little commercial interest and PLANTE was never to know the eventual commercial success of his invention.

THE FUEL CELL

Discovered in the first half of the 19th Century by GROVE, the fuel cell only became of interest for military applications because it was an efficient electrical generator producing electricity with little self heating.

The USA space programme was the spur to the development of the fuel cell, the first of which were used in the Gemini and Appollo space missions where, in addition to producing electricity the cells also provided a source of pure drinking water. The generous budget of the American Space Programme permitted the use of a platinum catalyst to enhance the reliability of the fuel cells.

Alkaline fuel cells were initially developed by ALSTHOM in France. This work was continued by I.F.P. who produced cells of 0.5Kw and 5Kw capacity whilst attempting to reduce the amount of precious metals used for electrodes.

FUEL CELLS CURRENTLY UNDER DEVELOPMENT

The Americans and Japanese lead in the development of fuel cells. In New York, UNITED TECHNOLOGY developed a phosphoric acid battery of 4.5Kw, but this did not receive financial backup. A second series was built in Tokyo using the experience of UNITED TECHNOLOGY. To date 40 batteries, with a capacity of 400Kw have been produced. Research agreements are now being negotiated between USA and Japan to produce batteries of even higher capacities which could be used to replace gas turbines for electrical utilities.

Gaston PLANTE

POWER

THE MECHANICAL REVOLUTION

Water drive machines of ancient design had an efficiency output of approximately 20%.

In 1827, this efficiency was raised overnight to 80% by Benoit FOURNEYRON (1820-1867) the inventor of the modern water turbine.

BERGES, THE FATHER OF HYDRO-ELECTRIC POWER

To provide for the mechanical needs of his pulp mill in Lancey, Dauphine Aristide BERGES (1833- 1904) succeeded in exploiting the first man-made fall of water (200 metres), thus obtaining an output of 1000 h.p.

He repeated this with similar falls reaching 600 metres, which gave him the nickname "father of hydro-electric power".

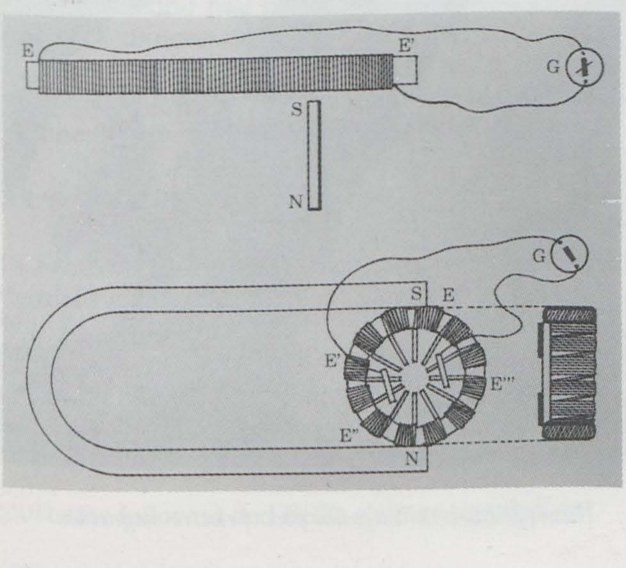
PARSONS AND THE FIRST STEAM TURBINE

Charles PARSONS (1854-1931) was born in Birr, Co. Offaly. He invented the marine steam turbine which was capable of driving propeller blades at high speeds. He built an experimental vessel, the Turbina, which achieved a maximum speed of 34 knots, this was faster than any other vessel afloat at the Royal Navy Review held in 1897 to commemorate the Diamond Jubilee of Queen Victoria.

