PHILIPS TECHNICAL REVIEW

A publication on Lighting, Electronics, X-Ray and other technical subjects

PHILIPS RESEARCH LABORATORIES

Printed in Holland

Philips Techn. Rev. Vol. 13, No. 1-2, pp. 1-48 July-August 1951

PHILIPS PUBLICATIONS

Philips Technical Review

A monthly publication dealing with technical problems relating to the products, processes and investigations of the Philips Industries. It contains articles on Lighting, Electronics, X-Ray and other technical subjects.
32 pages per issue, size 20½ × 29½ cm.
Published in English, French, German and Dutch.

Philips Research Reports

A publication containing physical, chemical and technical papers in the English and French languages, relating to the theoretical and experimental research work carried out in the various Philips Laboratories. Philips Research Reports are published in volumes of six issues, each of about 80 pages, size 15½ × 23½ cm.

Communication News

A quarterly publication on transmitters, transmitting valves, line telephony, line telegraphy and automatic telephony. 32 pages per issue, size 20½ × 29½ cm. Published only in the English language.

For particulars regarding these publications apply to the publishers mentioned on the back cover of this issue.

VOL. 13 No. 1-2, pp. 1-48 JULY-AUGUST 1951

Philips Technical Review

DEALING WITH TECHNICAL PROBLEMS
RELATING TO THE PRODUCTS, PROCESSES AND INVESTIGATIONS OF
THE PHILIPS INDUSTRIES

EDITED BY THE RESEARCH LABORATORY OF N.V. PHILIPS' GLOEILAMPENFABRIEKEN, EINDHOVEN, NETHERLANDS

PHILIPS' DIAMOND JUBILEE

It was sixty years ago, in the month of May, that the Philips' Lamp Works were established at Eindhoven. The Editors of Philips' Technical Review wish to take part in celebrating this memorable event by issuing this Jubilee Edition. In the 1941 volume of this Journal one might seek in vain for any mention of the commemoration of the 50th year of our Concern's existence. Under the conditions of enemy occupation it had been decided merely to celebrate that event unostentatiously at a meeting of the Management and the executives. Nevertheless that day in May 1941 turned out to be one of boisterous merry-making. Quite unexpectedly the tens of thousands of Philips workers spontaneously downed tools and set out in procession to give vent to their feelings of joy — and to their sense of national pride. Within a few hours almost the entire population of Eindhoven had enthusiastically joined in that demonstration. Although these festivities were abruptly brought to an end by the threat of armed intervention and prohibitions, there are many who regard that May day of 1941 as one of the most memorable days of their lives. Now that, on the occasion of this Diamond Jubilee, liberty and fraternity again reign supreme in our country, there is every inducement for celebration when looking back upon the past, as we shall do in this Jubilee issue. No attempt will be made here to set forth the history of the Philips' concern as a whole; this is to be done in some other way. It has been deemed

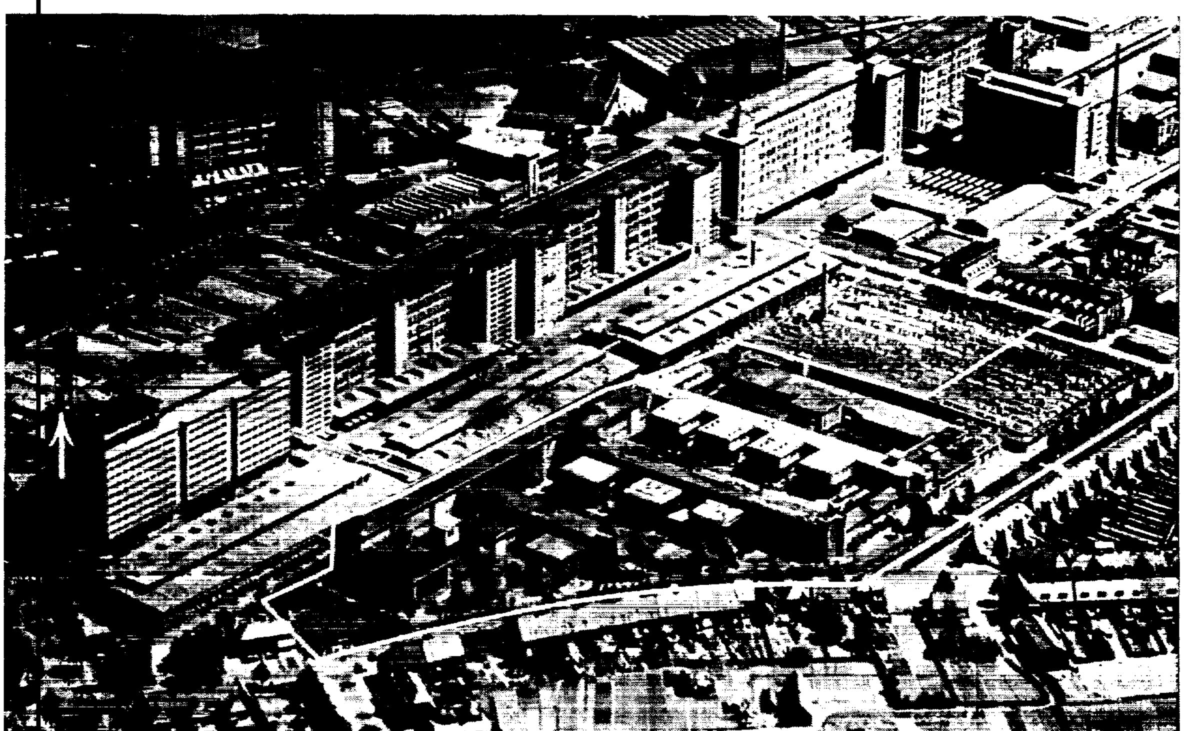
Spontaneous jubilation on the 50th anniversary of the foundation of the Philips' Works.

67060

best to confine the scope of this special issue to some aspects of the research work which, from about 1910 onwards, has been carried out mainly in the Physical Research Laboratory, and to throw light upon the importance of that work for the enterprises of our Concern. Dr. W. de Groot, who has been connected with the laboratory ever since 1923 and thus has been personally associated with the development of this research work for the greater part, having himself furnished valuable contributions towards it, was found prepared to write a review on the lines indicated above. It will not lay any claim to being a complete summing up of all research work carried out — such might well prove to be too dry reading — but rather it is to be regarded as an illustrated story about the laboratory, showing in particular the multifarious nature of the problems dealt with and the often unexpected new possibilities emanating therefrom.

In conclusion, on behalf of the whole of the editorial staff, we extend our sincere congratulations, on this Diamond Jubilee, to Dr. A. F. Philips, one of the two founders of the Concern, and further to the Board of Management and to all who have worked so hard to contribute towards the growth and prosperity of Philips Industries.

THE EDITORS



67084

Aerial photograph of part of the Strijp quarter of the Philips' Works at Eindhoven. The Physical Research Laboratory is outlined. On the extreme left, above the arrow, the tower with television aerial.

SCIENTIFIC RESEARCH OF PHILIPS' INDUSTRIES FROM 1891 TO 1951

INTRODUCTION

With the invention, at the beginning of the nineteenth century, of the voltaic pile and the galvanic battery, providing a source of current with an almost unlimited voltage and a relatively small internal resistance, in principle also the possibility of electric light was created. In 1808 *Davy* succeeded in passing current through air between two carbon rods of a few millimetres diameter. The tips of the carbons and the gas discharge radiated a bright light. Upon the carbon tips being spaced a couple of centimetres apart, owing to convection the discharge assumed the shape of an arc (an inverted U), which name came to be used to describe all gas discharges with a high current density and with a thermionic cathode.

In a certain sense the carbon arc is the precursor of modern discharge lamps and, in so far as the light originates from the glowing carbon tips, also of the incandescent lamp. A second forerunner of the incandescent lamp is the platinum wire brought to incandescence by an electric current, an experiment which was also carried out by *Davy* (1802). Carbon-arc lamps were known about 1850 and, as was subsequently disclosed in the famous law-suit between *Edison* and *Goebel* (1893), also electric incandescent lamps had already been made at that time. These sources of light were fed from galvanic batteries. It was not, however, until the invention of the dynamo (*Siemens* 1866, *Gramme* 1869) that electric light came to be introduced on any large scale. In 1879, on the one hand the differential-arc lamp of *Von Hefner-Alteneck* made its appearance and, on the other hand, *Edison's* carbon-filament lamp, which was demonstrated at the Paris exhibition of 1881, together with the machines for generating the current and the means of distributing it. That exhibition aroused interest everywhere, and it was shortly after this that *E. Rathenau* founded the A.E.G. in Germany.

All this greatly interested the young Dutchman Gerard Leonard Frederik Philips, born 9th October 1858 at Zaltbommel, who was studying at the Polytechnical School (now the Technical University) at Delft, where he graduated as an engineer in 1883. Shortly after that he was given the opportunity to install electric lighting in some ships at Glasgow, and there he made the acquaintance of *William Thomson (Lord Kelvin)*, who was likewise greatly interested in electric light. Later on he conducted negotations for *Rathenau* in Berlin between the A.E.G. and the municipality of Amsterdam about an electric-lighting project, but these negotiations broke down on account of the high price per kWh (fl. 0.60) asked for by the A.E.G.

In 1890, when 6800 arc lamps and 118,000 incandescent lamps were already burning in Paris, four electric power stations in Berlin were supplying current to some 3000 arc lamps and 70,000 incandescent lamps, and in London a generating station was being built for feeding 600,000 lamps of 10 candle power, whilst in the U.S.A. 23,500 arc lamps and 2,800,000 incandescent lamps had already been installed, Ir. Philips conceived the idea of starting a new incandescent-lamp factory in the Netherlands, where others had already been established, among which were the *Pope* and the *De Kothinski* works. This plan materialised in the month of May 1891 with the opening of the factory at Eindhoven. In the course of time G.L.F. Philips and his younger brother Anton Frederik Philips, who joined the firm in 1895, turned this small factory, with a starting capital of 75,000 guilders, into a world-wide concern, the parallel of which is but scarcely found.

It is not the intention to enter here into the history of this concern, for this will be found in a book which is to be published shortly. Instead of that, a review will be given of the development of the scientific research, both in the pure and in the applied sciences, of the Philips Industries and in particular that which has been carried out in the Physical Research Laboratory founded in 1914.

The first research work connected with the Philips business was carried out by Gerard Philips himself. For some time before the factory was started he was studying the preparation of the carbon filament and various other processes in a primitive workshop at home. In November 1890, when writing to one of the many people with whom he was negotiating for the establishing of the new factory, Ir. Philips wrote: "I am able to produce perfectly homogeneous cellulose filaments on a business scale". Considering, however, what the management of a rapidly growing young industry involved, and bearing in mind that up to 1895 both the commer-

Ir. G. L. F. Philips engaged with his first experiments for the manufacture of carbon filaments from cellulose (1890).

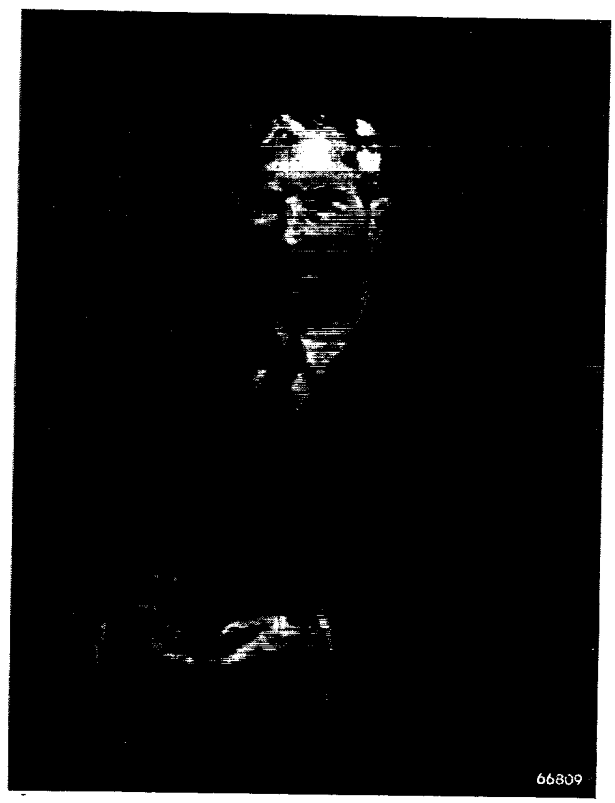
cial side of the business and the management of the works were in the hands of one man, obviously this research work was at first limited to what was absolutely essential. Technical and scientific help soon became necessary, especially when from 1903 onwards new materials, such as osmium, tantalum and tungsten, the last of which was destined to be the filament material of the future, came to be used in the manufacture of incandescent lamps. About 1907, at the time that incandescent lamps began to be made with squirted tungsten wire, P. N. L. Staal, A. de Brockert and H. Gooskens*) joined the firm as Gerard Philips's assistants, these being followed, respectively in 1908 and 1909, by the chemical engineers J.C. Lokker and A. de Graaff, and shortly afterwards by the mechanical engineers H. de Jong, H. Reufel and W. Koning.

In December 1911 the brittle squirted wire was successfully replaced by the more rigid drawn wire.

Thus a technical staff of some size was formed, comprising people trained in mechanics and in chemistry, but it was not long before also the need of physicists began to be felt when, in 1913, a new development was announced in the lamp-making world, in the form of the gas-filled lamp.

In the General Electric Company's laboratory at Schenectady (U.S.A.), where *Edison*'s work was carried on and physicists were available, in 1909 *Coolidge* had found an entirely new method for drawing strong, thin wires of tungsten. There soon followed, in 1913, in the same laboratory, *I. Langmuir's* invention whereby a coiled filament could be brought to incandescence in an inert-gas atmosphere, thereby counteracting vaporization of the tungsten and thus making it possible to heat the filament to a higher temperature, so that the luminous output of the lamps could be greatly increased. Within a very short space of time a number of other inventions followed from the same laboratory, such as X-ray tubes with heated cathode and gas-filled rectifying tubes.

In November 1913 also Philips brought gas-filled tungsten lamps on the market, under the name of "half-watt lamps". In the manufacture of these lamps and also, for instance, in their photometry so many problems arose which lay more in the domain of physics than in that of chemistry or mechanics that Ir. Philips decided to engage a physicist. Thus on 2nd January 1914 G. Holst joined the firm in that capacity, and this was the beginning of the



Prof. Dr. G. Holst, after a painting by *S. Schröder*.

*) In this review the names of people connected with the Philips Concern are spaced out, while those of others are printed in italics.

foundation of a physical laboratory. Some months later E. Oosterhuis joined the staff of this laboratory as second physicist.

It will be shown how the work of the laboratory established in 1914, starting with the problems of the manufacture of incandescent lamps, has expanded into such a multifarious programme, from which such a wide variety of other products have been born. In this growth three main periods are to be distinguished:

1) 1914-1923, the period which saw the first world war and during which the laboratory was located in a part of the lamp factory;

2) 1923-1940, beginning with the opening of a new laboratory specially equipped for the purpose (in 1929 it was considerably enlarged) and ending with the occupation of the Netherlands by enemy forces in the second world war;

3) 1940 up to the present day, covering the years of occupation and the revival of activity after the country's liberation.

Dr. E. Oosterhuis, after a painting by *S. Schröder.*

THE LABORATORY OF 1914 - 1923

After studying at the Technical University at Zürich — where he took his doctor's degree in 1914 — Dr. Holst worked for a number of years in the laboratory of *H. Kamerlingh Onnes* at Leyden, where, inter alia, he took an active part in the discovery of superconductivity. Thus, in addition to his bent for purely scientific work, Dr. Holst was also technically interested in taking up his new appointment with the Philips' laboratory. Although it was considered as his main task to study the physical questions arising in the manufacture of the tungsten lamp, it was felt at the same time that it should not be left at that, but that it was necessary to penetrate to the very roots of the phenomena to be studied. From the tackling of subjects on such a wider basis physical science was primarily benefited, but then this in turn bore fruit for technical science, often in a surprising manner, in the form of improvements of existing products and the opening up of new fields of activity.

The study of the tungsten lamp was therefore the starting point: first the behaviour of tungsten wire in the processing, and further its behaviour upon being heated by an electric current to a high temperature in a glass bulb either in vacuo or in the atmosphere of an inert gas; the current had to be passed into the bulb via vacuum-tight and fused-in wires.

Owing to the extensive programme of work the staff soon had to be enlarged. Dr. Holst received successively the assistance of P. G. Cath, S. Weber, C. Bol, H. C. Burger, G. Hertz, Balth. van der Pol, A. Bouwers, A. E. van Arkel, W. Geiss, J. H. de Boer, P. Clausing, R. Vermeulen, W. de Groot, C. Zwikker and others, whilst contributions towards this research were likewise furnished by L. Hamburger, D. Lely and J. A. M. van Liempt, who belonged to the chemical staff of the works.

As regards the physical problems directly related to the incandescent lamp, first of all there was the photometry to be studied, particularly of the gas-filled lamps, since their luminous flux is distributed in space in a less surveyable manner than that of vacuum lamps with a linear filament. In a series of "Communications of the Philips' Laboratory" (1918-1919), which in a sense may be regarded as the forerunners of this journal, conceptions in the field of illumination were explained and the basic elements of utility lighting, fittings, projectors, car lamps, sunlight lamps, etc. were dealt with.

Of a more fundamental nature was the investigation of radiation, such as the spectral energy distribution of incandescent lamps. At that time *Planck's* formula was still regarded with some scepticism and there was no thought of an "international relative luminosity curve" or an "international temperature scale". Much doubt existed as to the constant c_2 in *Planck's* formula, which it was important to know in connection with optical pyrometry.

Owing to the gradual decline in the luminous intensity of the incandescent lamps, and particularly of the vacuum lamps, due to precipitation of tungsten on the inside of the bulb, a matter which will be reverted to in the next section of this review, the study of such thin layers of metal and of the chemical processes taking place in residual gases was taken in hand (Hamburger).

In connection with the filament problems, the electrical conductivity and the thermal conductivity of graphite and tungsten were investigated, as also, in connection with the gas filling, the thermal conductivity of gases and the vaporization of tungsten in a gaseous atmosphere (Weber). Further, following upon the investigations which Holst had himself carried out and had seen conducted by others in the cryogenic laboratory at Leyden, extensive tests were made with the argon-nitrogen system, the mixture of gas used for filling the half-watt lamps.

As far as the metallurgy of tungsten is concerned, with the aid of the then new methods of X-ray spectroscopy and X-ray diffraction a start was made with the study of the structure of tungsten and other metals (Burger, Van Arkel), of the physical (e.g. elastic) properties of tungsten (Geiss) and of the chemistry of tungsten compounds (Van Liempt and others).

Of importance, for its future consequences, was the investigation of electrical conductivity in gases and their emission of light when an electric current is passed through them. This came about as a result of the method applied in the factory for testing the degree of evacuation in vacuum lamps and the purity of the gas in gas-filled lamps with the aid of a *Tesla* discharge (spark test). Another, no less important, reason for this investigation being started was the occurrence of electrical breakdown between the extremities of the filament in gas-filled lamps, both when the lamps were burning and when the filament was broken.

To combat this breakdown it was necessary to make a thorough study of the passage of electricity through gases. The investigation of gas-discharge phenomena, already studied by *Faraday* and more intensively by *Plücker, Hittorf, Crookes, H. Hertz, Lenard, J. J. Thomson, Townsend* and others, reached a new stage when it appeared that these phenomena could be related to *Bohr's* new theory of the atom (1913). This theory, just as was the case with *Planck's* quantum theory, was at first received with a certain reserve. Moreover, the outbreak of the 1914-1918 war held back more or less the propagation of *Bohr's* ideas. Of importance for the laboratory in this connection were the lectures given in Eindhoven by *P. Ehrenfest*, since 1912 professor in theoretical physics at the Leyden University and a keen advocate for the ideas held by *Bohr*, whilst in 1920 the laboratory staff was supplemented by G. Hertz, who in 1914, together with *J. Franck*, had established the relationship between *Bohr's* theory and the phenomena of electric conductance in gases, for which, in 1926, they were both awarded the Nobel prize. Hertz's investigations will be discussed in the next section.

