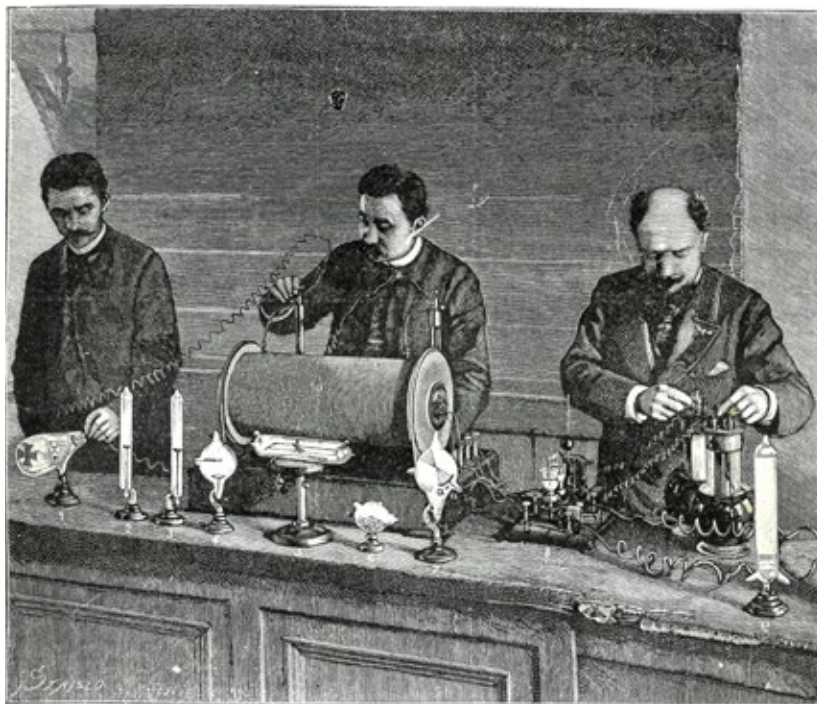


Vacuum tubes and light bulbs at the Musée d'histoire des sciences



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*Cover: Experiments with discharge tubes
Desbeaux Emile, La physique populaire, Paris, 1891
Library of the Musée d'histoire des sciences*

Electric light

Since the 18th century, physicists have observed that high tension electrical discharges under a partial vacuum in glass tubes produce spectacular light effects. In the mid-19th century, manufactured glass tubes containing rare gases were a huge success. The colour of the lights depended on the type of gas in the tube. These so-called "Geissler" tubes, named after their inventor, are looked upon as the ancestors of our modern fluorescent lights.

Towards the end of the 19th century, research on electrical discharges in rarefied gases came to a close with the discovery of cathode rays, later revealed to be streams of electrons. They would be used in the 20th century to produce images on TV screens. Studies on cathode rays led to another discovery, X-rays, which were capable of crossing through matter including human bodies.

During the last years of the 19th century another lighting technique was discovered. A glass bulb which produced light, not by discharge, but by the continuous passage of an electrical current through a carbon filament: this was the incandescent light bulb which became the most widely used lighting in the 20th century.

Blue glows

The light effects when mercury meets glass

In the 18th century physicists noted that, when a barometer is shaken in the dark, gleams of light appear in the upper part of the glass tube which contained mercury. They tried to reproduce the phenomenon using a glass tube partly emptied of air and containing small quantities of mercury. The result was light effects similar to those observed in barometers. As the lights only appeared when the tube was shaken, the scientists concluded that they were caused by friction of the mercury against the glass surface.