THE INVENTION OF THE DYNAMO

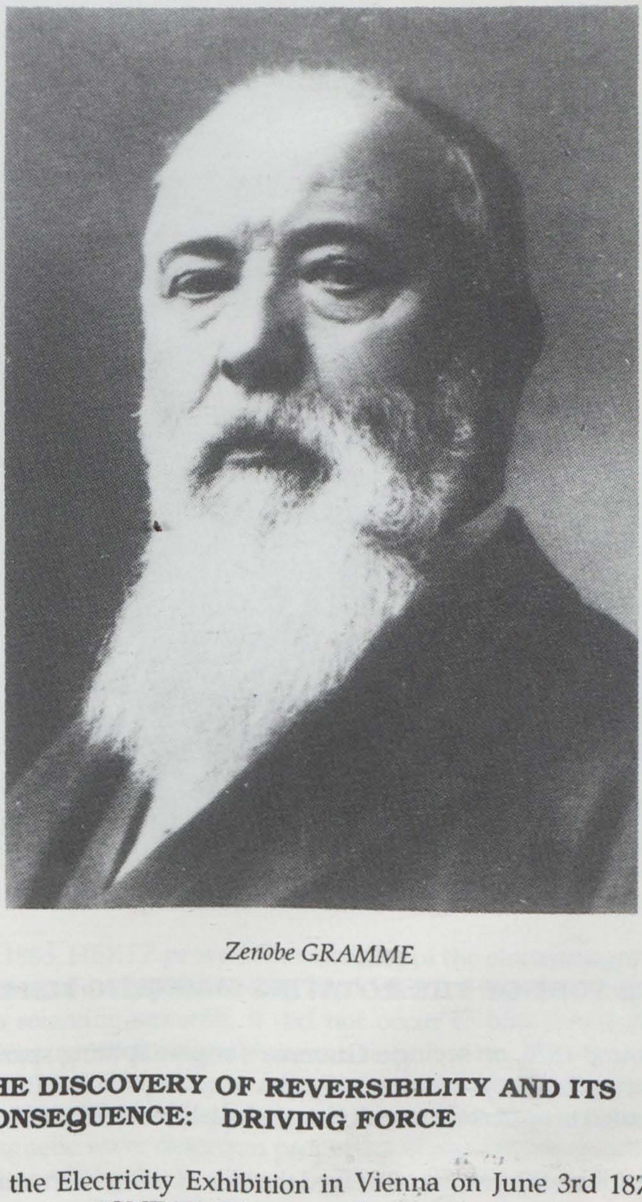
Faraday's fundamental discovery in 1831 took a long time to be put to use.

The persistence of the Belgian, Zenobe GRAMME (1826-1901) led to the first dynamo.



Gramme's dynamo combined two major innovations:
- the ring armature obtained by closing the conventional induction coil.
- a current collector electrically linked to the ring armature at several points allowing the current to exit through two contact brushes or commutators.

Overnight the cost of electricity was divided by over 100. A considerable number of engineers began to improve the dynamo, the two most famous names of whom were the German Werner SIEMENS (1816-1892) and the American Thomas EDISON (1847-1931).



Zenobe GRAMME

THE DISCOVERY OF REVERSIBILITY AND ITS CONSEQUENCE: DRIVING FORCE

At the Electricity Exhibition in Vienna on June 3rd 1873, Hippolyte FONTAINE (1833-1917) of the Gramme Machines Company demonstrated the reversibility of Gramme's dynamo, hence inventing the first modern electric motor.

This discovery was then exploited in 1879 by SIEMENS to build the first electric railway. The next step was the electric tramway of the 1881 Paris Exhibition.

SOMETHING NEW AND WONDERFUL IN OLD MANHATTAN

Having made the incandescent lamp a reliable proposition, EDISON built the first electric power station in the world in 1882. It was in New York and it supplied 10,164 lamps distributed amongst 508 customers around Pearl Street.

THE TRANSPORT OF ELECTRICITY

Long distance transport of electricity was made possible by Marceau DEPREZ.

In 1882, DEPREZ powered the electric pump for the Munich Exhibition fountain from Miesbach a distance of 56 km between Paris and Creil.

It was however the systematic use of alternating current and of the transformer that led to the development of the modern distribution system.

THE POET OF THE ROTATING MAGNETIC FIELD

Around 1876, on seeing a Gramme's engine spitting sparks from its brushes, a young Yugoslav student Nikola TESLA decided to undertake research on the brushless electric motor.

The following year he conceived the idea of using alternating current to create a rotating magnetic field. It was however not until 1882 in Strasbourg that TELSA succeeded in realising the first synchronous brushless electric motor.

ROTATING FIELD AND THE SYNCHRONOUS MOTOR

Two electro-magnets whose axes were perpendicular were powered by alternating current of the same frequency but out of step by a 1/4 period.

Thus a rotating magnetic field which completed a full rotation in one cycle of the current was obtained. That is to say a rotation takes 1/50 sec. if $50H_z$ current is used.

A magnetic rotor in the centre of the device would then turn in step with the field created by the coils.