The most important result of the investigation of gas discharges in the period 1914-1923 was the deeper insight thereby gained into the phenomena of electrical breakdown, in particular at low pressure, in rare gases between plane, parallel, cold metallic electrodes, and the deeper knowledge gained of the transition from the non-self-sustained to the self-sustained discharge (Holst, Oosterhuis). One of the facts thereby established was that the production of electrons in the glow is due to the action of the positive ions upon the cathode and not, as *Townsend* imagined it to be, as a result of direct ionization of the gas by the positive ions.

The first practical outcome of the investigation into gas discharges was the appearance in this period of the neon glow lamp (1917) and the tungsten arc lamp with neon-filling (1920).

The investigation of rare gases was facilitated by the fact that since 1916 the Philips' works had been making (under the guidance of H. Filippo) their own liquid oxygen and nitrogen, from which the rare gases could be distilled.

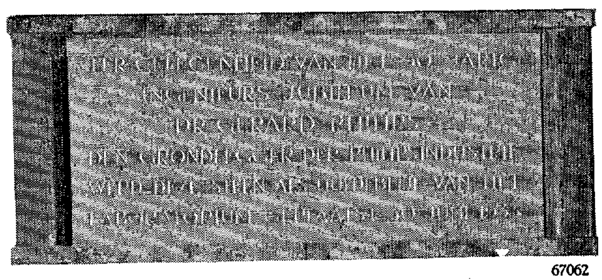
Since during the war the importation of X-ray tubes was stopped medical practitioners in the Netherlands sent their tubes to the Philips' works for repair. Thus interest also came to be taken in these tubes, not only in respect to the gas-filled tubes that were then being used but also in the new Coolidge vacuum X-ray tube with a heated tungsten filament as electron source.

The study of the manner in which the metal leads could be passed through the glass of the lamp bulb led to the production of ferrochromium alloys which have about the same coefficient of thermal expansion as that of glass and which can be fused onto glass. Prior to this, the leads were of platinum wire, later of iron wire coated with copper; for other glass-metal joints pure copper was used, which differs in expansion from glass but owing to its softness changes shape while cooling. With the new alloys (Bol, Bouwers, B. Jonas) there was no need to make allowance for any deformation during cooling, so that the leads and connections could be made much stronger and fusing-in was no longer confined to thin-walled tubes. This led to the construction of metal transmitting tubes and metal X-ray tubes. In connection therewith it was of importance that in 1916 Philips had started a glass works of their own (P. J. Schoonenberg).

In 1883 *Edison* had discovered that an electric current flowed through the vacuum between the poles of the filament in his incandescent lamps, a fact which we now know to be caused by electron emission. Following upon *Richardson*'s investigation of electron emission, in 1904 *Fleming* had invented the diode and in 1907 *Lee de Forest* had made the first triodes by adding a grid. Simple receiving triodes were produced by Philips in 1917, these being followed by transmitting triodes and diodes for rectifying alternating currents. Soon a systematic study of the phenomena in the radio valve was started. In 1922 Balth. van der Pol (a former pupil of *H. A. Lorentz*) was charged with radio research*).

In connection with the manufacture of radio valves, whereby use was made of the electron-emitting properties of tungsten, further investigations were carried out with a view to finding materials which could replace tungsten and give a greater emission for a smaller filament power. In 1921, as a result of new ideas about the theory of atoms, *Coster* and *Hevesy* discovered the element hafnium, related to zirconium. Great expectations were held about the thermionic emission of this element, and the preparation and study of this new material was energetically taken in hand in the Philips' laboratory. Though this did not culminate in the important results that were expected of it, the chemical and metallurgical experience thereby gained was useful in many respects.

The ever-increasing amount of research work to be carried out demanded more space, so that in 1922 it was decided to build a new laboratory, which was completed and taken into use in 1923.



67062

Memorial tablet in the hall of the Research Laboratory presented to Ir. G. L. F. Philips on the occasion of his 50th anniversary as Engineer in 1933.

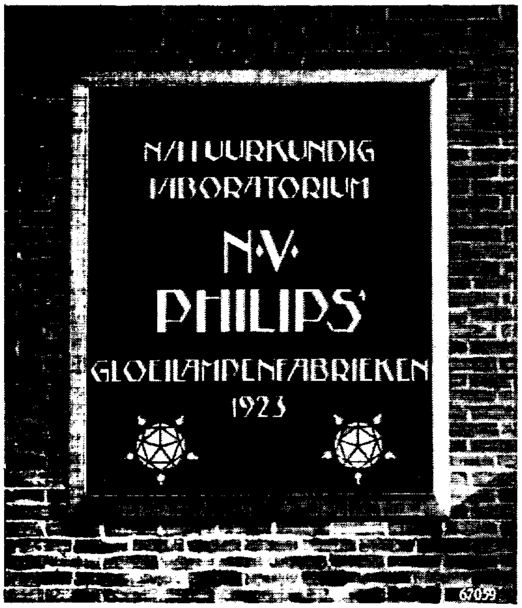
On 1st April 1922 Dr. Ir. G. Philips, who during the first world war had had the honorary degree of doctor in the technical sciences conferred upon him at Delft, resigned his co-directorship at the age of 63. He died at The Hague on 26th January 1942.

THE NEW LABORATORY 1923 - 1940

The new laboratory, situated in a part of Eindhoven which in 1923 was still on the outskirts of the town, was taken into occupation in November that year by a staff of 15 graduated physicists, chemists and engineers with about 20 assistants, instrument-makers, glass-blowers, etc. By 1939 there were 106 scientists and 360 assistants. The number of publications issued by the laboratory in the period 1914-1923 was about 150 and in the period 1923 - 1940 about 1500. A review of research done in this latter period must therefore be limited to the main lines and some outstanding points.

The work begun in the old laboratory was continued in the new under more favourable circumstances. With the larger space available and the increase of staff there was more opportunity for deeper and more far-reaching investigations. It should be mentioned that Dr. Holst always left his scientific staff a high degree of freedom.

*) Since 1949 Prof. Dr. Balth. van der Pol has been Director of the Comité Consultatif International des Radiocommunications at Geneva.



It is impossible, in this short survey, to give a proper account of the various ways in which Dr. Holst stimulated his many co-workers. The few places where Holst is explicitly named here, certainly give an imperfect impression in this respect. The same applies to Dr. Oosterhuis, who (until 1946) held the position of Vice-Director and supervised a team of workers engaged in practical radio research.

Of course research work was still bound to a certain extent to the factories and their production. The laboratory was expected not only to evolve new ideas leading to new products or to the improvement of existing ones — ideas which were suitable for patenting — but these ideas had also to be brought to fruition for manufacture. Further, a certain amount of service was called for, such as the calibrating of measuring instruments, examination and testing of materials, etc. Thus, side by side with the purely scientific work, more and more work of a different nature had to be done. This is the reason why the number of publications issued year by year did not grow in proportion to the growth of the staff.

For a better comprehension of the vastness of the laboratory work this has been divided into five main groups, viz:

I. Light and the production of light, including gas discharges.

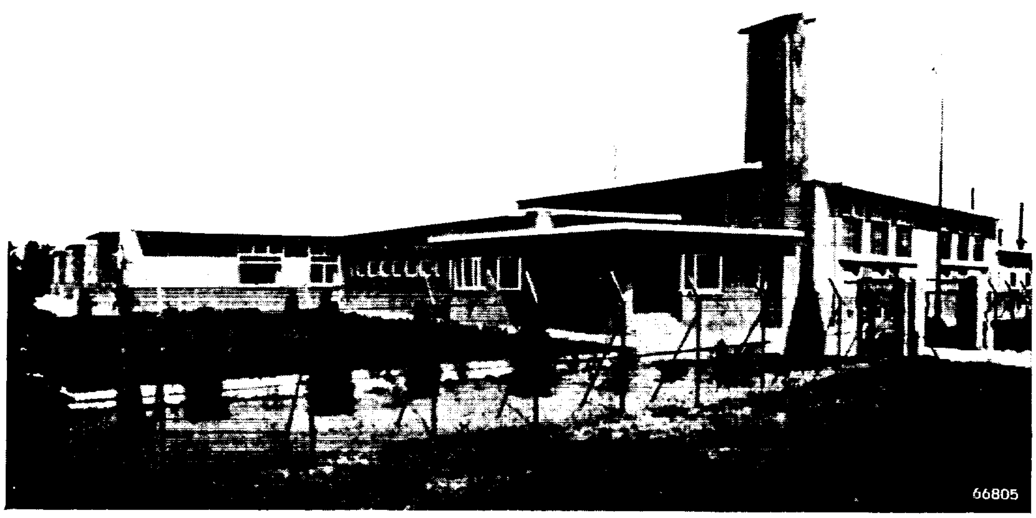
II. Electrotechnics and radio, including acoustics.

III. Chemistry, including metallurgy.

IV. X-ray investigations.

V. Mathematics and mathematical physics.

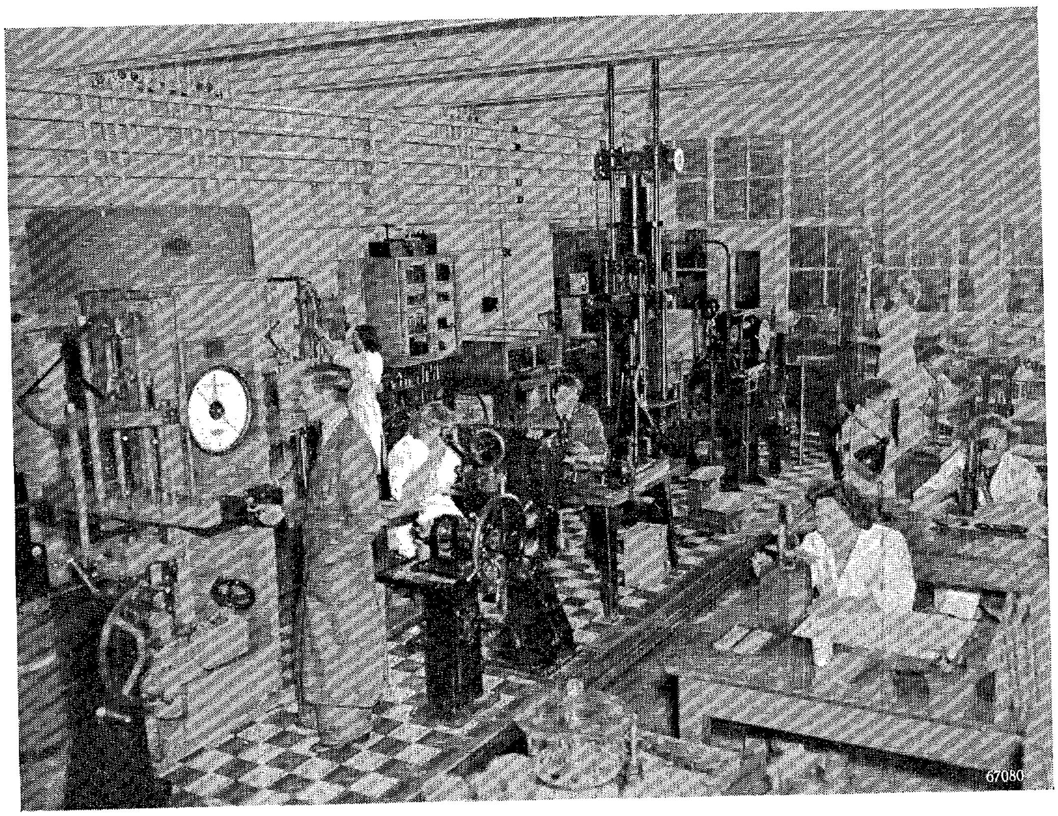
These main divisions have to be taken broadly, and furthermore there are important connections between them. The X-ray examination of crystals, for instance, forms a link between the groups III and IV, the examination of magnetic materials links up groups II and III, whilst the problems coming under the heading V mostly arise from other groups, especially from group II.



The Physical Research Laboratory in 1923.

I. Light and gas discharges

Investigations in connection with incandescent lamps, as far as the new laboratory is concerned, were more or less terminated about 1925 by Zwikker's thesis on the physical properties of tungsten as functions of temperature, which work can be placed side by side with similar work in the U.S.A. In the lamp factory, where a physico-chemical laboratory continued to be maintained, for many years much important work was done by Van Liempt, Geiss and others in the field of the chemistry of tungsten compounds and the metallurgy of tungsten.



Department for testing materials used in the Philips' Works.

The investigation of gas discharges, which had been begun by Holst, Oosterhuis and Hertz in the old laboratory, was continued in the new one on a wider scale. Hertz had worked out methods for accurately measuring excitation and ionization potentials, mainly of rare gases, and established a relationship between these quantities and the spectrum (term diagram). The resonance lines of all rare gases were photographed with the vacuum spectograph and their wavelengths accurately determined. Furthermore, following up the investigations of Holst and Oosterhuis, the low-tension arc was investigated, when it appeared that an arc discharge can take place in a rare gas when there is a potential difference between anode and cathode lower than the lowest excitation potential. Other investigations concerned the negative glow discharge, especially the heating of the anode when electrons enter it, and the thermal effects arising at the electrodes of the tungsten arc lamp. Important work was by done by F. M. Penning in regard to electrical oscillations in a D.C. discharge in mercury vapour of low pressure; in deviation from *Langmuir's* findings (1925) it was proved that abnormal velocities of electrons in such a discharge are due to the said oscillations.

For Hertz's experiments an equipotential cathode was used which had been coated with barium oxide, obtained by oxidation of barium applied to the cathode in the form of an azide and then thermally decomposed. The experience gained with these oxide-coated cathodes was of direct use for the manufacture of radio valves. Tungsten as electron-emitting substance was very soon replaced by materials (dull-emitters) which already give adequate thermionic emission at a lower temperatue.

Oxide-coated cathodes soon came to be used also for rectifying tubes filled with argon and mercury and for gas-discharge lamps (mercury lamps, neon tubes).

The study of the spectra of rare gases had revealed that the atoms of these gases, namely of argon and neon, may be in an excited state which cannot be transformed into the ground state by radiation, such a state being called a metastable state. After the departure of Hertz in 1925, H. B. Dorgelo, who in collaboration with *Burger* and *Ornstein* had been studying in Utrecht the intensity rules for multiplets in spectra, which study was continued in Eindhoven, took up the study of metastable atoms. These atoms are capable of absorbing and re-emitting certain spectral lines which the normal gas allows to pass through unhindered. With the aid of this absorption the lifetime of metastable atoms was investigated with respect to the influence of temperature and gas pressure.

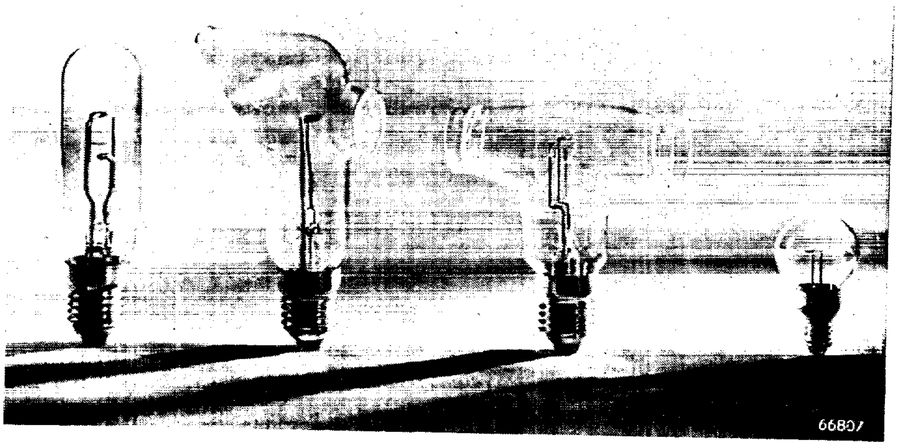
Owing to their energy of excitation, in a gas mixture metastable atoms of one atomic kind (say neon) may ionize other atoms (say of argon), such being possible under the condition that the ionization potential of the second gas is lower than the potential corresponding to the metastable levels of the first gas. In such gas mixtures various factors, such as the breakdown voltage, are greatly influenced by small amounts of the readily ionizable component.

This was further investigated by Penning. The fact that the lowering of the breakdown voltage is due to the action of metastable atoms was proved by demonstrating that the breakdown voltage of neon, lowered by the addition of argon, rose again when the neon was irradiated with light which is absorbed by the mestastable atoms, as a consequence of which these atoms, while emitting resonance radiation, show a transition to a non-metastable state and then to the ground state. It was also found possible by this means to raise the voltage drop of a positive column in a mixture of neon and argon by irradiation with neon light, and even to quench the discharge if the voltage applied is low enough.

The effect of the ionization through metastable atoms is also apparent when investigating the breakdown voltage V_s between plane parallel plates as a function of the product p_0d (p_0 = pressure reduced to 0 °C, d = distance between electrodes), thus determining the *Paschen* curve. Instead of just one minimum (optimum ratio of ionization and excitation) this curve then shows two minima, owing to an increase of metastable atoms and thus the formation of "secondary" ions accompanying increased excitation.

Another anomaly of the *Paschen* curve occurs at values of $p_0d < (p_0d)_{min}$. Normally V_s increases monotonically with decreasing p_0d, or, what amounts to the same thing, p_0d decreases monotonically with increasing V_s. In the case of helium it is remarkable that p_0d as a function of V_s shows a minimum and a maximum, so that in a certain range of p_0d values three critical values of the potential are found, V_1, V_2 and V_3. Breakdown only takes place if the applied voltage V_a answers to $V_1 < V_a < V_2$ or $V_a < V_3$. The same anomaly is found when in the case of stronger currents the voltage is investigated as a function of the current.

The study of the relation between the current i and the voltage V in discharges, as described above, led also to interesting data being collected in regard to the stability of gas discharges, a subject which



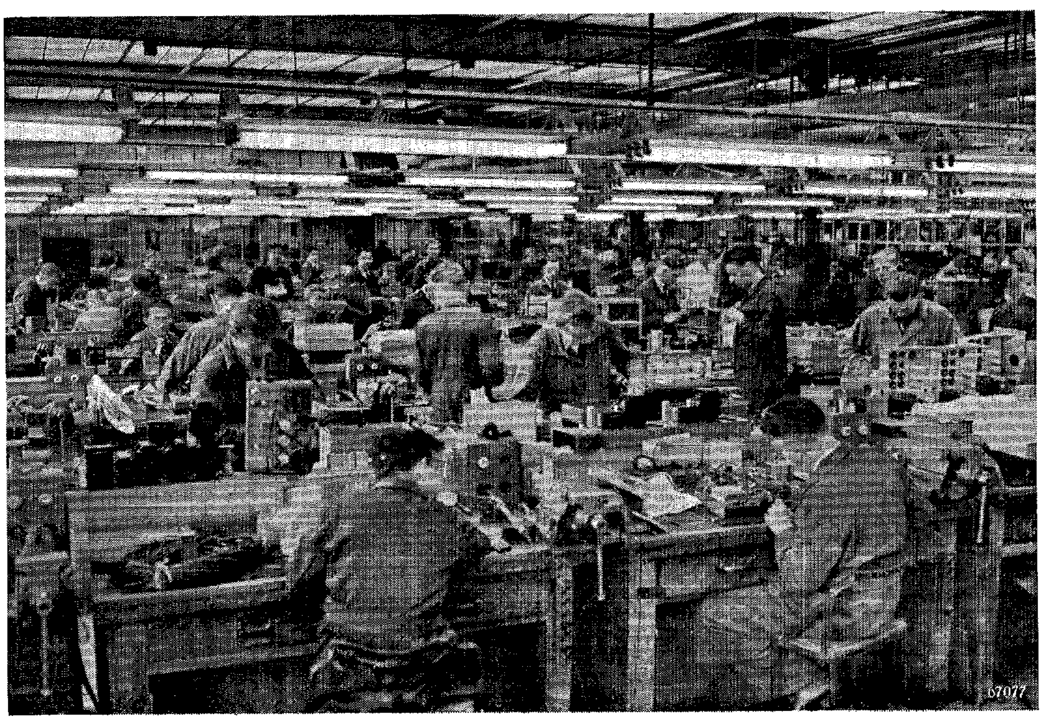
Tungsten-ribbon lamps made in the laboratory to serve as light sources for various optical methods of measuring. The second lamp from the left has been so shaped that the light reflected by the bulb does not pass through the (plane-parallel ground) window and thus does not interfere with the measurement. The third lamp from the left has two flat windows placed somewhat obliquely, this being useful for optical pyrometry.

was further investigated later in the Laboratory for Technical Physics at Delft University by Prof. *H. B. Dorgelo*, *Chr. van Geel* and *C. Verhagen*.