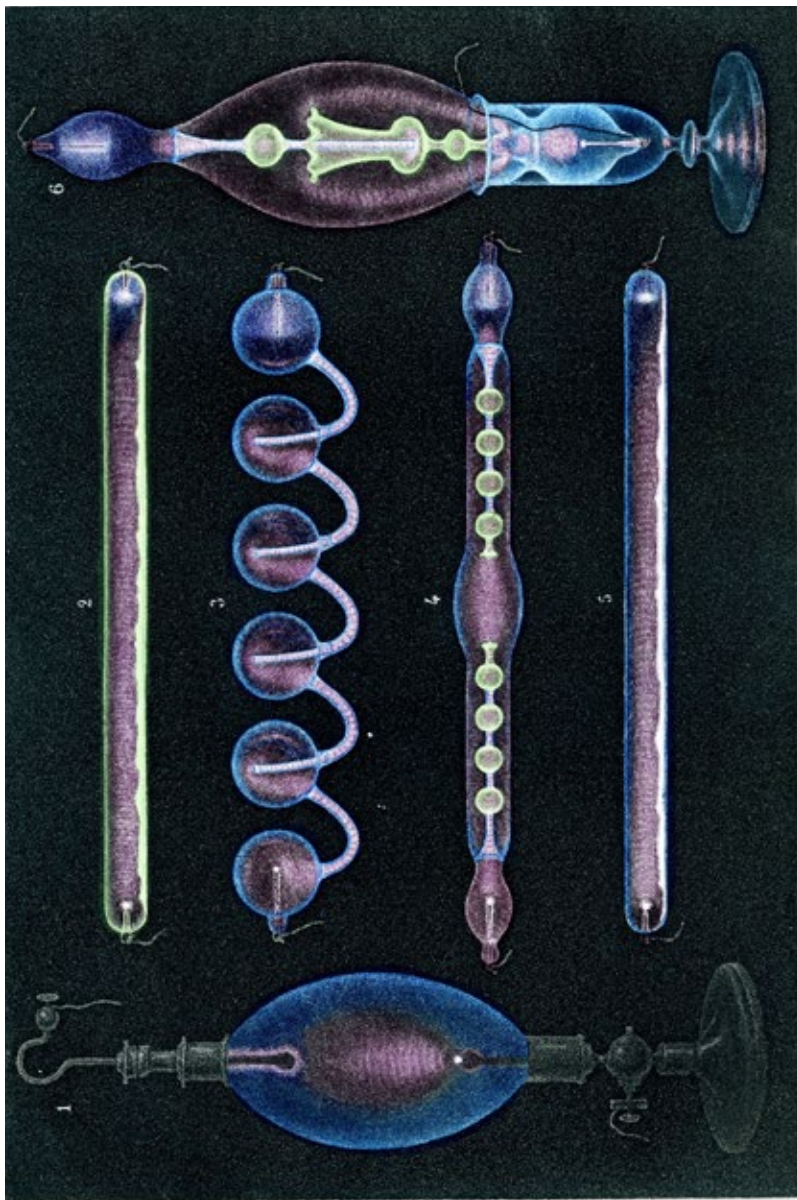
In England, Francis Hauksbee (1660-1713) mechanised the process. He made a machine that rotated a glass globe containing mercury to which friction was applied manually by the experimenter: the same light effects appeared. Even more surprising, the light phenomena was present in a globe that had been subject to friction but did not contain mercury. As the external surface of the globe was also attracting lightweight objects, a sign of electrostatic attraction, Hauksbee concluded that the two processes were linked.



Aurora tube

MHS 1475

Glass, mercury, 19th century (?)



Electrical discharges in tubes containing rarefied gases
Guillemin Amédée, *Les phénomènes de la physique*, Paris, 1869
Library of the Musée d'histoire des sciences

Luminous discharges

Under low pressure gases colour in the presence of electrical current



Studies of the luminous effects produced by electrical discharges expanded in the 19th century. Physicists made specifically designed experimental apparatus, so-called 'electrical eggs', a type of glass globe equipped with a tap connected to a vacuum pump. Electrical discharges, produced by an electrostatic machine, passed between two electrodes inside the globe.

As pressure in the globe was gradually lowered, observers noted the appearance of a rose-coloured jet between the two electrodes. When pressure was reduced even further, the jet disappeared.

