HIGH-VOLTAGE EQUIPMENT

uit The Story of the Philips Laboratory at Eindhoven

Introduction

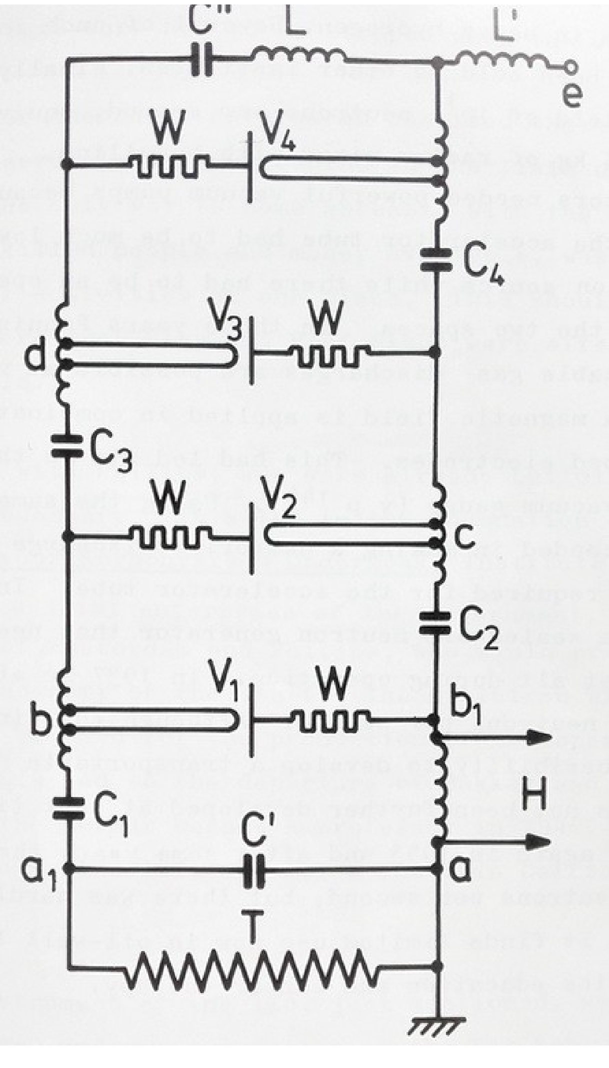
The discovery of the neutron by J. Chadwick in 1932 and of the first artificial radioactive isotopes by I. Joliot-Curie and F. Joliot in 1934 opened a new era in nuclear physics. It was thought that neutrons, having no electric charge, would penetrate more easily into the atomic nuclei than charged particles, which need acceleration to high energy. This proved to be true and led to the discovery of many new nuclear reactions.

At the Nat.Lab. it was especially Bouwers, with his experience on X-ray generators, who thought that Philips could play a role in this field by making apparatus and finding applications for neutrons and artificial isotopes. Holst, however, feared that this would never become an important market, and that nuclear physics would remain an academic science with few industrial applications. Both men were partly right, but the enthusiasm and skill of Bouwers (v Part I , P 229)and his people led to some real successes , This went on after World War Two, when A.C. van Dorsten led the group, then working on particle accelerators, cyclotrons and electron microscopes.

High-voltage generators

In 1932, J.D. Cockroft and E.T.S. Walton of the Cavendish Laboratory, Cambridge, England built their famous 500 kV accelerator-with which they showed that accelerated particles could induce nuclear reactions. Hearing of their results Bouwers expected that many people would soon want similar instruments. His department, the Philips X-ray Laboratory, could make much better generators than that of Cockroft and Walton, which was rather dangerous and unreliable. So he started building a 700 kV generator. The circuit he used proved to be the same as that of the Cavendish people, it was based on voltage multiplication by a cascade of capacitors and rectifiers.

The principle of this circuit had already been mentioned by Greinacher in 1920. As rectifiers he used mercury-vapour oxide-cathode gas discharge tubes. The problem of the heating of the cathodes, which are at high voltage, was solved by A. Kuntke of the Nat.Lab. by introducing a high-frequency current through the circuit (see figure).