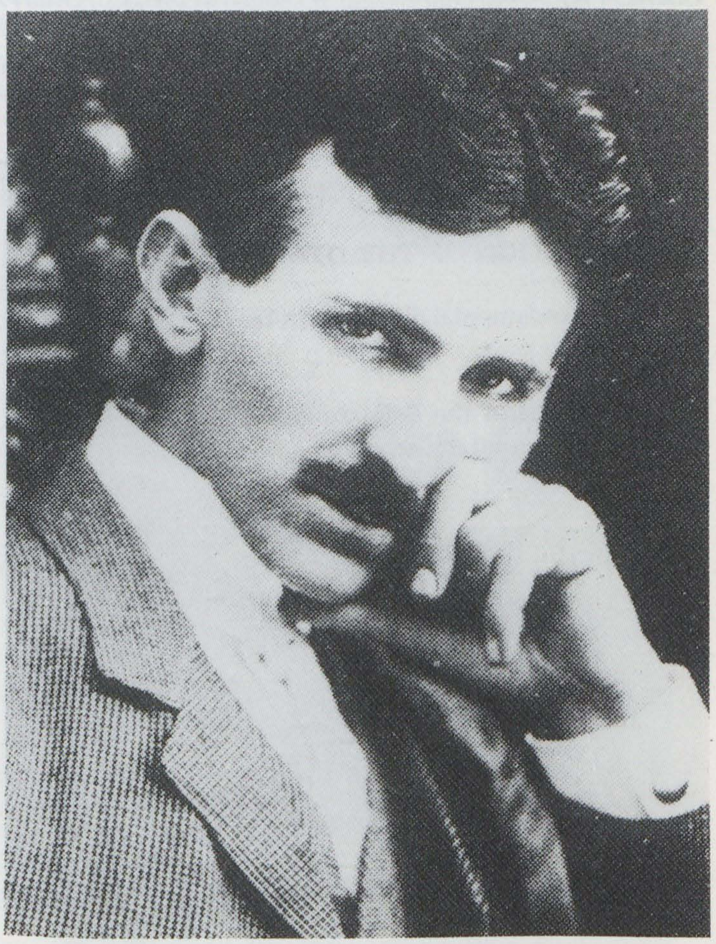
THE BATTLE OF THE CURRENTS

In 1888, the American Railway magnate WESTINGHOUSE bought all Telsa's patents, his alternating current dynamo, transformer, motors ... and engaged in a battle against EDISON, promoter of direct current.

THE VICTORY OF THE THREE-PHASE

The spectacular demonstration in 1891 of the transport of power by three-phase current to Frankfort (177 km) confirmed Telsa's mastery of poly-phase currents.

As early as 1893, the choice of alternating current for the Niagara Falls power station marked the victory of alternating current over direct current.



Nikola TELSA, the Yugoslav poet of electro-magnetism

COMMUNICATIONS

TELEGRAPHY

As soon as the high speed of propagation of electric current was discovered, the possibility of using it for communications purposes was considered. First of all, however, a battery producing a stable output was needed. This research led to the DANIEL cell which, together with Oersted's discovery culminated in a communications system set to revolutionise the 19th century.

In 1832, Henry's experiment on the electromagnet provided the inspiration for the painter Samuel MORSE who was deeply interested in physics.

In 1837 MORSE invented his famous alphabet composed of dots and dashes and then a key which perforated thin bands of paper to register the message.

In 1844 the first telegraph line was tested. It covered the 60 km between Baltimore and Washington.

CONQUERING THE WORLD

The development of a world-wide telegraphic network meant that seas and oceans had to be crossed. In 1849, Werner SIEMENS solved the problem of underwater insulation. The wire conductor was coated with a layer of gutta percha, a natural rubber.

In 1850, the first cable between England and France was laid. It did not last very long as it was soon accidentally cut by a fisherman. NAPOLEON III instigated the laying of a second cable in 1851 which remained operational for a considerable length of time.

It was not until 1864, on the fourth attempt, that the famous "Great Eastern" laid the first operational transatlantic cable.

During the second half of the 19th century a world-wide network of underwater cables was laid. This allowed messages to travel around the earth in seven minutes, notwithstanding the numerous retransmissions required to overcome the attenuation of the signal with distance.

BELL'S TELEPHONE

In 1876 the first instrument which could transmit the human voice made its appearance.