In the middle of the 19th century, Heinrich Geissler (1815-1879), a German physicist and glass blower, made a new type of discharge tube which met with great success. The tube contains gases at very low pressure. When an electric current passes through the gases spectacular, very intense, colours are produced. The colours depend on the type of gases in the tube: orange-red for neon, blue for mercury, purple for helium. Geissler's tubes are at the origin of the neon tubes and signs which appeared at the beginning of the 20th century, and today's luminescent tubes, misleadingly referred to as neon. These do not contain neon, but have mercury vapour which makes their interior surfaces fluorescent when they are subjected to electrical discharges.

Electric egg
MHS 1956
Egg, brass, 19th century



Geissler tubes
MHS 2574
Glass, copper, 19th century

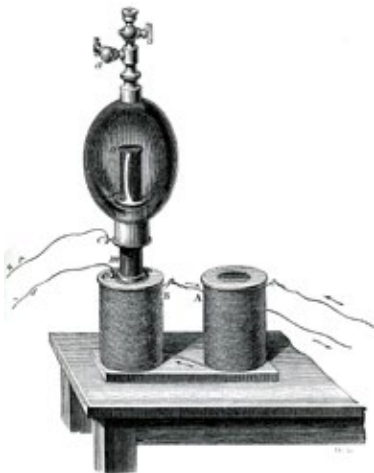


Electric eggs

Reproducing the polar aurora in the laboratory

In about 1848, the Genevan physicist Auguste de la Rive (1801-1873) showed that the luminous jets produced by electrical discharges in rarefied gases are deviated by a magnet. To demonstrate, he used a slightly modified electric egg. A soft iron probe is inserted into the globe though an opening at the base of the egg. The probe is entirely covered with thick insulation except at the upper extremity. A copper ring connecting to the exterior and serving as an electrode encircles the base.

A vacuum is created inside the globe, some drops of ether are introduced and then the egg is connected to an induction coil. A coloured, luminous cloud forms around the probe, between its upper section and the copper ring. When the soft iron probe is magnetised with an electromagnet, the appearance of the phenomenon changes; the shower condenses and a luminous jet plays around the soft iron probe. The direction of rotation of the jet varies according to the direction of the current and the degree of magnetisation.



This experiment allowed De la Rive to demonstrate his theory of the formation of polar aurora. According to De la Rive, these natural coloured phenomena were the result of the action of earth's magnetism which prints rotational movement on electrical discharges operating near the poles between the positive electricity of the atmosphere and the negative electricity of the earth.

De la Rive's electric egg

*Alphonse Ganot, Traité de physique, Paris, 1884
Library of the Musée d'histoire des sciences*



Electric egg

MHS 2030

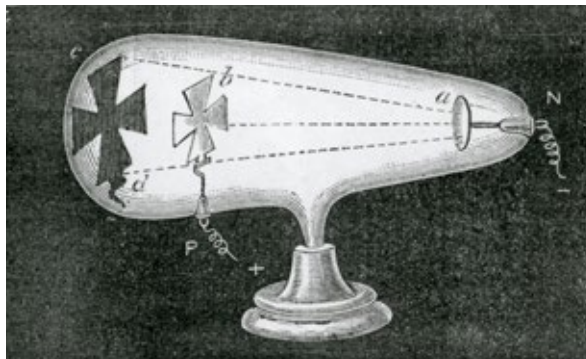
Iron, glass, brass, De la Rive, Geneva, around 1850

Invisible rays

Electron streams emitted by the cathode

During the second half of the 19th century, scientists subjected glass tubes nearly empty of air to even higher electrical currents. They observed that, at very low pressure, the luminous trails caused by the discharges disappear and that the glass suddenly becomes fluorescent.

In 1887, the English physicist William Crookes (1832-1919) showed that the green coloration was caused by the impact on the glass of invisible rays which he called cathodic because they appeared to originate from the cathode, the electrode connected to the negative pole of the induction coil. Crookes placed a Maltese cross on the expected path of the cathode rays in the glass tube. When electricity was run through the device, the cathode rays followed a straight line towards the far end of the tube. The cross was projected as a coloured shadow on the fluorescent glass. Following up on Crookes' work, another British physicist, Joseph Thompson (1856-1940) showed experimentally that the cathode rays are composed of a type of particle fundamental to the atom: electrons.