Finally there were interesting investigations into the influence of magnetic fields upon discharges. Apart from the fact that the discharge as such forms a "current conductor" which in the magnetic field is subject to a force perpendicular to the current and to the magnetic lines of force, there is the influence of the magnetic field upon the paths of the individual electrons. The latter is particularly manifested at low pressures, where the electrons have a long free path. Following upon Penning's investigations into this field a vacuum meter was constructed in which the current in a gas placed in a magnetic field serves as a measure for the pressure. With this meter direct readings can be taken of pressures between 10^{-5} and 10^{-3} mm Hg and, for example, the improvement of the vacuum in pumping installations (such as in the case of the electron microscope and the cyclotron) can be followed from one minute to the next.

We must now consider the development of gas-discharge lamps. In 1923, following *Claude's* example (1910), the manufacture of neon tubes for advertising purposes was begun. These tubes had (cold) iron electrodes. Instead of neon, which gives a typical red light, other rare gases, such as helium, were used and also mixtures of a rare gas and mercury vapour. The colours could be given more variation by using coloured glass for the tubes. Later on, also fluorescent glass was used and fluorescent powders were applied to the inside of the tubes so as to produce new colour effects. With the introduction of the oxide-coated cathode, already applied for rectifying valves, it was possible to make neon tubes for stronger currents and a lower voltage, which came to be used as beacon lights for airfields and as light sources for special purposes (irradiation of plants).

Scientific research kept pace with this development. As is known, in the case of a discharge in an elongated tube *Faraday* had already distinguished a cathodic part (glow discharge) and an anodic part (positive column), the two being separated by „*Faraday*'s dark space". It is the positive column that produces the light in neon tubes, the glow discharge at the cathode being of no importance in this respect. The positive column was thoroughly investigated, theoretically as well as empirically, by M. J. Druyvesteyn, after *Schottky* had yielded an important contribution to the theory of this discharge. An important concept is that of the electron temperature, which characterizes the velocity distribution of the electrons in the column and can be measured with the well-known probe method of *Langmuir*. Druyvesteyn was able to deduce that in the absence of cumulative processes the electron temperature is, to a first approximation, proportional to the ionization potential of the gas.



Central workshop of the Physical Research Laboratory.

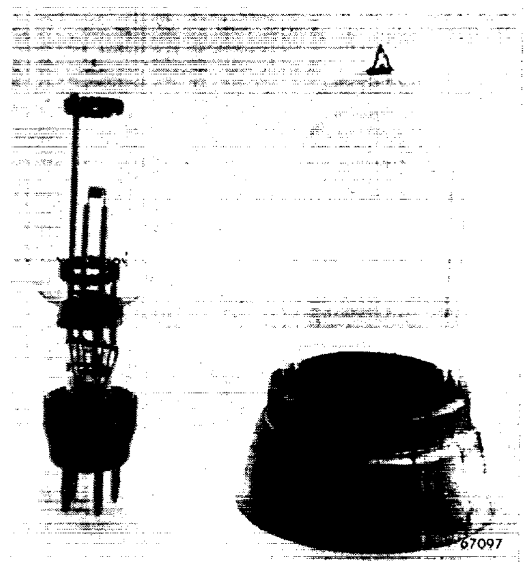
Among the discharge lamps with a filling of rare gas and metallic vapour the sodium lamps occupy a special place. It is well worth while outlining the development of the sodium lamp in the Philips' laboratory. Discharges in sodium vapour had already been investigated and used. In 1919, for instance, such a discharge was described by *R. J. Strutt* (*Lord Rayleigh*'s son). In 1923 *A. H. Compton* and *Van Voorhis* (Westinghouse) investigated a large number of gases and vapours for their ability of producing light and thereby found also the high light-yielding capacity of sodium vapour. They even patented a special kind of glass resistant to sodium, but this did not lead to any useful lamp being developed.

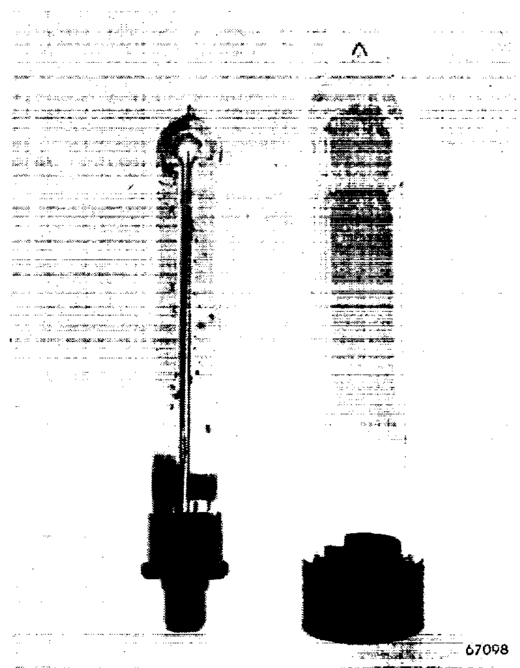
In 1925 *G. Hertz* demonstrated in the laboratory a low-tension arc in sodium vapour in a bulb of about 7 cm diameter. The bulb was fitted with an oxide-coated cathode and an anode, and the sodium was introduced into the bulb by electrolysis through the glass wall, with the cathode acting as negative pole and a bath of molten $NaNO_3$ as positive pole (*Warburg*'s method, 1890). This lamp was placed in a furnace with a temperature of about 250 °C in order to maintain a sufficiently high vapour pressure of the sodium.

Attention was again drawn to sodium as a source of light when G. Zecher set out to improve, in the Philips' laboratory, the yield and the colour of the light of neon tubes by introducing a small amount of lithium into the tube. This was an obvious means, since from the works of *Kirchhoff* and *Bunsen* it had become known that lithium gives a flame a bright red colour. However, something quite unexpected happened: the lithium attacked the wall of the tube and thereby released sodium, so that a sodium lamp was formed unintentionally. This lamp and a number of similar tubes, in which sodium was purposely added to a rare gas, have been used as polarimeter lamps in the laboratory for a number of years.

Meanwhile investigations conducted by *Pirani* in the Osram works had shown that under favourable conditions more than 95% of the energy absorbed by the column could be converted into sodium light, and the Osram works also brought a polarimeter lamp on the market.

At that time the investigations carried out in Philips' laboratory had turned in another direction. The use of the mercury lamp as a source of light for medical ray treatment had led to a closer study being made of the connection between vitamin D and rachitis. It appeared that vitamin D could be produced by irradiating ergosterine with light of a wavelength between 2800 and 2900 Å, which could be produced by a mercury lamp or a magnesium spark. This complexity of phenomena was investigated by E. H. Reerink and A. van Wijk. The demand arose for a special source of light for the production of vitamin D and for anti-rachitic ray treatment. Magnesium proved to be the most suitable element for this. This led to the construction of a low-tension arc lamp with a mixture of rare gas and magnesium vapour; the magnesium





An old sodium lamp (for direct current) and a lamp for connection (via a choke) to 220 V alternating current, each with its vacuum envelope. The D.C. lamps, in groups of 30 to 40 connected in series and fed from a rectifier, were used for the first installations for road lighting with sodium lamps (1932).

was contained in the anode and evaporated into the discharge.

This opened the way to the construction of other metallic-vapour lamps by the same means. In connection therewith, for instance, sodium was investigated anew and this led to the production of a low-tension arc lamp fed with direct current and filled with a mixture of neon and sodium vapour, which has a favourable luminous efficiency (50-60 lumens per watt) (De Groot and E. G. Dorgelo). In order to give the sodium sufficient vapour pressure the bulb was thermally insulated by placing it inside another, evacuated, bulb. Experimental lighting systems installed in a corridor in the laboratory and later on in one of the roadways on the factory site soon demonstrated the excellent qualities of sodium light for road-lighting purposes. After the construction of the lamp had been improved and it had been given the form of a single bulb contained in a *Dewar* flask, these experiments were continued on a more extensive scale, inter alia in cooperation with Prof. Dr. *H. C. J. H. Gelissen*, on stretches of road forming part of the Dutch network of highways (1932). Meanwhile Druyvesteyn and W. Uyterhoeven had been further investigating the positive column in mixtures of sodium and rare gas, whereby it was found that this discharge, in a tube placed in a *Dewar* flask, is less susceptible to changes in the ambient temperature than the low-tension arc lamp. It is to the merit of Bol, who had also given the low-tension arc lamp a shape suitable for manufacture, that the A.C. column lamp with vacuum envelope was developed into a practical unit which for the greater part can be manufactured mechanically, also as far as the glass envelope is concerned. The discharge tube proper has the shape of an elongated U. By 1940 more than 100,000 of these lamps had been installed. Abroad too, where similar lamps had likewise been developed, numerous lighting projects were carried out with sodium lamps, some of which by Philips.

Lighting with mercury lamps has also to be discussed. Compared with sodium lighting, at first Philips took little interest in mercury lighting. Since the investigations of *Küch* and *Retschinsky* (1907), which resulted in the appearance of the quartz-mercury lamp with mercury-pool electrodes (artificial sun), it had been found that with mercury vapour under high pressure (1-3 atm) a source of light of high efficiency could be obtained. The spectral composition of this light shows a striking lack of red and as a consequence colour rendering is inadequate. But with sodium there is still less colour rendering and when this drawback came to be generally accepted for the sake of the other, favourable, qualities of sodium light (efficiency, visual acuity, contrast) there was every inducement to try out also the mercury lamps. Great Britain set the example by installing experimental lighting with high-pressure mercury lamps, with oxide-coated cathodes, on some highways. Eindhoven, too, very soon started producing these lamps. But meanwhile further developments were taking place. The experimental and theoretical investigations carried out by W. Elenbaas very soon made it possible to survey the whole field of mercury discharges as functions of the various parameters (dimensions of the tube, mercury pressure, current and voltage). For instance, a principle of similarity could be worked out, whereby the number of essential parameters could be reduced and it could easily be predicted what the behaviour would be of a lamp with certain dimensions and containing a certain amount of mercury.

It was again Bol who succeeded in drawing practical conclusions from this study and arrived at a very compact construction of mercury lamps, which, however, only became possible after H. J. Lemmens had worked out a method of fusing tungsten leads to quartz, using only one intermediate glass. These lamps, only a few centimetres in length and with an internal diameter of 2 mm, were so designed that part of the mercury remained in the liquid state. Owing to the considerable heating of the wall of the tube these lamps were cooled with water. The internal pressure amounted to 100 atm and more. These lamps are being used for cinema projectors, in television studios and in searchlights, in general wherever there is no serious objection against the installation of a water-cooling system.

Another type, with a determined quantity of mercury which entirely evaporated during the operation of the lamp, had no need of any forced cooling. The equilibrium pressure was 5 to 10 atm. This type of lamp found extensive use for road lighting. In order to limit the preheating time the lamp proper, which has an internal diameter of 10 mm and a length of 35 mm, was placed in a normal incandescent lamp bulb filled with an inert gas to prevent oxidation of the leads. Notwithstanding the fact that at this high pressure the mercury spectrum shows, in addition to the much widened mercury lines, a continuous background extending into the red, colour rendering is inadequate, just as is the case with the lamp with a pressure of 1 atm. This drawback can be remedied by admixing incandescent light, but then the efficiency of the whole is reduced. Later it was found possible to improve the colour rendering by coating the inside of the outer bulb with substances which fluoresce under the influence of the ultra-violet rays of the mercury light.

Even when corrected with incandescent light or by means of a (red) fluorescing substance, however, for various reasons these lamps are not suitable for indoor lighting. In this direction gas-discharge lamps appeared in a different form. Starting from the low-pressure mercury discharge, whereby the emission of the visible mercury lines is only small and mainly the ultra-violet resonance lines of 2537 Å and 1849 Å are produced, these ultra-violet rays were converted into visible light by means of fluorescence. Philips contributed much towards the development of these "TL" tubes. By coating the inner wall of the discharge tube with a suitable mixture of fluorescent substances ($MgWO_4$, $(Zn,Mn)_2SiO_4$, $Cd_2B_2O_5$-Mn, $(Zn,Be,Mn)_2SiO_4$, and later also other substances, such as halophosphates) it was possible to produce a white light with a spectral energy distribution sufficiently approximating that of daylight or of incandescent light.

Such lamps as these, with a gross output of 40 to 50 lm/W, are being used more and more for all forms of utility lighting, such as in the home, workshops, offices, shops, etc., and for road lighting.

J. Voogd and others have been occupying themselves with the photometry of gas-discharge lamps.

The development of gas-discharge lamps with their spectral energy distribution differing so greatly from incandescent light, their extensive applications for road lighting and the problems of colour rendering all called for a profound study of the properties of the human eye and the faculty of seeing under different levels of brightness. In the Philips' laboratory these problems were energetically tackled by P. J. Bouma and A. A. Kruithof. Bouma revived interest in the more or less forgotten work of *A. König* (1891) on the subject of seeing at low brightnesses and he strongly advocated the ideas of *Schrödinger* (1920) in regard to the use of the colour space for colorimetric problems. His division of the visible spectrum into eight sections as a means of judging colour rendering has come to be of almost universal use, at least in Europe. For the practical application of the eight-section analysis a special photometer was constructed by P. M. van Alphen.

II. Electrotechnics, radio and acoustics

From the manufacture of incandescent lamps a number of important electrotechnical products have emerged which are related to the property of the filament to emit electrons, an effect which, as already remarked, was discovered in principle by *Edison* and subsequently investigated quantitatively by *Richardson*.

Library of the Physical Research Laboratory.

As a result of this investigation there appeared, as we have seen, first rectifying valves and radio valves with tungsten filament in vacuo, whilst Philips followed the G.E.C. in producing gas-filled rectifying valves with coiled tungsten filament. An important improvement was the replacement of the helicoidal tungsten filament in these valves by an oxide-coated cathode (J. Bruynes).

With the introduction of the oxide-coated cathode many more uses were found for rectifying valves, because on the one hand larger emission currents were obtained, thereby extending the field of application to heavy currents, whilst on the other hand the lifetime of these tubes was so extended as to be dependent only upon the chance of accidental damage (breakage or breakdowns) and not upon exhaustion of the thermionic properties of the filament (J. G. W. Mulder).

The field of rectifiers is an interesting example of a case, often seen, where a phenomenon first found as a small effect, so small that its existence might be doubted, ultimately finds application on a scale precluding any doubt as to its reality. The currents studied by *Richardson* could at first only be measured with a sensitive galvanometer. Now a rectifying valve with an emission current of 100 A is nothing rare.

Rectifying valves are now being made for high as well as low voltages. Valves for low voltages (some tens of volts) are used, for instance, for charging batteries and feeding cinema arc lamps (D. M. Duinker). In X-ray practice, on the other hand, rectifying valves are employed which can withstand voltages exceeding 100 kV, thanks to their being given a suitable shape. Another important product was the welding rectifier, characterized by a very heavy current (H. A. W. Klinkhamer).

Within the scope of rectifier research mention is to be made also of the work done in developing blocking-layer rectifiers, and in connection therewith the investigations with selenium (W. Ch. van Geel, N. W. H. Addink).

With the advent of the triode as receiving and transmitting valve round about 1914, radio entered upon a new era, a development to which Philips laboratory contributed in no small degree.

It is remarkable how often in the field of radio practice has been far in advance of the theory. The triode proved to answer its purpose well and was already being applied on a large scale ever before the relative problems, such as the calculation of the field between the electrodes and the behaviour of the electrons in that field, had been really mastered; the propagation of the radio waves over long distances had been found practicable long before scientists had got to the bottom of the actual reason for it and before the electromagnetic equations governing the propagation along the earth's surface had been satisfactorily solved. In the long run, however, it is essential to gain the fullest possible insight into the theory of the phenomena, and for that reason Philips have always devoted much attention to their theoretical investigation. Many other problems remained to be

A corner of the glass-blowing shop of the Physical Research Laboratory.

solved in connection with the practical application of radio valves, and so in the new laboratory radio investigations were divided among a number of groups of research workers. B. van der Pol was charged mainly with the conducting of theoretical radio investigations, whilst the more practical investigations were carried out by E. Oosterhuis, P. R. Dijksterhuis, Y. B. F. J. Groeneveld, H. Rinia, B. D. H. Tellegen and many others.

Van der Pol had begun in 1922 with the study of the triode. It had been found that the flow of electrons to the grid and the anode, respectively i_g and i_a, is a function of the voltages V_a and V_g respectively at the anode and at the grid with respect to the cathode. A three-dimensional plaster model was constructed with which this relationship could be visualized. Then attention was paid to the paths followed by the electrons under the influence of the field and to the secondary emission caused by the electrons impinging on the anode, the effect of which can be demonstrated with the plaster model. Further problems were the distribution of the electron stream between grid and anode and the effect that space charge has upon the field; for the study of these problems a foundation had been laid by the theoretical investigations of *Langmuir* and *Epstein*.

The problem of the motion of the electrons, which has always demanded attention in connection with the construction of radio valves, was subsequently investigated by P. H. J. A. Kleynen and J. L. H. Jonker with the aid of a model employing small steel balls made to roll over a sheet of rubber. This device has proved to be of great value in cases where the mathematical approach to the problem is too complex. Another means of circumventing mathematical difficulties was the measuring of fields of complex electrode systems with the aid of the electrolytic tank.

In connection with the phenomena arising in the radio valve mention is also to be made of the extensive investigation of fluctuation phenomena (noise) carried out by C. J. Bakker and M. Ziegler, which later on was extended to higher frequencies by M. J. O. Strutt, A. van der Ziel and others.

Further, there was the investigation made by H. Bruining into the secondary electron emission of solids, not only in connection with the occurrence of this emission in ordinary radio valves but also with a view to the construction of special valves in which secondary emission is brought about purposely in order to produce special effects.

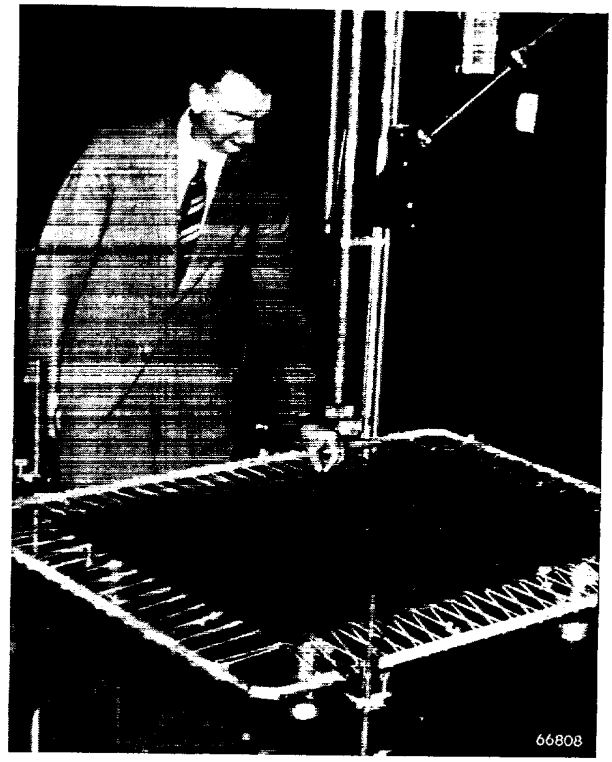
Following upon the study of the radio valve as such, its behaviour was investigated when employed as an amplifier or as an oscillator in a network comprising capacitances, resistances, self-inductances and mutual inductances.

An electric network is a system which as a rule is governed by a number of linear differential equations. With the introduction of radio valves in the network not only are negative resistances introduced, which make it possible for oscillations to be generated, but also non-linear terms then enter into the equations and make the problem more complicated.

Van der Pol succeeded in working out a non-linear differential equation in a simple form (the Van der Pol equation) which incorporates all essential data involved in the case of oscillations and the limiting of oscillations in networks. This equation,

$$\ddot{v} - \varepsilon(1 - v^2)\,\dot{v} + v = 0\,,$$

contains as parameter the factor ε, which to a considerable degree determines the behaviour of the solution. It appeared that within a certain range of values ($\varepsilon \gg 1$) the oscillation bears a character differing greatly from the known behaviour. Van der Pol named these relaxation oscillations. As opposed to "ordinary" oscillations as may occur when the system comprises mainly C's and L's, and which have a sharply defined cycle, while the amplitude depends upon various secondary conditions, relaxation oscillations may arise in systems which are governed mainly by C's and R's. In the latter case the amplitude of the oscillations is determined by the system, while their frequency is highly sensitive to external disturbances. Thus a system showing relaxation oscillations, such as a glow lamp shunted by a capacitor charged by a voltage source via a resistor, can easily be synchronized with a periodical signal, a principle widely used nowadays in television.