Circuit diagram of a high-voltage unit with high-frequency cathode heating, as designed by Kuntke.
The capacitors C1, C2, C3 and C4 and the valves V1, V2, V3 and V4 form the original Greinacher circuit, fed by the transformer T. The cathodes of the valves are heated by a 750 kHz current generated by the transmitter H. This current can pass the capacitors, but the valves are blocked by the resistors W.
With regard to the rf losses of the capacitors, this current is limited to 0.7 A.
Because the valves require 3.5 A, special air-core transformers are used, b,c etc. The rf circuit is closed by the capacitor C' and the resonant combination of C'' with the self-inductance L.

Seeing the advantages of this high-voltage generator, Prof Rutherford of the Cavendish Laboratory in 1936 asked Bouwers to build a 1250 kV generator and some years later he even ordered a 2 MV generator. The latter could not be tested at the Nat.Lab., the 'circus' was not large enough for it, the final tests had to be taken in Cambridge.
The installation of these apparatus was mainly the task of H.P.J. Breeko, who also had to solve many problems in cases of breakdown.

After the war a number of high-voltage generators have been built at Eindhoven for institutes in several countries. It is interesting to note that many customers were former students of Prof. Rutherford.

Neutron Generators

The first source of neutrons was a mixture of radium and beryllium, which produced neutrons by a reaction of alpha particles with beryllium nuclei. Owing to the scarcity of radium, this was a rather expensive way of neutron production.

Cheaper and more powerful sources became possible when it was discovered that several materials emit neutrons when bombarded with deuterons, the nuclei of heavy hydrogen.

For exploring this new field, Holst formed a little group of three men, W. de Groot, F. A. Heyn and C. J. Bakker. Later A. H. W. Aten, a chemist interested in the use of isotopes, joined them.
With the help of Bouwers and Kuntke, Heyn made a neutron generator. As source of deuterons they used a gas discharge in heavy hydrogen. Several of such installations have been sold to other institutes. Finally they attained a yield of 10^{11} neutrons per second, equivalent to a source of 5 kg of radium mixed with beryllium.
These generators needed powerful vacuum pumps because the pressure in the accelerator tube had to be much lower than that in the ion source while there had to be an open connection between the two spaces.
In those years Penning had just found that stable gas discharges are possible at very low pressure if a magnetic field is applied in combination with properly shaped electrodes.
This had led him to the invention of the vacuum gauge. Using the same principle he succeeded in making a deuterium discharge at the low pressure required for the accelerator tube.
In addition he designed a sealed-off neutron generator that needed no vacuum pump at all during operation. In 1937 he attained a yield of 10^6 neutrons per second. Although this invention opened the possibility to develop a transportable neutron source,it has not been further developed at that time. It was taken up again in 1955 and after some years the yield reached 10^8 - 10^{12} neutrons per second, but there was hardly a market for it. It finds limited use now in oil-well logging, nuclear physics education and cancer therapy.

Applications of neutrons

At the Nat Lab one also tried to find applications for the new type of radiation.
They had contacts with the Kaiser Wilhelm Institute in Berlin for biological applications and with the Cancer Institute in Amsterdam for medical applications.

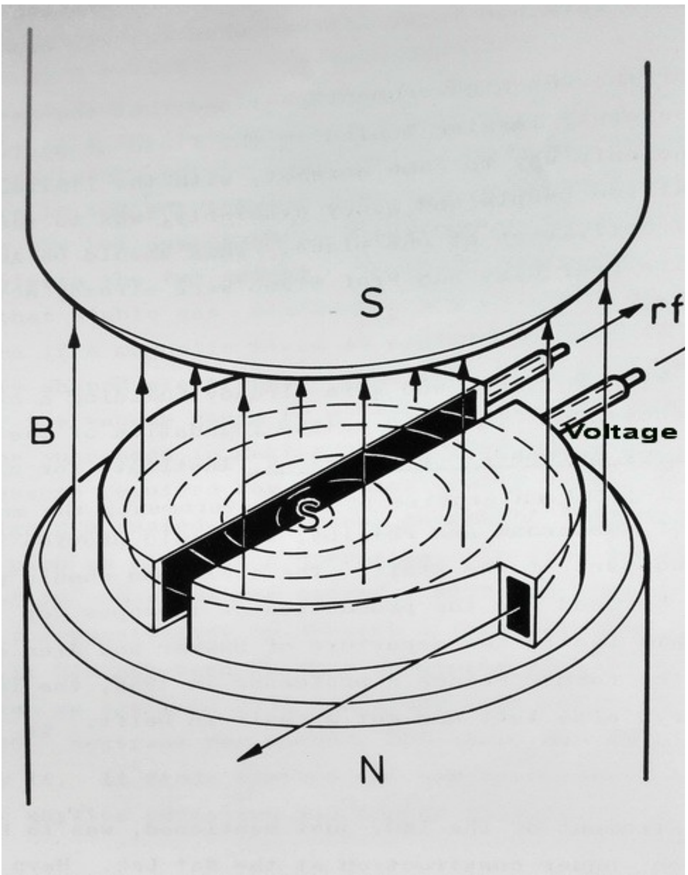
In 1936 Heyn discovered a new nuclear reaction. When copper or zinc are bombarded with neutrons, their nuclei emit two neutrons. This reaction, which occurs with many heavy elements, is now known as the (n,2n) reaction. Very soon after 0. Hahn and L. Meitner discovered the fission of uranium and thorium by means of neutrons in 1938, Heyn, Aten and Bakker studied these reactions and analysed the fission products. This work had to be stopped when the war broke out.