Crookes' tube in operation

Placed in the path of the cathode rays produced at (a), the metal cross (b) projects a shadow (d) at the end of the tube (c).

Library of the Musée d'histoire des sciences



Crookes' tube

MHS 2235

Aluminium, wood, iron, glass, 19th century

Cathode tubes

The foundation of 20th century television

During the 20th century, television, radar and oscilloscopes sprang from the development of cathode tubes. Using high tension current, electrons are produced by the cathode and accelerated towards, and then pass through, the anode. During their trajectory, they are diverted by magnetic fields produced by coils placed around the tube, then concentrated to form a luminous point on a screen. The concentrated flow of electrons sweeps the surface of the screen line by line from top to bottom, producing more than 25 images per second.



Model of a cathode tube

MHS 2720

Glass, copper, plastic, 20th century

Cathode tube televisions were abandoned in the 21st century in favour of plasma and liquid crystal screens which consume less energy and produce better quality images.

Before the arrival of electronic transistors in the 1950s, radio sets were also equipped with vacuum tubes. Filaments emitted electrons when they were heated to a certain temperature. The tubes provided amplification, resistance or rectification of current.



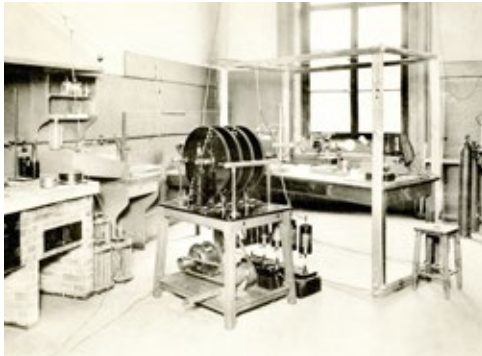
Television cathode ray tube
MHS 2725
Steel, aluminium, glass

Guye's electron canon

A cathode tube to verify Einstein's theory of relativity

Between 1907 and 1915, the Genevan physicist Charles-Eugène Guye (1866-1942) experimentally verified one of the most famous formulae in the history of physics, $E=mc^2$, proposed by Albert Einstein in 1905.

The main thrust of the experiment conducted in the Physics laboratory of the University of Geneva was to produce, then accelerate, electrons in a cathode tube using a high-tension generator. The electrons cross magnetic and electrical fields of variable intensity (regulated by the experimenter) which diverts and projects them onto the end of the glass tube which was covered in a phosphorescent substance. The points of impact of the particles can be seen and photographed. By measuring the deviations of the electrons as well as the strength of the deviation fields, Guye was able to demonstrate that the mass of electrons indeed varies as a function of their speed, thus confirming Einstein's theory. The two tubes used by Guye for his experiments are now preserved in the Musée d'histoire des sciences.



Photograph of Guye's experimental apparatus in the physics laboratory at the University of Geneva, around 1915.

In the foreground is the 8-disc electrostatic machine which supplied the discharge tube. The latter was placed on the table in the centre of the compensation frames which were designed to insulate the apparatus against the earth's magnetic field.

Charles-Eugène Guye, Experimental verification of the Lorentz-Einstein formula, Mémoires de la société de physique et d'histoire naturelle de Genève, vol. 39, fascicule 6, Geneva, 1921.



Cathode tube

MHS 8

Glass, aluminium, brass, Guye, Geneva, 1910

X-rays

A mysterious ray that penetrates matter including the human body

By subjecting discharge tubes to increasingly higher tension, the German physicist Wilhelm Röntgen (1845-1923) discovered in 1895 that, alongside cathode rays, another type of ray is emitted which he called X. He found that X is immune to magnets, is capable of penetrating the human body and of blackening photographic plates. Röntgen produced the first X-ray image of a human hand which was, in fact, that of his wife.

This discovery revolutionised medicine, and society too. Thanks to these rays which penetrate flesh but not bones, it finally became possible to see what is inside the human body without having to open it up. In the 1920s, everyone wanted to have an X-ray picture of their own skeleton. In shoe shops, X-ray machines called pedoscopes allowed sales staff and clients to see the position of feet inside shoes.