Small steel balls made to roll over a sheet of rubber give a picture of the paths followed by electrons in, for instance, electronic valves.

With the aid of relaxation oscillations it is also easy to demultiply frequencies (frequency dividing) and to produce the sub-harmonics, in contrast to the formation of higher harmonics, which can be obtained by connecting non-linear impedances to a normal oscillatory circuit.

As Van der Pol pointed out, the concept of relaxation oscillation is also of biological importance, where the rôle of "resistance" is performed by some diffusion phenomenon governing the biological process. Examples are the reaction of plant foliage to the alternation of day and night and the functioning of the human heart.

Van der Pol and J. van der Mark succeeded in constructing an electrical model of the heart, built up from a number of glow discharge lamps, capacitors and resistors, with which not only the functioning of the normal heart but also certain pathological aberrations could be imitated. To our minds the medical world was too sceptical about the value of that model at the time. Fortunately, however, medical scientists of the present day are showing more and more interest in the results of electro-physical and electrotechnical work, as for instance in neurophysiology. There are many indications that in the near future closer cooperation between the medical practitioner, the physicist and the electrical engineer, with mutual appreciation for the experiences and views of each, will prove to be of great advantage to all concerned, including the patients.

An important part of radio research is that concerning the propagation of electric waves and the interaction between these waves and matter. First of all mention is to be made of the investigations relating to skin effect and to the penetration of electromagnetic alternating fields in conductors. The practical side of this subject was made manifest in the manufacture of radio valves, whereby the valve was placed in a high-frequency magnetic field for degassing various parts mounted in it. It was of importance to be able to predict the degree of heating of the parts (plate, cylinder, grid) as a function of the field strength and of the orientation in the field; this problem was thoroughly investigated in the laboratory by M. J. O. Strutt and others. Of particular interest are the phenomena taking place in bodies of a magnetic material, for there it may happen that above the *Curie* point ($\mu \approx \mu_0$) the product $\mu\delta$ ($\mu = \mu_0\mu_r$ = permeability, δ = depth of penetration) is small with respect to the dimensions and below the *Curie* point ($\mu \gg \mu_0$) large. As demonstrated experimentally by J. L. Snoek, this has remarkable consequences when small objects of magnetic material are subjected to high-frequency heating. Upon the field strength being reduced the temperature remains high, owing to sufficient power being absorbed even when the field is weak. When, however, the temperature drops below the *Curie* point the absorption of power rapidly decreases and the field has to be made much stronger to heat the body to a high temperature again.

The radiation from aerials was investigated both empirically and theoretically. As far as the experimental work is concerned, extensive measurements were taken, for instance, of the field strengths in areas covered by various broadcasting stations all over the Netherlands (R. Veldhuyzen).

Theoretically the problem of wave propagation for a free radiating dipole had already been solved by *H. Hertz*. When the dipole is placed over an infinite, perfectly conducting, "flat earth" the field of the dipole and that of its reflected image can simply be added together. Considering, however, that the conductivity of the earth is finite and that it has a finite relative dielectric constant, the problem is much more complicated. For this case *Sommerfeld* arrived at an exact formula as far back as 1909, but this formula is not suitable for calculations. Therefore at the same time an approximative formula was given for calculating the field strength at the earth's surface. In 1919 the same problem was tackled once more, but in a different way, by *Weyl*, and in 1926 *Sommerfeld* showed that *Weyl's* result agreed with his own. But he then put his approximative formula in a somewhat different form. Much has been written on the question which of the two formulae, that of 1909 or that of 1926, was the "correct" one and what was to be decided by experiment. Important contributions on this subject were given by Van der Pol and his co-worker K. F. Niessen (one of *Sommerfeld*'s pupils), who arrived at a strict solution in a new form, and further by the Americans *Norton* and *Burrows*; the exact experimental determinations carried out by the latter proved to be in agreement with the formulae given by *Weyl* and by Van der Pol and Niessen.

Another question of practical importance is what part of the energy radiated by a dipole is dissipated in the earth, since from that the efficiency of a transmitter can be calculated. This mathematically complicated problem was solved by Niessen (1940) by employing *Sommerfeld*'s exact formula.

The problem of the propagation of the waves over a spherical surface has been the subject of an intensive investigation by Van der Pol and H. Bremmer following upon *Watson*'s work. Since in the formulae the dimensions of the spherical surface and the wavelength are not bound to certain values, these apply also in other realms of physics, such as for the interaction between light waves and droplets of water (the rainbow). A remarkable theoretical result, for instance, is that the radiation of the rainbow shows polarisation. This can now easily be verified with the aid of "Polaroid" spectacles; it seems that meteorologists had never noticed it.

In the investigations referred to, the atmosphere was regarded as a homogeneous medium. Later, Bremmer contributed important information on propagation in an inhomogeneous atmosphere (the ionosphere, "ducts"). In Great Britain the investigation of the ionosphere had been taken up experimentally on a wide basis by *Appleton*, who gave a lecture on this at Eindhoven in 1930. The root of the problem, for which no solution had then been found, lay in the relation between the virtual height (velocity of light in vacuo × half the reflection time) as a function of the frequency and the concentration of free electrons as a function of the height above the earth. From the discussions held at Eindhoven it appeared that, when ignoring the magnetic field, this relationship is given by an integral equation of *Abel*, so that the result can be written explicitly.

At certain frequencies the reflection time is infinite. Van der Pol saw in this a connection with the mysterious "delayed echos" which at that time were puzzling many radio amateurs. It is to be noted, however, that *Störmer* had quite a different explanation for this phenomenon and attributed it to charged particles coming from the sun at a great distance from the earth (10^6 km and more).

A remarkable effect of the ionosphere, discovered at Eindhoven, is the interaction of radio waves of different frequencies. In the empty space, owing to the linearity of the *Maxwell* equations, the principle of superposition applies exactly, so that two wave systems may penetrate each other without any mutual interference. In the ionosphere, however, the interaction is partly of a non-linear nature, with the result that waves propagated through the ionosphere over a powerful transmitter become modulated with the frequencies of that transmitter. Tellegen observed this at Eindhoven in the case of signals from the Beromünster station, which were subject to interference from the powerful Luxemburg station.

In addition to this, for the greater part, purely scientific research a considerable amount of work was directed towards the practical side of radio, in connection with both radio valves and further radio equipment. Above all, as was only natural, radio valves underwent repeated changes. There was a universal rational dimensioning of the various electrodes. In many cases the filament was replaced by an indirectly heated cathode. A second grid was introduced, first as space-charge grid and later as screen grid (*Hull*), so as to render the i_a-V_g characteristic less sensitive to anode voltage fluctuations and, furthermore, with the object of reducing the capacitance between the control grid and the anode, which was found desirable on account of the ever higher frequencies at which transmitting stations were working.

With the tetrode thus formed much trouble was experienced from the secondary emission of the anode. Tellegen therefore introduced between screen grid and anode a third grid (suppressor grid) to hold back the secondary electrons. Thus arose the five-electrode valve or pentode, which at first was used as output valve and subsequently came to be applied also in other circuits. On first sight this may not seem to be a very drastic change, but it has proved to be an exceptionally important improvement, since now, with a very few exceptions, all radio valves are pentodes.

Much work has been done in investigating the behaviour of these and other types of valves in various functions, such as for high-frequency and audio-frequency amplification (A. J. Heins van der Ven, J. van Slooten, H. van Suchtelen, and others).

Considerable attention has also been paid to the construction of transmitting valves, partly in connection with the employment of short waves (15-50 m) for long-distance radiotelephony. An experimental transmitter was built (J. J. Numans), provisionally equipped with a "dummy aerial", in which the energy normally radiated could be dissipated. A milestone was reached in the history of the laboratory in March 1927, when this transmitter was connected to an aerial and communication was established with what at that time was the Netherlands East Indies. This soon gained world fame, especially when, on 1st June 1927, *H. M. Queen Wilhelmina* used the transmitter (station PCJJ) to broadcast an address to the overseas territories.

In connection with the ever higher frequencies that were being used, there was also the development of the magnetron as transmitting tube. Philips Research Laboratory contributed much towards a proper understanding of the working of this tube. The treatises by K. Posthumus on the functioning of the magnetron with split anode still form the basis for all theoretical expositions in this field. Experiments in range finding by means of radio waves of 1 m and smaller generated by a magnetron transmitter were carried out in the laboratory before 1940; in the period 1940-'45 this principle was applied on a large scale elsewhere in the form of "radar".

The designing and manufacture of radio valves calls for great care and special methods. As higher

H.M. Queen Wilhelmina, accompanied by H. R. H. Princess Juliana, addressed Her subjects in overseas territories via the Philips' transmitting station PCJJ on 1st June 1927.

frequencies came to be used the connections had to be shorter and so different methods had to be found for constructing the electrode lead-ins. The solution was found by applying pressed glass or sintered glass (Lemmens) and special metals for the leads. This development came for a large part from the factory laboratories.

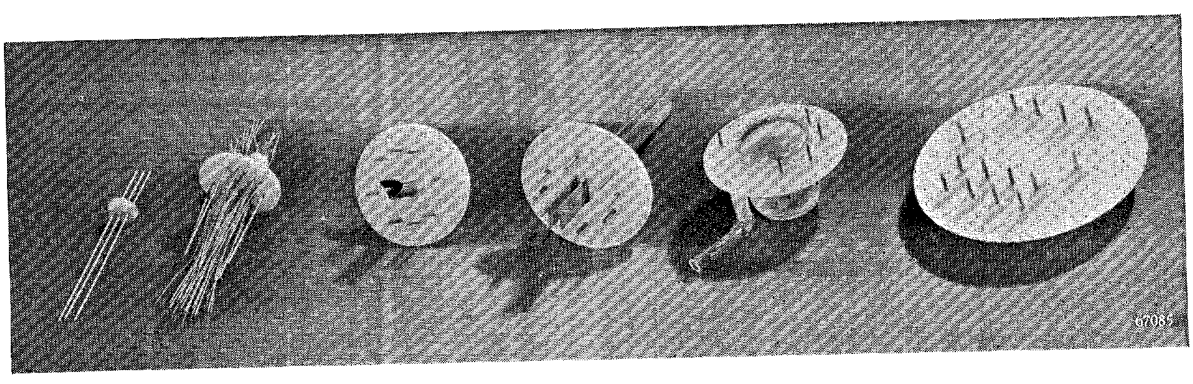
At first radio valves and some radio parts, such as high-tension units, audio-frequency transformers and resistance-capacitance couplings, used by amateurs and set makers, were the only radio products manufactured in the works. However, with the increasing popularity of radio broadcasting there was such a big demand for radio receivers that it became worth while to start manufacturing complete receiving sets. Looking back now, it is hardly imaginable that 25 years ago this was regarded as being something out of the ordinary.

Almost at once the need was felt for an apparatus that could be worked without batteries by feeding it entirely from the mains. This was made possible by employing the indirectly heated cathode which had meanwhile been developed at Eindhoven.

In the construction of radio sets, as already remarked, a great many problems were involved which had to be solved in the laboratory, in the beginning even in all sorts of constructional details (Bol, C. J. van Loon, J. M. Unk). On the one hand there was a need of certain circuits which had to be as efficient as possible while at the same time being easy to make and to repair, and on the other hand accurate methods of measuring were needed for testing the functioning of experimental circuits.

Much attention was devoted to the coils. By making these as loss-free as possible (according to a principle evolved in this laboratory by H. Rinia) greater selectivity was obtained and a "straight set" could be built with four tuned circuits, which for a long time answered the purpose very well. As the "ether" became more and more crowded with the increasing number of stations working within the allotted frequency bands, so that short waves came to be used for broadcasting, receivers had to be built on the superheterodyne principle.

Of great importance was the invention, by



Metal leads and supporting rods can be fused into bases of sintered glass in an almost unlimited number and in any order.

Posthumus, of negative feedback, for which patents were obtained already in 1928. This principle, which reduced distortion due to curvature of the valve characteristics, was very soon introduced in the Philips receivers. It proved, however, to have a much wider scope than this, so that at the present day it is being employed in practically all amplifiers and in all kinds of regulating devices, etc.

For those cases where a highly constant voltage (low internal resistance) is required for feeding radio apparatus a self-regulating high-tension supply unit was developed (Rinia, H. J. Lindenhovius). In connection with smoothing systems for the feeding of radio apparatus mention is to be made of the considerable amount of work done in the field of electrolytic capacitors (Van Geel, A. Claassen).

A difficulty encountered in the manufacture of radio sets lay in the lack of uniformity of electrical networks, especially since there are both direct and alternating current mains. J. W. Alexander constructed vibrator-converters capable of converting direct voltages of 100 to 200 V into an alternating voltage. Such vibrators are now commonly used with car radio sets for converting the battery voltage of 6 or 12 V into an alternating voltage of 220 V.

Another problem lies in the feeding of receivers in places where no mains are available. In the place of accumulators and dry-cell batteries the thermoelectric generation of current was thought of, but this is too uneconomical. This subsequently led to the development of the air engine, which before long will be able to take the place of the petrol engine now used for this purpose.

In the development of radiotelephony there is also the problem of conversion of the radio signal into audible vibrations of the air, thus into speech or music. As a consequence acoustics, and especially electro-acoustics, have become inseparably connected with radio. In 1925, when under the guidance of R. Vermeulen Philips started making loudspeakers, these were built on the electromagnetic principle, whereby the movement of an armature is transmitted to a diaphragm. Then there appeared the moving-coil loudspeaker, in which the cone-shaped diaphragm is connected to a small cylindrical coil through which the varying signal current flows and which is placed in a radial magnetic field. This magnetic field was at first produced by means of a soft-iron circuit excited with direct current. Philips very soon replaced this circuit by a permanent magnet. This development involved intensive research in connection with magnet steel, a subject which will be referred to again elsewhere. The new magnetic materials also made it necessary to give the magnets a different shape, so that attention had to be paid to the designing of magnetic circuits (A. Th. van Urk).

In addition to the work involved in the development of loudspeakers, much work has also been put into the development of power amplifiers, which in turn led to great activity in the field of line telephony (W. Six, H. G. Beljers, J. te Winkel).

In connection therewith attention may be drawn to the various measuring instruments developed in the laboratory, such as a measuring bridge for measuring losses in coils and capacitors, with which phase angles can be measured with an accuracy of 10^{-6} in a frequency range of 10^3 - 10^5 c/s (J. W. Köhler, C. G. Koops).

Further research work led to the development of various types of microphones, gramophone pick-ups and gramophone motors, and finally sound reproduction for the sound film and for broadcasting studios. An important part has been played in this by the Philips-Miller process, whereby a width-modulated track is cut in a celluloid tape coated with a lacquer, after which it is scanned by the known optical means. An advantage of this system was that the recording could be played back at once and thus corrected where necessary.

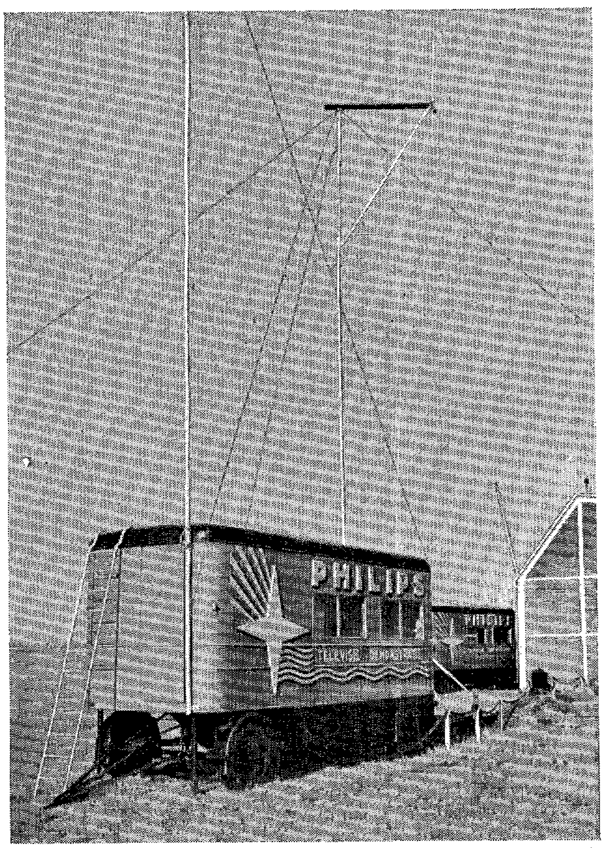
In this connection mention is to be made of a system, developed by K. de Boer, for stereophonic sound reproduction, both direct and by means of gramophone records or a Miller tape.

Important work has also been done in the field of the physiology of hearing. Particular mention is to be made of J. F. Schouten's investigations into the validity of the so-called *Ohm's* acoustic law, from which it appeared that in a mixture of frequencies which are a multiple of a certain fundamental frequency the latter can sometimes be heard even if it is not itself present in the mixture (the "residue" theory).

Further, L. Blok designed various signal generators, which have been applied, inter alia, for audiometric investigations.

Other developments in the technique of sound reproduction will be dealt with in the last section of this review.

The development of television began already in the thirties. In its earliest stages a *Nipkow* disc with 48 lines was used both at the transmitting and at the receiving end. Subsequently a cathode-ray tube was used in the receiver, whilst the *Nipkow* disc, still employed for the transmission, was perfected for televising films (Rinia). Later on the *Zworykin* iconoscope, meanwhile developed in the U.S.A., came to be used for TV transmission, first for the 180-line system and later for larger numbers of lines (Van der Mark, G. Hepp, A. Venis). Experience was gathered in the construction of amplifiers (J. Haantjes and others) and the building of transmitters (W. Albricht). Experiments



In 1937 already a transportable installation for television transmission and reception was completed and taken on tour for demonstrations over a large part of Europe. It could be worked on the system of 405 lines or on that of 567 lines.

were also carried out with projection television by means of lenses, employing a cathode-ray tube with concave screen (M. Wolf). Complete mobile television apparatus was built and installed in two motor-vans, with which demonstrations were given in various places in Western Europe (Utrecht, Brussels, Antwerp, Copenhagen, Stockholm) and also in Eastern Europe (Budapest, Bucarest, Zagreb, Belgrade, Warsaw). Owing to the outbreak of the war these tours came to an abrupt end in 1939.

III. Chemistry

It would be saying too much to maintain that all the chemical problems tackled in the Philips laboratory in the course of time likewise emanated from the incandescent lamp, but for a very large part such is indeed the case, either directly or indirectly.

Disregarding the metallurgy of the tungsten and the making of the glass, in the manufacture of the incandescent lamp chemical problems arise from the action of the gases released from the wall of the bulb and the metal leads upon the glowing tungsten filament, whereby traces of water vapour have a particularly disastrous effect. In the dissociation of the water vapour by the filament oxygen is combined with the tungsten and forms a volatile tungsten oxide which is precipitated on the glass wall of the bulb. The remaining hydrogen in turn reduces this oxide to metallic tungsten. Thus, owing to this "*Langmuir*'s cycle", tungsten is continuously being transported to the wall of the bulb, so that gradually this is blackened. It is therefore essential to remove water vapour and other gases, and this is done by introducing into the bulb a substance, such as phosphorus, which combines with the residual gases into a non-volatile and harmless product. Such a substance is called a "getter". In radio valves, where phosphorus cannot be used on account of its high vapour pressure and residual gases are moreover obnoxious because in the ionized state they affect the oxide-coated cathode and give rise to grid currents, and in X-ray tubes, where residual gases increase the risk of breakdown, metals like barium and zirconium are used as getters.

Even though the bulb of an incandescent lamp may not contain any gases attacking the filament, still evaporation of the tungsten takes place. In course of time this evaporation likewise turns the bulb black and thus the yield of light is reduced. Furthermore, the filament itself is reduced in thickness and as a result eventually collapses. The same applies in the case of the gas-filled lamp. The prevention of the evaporation by the gas-filling as such is offset by the filament being heated to a temperature so much higher that the lamp has about the same lifetime, so that the only advantage gained is the higher efficiency.