Graham BELL and Elisha GRAY both carried out independent research and each filed a patent claim within two hours of each other on the very same afternoon. Each claimed he had discovered how to transmit the human voice electrically.

A court case followed and Bell's claims were upheld.

EDISON invented the carbon granule microphone. A metal plate, vibrating under the action of the human voice, compresses the carbon whose resistance then varies. This system was much more sensitive to sounds than Graham Bell's original microphone.

Graham Bell's public demonstration of his telephone

THE EARLY STAGES OF THE WIRELESS

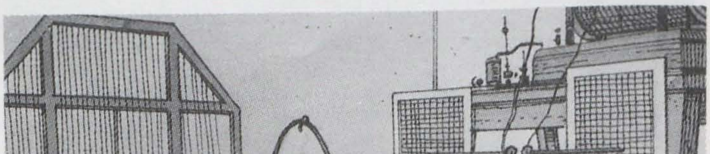
In 1888, HERTZ proved the existence of the electromagnetic waves, already predicted by MAXWELL. However, despite his scientific research, it did not occur to him to use this phenomenon for signal transmission.

In 1890 BRANLY discovered the extraordinary electromagnetic wave detection properties of an iron filings-filled tube or Coherer.

In 1894, LODGE transmitted the first radio message in Morse Code from the Royal Institution over a distance of 3 metres!

The first star of the airwaves: MELBA, the famous opera singer

Gugliemo MARCONI



HERTZ

In 1895, Alexandre POPOFF showed that an aerial could greatly increase the sensitivity of the receivers.

In 1895 Gugliemo MARCONI sent radio signals over a distance of 1 mile and by 1899 he had established a wireless station in the South of England to communicate with France. In 1901 MARCONI bridged the Atlantic Ocean when he transmitted the letter "S" in morse code from Poldhu in Cornwall to St John's, Newfoundland, a distance of 3,200 km (2,000 miles).

FROM THE COHERER TO THE TRANSISTOR

A former student of the Ecole Normale and a medical doctor, Edouard BRANLY studied the nervous system, the anatomy of nerves and, in particular, the anatomy of those nerve junctions called ganglia. Nerve endings are in themselves conductors of impulses and they extend to form very fine strands which merge in a complex tangle.

The question BRANLY asked himself was: how are nerve impulses guided through this tangle of imperfect contacts? Using a variety of objects, BRANLY set about creating models of imperfect contacts. While he was examining the conduction of a tube filled with filings, an electrostatic machine which was producing recurring electric discharges in an adjoining room, transformed his tube into a conductor. A simple thump or blow returned it to its former state of non-conduction.

BRANLY presented his metal filings Coherer to the Academy of Science on the 24th of November 1890.

Scientists had difficulty in understanding the mechanics of the Coherer. The study of Branly's imperfect contacts continued for some years. It led to the discovery of similar properties in lead-sulphide or galena crystals, which was to lead to the production of extremely simple small radio receivers.

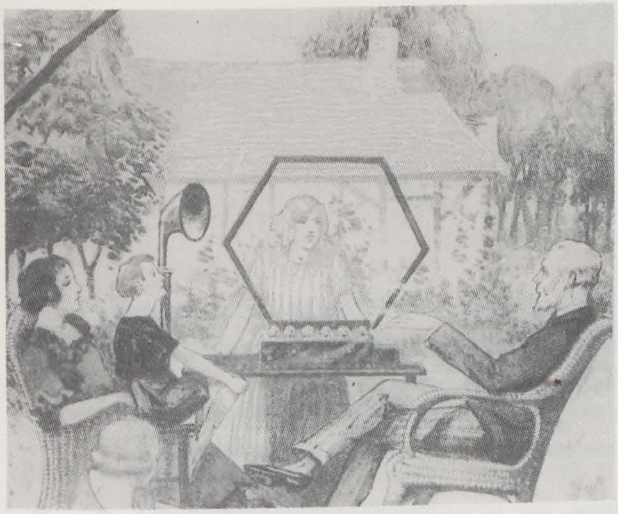
Research into the properties of galena led the researchers to place a second electrode beside the imperfect contact. The resulting effects were quite significant.

The principle of the transistor had just been discovered and, yet, scientists still did not know how Branly's Coherer worked!