After the war the Dutch government realized that the Netherlands were severely lagging behind in the field of nuclear physics. The only way to come abreast, with the limited amount of skilled people and money available, was to concentrate all activities at one place. This should be Amsterdam, where Prof. Clay and Prof. Sizoo were already active in this field.

Cooperation with Philips, who were already building a cyclotron, was necessary. This led to the foundation of the IKO (Instituut voor Kernphysisch Onderzoek, Institute for nuclear research) as a joint enterprise of the government, the municipal university of Amsterdam and Philips, who would provide the cyclotron and part of the staff. The cyclotron should part of the time be used for the production of isotopes for Philips. This led to the departure of Bakker and Aten to Amsterdam, the former became a professor in 1946, the latter in 1950. Heyn also left and got a chair in Delft.

Cyclotrons

The main instrument of the IKO, just mentioned, was to be the cyclotron under construction at the Nat Lab. Heyn and Bakker had made the plans for it already during the war, but then they aimed at a cyclotron similar to the first one made by 0. Lawrence in 1932 (see figure).
This had a constant frequency and therefore an energy limit of about 10 MeV due to the relativistic increase of the mass of the particles. It suffered also from beam instabilities,which were not understood in those days. In 1946, however, the synchrocyclotron, which has several advantages over the earlier type, was invented in Russia as well as in the USA.



Schematic diagram of a cyclotron showing the pole pieces S and N of the magnet generating the magnetic induction B, the two semicircular metal boxes, or dees D_1 *and D2, the ion source S, the connections to the rf-voltage between the dees and the wind ow at the front side where the accelerated particles leave the cyclotron. The dotted spiral indicates the path of the particles. The particles are accelerated when they pass the gap between the dees. Hence, the period of the rf-voltage should be equal to the time of revolution of the particles. This time is independent of the radius of their orbit as long as relativistic effects can be neglected.*

It can reach higher energies, needs a lower rf-voltage (e.g. 15 kV instead of 100 kV) and shows less beam instability. The main difference with the original cyclotron is a modulation of the radio frequency. Hence Bakker and Heyn changed their design into a synchrocyclotron. Its oscillator frequency was 10.5 MHz modulated with 2 kHz.
For the magnetic field of 1.38 Wb/m2 an amount of 200 tons of magnet steel was needed and 32 tons of copper for the magnet coils. The cyclotron was put officially into use in Amsterdam in 1949. It could accelerate deuterons to an energy of 28 MeV, slightly above expectation.
After this Philips has built several other cyclotrons for various institutes, also in other countries. The Nat.Lab. contributed by a new design, the AVF (azimuthally varying field) cyclotron, based on the study of beam stability.

Reorganization of the X-ray group

The activities described above were continued after Bouwers left the Nat.Lab. in 1941 to become the director of the optical industry 'De Oude Delft'. His successor as leader of the X-ray group was prof Casimir. When Casimir became one of the directors of the Nat.Lab. in 1946, the group was split into two parts. A. C. van Dorsten became head of the high-voltage group and W.J. Oosterkamp of the X-ray group.