The manner in which this evaporation of the tungsten takes place differs according to whether the lamp is filled with gas or evacuated. In a gas-filled lamp the tungsten atoms come into collision with the gas molecules time after time, so that they have an opportunity to combine into aggregates which move about in the gas in the form of submicroscopical flocculations and eventually settle upon the wall of the bulb. Owing to convection this shows a preference for that part of the lamp which in the burning position is uppermost, thus not the part through which most of the light passes. With the vacuum lamp the situation is different: the tungsten atoms travel in a straight line from the filament to the inner wall of the bulb. It can be imagined that upon striking the glass wall the tungsten atom is repelled like a minute metal ball, but we know that ultimately it adheres to the glass, so every time the atom strikes against the wall it must lose some of its kinetic energy. *Langmuir*'s conception was that upon collision with the wall the atom temporarily adheres to it and is then, as it were, again evaporated, thus implying a certain "adhesion time". By accurate experimentation this has been confirmed by Clausing. It is true that in the case of cadmium atoms only an upper limit (10^{-6} sec) could be found for this adhesion time, but in the case of argon atoms on glass at temperatures of 80 to 90 °K adhesion times of 10^{-4} to 10^{-5} sec were found.

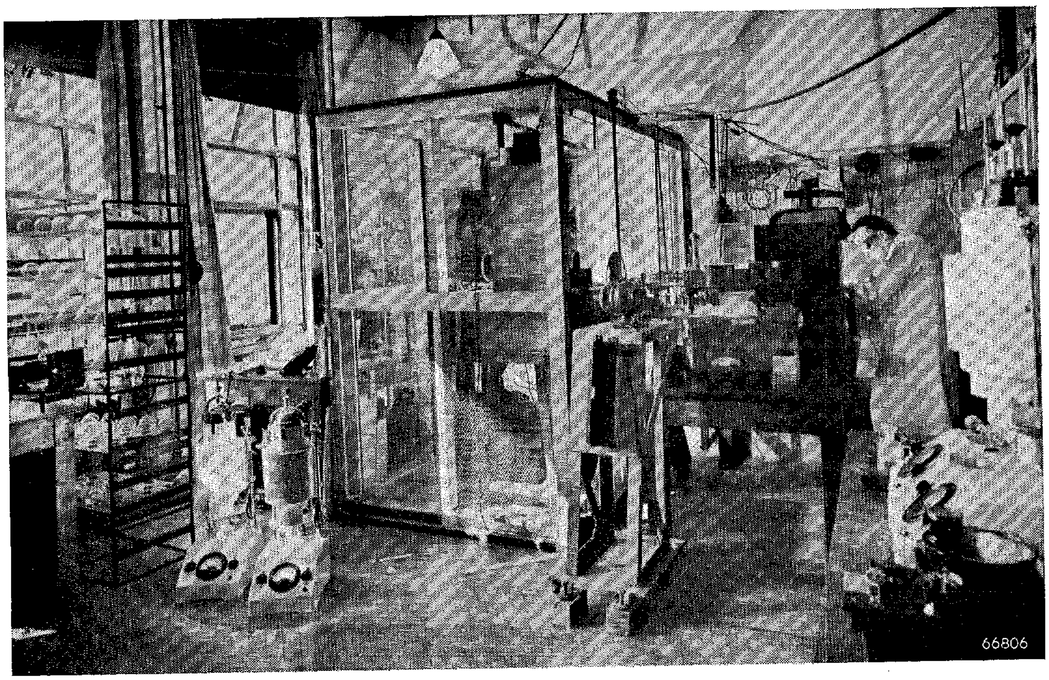
This matter of the evaporation of tungsten has been dealt with at some length because the investigations carried out in connection therewith formed an introduction to further investigations into the adsorption of tungsten atoms and the resultant absorption of light. So long as the tungsten atoms remain isolated on the wall of the bulb there is no appreciable absorption of light, but the position is different when they form a continuous layer of metal. In order to minimize the absorption of light, therefore, before the mount is fused into the bulb the filament is sprayed not only with the getter but also with a little salt, say CaF_2. As soon as the filament is heated to a high temperature this salt evaporates and is precipitated on the wall of the bulb as an invisible thin layer. The tungsten atoms coming from the filament shoot into this layer of salt, the particles of which keep the atoms separated, so that very much less light is absorbed.

About 1920 little was known with certainty about the effect of such layers of salt. Investigations into their action carried out in Philips laboratory, mainly by J. H. de Boer, extended over a period of more than 15 years. It has thereby been found that the layer of salt is not to be regarded as a homogeneous mass but as an agglomeration of minute crystal lamellae about 10^{-6} cm thick lying criss-cross one on top of the other and thus forming a very large active surface, tens of times greater than the surface of the glass covered by them. The tungsten atoms are adsorbed on the surface of the crystals. The intensive study of the adsorption of atoms and molecules (e.g. caesium and iodine) in such layers of salt (De Boer, C. J. Dippel, C. F. Veenemans) has yielded very important results.

Metals like caesium may be adsorbed also on the surfaces of metals, in which case they have the property of reducing the work function of the metal and thus increasing the electron emission, both the thermionic emission and that brought about by irradiation with light — photo-electric effect. By oxidizing the adsorbed layer and again precipitating caesium onto the layer of oxide it is possible to produce complex layers with an exceptionally strong photo-electric effect (M. C. Teves). The study of this emission was of importance for the construction of photocells, for which there was a need in connection with the sound film. The deeper insight gained into the nature of these layers opened up new possibilities, such as the employment of the "light transformer" for converting infra-red rays into visible light (Holst, De Boer, Teves), the construction of the electron-multiplying valve and, later, the television pick-up tubes.

The investigations into the vaporization of CaF_2 also led to other compounds, such as H_3BO_3, K_2BF_4, being tried out for the same purpose, as a result of which the volatility of various compounds was studied. Why, it may be asked, is NaCl for instance a substance having a high melting point and a negligible vapour pressure at room temperature, whereas WCl_6 is a substance that readily melts and is easily evaporated? From the point of view of the theory of heteropolar chemical compounds the answer is simple. The molecule of NaCl is built up from a positive sodium ion and a negative chlorine ion, which together form an electric dipole, so that two NaCl molecules exercise a very strong attractive force upon each other. In the case of WCl_6, on the other hand, the central metallic ion is surrounded by six chlorine ions screening off the charge of the central ion, so that there is no great attraction between neighbouring molecules. The theory of the heteropolar chemical bond was formulated by *Kossel* in 1920, following upon *Bohr*'s work. It is mainly due to the work of Van Arkel in this direction that a more or less coherent explanation was established for the most important facts in anorganic chemistry, an explanation that is of great value as a basis for chemical thought and for education in chemistry. It is fortunate that this was more or less completed before the conception of the homeopolar bond came into more prominence as a result of the development of quantum mechanics. Thus the one-sided-heteropolar aspect could gradually be introduced into the new system without losing its value.

In connection with these investigations the energy of formation of a number of molecules and crystal lattices was calculated and the relative stability of various molecule models investigated. known that WCl_6 and hydrogen on the surface of a heated tungsten filament may react one upon the other and form tungsten, which is deposited on the wire. When a mono-crystalline wire is taken (*Pintsch* wire) also the growing metal becomes a mono-crystal. In the Philips laboratory it was found that dissociation of WCl_6 at elevated temperature takes place also without hydrogen; attempts were made to produce other metals in the pure



Measuring the spectral transmission of various materials in the ultra-violet range. On the right the source of ultra-violet radiation and the monochromator. In the centre, in a screening cage, the measuring apparatus with photoelectric cell.

The above conceptions were also applied to the relation between physical properties of homologous organic compounds, as for instance the relation between the boiling points of CH_4 and of the compounds obtained when replacing in CH_4 one or more hydrogen atoms by atoms of F, Cl, Br or I. Subsequently, after Van Arkel's appointment as professor at Leyden, this investigation was extended by him and his students to a large number of other compounds. Also worthy of mention is the study of the dielectric behaviour of organic dipole molecules in solution, which led, inter alia, to the "Van Arkel and Snoek formula", which was later investigated theoretically by *Onsager* and by *Böttcher*.

The study of the volatility of metal compounds had also important technical consequences. It was state in this way. Perhaps the most striking result was the preparation of titanium, zirconium, hafnium and thorium from their iodides by precipitating the latter on a thin tungsten wire as core (De Boer and J. D. Fast). In this way titanium and zirconium, known as being greyish brittle substances of a doubtful metallic character, were obtained in the form of fine lustrous metallic products. The rods, consisting of a few large crystals, proved to be highly ductile, so that they could be drawn into wire and rolled into foil. This is particularly of importance in the case of titanium, considering the interest taken in this metal in recent years. Ductile zirconium has found important applications in vacuum technics. Applied to the anode of a transmitting valve it proves to be an excellent getter, on account of the almost unlimited capacity of this metal to adsorb oxygen and other gases. The oxygen taken up in the metal has a negative charge, as appears from the fact that in an oxygen-charged rod of zirconium through which a direct current is passed the oxygen migrates towards the positive pole.

The knowledge of metals and their interaction with gases proved to be of great value to the laboratory staff when it was decided to manufacture welding rods (J. Sack, P. C. van der Willigen), in addition to the welding rectifiers and rectifying valves already being produced.

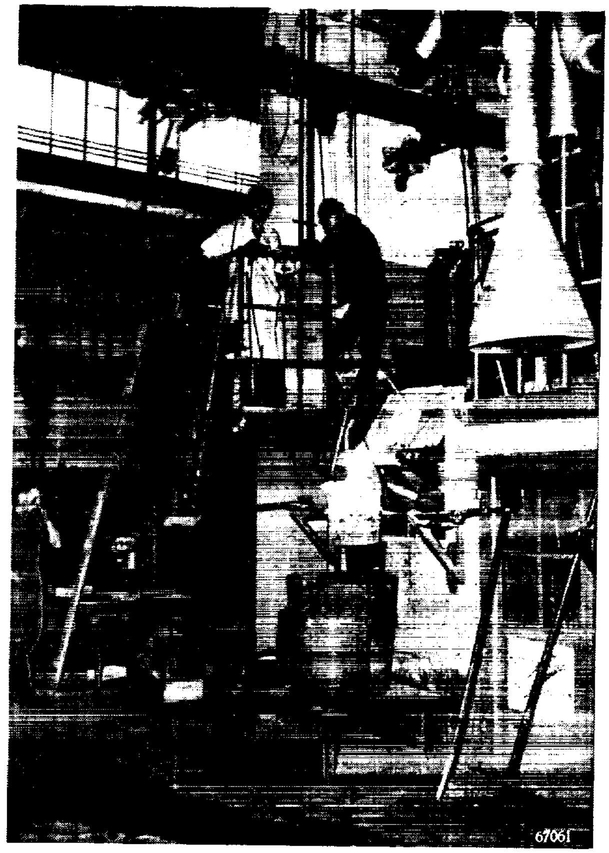
The study of tungsten wire and the behaviour of tungsten in processing led to extensive research in the domain of recrystallization. A substance particularly suitable for this is aluminium, which is easily deformed and recrystallized at comparatively low temperatures (< 600 °C), while the process of this recrystallization can be followed by etching in aqua regia after removal of the superficial oxide with caustic soda or hydrofluoric acid. This simple technique, supplemented by crystallographic study (W. G. Burgers, J. F. H. Custers), led to a deeper insight into the essence of the formation of crystal nuclei. This study is still being continued at the present day by Prof. *W. G. Burgers* in the inorganic-chemical laboratory of the Technical University at Delft.

Finally, in connection with applications in the field of electrotechnics and acoustics (transformers, loudspeakers), extensive research has been carried out in regard to the magnetic properties of metals, particularly of iron and iron alloys (G. J. Sizoo, W. F. Brandsma, Elenbaas, Jonas, Snoek, Six, G. W. Rathenau, J. J. Went, H. J. Meerkamp van Emden).

Special products, the fruit of years of study in this domain, were the rolled nickel-iron ("Fernicube") with strong anisotropic properties, for loading coils, and magnet steels with exceptionally high coercivity and high value of the (HB_{max}) product, which are widely used not only in loudspeaker magnets but also in pocket and bicycle dynamos.

Of importance for the investigations both of magnetic and non-magnetic metals was the work done by Snoek in studying the magnetic after-effects of iron, whereby it was found that these effects are related to the presence of traces of carbon and nitrogen, which influence not only the magnetic but also the elastic after-effects. Both these are governed by a sort of diffusion of C and N atoms present in interstitial places to neighbouring interstitial places.

Other materials studied at the time in the laboratory are the ferrites, which since 1934 have been further investigated by Van Arkel, Snoek and E. J. W. Verwey.



Preparation of magnet steel. Emptying the furnace in which the alloy has been melted by induced high-frequency currents.

This led, inter alia, to the view (De Boer and Verwey) that a substance like Fe_3O_4 derives its conductivity from the fact that ions of one and the same element but of different valency are present in crystallographically identical places and thus make it possible for an electron to pass over from one ion to another.

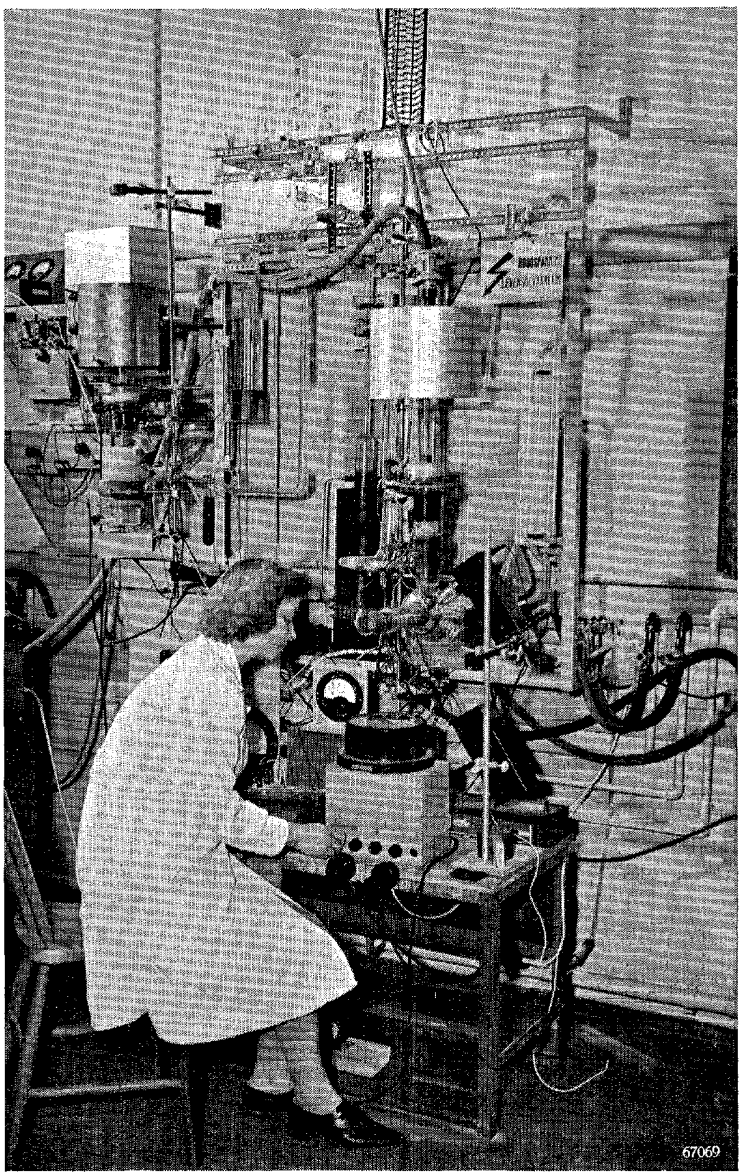
In the course of the resultant investigations our research workers became familiar with various problems of the solid substance, in particular with oxidic systems, of which the spinels form an interesting sub-group. The latter were further studied both in respect to their electrical properties (Verwey and others) and with regard to their magnetic properties (Snoek). The study of the electrical properties led to the development of semi-conducting materials, while that of the magnetic properties yielded the important magnetic material "Ferroxcube", which will be dealt with later.

The previously mentioned work by De Boer and others on the adsorption of atoms on crystals was extended to cases where atoms are built into a crystal lattice, a subject to which much attention was devoted in Germany by *Pohl* and his pupils. What is particularly due to De Boer is the disclosure of the fact that the place of a lacking negative ion in an ion lattice may be occupied by an electron and that, at the cost of only a little energy, this electron may be brought into a state in which it acts as a conduction electron.

It was at that time that the programme of work on solids was given shape, which later on was to occupy the minds of such a large part of the scientific staff of the laboratory and comprised, among others, the investigation of luminescent substances.

The luminescent substances (luminophores or phosphors) used for converting the ultra-violet light of gas-discharge lamps into visible light are prepared according to methods evolved by *Lenard* round about 1890. These investigations in the field of luminescence are to be regarded as classical and have not yet lost any of their value. They revealed in particular the fact that the luminescence of substances like zinc sulphide is due to the presence of extremely small admixtures of certain metals, such as copper and silver (activators).

When it became evident that large quantities of luminescent materials would be needed for lighting purposes Philips began to take up the manufacture of these substances and, at the same time, the study of the phenomena of luminescence. This study covered both the physical aspects — such as the spectral composition and the intensity of the luminescent light as a function of that of the incident rays, the decay of luminescence as a function of time in the case of discontinuous irradiation, the relation between luminescence and temperature, luminescence under the influence of cathode rays and X-rays — as well as the chemical aspects, such as the influence of the composition and of the conditions during preparation upon the luminescence, and the influence of admixtures (quenchers, sensitizers) upon the intensity of fluorescence. Often the chemical and the physical problems are so closely interwoven as to be inseparable, so that close cooperation between physicists and chemists or the combination of physicist and chemist in one person is essential for these investigations.



Phosphors are exposed to an electron beam in a vacuum tube and tested for their fluorescing properties.

Important physical results lay in the deeper insight thereby obtained into the mechanism of fluorescence and phosphorescence, the transfer of excitation energy in phosphors and the relationship between persistence and quenching as a function of temperature (F. A. Kröger, H. A. Klasens).

Chemical results lay in the deeper insight gained into the properties of zinc sulphide and related compounds and of substances such as Zn_2SiO_4-Mn_2SiO_4 and other manganese phosphors (Kröger).

In the foregoing some cases have already been mentioned where organic compounds were studied. Mostly these concerned simple organic molecules which are very closely allied to the inorganic compounds.

But work has also been done in the field of organic chemistry proper, namely in that of compounds with large molecules, such as gelatin, cellulose, proteins and synthetic resins. Gelatin was thoroughly studied because this substance serves as base for the Philips-Miller tape (Dippel, Vermeulen) used for sound reproduction; this tape consists of a celluloid carrier with a transparent coating of modified gelatin, covered by a non-transparent layer of HgS-sol in which the cutter of the recording apparatus traces a "sound track".

Artificial resins were originally studied with a view to the possibility of using these materials for making the bases of radio valves and loudspeaker baffles, and later for making various parts and the cabinets of radio sets from these materials. The phenols hardened with formaldehyde, which had been named bakelite after the Belgian chemist *Baekeland*, were placed on the market by Philips in a large number of varieties under the trade name "Philite".

A third group of organic compounds, the diazo compounds, was intensively investigated in the Philips laboratory when it was contemplated to produce dye-line paper, in addition to the mercury lamps destined for the dye-line process. With the aid of these compounds in various carriers, such as cellophane, paper, cellulose esters, etc., materials for photographic reproduction were produced which, via conversion of the products of dissociation through light into a developable latent metallic image, ultimately yield silver images with a resolving power of 1200 lines per mm, which appear to present interesting possibilities of application (Dippel, R. J. H. Alink, K. J. Keuning).

Attention was also given to the study of colloid-chemical problems. One result of these investigations, which was of importance for the manufacture of radio valves, was a new method of coating cathodes with a layer of oxide, covering them by means of electrophoresis with finely distributed carbonates of barium and strontium, which are afterwards turned into oxides. Also the insulating layer around the filament of indirectly-heated cathodes is applied in this way (De Boer, Verwey, H. C. Hamaker).

This concludes the review of chemical research in the Philips laboratory prior to 1940. A number of investigations carried out with metals and with non-magnetic and magnetic ceramic materials, glass and semi-conductors will be dealt with in the last section.