X-ray tube

MHS 961

Glass, aluminium, tungsten, Muret, France, late 19th century

Over the years it became evident that high doses or prolonged exposure to X-rays could lead to death. Its use was thus drastically curtailed. Today, over one hundred years after their discovery, X-rays are still widely used in medical imagery and also in security and science.



Pedoscope
MHS 913
Wood, glass, tungsten,
Eberhard, Zurich, 20th century

In search of a vacuum

More efficient pumps to reduce pressure in tubes

Studies on the light effects of electrical discharges would not have been possible without the development of a fundamental piece of equipment: the vacuum pump. At the beginning of the 19th century only hand-operated models were used. They produced a vacuum 1000 times lower than atmospheric pressure which allowed observation of continuous luminous discharges between two electrodes in an electric egg.

When he was designing his tubes, Heinrich Geissler needed to obtain a higher vacuum (1/10000 atmospheric pressure). He therefore made a new vacuum pump which used mercury, the aim being to create a vacuum using a column of mercury, which dropped or rose like a piston in a closed tube linked to the container.

In 1865, the German chemist Hermann Sprengel (1834-1906) designed an even more effective mercury pump and, above all, one that was easier to use. A column of mercury was made to flow from a reservoir through a recipient which communicated with the tube to be purged and a capillary tube. On reaching the capillary tube, the mercury separated into fine drops which drew in air molecules as they fell.

Sprengel's vacuum pump was used extensively by William Crookes for his work on cathode rays. In particular, it helped Joseph Swan (1828-1914) and Thomas Edison (1847-1931) to create vacuum in their new electric bulbs.



Mercury vacuum pump

MHS 575

Wood, glass, Alvergnyat, Paris, around 1880

The electric light bulb

Not much light but a lot of heat!

At the beginning of the 19th century, the English physicist Humphrey Davy (1778-1829) developed the first electric lighting equipment. Using a voltaic pile, he produced a strong electrical current which circulated through two carbon rods heated to incandescence and separated from each other by a few millimetres. On evaporating, the carbon vaporises between the two rods through which the current flows shining very brightly. Electric arc lighting was born! It wasn't until the 1880s, however, that the first electric arc lamps were installed along town streets. In spite of many attempts, the electric arc technique was never adopted for domestic lighting.

In 1879, the American Thomas Edison (1847-1931) and the Englishman Joseph Swan (1828-1914) 'invented' the incandescent light bulb. Within a small glass globe, they enclosed a carbon filament which they brought to incandescence by running electricity through it. As it is resistant to electrical current, the filament heats up and becomes coloured, emitting a very white light. To avoid the filament catching fire, the bulb is nearly entirely emptied of air and, especially, of oxygen.

After a halting start, the incandescent electric light bulb was perfected in the 20th century. At the beginning of the 21st century it was decided that it consumed too much energy and was withdrawn from sale.



Incandescent light bulbs
MHS 1617
*Copper, carbon, glass, 19th
century*

Domestic lighting today

Better light using less energy

Too greedy in energy, producing too much heat and not enough light, incandescent electric light bulbs have served their time. Sales are forbidden in Switzerland and EU (with the exception of a few low-consumption halogen lamps). They have been replaced by more economic lighting and by LED lamps.

Low energy lamps, also referred to as compact fluorescent tubes, are distant relations of Geissler and other discharge tubes invented in the 19th century. They contain rare gases (argon and mercury vapor) through which an electrical current flows. The gases emit ultraviolet light which stimulates the phosphorous layer covering the inside of the tube which then becomes luminescent.

Still being developed technologically, LED (Light-Emitting Diode or electroluminescent diode) lamps are taking over the market. They are made of semiconductor materials that emit light when an electric current is passed through them. They are robust, reliable and economic. They have many advantages except, perhaps, the quality of their luminescence which sometimes lacks visual warmth.



Compact fluorescent tube
Glass, mercury, 20th century

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