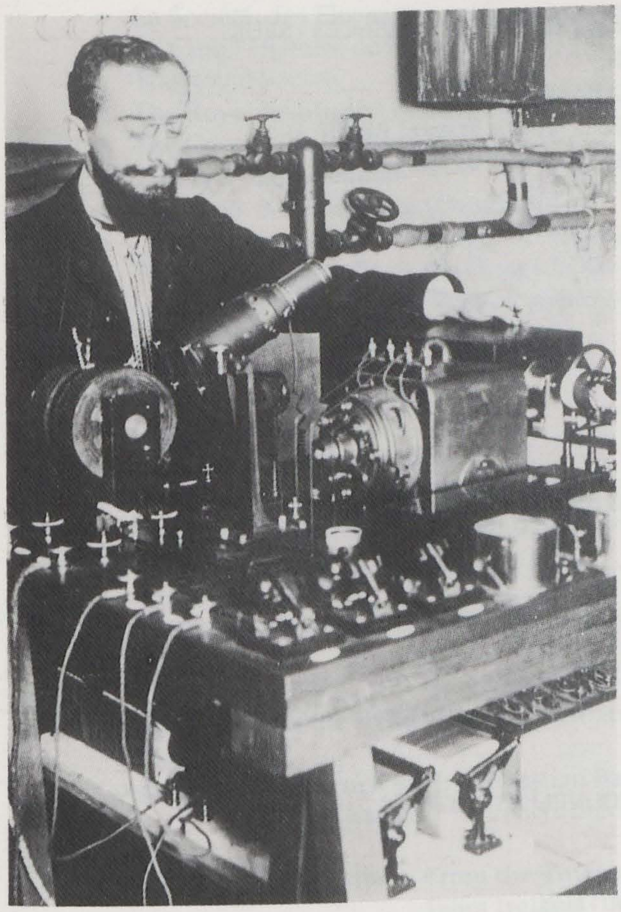
THE EARLY STAGES OF ELECTRONICS

In 1884, EDISON discovered that metal, heated in a vacuum, emits electrons. Although it was called the "Edison Effect", it was, however, one of the few discoveries made by EDISON which did not earn him any money!

In 1904, John Alexander FLEMING placed an electrode inside an empty tube near the incandescent filament. With two of these valves he was able to convert alternating current into



Forerunner of the transistor Radio



BELIN with his Belinograph

BARTHELEMY completed the first NIPKON disk television set in 1931

direct current. Thus it was that the first electronic valve, known as the diode, was invented.

In 1907, an American called Lee de FOREST, transformed the diode into a triode by inserting a metal grid between the diode's two electrodes. This triode had exceptional amplifying properties. With the discovery of the triode, wireless telegraphy progressed to radio. This triode heralded the beginning of long-distance telecommunications and the introduction of the first computer. This was due to a double triode valve, where feedback to the grids gave a bistable of flip-flop output.

THE TRANSMISSION OF PICTURES

In 1907, a German named KORN succeeded in transmitting a photograph by telephone wire from Paris to Berlin. BELIN immediately set about perfecting this process. In 1912 he presented the "BELIN Case" or belinograph. The device, which is electromagnetic, allows rapid transmission of photographs.

For a number of decades to follow the "BELINO" became one of the tools of their trade used by all journalists. The "BELINO" became obsolete only comparatively recently with the advent of computer technology.

THE INTRODUCTION OF TELEVISION

In 1884, a German called NIPKON devised a method of image scanning. The distinctive feature of the NIPKON system was the spirally apertured rotating disk that provided, at both sending and receiving ends, a simple method of image scanning. The disk, rotating in front of the picture being analysed, rapidly scans each element in the picture.

In 1927, an American called Vladimir ZWORYKIN perfected the iconscope which enabled him to replace Nipkon's mechanical scanning method with an electronic system.

In April 1931, in the Ecole Supérieure d'Electricité, René BARTHELEMY demonstrated television to the public for the first time.

By 1935 a regular television broadcasting service had begun in Germany using 180 lines. This produced a picture with poor definition.

In 1931 Electrical Musical Industries (EMI) set up a research team in the UK under the leadership of Issac SHOENBERG, which led to the development of the EMITRON, the forerunner to the modern television tube.

In 1936 the British Broadcasting Corporation launched the world's first public high definition broadcasting service in London using the EMI system with 405 lines. This remained a standard until the mid 1960s and was superseded in Europe by today's 625 line system.

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