IV. X-rays

From the radio valve it is but one step to the X-ray tube. Any diode is in principle a source of X-rays, and it does in fact become so when the electrons strike the anode with sufficient energy. With the X-ray tube problems arise which are similar to those encountered with the radio valve, such as the shaping of the electrodes with respect to the nature of the electric field, the paths followed by primary and secondary electrons, and the focusing. To these are added the typical problems connected with high tensions, as for instance the efficient distribution of potential differences. Since only a small fraction of the electron energy is converted into X-rays and the rest is absorbed in the anti-cathode in the form of heat, it is a great problem how to carry off that heat: by providing for sufficient dissipation of this heat and giving the anti-cathode a suitable construction it has to be ensured that in the focus the material struck by the electrons does not melt.

Of physical importance is the measuring of the intensity of the X-rays and the strength of the dose. Much attention has therefore been devoted to this problem by A. Bouwers, who took up X-ray research in the Philips laboratory in 1920.

In the construction of X-ray tubes one is confronted with such problems as the safeguarding of the users of X-ray apparatus against scattered rays and high tension, the raising of the specific load, the requirement of easy handling, and the applications in connection with a proper formulation of the optical requirements which the apparatus has to answer; these applications may be of a medical (diagnostics and therapy), a physical (examination of crystals with X-rays) or a technical nature (examination of materials).

An important discovery was the possibility of fusing glass to metal, for which the chrome-iron already mentioned was used. This made it possible for Bouwers to build rugged X-ray tubes, which, since the part where the rays are generated is entirely enveloped in metal, afforded the maximum of safety against undesired radiation and, moreover, allowed of a simple safeguarding of the user against high tension by earthing the metal shield.

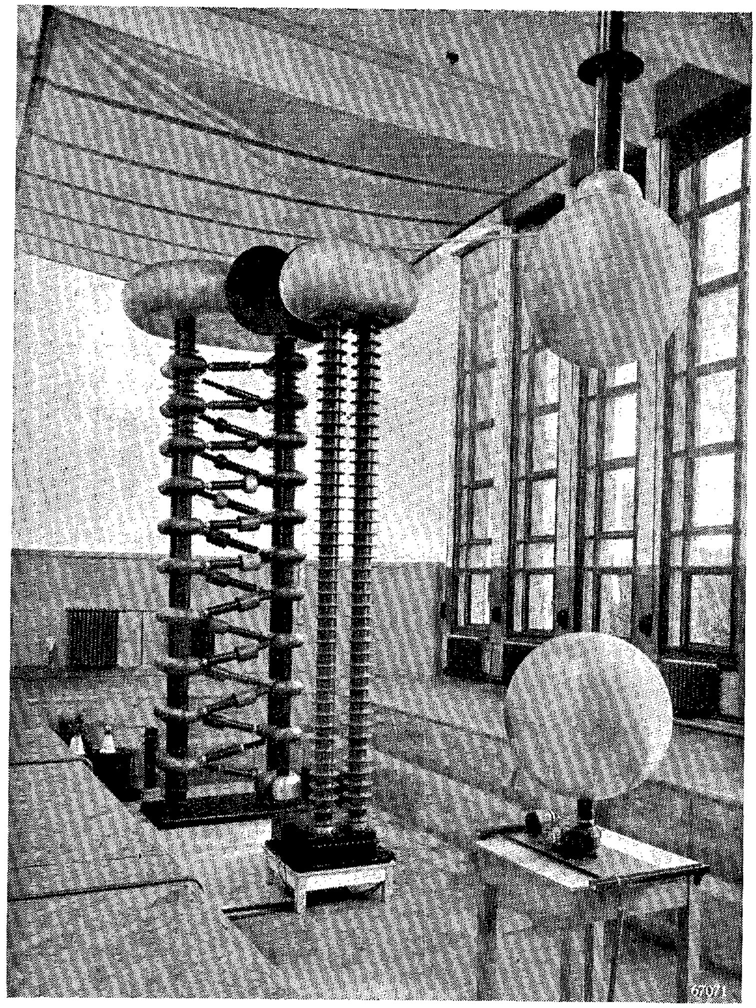
Tubes came to be developed for still higher voltages and for larger powers, both for diagnostic purposes and particularly for therapy.

A special form of X-ray tubes which should be mentioned is the rotating anode tube, which was first developed by Bouwers in cooperation with J. H. van der Tuuk. The problem of the dissipation of heat in these and other anodes was thoroughly investigated by W. J. Oosterkamp.

Further, special tubes were designed for crystallographic research with the aid of X-rays, in which the anticathode was made of special materials, such as molybdenum, copper, iron, etc., because these are required to yield approximately monochromatic rays of a known wavelength.

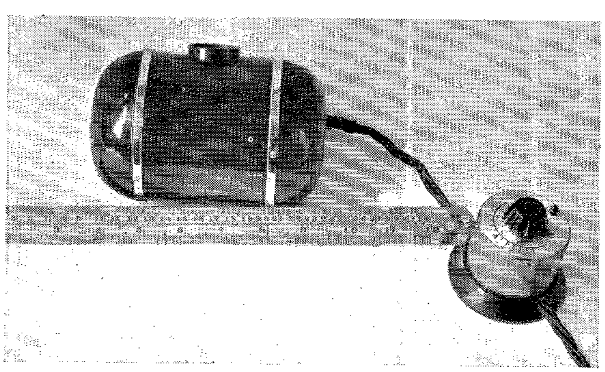
In the beginning all X-ray tubes were made in the laboratory, but later a separate factory was opened. The main features in the manufacture of X-ray tubes are well studied and well applied technology (getters!) and the exercising of extreme cleanliness in handling the materials.

Apart from the development of the X-ray tubes themselves, that of the apparatus for supplying the high tensions required for the working of the tubes, as also that of the control desks, forms a considerable part of Philips' activity in the field of X-rays. Often alternating voltage has to be transformed into direct voltage, for which special rectifying valves are needed, which formerly had a tungsten cathode but now have either an oxide-coated cathode or one of thoriated tungsten.



One of the first practical executions (1937) of a cascade generator, for 1.7 MV direct voltage.

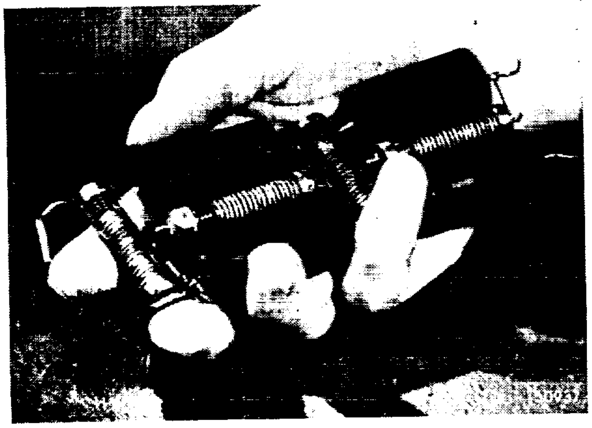
Side by side with the aim towards higher tensions and greater powers, provision was also made for cases where a relatively low voltage and a small power suffice. Small X-ray apparatus was therefore developed in which the tube and the transformer are incorporated in one single unit. Such units serve as portable apparatus for diagnostic work and, for example, as X-ray apparatus in dentistry. It has even been possible to produce a complete X-ray apparatus so small that it can be carried in the pocket, and yet it yields a satisfactory beam of X-rays.



67064

One of the first experimental X-ray units of very small dimensions (1933), a forerunner of the "Centralix" and "Oralix" apparatus.

From investigating current sources for high voltages Bouwers arrived at the principle of voltage multiplying by means of a cascade circuit. Subsequently it appeared that this principle had already been recorded by *Greinacher* and that it had also been applied by *Cockcroft* and *Walton* for nuclear-physical research in the Cavendish laboratory. As a special feature of Philips' development in this field is to be mentioned the elegant solution of the heating of the filaments in the valves by high-frequency current (A. Kuntke). A number of high tension generators of this type, for tensions

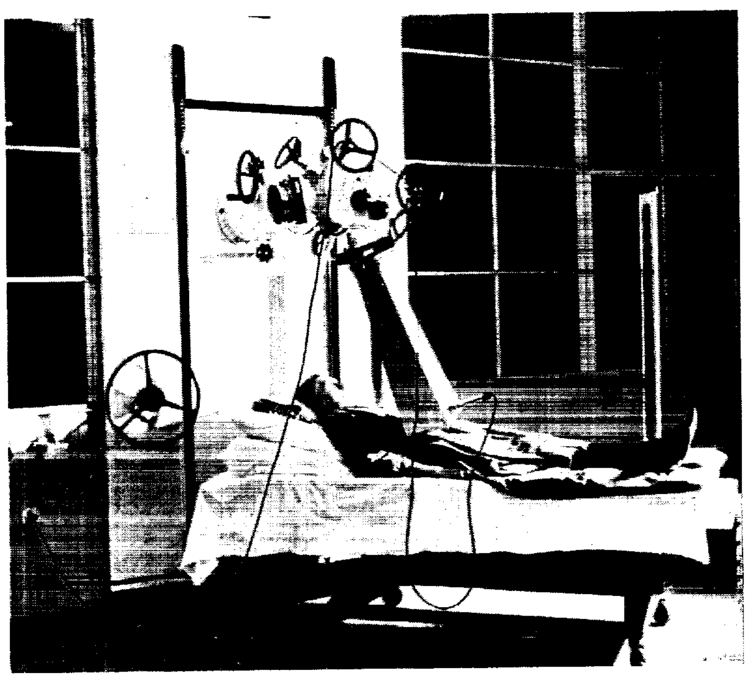


Small rectifier in cascade connection, consisting of selenium valves and capacitors. Connected to 220 V alternating voltage it yields 1200 V direct voltage, with which, for instance, a radiation counter tube can be fed.

up to 2 MV, have been built at Eindhoven for institutions in several countries.

Once it became possible to generate high tensions it was only a logical sequence to take up also research in nuclear physics. Bouwers and F. A. Heyn designed an ion-accelerating tube with which the ions of deuterium, formed in a separate ion source, could be accelerated to an energy of 1.2 MeV and focused upon a target of beryllium or lithium. Thus a powerful neutron source is formed by means of which materials placed in its vicinity can be made radioactive. In order to gain experience in the working of this apparatus, scientific nuclear research work was carried out with it. In the course of that work Heyn discovered the $(n, 2n)$ reaction with the elements Cu and Zn, by which reaction the nucleus is struck by one neutron and yields two neutrons, this being accompanied by the formation of a radioactive isotope of the same atomic number but lighter than the basic isotope. In 1939 A. H. W. Aten, Bakker and Heyn studied the transmutation of uranium and thorium by neutrons.

In this connection mention is also to be made of a neutron tube without a separate ion source constructed by Penning, whereby deuterium ions are accelerated in a gas discharge and the target is placed in the discharge tube itself. In order that sufficiently high voltages can be applied and the free path of the ions made large enough, the tube is filled with deuterium under a very low pressure and the discharge space is placed in a magnetic field so as to constrain the electrons to follow long paths, just as in the case of the manometer described earlier, thus making it possible for the discharge to be maintained under the low pressure.



Installation for X-ray therapy, working with a voltage of 400 kV, supplied in 1941 to the Academic Hospital at Groningen.

V. Mathematics and theoretical physics

With the growth of the laboratory more and more interest was taken in theoretical-physical and mathematical research. Whereas on the one hand, besides development work for practical applications, experimental physical research is necessary to obtain a deeper insight into the problems, so on the other hand fruitful experimentation is only possible when at the same time the necessary attention is devoted to theoretical physics. This implies that the necessary mathematical apparatus has to be mastered and where possible further developed. This applies more or less to each of the groups already dealt with. Both the study of gas discharges and radio research, as well as the physico-chemical studies and the work on X-rays, had each in turn their own mathematical problems.

In regard to gas discharges there was the mathematical treatment by G. Hertz of the diffusion of electrons in an electric field. The method followed by Hertz has served as an example for many theoretical calculations in this field (Druyvesteyn, Penning, De Groot). This brought us a step nearer to the ideal: to explain the various forms of discharges with the aid of a small number of data concerning elementary processes (the probability of excitation and ionization in the case of collision of electrons and atoms, etc.), in much the same way as the kinetic gas theory relates the measurable quantities, such as pressure and temperature, to the elastic collisions between gas molecules.

Further it has already been seen, for instance, that with the aid of considerations of similarity the phenomena in discharges in mercury vapour of high pressure can be reduced to one single aspect. Once he had become familiar with this method of calculation, and following upon a publication by *Nusselt* (1916), Elenbaas was able to apply similar considerations to the phenomenon of thermal emissivity through natural convection. The need for this arose from the manufacture of blocking-layer rectifiers in connection with the dimensioning of cooling fins, but also other problems of convection can be considered in this light, such as the heat dissipation of horizontal cylinders, which brings us back to the gas-filled incandescent lamp designed by *Langmuir*.

The part of the work programme that lent most stimulation to the practising of mathematics was radio. Mention has already been made of important mathematical problems which arose in connection with the propagation of waves. Van der Pol took up the study of the wave equation and the potential equation, not only in three dimensions but also in the cases of fewer or more than three dimensions.

As is known, the propagation of waves can be treated in two ways, either as a whole, by the solution of a "wave equation", or by an approximative solution of the behaviour of a narrow beam or "ray". The latter method is well known from the theory of light; the image produced by a lens is not usually studied by starting from the representation of a wave but by investigating how the rays of light are refracted by the lens. In the case of radio waves Bremmer has investigated in how far results can be reached with this geometrical-optical approximation.

In addition to radio, particularly the theory of atoms has formed grounds for excursions into the field of mathematics. It is remarkable how closely the mathematics of these problems are associated with the mathematics encountered in the field of radio and acoustics. In 1925 *Schrödinger* showed, for instance, that the motion of an electron under the influence of an electromagnetic field has to be described by a wave equation which shows a certain resemblance to the equation representing the propagation of light or sound in an inhomogeneous medium, and that the classical consideration of an electron as a "particle" describing a "path" is to be compared to that conception as geometrical optics compare to wave optics. The quantity used by *Schrödinger* to play the part of "field strength" or "deformation" of the medium, and which he denotes by Ψ, has the property that $|\Psi^2|$ is a measure for the probability of finding a particle at a certain place. Owing to the similarity between these problems and those of the propagation of waves encountered in radio and acoustics, theorists in the respective fields soon understand each other and find interest in the results of each other's work.

In dealing with the problems connected with oscillations in networks or the propagation of radio waves one mostly has to do with more or less complicated differential equations. *Heaviside* showed that in many cases the differential symbol, d/dt, can be regarded as an algebraical quantity (usually represented by D), with which ordinary arithmetical operations can be carried out. In this way he was able to derive deep-lying results by simple means.

This operational or symbolic calculus was at first received with much scepticism, but later *Carson* (1926), for instance, found it to be justified. What *Carson*'s formula amounts to is the furnishing of a function $f(p)$ corresponding to a function $h(x)$ by the *Laplaec* transformation:

$$f(p) = p \int_0^\infty e^{-px}\, h(x) dx.$$

The shape of $f(p)$ depends, of course, upon $h(x)$. This function $f(p)$ is said to the be "image" or the "translation" of the function h(x) and it is denoted by the symbol:

$$f(p) \doteq h(x).$$

The functions x^n, e^{-x}, sin x and cos x, for instance, have as their images

$$\frac{n!}{p^n},\quad \frac{p}{p+1},\quad \frac{p}{p^2+1}\quad\text{and}\quad \frac{p^2}{p^2+1},$$

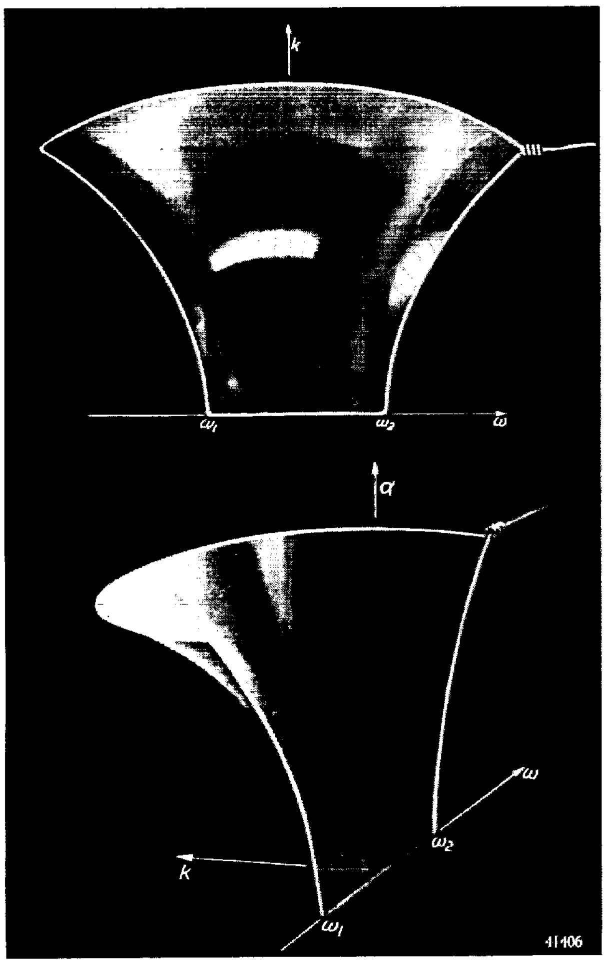
from which it is to be noted that often the image is a simpler function than the original. Thus relations between different originals can be deduced via simpler relations between their respective images.

Van der Pol and Niessen have worked out a great many images and from them derived new relationships between functions. Mention has already been made of the problem of the aerial over the flat earth, and for that, too, the symbolic calculus was employed, with the further help of the methods followed in the theory of the functions of a complex variable.

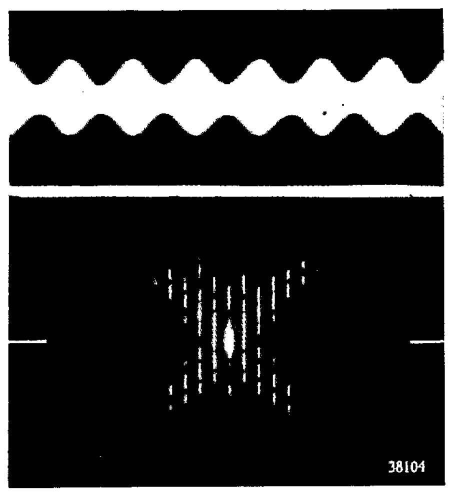
These results were obtained with the aid of the one-sided *Laplace* integral, with the integration extended from 0 to ∞. Later, Van der Pol and Bremmer went deeply into a symbolic calculus based upon the two-sided *Laplace* integral (integration from —∞ to +∞).

The space available does not permit us to enter into details regarding other mathematical work in connection with radio and acoustics. We can only refer to the numerous publications by Strutt on acoustic and antenna problems, Niessen's calculations on aerials and cavity resonators, C. J. Bouwkamp's work on radiation properties of antennae and acoustic and electromagnetic diffraction problems, that of F. H. L. M. Stumpers and Th. J. Weyers on frequency modulation, Tellegen's studies of network synthesis, from which the "gyrator" subsequently appeared as a new network element, and finally Kleynen's investigations of electric fields in radio valves, etc.

As regards mathematical and theoretical-physical contributions outside the realm of radio, reference is to be made to the investigations of J. Haringx into problems of applied mechanics, the publications by Bouma and G. Heller on the geometry of colour space, and those by Niessen on diamagnetism and by Verwey and J. Th. G. Overbeek on the theory of lyophobic colloids.



In the course of development of carrier telephony it was necessary to investigate how the behaviour of electric filters is affected by losses. This behaviour is governed by the *Laplace* differential equation. A graphical solution of this equation, with given boundary conditions, is obtained by stretching a film of soap between three-dimensional curves corresponding to the boundary conditions. The case illustrated here relates to a bandpass filter (frequency limits ω_1 and ω_2); k is a measure for the losses, α a measure for the damping.