Bouwers' group had a special position, separate from the Nat Lab organization. The first task of Casimir was to integrate this group into the Nat Lab· He also modernized the program of the group. So he diminished the research on X-ray generators, where no fundamental improvement was to be expected. He saw the importance of the X-ray image intensifier for X-ray practice and strongly promoted its development, which was carried out in a different group.

<u>Electron Microscopes</u>

The interest in electron microscopy is based on the fact that the De Broglie wavelength of electrons of a reasonable energy is many orders of magnitude smaller than that of light so that an electron microscope allows much higher resolution than an ordinary microscope. X-rays have the same advantage, but for them there exist no lenses. For electrons there are two types of lenses, electrostatic and electromagnetic ones, of which the latter are mostly used.

Research on electron microscopes in The Netherlands started at the Delft Technical University. Prof Dorgelo, formerly at the Nat Lab, was very much interested. When in 1939 one of his students, J. B. Le Poole, proposed to build one, he readily agreed. It was completed in 1941, but since its high-voltage was only 45 k V, it was extremely difficult to prepare such thin specimens that the electrons could penetrate them without energy loss. One clearly needed a higher voltage. Since no-one in Delft could build such a high-voltage supply with the required stability, Prof . Dorgelo went to Bouwers, then already in Delft, who advised him to ask Van Dorsten, formerly an assistant of Dorgelo, but since 1937 at the Nat.Lab. working on high-voltage equipment. Van Dorsten accepted the challenge and built the required unit for 150 kV. Le Poole's second microscope, with this unit, came ready in 1944. It had then to be hidden for the Germans. When the war was over in 1945, it was reassembled. It had some new features, such as a continuously variable magnification, made possible by the introduction of two lenses between objective and projector (see figure). With a resolution of 3 nm it was the best microscope of the world at that time.

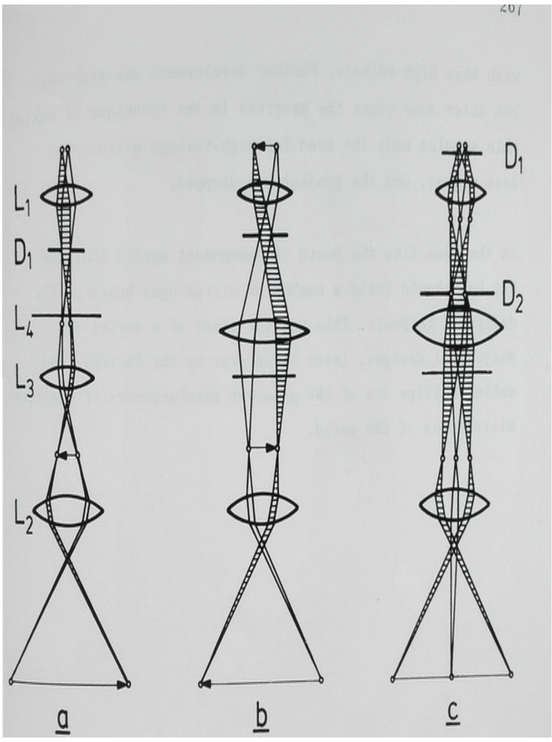


Diagram explaining the three modes of operation of the electron microscope developed during World War Two by Philips and the Technical University of Delft.
L1 is the objective lens, L2 the projector lens, L3 the intermediate lens and L4 the diffraction lens. D1 is the objective diaphragm (not used in c), D2 the diffraction diaphragm used to select that part of the object of which one wants to study the diffraction pattern.

a) For high magnification (6000 to 80.000 times) the intermediate lens is used.
b)For low magnification (1000 to 6000 times)only the diffraction lens is used.
c) For observing the diffraction pattern, the 'primary image' of this pattern, in the focal plane of the objective lens, is magnified and projected on the final screen by the diffraction lens and the projector.

About 1942, this cooperation between the Technical University and the Nat.Lab. had led to the plan of building a 400 kV microscope for the investigation of still thicker samples.

The prototype came ready in Eindhoven in 1946 and aroused much interest because it was the first microscope working with this high voltage. Further development was started, but after some years the progress in the technique of making thin samples made the need for high-voltage microscopes less urgent, and the project was dropped.

In the mean time the Board of Management agreed that the Nat.Lab. should build a number of microscopes based on the design of Le Poole. This was the start of a series of successful designs, later taken over by the factory, and making Philips one of the greatest manufacturers of electron microscopes of the world.