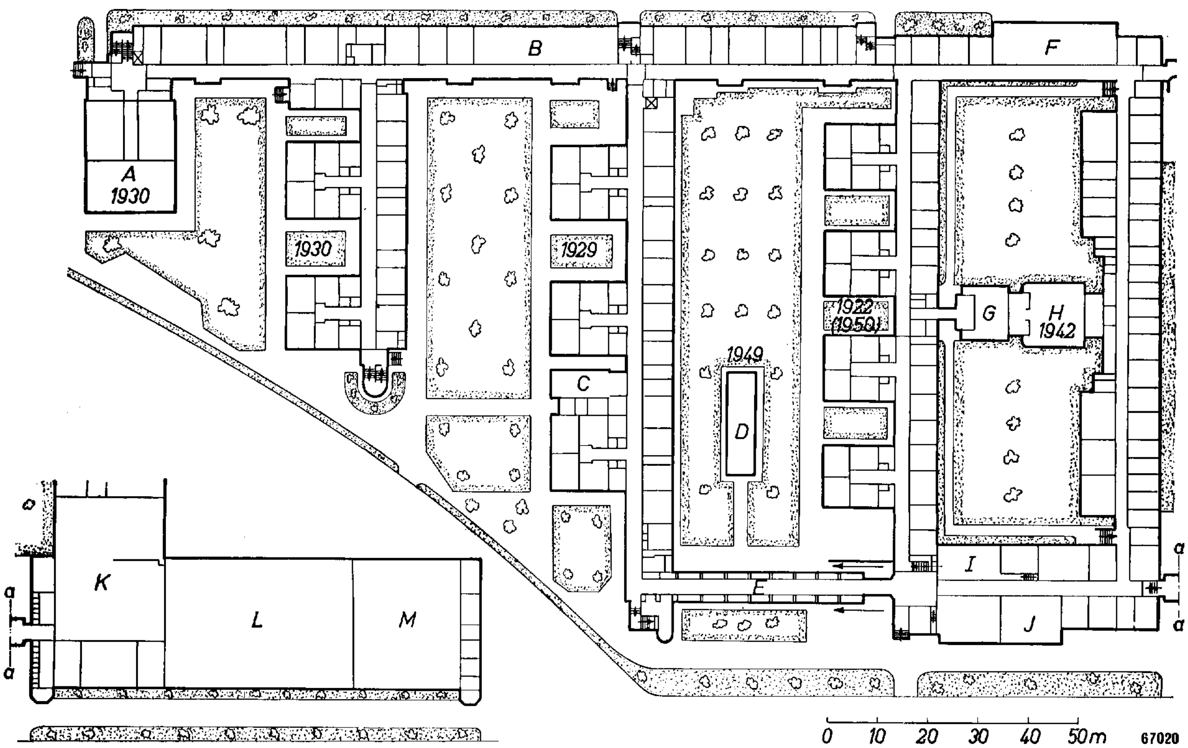


Philips-Miller tape (upper picture) in which a sound track (10 times enlarged) has been cut. When light passes through the tape a diffraction spectum is obtained (lower picture) from which the *Fourier* analysis of the recorded sound can be read. In this case (sinusoidal signal) the spectrum consists only of components of the zero and first orders.

THE PERIOD 1940-1951

In the foregoing section an attempt has been made to give a review of the scientific research work undertaken in the period 1923-1940, and incidentally mention has been made of the technical products that emanated from that work.

The development of this research suffered a check when on May 10th 1940 enemy forces invaded the Netherlands and shortly afterwards Eindhoven and the Philips' works came under military occupation.



Ground plan of the Physical Research Laboratory as it has been since 1942. *A* high-tension room, *B* material-testing department, *C* television studio, *D* horticultural glass-house, *E* small greenhouses with artificial climate, *F* one of the chemical departments, *G* one of the battery rooms, *H* library, *I* installation for carrier telephony, *J* engine room, *K* glass-blowing shop, *L* central workshop, *M* room for testing transmitting valves. The wing *K-L-M* adjoins the main diagram at *a-a* on the right. Most of the buildings have either one or two upper storeys.

It is not the place here to enlarge upon the course of affairs during the period of occupation, which, as far as Eindhoven was concerned, lasted until September 1944. As everyone will realize, the state of tension arising from war conditions and the frequent acts of injustice, coupled with more direct causes such as scarcity of foodstuffs, clothing and means of transportation (bicycle tyres), and further a number of air attacks on the works, repeated air-raid warnings, etc., all tended to create an atmosphere adversely affecting work. It would be wrong to suppose, however, that scientific research was thereby brought more or less to a standstill. On the contrary, many investigations not directly concerned with practical applications were widened in scope and in some fields important results were reached, though care was taken to keep them secret from the occupying forces. The long working hours imposed by the enemy administrators were further turned to use for the exchange of experiences in all sorts of domains by organizing lectures, courses of instruction, etc.

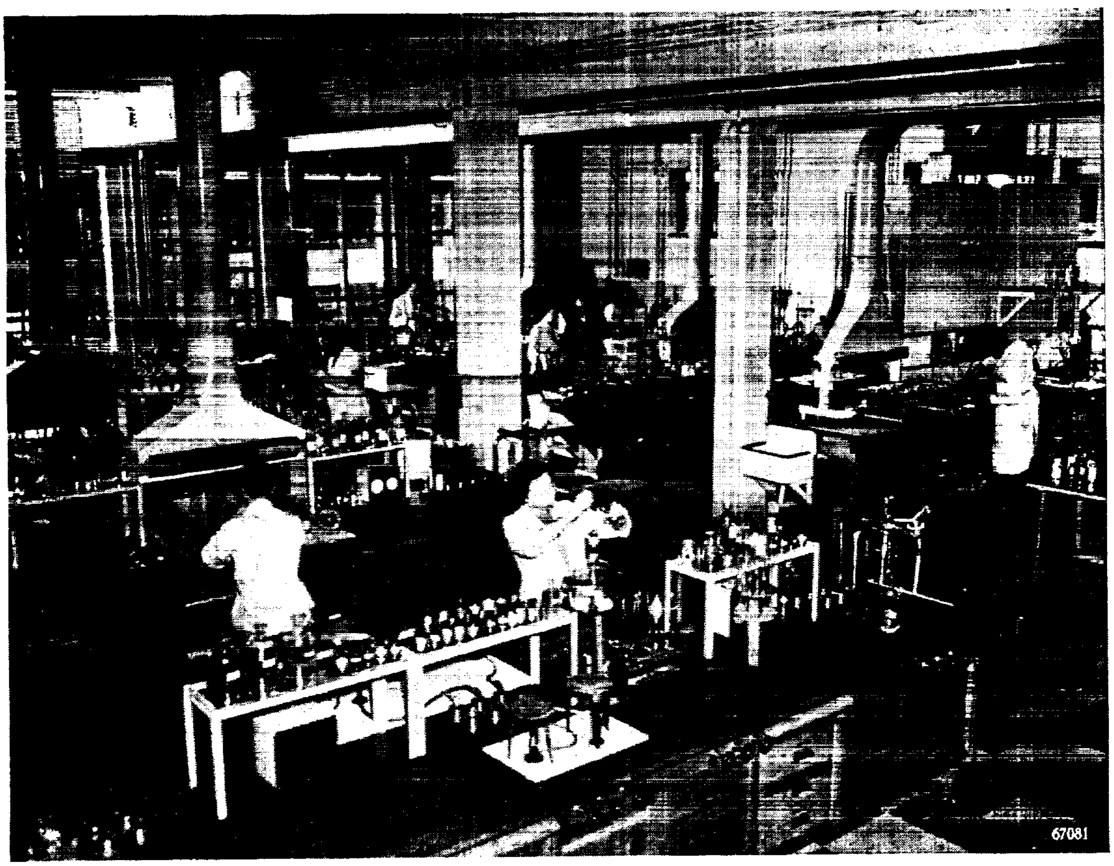
After the liberation of Eindhoven in 1944 it took some time before a return to normal conditions could be established. In the first half of 1945 the northern half of the country was still in enemy occupation and even after its liberation there was no regular contact with the rest of the country owing to the lack of railway communications. In order to help university students, with permission of the government in February 1945 a temporary academy was set up at Eindhoven where a large number of Philips' scientists assumed the rôle of professor, and this continued up to November 1945.

In this connection it may be well to point out that relations between the Philips laboratory and the higher educational authorities have never been confined to that special occasion. Long before that there had developed in the course of time a more and more intimate relationship between the laboratory and the universities, including the Technical University at Delft, partly on account of the fact that quite a number of scientists have in course of time left our laboratory to take up a professorship.

During the occupation one began to feel more and more the lack of literature from the outside world, so that as far as scientific work was concerned one had the feeling of living as it were in a vacuum. The possibility of publishing was also greatly restricted. The publication of Philips Technical Review, begun in 1936, had to be stopped in 1942, and publications in the Dutch journal "Physica" could only be made in the native language.

It was not until 1946 that journals and books began to come into the country again from abroad. On 1st January 1946 Philips Technical Review appeared again. Meanwhile, in October 1945, the first number had been issued of a new publication under the name of Philips Research Reports, containing scientific articles which bear a decidedly Philips character or which owing to their volume cannot easily be published elsewhere. Furthermore, part of the material suitable for publication which had been collected during the years 1940 to 1945 was published in book form.

Meanwhile the need of more space was being felt in the laboratory, which in 1929 had already undergone a considerable expansion increasing ten-fold the amount of floor space originally available in 1923. A new wing had already been built in 1942, for the administrative staff and the library, but



Department for analytical chemistry in the new part of the Physical Research Laboratory (1950).

until 1945 the latter had been housed elsewhere owing to the risk of fire due to air attacks. In 1950 a second floor was built onto the oldest single-storey part of the laboratory first erected in 1922, and that new floor was destined mainly for chemical work.

In 1946 a change was made in the management of the laboratory, Prof. Holst, whose 25th year of directorship had been celebrated in the laboratory in 1939, retired from that function. As adviser to the concern, he has still at the present day a word to say, be it indirectly, in the course of affairs, whilst at the same time he is devoting himself to the interests of the Technical University at Delft, where he holds of the Presidency of the Board of Governors. The direct management of the Philips laboratory was placed in the hands of a triumvirate formed by the physicist Prof. Dr. H. B. G. Casimir, the electrotechnician Ir. H. Rinia and the chemist Dr. E. J. W. Verwey.

For reasons which will be understood, in this section it will not be possible to do full justice to all the research work which has been undertaken in the Philips laboratory in the course of the last decennium and which, in part, is still in progress. Neither will it be possible to mention the names of all those engaged in the various investigations in the laboratory.

More so than in the preceding sections, here attention will be paid to materials and products and their applications.

Materials

It has been seen that in the period 1923-1940 scientific interest was directed for a large part towards gases, particularly as carriers of electric discharges. In addition, in various ways more and more interest came to be taken in solids. Mention has already been made of the investigation of thin crystal layers adsorbing foreign atoms. Activity in the field of radio demanded a closer study of the dielectric properties of glass and other insulators. For illumination engineering, too, glass had become an important material, as a result of the demand, for instance, for ultraviolet-transmitting glass and for intermediate glasses for combining glass with quartz glass. For the fusing of glass to metal suitable kinds of glass and alloys were required. In the technique of lighting fluorescent substances came to be applied more and more, so that the phenomenon of luminescence had likewise to be studied in the laboratory. Further, attention has also been drawn to magnetic materials, such as magnet steels and ferrites.

Generally speaking it may be said that round about 1940 interest was centred upon solids and the problems relating to the solid state, both from the point of view of purely scientific investigations and in respect of practical applications. In the following a number of materials will be briefly dealt with, but since it will be mainly the results that will be brought forward it is well to point out once more that in many cases these results are due for a large part to purely scientific research. As an example may be mentioned the investigations into "induced valency", which led to improved methods of preparing semi-conductors and luminescent materials, and the insight gained into the structure of "spinels", which resulted in a greater variety of "Ferroxcube" products.

Luminescent substances

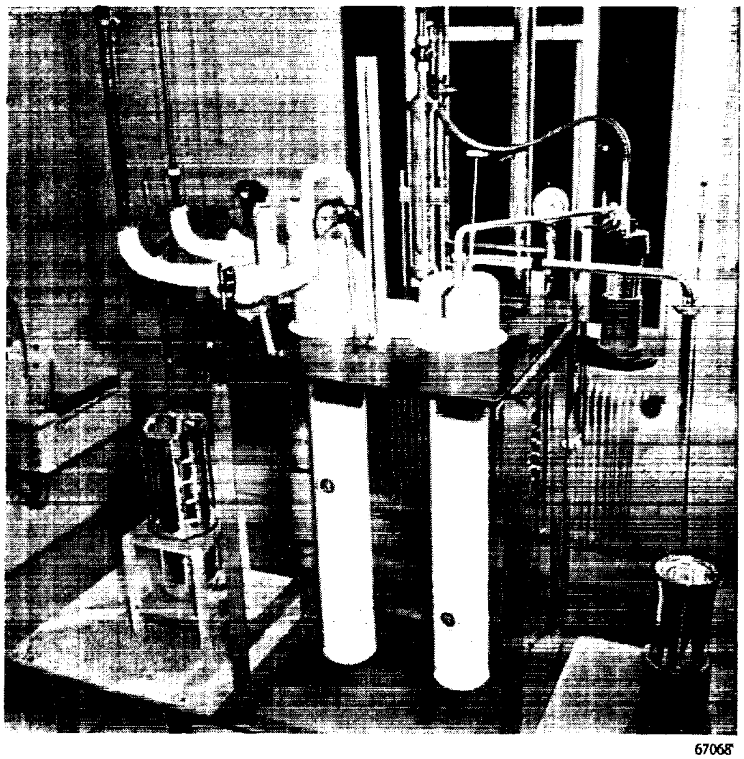
The investigation of luminescent substances begun about 1935 led not only to the results already mentioned but also to a wider knowledge of luminescent tungstates and molybdates and of some activators such as Mn, Ti and U in different states of ionization.

Of particular practical importance were the silicates activated with Ti and magnesium arsenate activated with tetravelent manganese. With the latter substance, which shows a strong red fluorescence, it is possible, for instance, to improve considerably the colour of the light from the small high-pressure quartz mercury lamps.

The investigation of sulphides gave a better insight into the part played by "fluxes", such as NaCl, used in the preparation of luminescent substances. It appeared that it is the Cl^--ions that make it possible, for instance, for monovalent Cu^+-ions to be "built into" the lattice. The same can be reached by introducing into the lattice, which consists normally of bivalent ions Zn^{++} and S^{--}, trivalent cations such as Al^{3+}.

Results were also achieved in respect to luminescence brought about by bombardment with cathode rays; a deeper insight was gained into the phenomenon of saturation with increasing current.

For some purposes, such as radar, it is not the fluorescence but rather the phosphorescence (persistent after-glow) that is of importance. It was found possible to obtain a fluorescent screen with long persistence by making it in two layers, the first of which gives a blue fluorescence under the influence of the cathode rays, this blue fluorescence then being suitable for producing a green phosphorescence in the second layer. For other purposes, such as the televising of films, substances with a short persistence are desired: a "field" produced on the fluorescent screen by an unmodulated electron beam is imaged onto the film, whilst behind the film is a photocell. This converts the light passed through, which is modulated by the variations in density of the film, into a signal which is passed to the transmitter.



A simple hydrogen liquefactor has been constructed for the examination of solids at low temperature (20 °K). The hydrogen gas is fed in under high pressure and precooled to the temperature of liquid nitrogen, after which, through expansion, by employing heat exchangers according to the *Linde* method, it becomes partly liquid (*Joule-Kelvin* effect). This installation has an output of about 2 litres liquid hydrogen per hour.

Many other important applications of luminescent substances which have been investigated in the laboratory have to be passed over here.

Ceramic materials and glass

Ceramic materials are obtained by sintering together small particles which in themselves have a crystalline structure. We do not refer here to the more common materials like porcelain, steatite, etc., about which little research work has been done, but to special materials, as for instance those with a high dielectric constant, such as rutile (TiO_2), and titanates such as $BaTiO_3$, with which important work has been done in recent years.

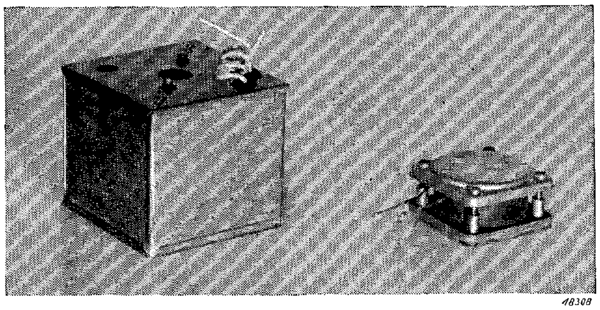
Particular mention is to be made of the magnetic ceramic materials (ferrites), because these have proved to be of great importance for high-frequency technique (radio and telecommunications).

Of theoretical importance was the interpretation of the losses which the magnetic ferrites show at very high frequencies (10^5 to 10^7 c/s): these losses were ascribed to the gyromagnetic effect prophesied by *Landau*, and this conception was confirmed experimentally.

Of practical importance was the resultant knowledge gained of the fact that the less the initial permeability of the substance in the low-frequency range, and thus the greater its crystal anisotropy, the higher is the frequency at which the gyromagnetic losses become perceptible.

The ferritic materials, which combine great hardness and relatively light weight with a very small electric conductivity and favourable magnetic properties, such as low losses in a wide frequency range, are now being manufactured by Philips under the name of "Ferroxcube" in various compositions.

In addition to the ferrites, of equal importance are the ceramic semi-conductors, which will be dealt with below in a separate section devoted to semi-conductors.



Improved quality and saving of space are important advantages of the magnetic material "Ferroxcube" as compared with metallic magnetic materials. *Left:* can containing a bandpass-filter coil for carrier telephony, the core of which consists of nickel-iron wires and the jacket of dust-core material. The can is necessary on account of the small effective permeability of the dust-core material. Quality factor $Q = 220$ at 60 kc/s, volume 210 cm³. *Right:* coil with core and jacket of "Ferroxcube", $Q = 600$ at 60 kc/s, volume 44 cm³.

Glass is a material of fundamental importance for the manufacture of incandescent lamps and radio valves. Apart from the obvious physical properties, such as the softening point, coefficient of expansion and specific gravity, there are many other properties to be considered, such as the dielectric constant, dielectric losses in high-frequency electric fields, electric conductivity, spectral transmission, etc. Considering the large number of ingredients from which glass is mostly made, and consequently the numerous possible variations in composition, it would seem to be an almost impossible task to gain a clear insight into the effect of the composition of a glass upon its physical properties. Yet in recent times considerable success has been attained in this direction, particularly due to the better theoretical knowledge acquired as a result, i.a., of the work done by *Zachariasen*. It is now possible to form an idea of the internal structure of glasses and from that to predict their properties. Even though the reality proves to be more complicated than the theoretical model, the latter anyhow points the way to approximating the correct relations of the phenomena and for investigating those relations which are most promising for gaining the insight desired.

In cooperation with the glass works the following practical results have been obtained: soft glasses with small dielectric losses, glasses which have small dielectric losses independent of frequency, glasses which under the influence of X-rays do not discolour or which, on the other hand, very readily change colour, and glasses which are transparent to ultra-violet radiation.

Metals

Metals form an important and extensive group of materials. The investigation of tungsten and molybdenum and of metals like titanium, zirconium, hafnium and thorium has already been mentioned, as also that of alloys such as chrome-iron.

The investigation of magnet steels has likewise already been referred to. The very important "Ticonal" (an alloy of iron, titanium, cobalt, nickel and aluminium) with a high value of the product $(BH)_{max}$ and great coercive strength, was further improved by making it anisotropic by cooling in a magnetic field or by some other means.

The nickel-iron with anisotropic structure obtained by rolling, for use in loading coils, has also been mentioned elsewhere. Extensive investigations have been carried out as to the manner in which the texture of this material could be influenced by a suitable thermal and mechanical treatment.

Another group of products is formed by the welding rods, the coating of which has been the subject of particular study. Special mention is to be made of the new method of contact welding, for which purpose the rods are given a special coating with a high iron content.

It is partly in connection with this that extensive investigations have been carried out into the diffusion of gases in metals. This subject had become of real importance as soon as the manufacture of water-cooled metal transmitting valves and metal X-ray tubes was begun, and it proved to be of particular interest in connection with welding problems, especially as regards the penetration of hydrogen into the metal of the welding bead, causing porosity, cracks and fractures. In this connection mention is also to be made of more fundamental research, as for instance that concerning ageing phenomena such as occur, inter alia, in welding.

The absorption of gases by metals has particularly also been studied in the case of metals like zirconium and titanium, which are used as getters in X-ray tubes and transmitting valves. Incidentally reference is to be made here to the coating of anodes of transmitting valves with zirconium to give them a black surface with good heat-radiating properties and also to reduce secondary-electron emission. Investigations of a more technical nature in the field of metals led to new methods of shaping and improved methods for determining the properties of samples of metal, an example of the former being the so called "lost wax" casting of metallic parts of instruments and apparatus which would be too costly if the ordinary methods of processing were followed, whilst an example of the latter is to be found in the micro-hardness meter.

This section on metals will be concluded by a short reference to investigations concerning oxidation and corrosion. Interesting aspects are presented by the method of hardening alloys by internal oxidation. A study of corrosion at high temperatures revealed that small quantities of molybdenum oxide may have a harmful effect. Investigations into the non-oxidizing property at high temperatures and the solderability of non-oxidizing metals were particularly of importance in connection with the development of the hot-air engine.

Semi-conductors

Between the insulators of an inorganic and an organic nature, such as glass, porcelain, amber, polystyrene, on the one hand and the metals as good conductors for electric current on the other hand, there is an important group of substances which as compared with metals show little conductivity, e.g. iron oxides, copper oxide, selenium, germanium, etc. These are of interest because they possess typical properties lacking in the other two groups.

Their principal property is a large, negative, temperature coefficient of their resistance, a property found in practically all representatives of this group. Some of them also show photo-conductivity, in that when exposed to light their resistance is reduced. Others, when provided in a certain way with electrodes, appear to have rectifying properties, which means to say that when the current flows in one direction the resistance is many times, say 1000 or more times less than in the other direction. There are also certain materials whose resistance appears to be dependent upon the electric potential gradient.

Although these properties have been known for a long time it is only during the last 10 to 15 years that it has been found possible to utilize them. Obviously a high temperature coefficient of the resistance offers many possibilities. Mention may be made, for instance, of the measuring of temperature and of radiation; furthermore, owing to the negative sign of the coefficient, there is the possibility of suppression of current peaks and application in delay devices, regulating apparatus, etc.

A peculiar feature of these materials is that often their specific resistivity is not a property inherent in the material, as is the case, for instance, with a metal, but that it depends to a large extent upon the antecedents, such as the temperature and the gas atmosphere applied in the preparation, the presence or not of impurities and many other factors.

In the field of oxidic semi-conductors some extensive crystal-chemical investigations have led to the production of semi-conducting materials answering high requirements of reproducibility and stability. Such a material is being marketed in various forms as "N.T.C. resistors" (negative temperature coefficient resistors).

Much attention was paid also to selenium. The resistance of selenium can be varied by the addition of foreign substances. This investigation has led to the production of rectifiers suitable for low voltages, e.g. 18 V, and, by connecting them in parallel, for high currents. On the other hand very small rectifiers are being made for currents of a few milliamperes, as used in the amplifying technique, for example, for modulator cells, which play an important part in carrier-telephony, and in series-connected small cells for rectifying high voltages. By a certain treatment of the surface of the selenium and choice of the electrode material it is possible, to a certain extent, to determine the voltages which are to be applied per rectifying unit.

During the years 1940-1945 there has been renewed interest in the crystal rectifier, a component used in the early days of radio. It appears that in the range of ultra-short waves, which has become of such importance, this element in a more perfected form offers advantages over rectifying valves. Extensive investigations are proceeding in the laboratory also in this field and have already led to a rapidly increasing manufacture of various types of crystal rectifiers.

There are indications that the possibilities of applications in the field of semi-conductors are not by any means exhausted, and that, by the very reason of their abnormal properties, we are only at the beginning of a development of great importance for electrotechnical engineering.

Products

This review will be concluded by referring to some products which have particularly come into existence in the last ten to fifteen years as a result of laboratory work. The reader is not to expect a catalogue with detailed descriptions. Many of the products which will be mentioned have already been described more or less fully in recent volumes of this journal, whilst a description of some others will shortly be appearing in our columns. Suffice it, therefore, to mention in a few words only the most important products.

Sources of light

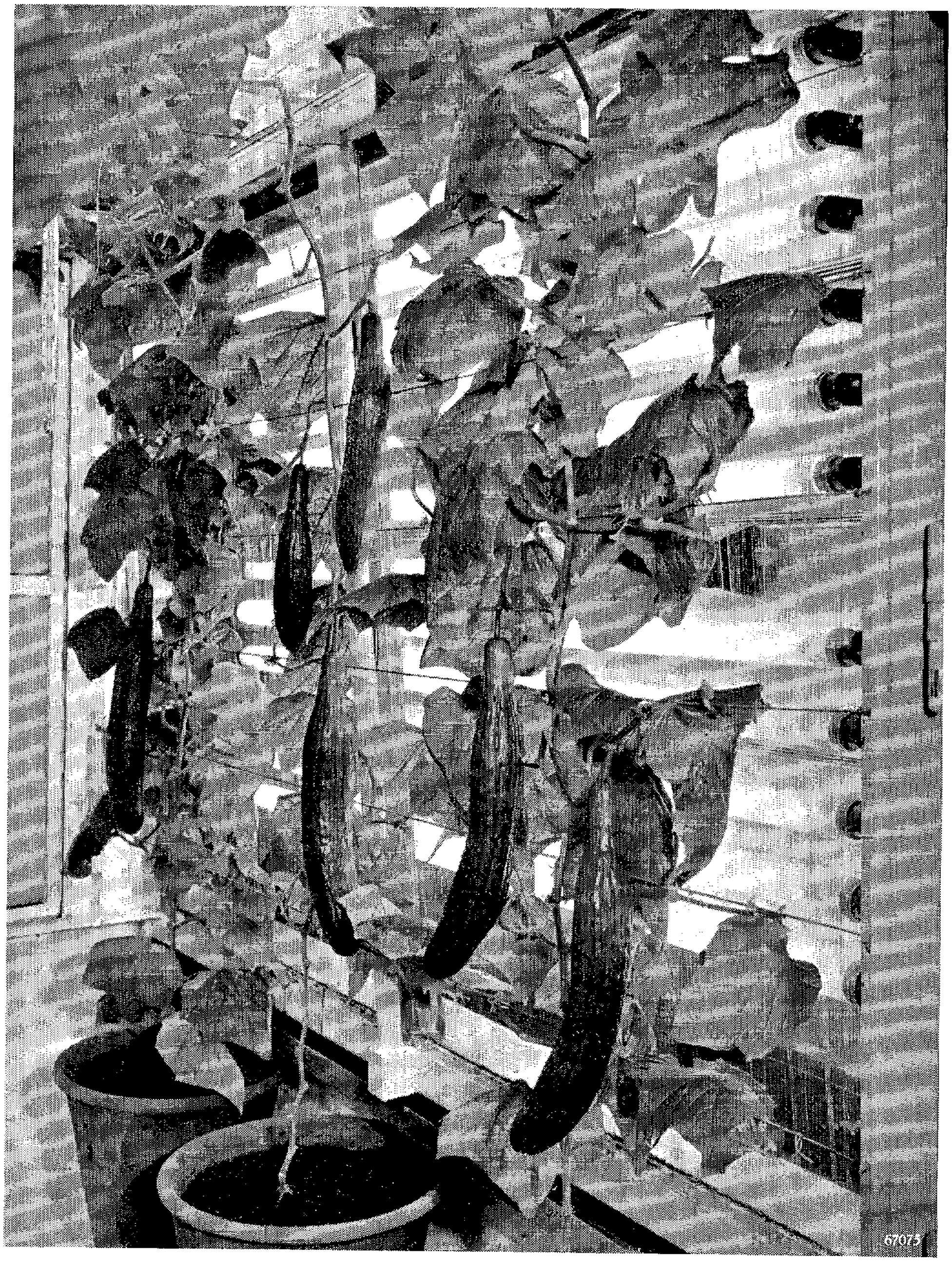
In the field of lighting we have already referred to the "TL" lamps, which as such have already long passed the laboratory stage of development. Further investigations in connection with these lamps are being carried out in regard to their colour rendering, for instance with new phosphors used in their manufacture. Particular mention is to be made of the application of "TL" lamps for irradiating plants. Since 1949 the Philips laboratory has had a large horticultural glasshouse at its disposal, in which various plants are being cultivated, and also a dozen smaller glasshouses illuminated exclusively with artificial light. With the large variety of phosphors available it is possible to investigate how the growth and flowering of plants are affected by the spectral energy distribution and the intensity and duration of radiation.

Further, there is the low-pressure mercury lamp without any fluorescent material but made with a glass which is transparent to ultra-violet radiation (2537 Å), viz. the so-called germicidal lamp. Other special sources of light are the flashlamp for the illumination of *Wilson* chambers and for other photographic instantaneous exposures, and a point source of light in the form of a gas-discharge lamp the light of which can be modulated up to high frequencies.

Glasshouse for biological investigations.

Radio, television, etc.

In the field of radio conditions had already reached such a stable state before 1940 that the normal development of valves and apparatus no longer belonged to the work of the laboratory, so that attention could be directed towards new developments. In the first place mention is to be made of the new valves for ultra-short waves (decimetric and centimetric waves). Development of these valves had already reached an advanced stage abroad during the war years, so that in 1945 Philips had a great deal to catch up with. Extensive investigations had already been carried out with radio valves in the metric wave range. Special tubes were developed based upon the velocity modulation of



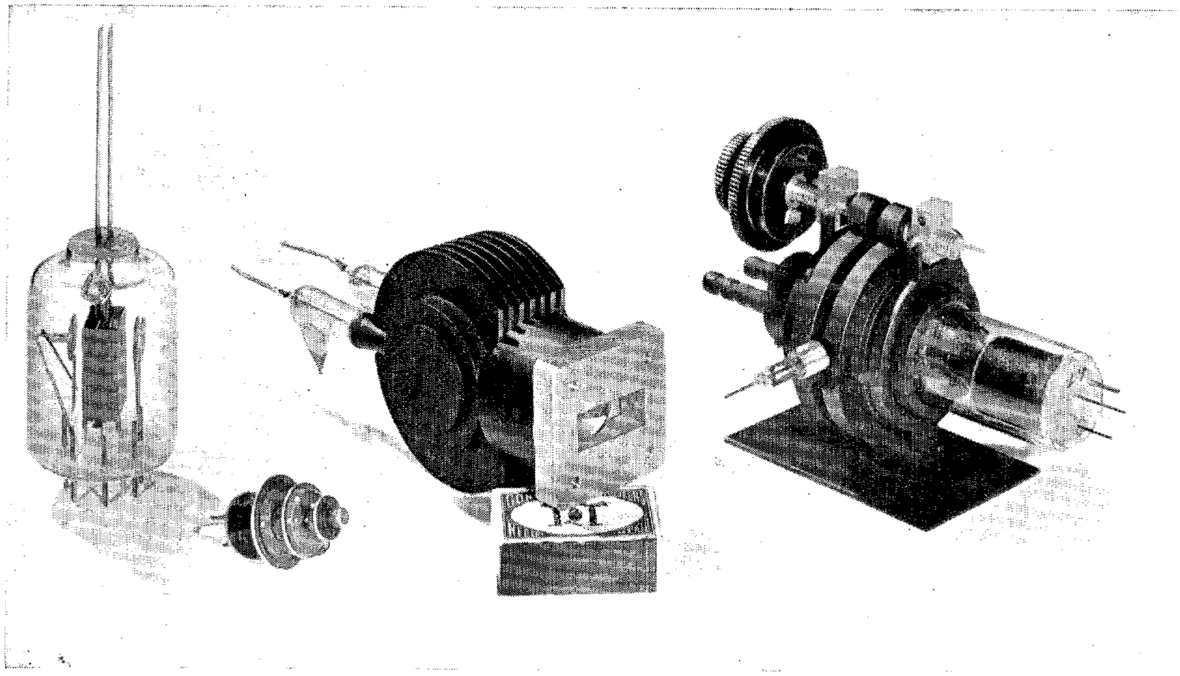
Cucumbers cultivated entirely under artificial light. The light is supplied by "TL" lamps. The temperature inside is prevented from rising too high by causing tap water to flow down the pane of glass in front of the lamps. Half-way down between the "TL" lamps is a TUV lamp, the ultra-violet radiation from which prevents the growth of algae on the glass.

electrons (the velocity-modulation valve, the klystron, the multireflection tube), employing a number of Philips' own inventions.

An important improvement of heated cathodes is the L-cathode, which contains a reservoir filled with barium oxide and enclosed by a porous wall of tungsten acting as the source of electron emission. With the aid of this cathode a disc-seal triode can be built for wavelengths down to 8 cm with a clearance of only 40 μ between cathode and grid. This new type of cathode offers important possibilities for many other applications as well.

An intensive study is being made of the special circuits for generating ultra-short waves, by employing cavity resonators, and of modern means for conducting high-frequency energy with the aid of wave guides.

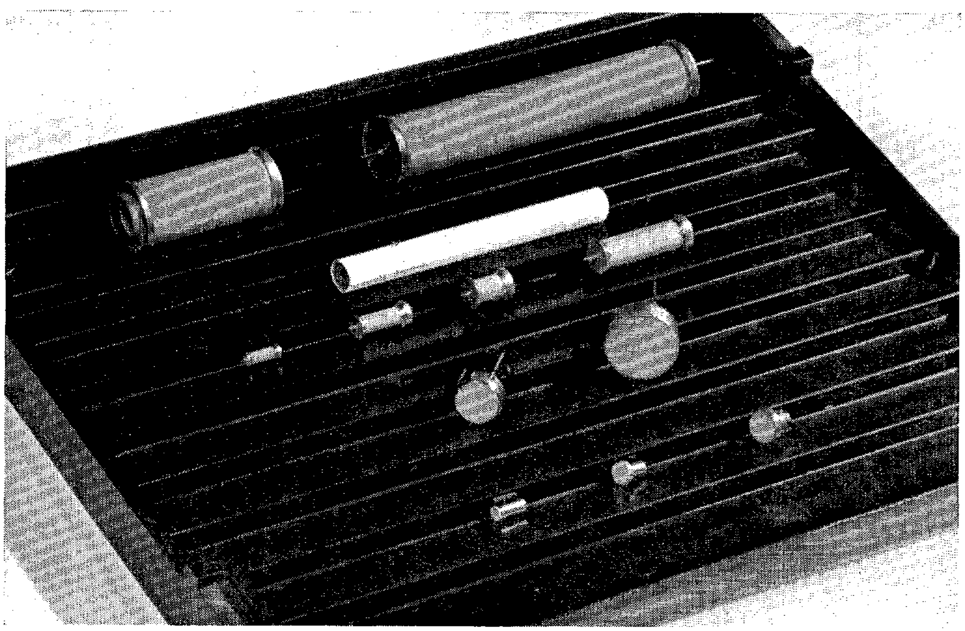
After 1945 the development of television had to be taken in hand again in the laboratory on account of the greater interest being shown in it everywhere.



67086

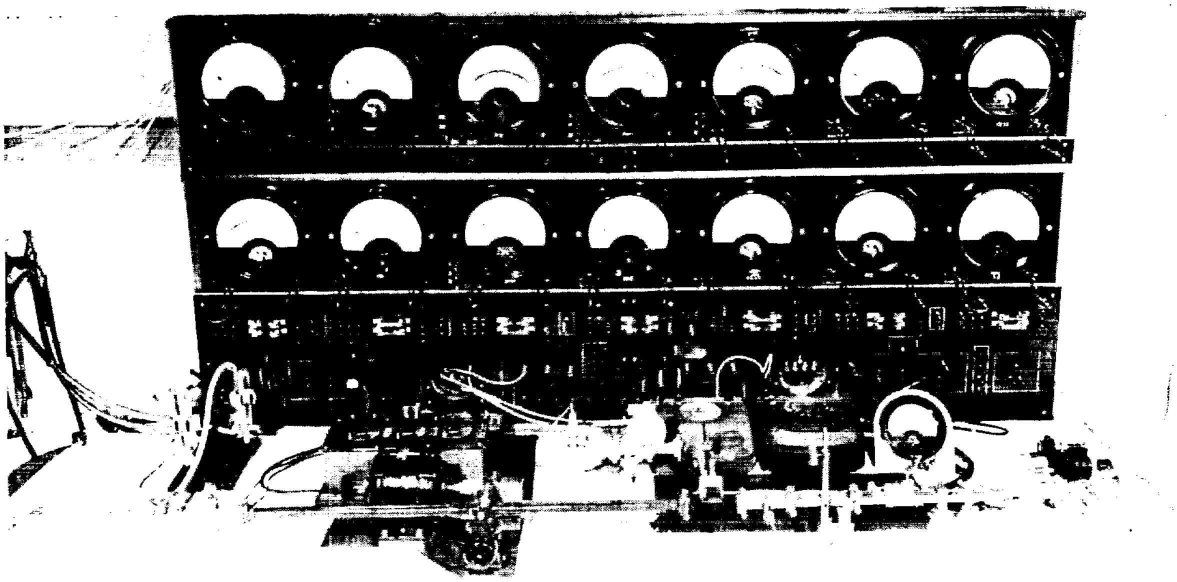
Tubes for centimetric waves. From left to right: a multireflection tube with a continuous output of 20 W on a wavelength of 12 cm; a receiving tube of the "lighthouse" shape for amplification of wide frequency bands (gain 10 at a bandwidth of 50 Mc/s, noise figure 10 db at a wavelength of 10 cm); a magnetron yielding pulses of 1000 kW at a wavelength of 3 cm; a velocity-modulation valve with a continuous output of 100 W at a wavelength of 3 cm.

At first a system of 567 lines was used, with 25 frames per second. In the audio channel frequency modulation was applied. As a result of many discussions on the question of the number of lines the transmitting apparatus was designed so that it could quickly be changed over to different numbers of lines. This proved to be of great value for judging the relative merits of various systems. When, later on, the Netherlands Television Committee advised the adoption of a system with 625 lines



67074

Some L cathodes (with a cigarette for comparison of size). The L cathode has a porous, metal, emitting surface and can withstand heavy loads, say 100 A per cm^2.

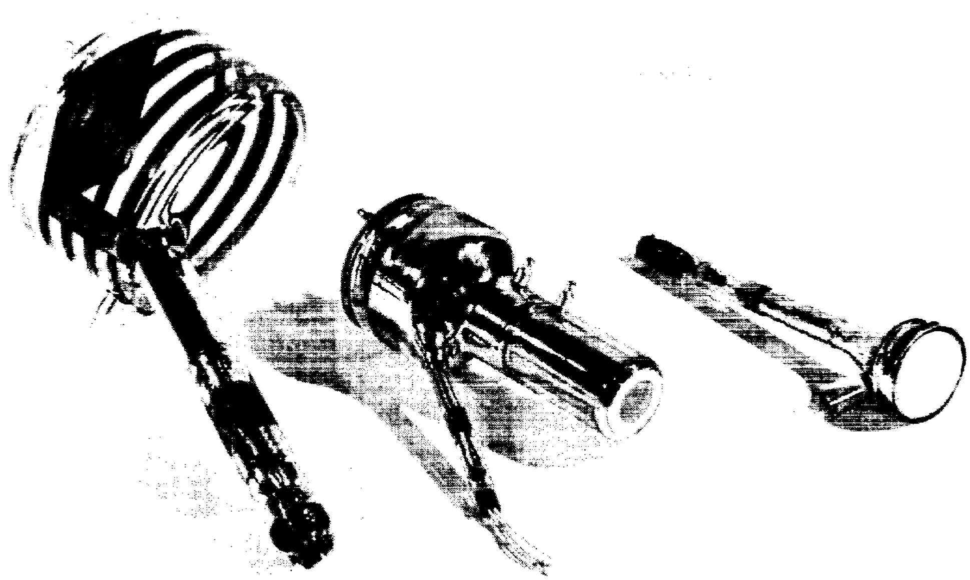


67087

Set-up for taking measurements of a velocity-modulation valve (on the extreme right) at a wavelength of 3 cm. Here wave guides are used for conducting the energy.

and 25 frames per second the installation was made suitable for that system.

Further, attention was devoted both to the problems encountered at the receiving end and to those arising in the transmission. As far as reception is concerned, based upon the results of experiments already mentioned a system of projection television was worked out with the aid of a *Schmidt* optical system, using very small projection tubes with the screen coated with phosphors suitable for the purpose. Special precautions had to be taken against discoloration of the glass of these tubes under the influence of cathode rays and X-rays. In the optical system proper, use was made of a correction plate made of gelatin, for which a separate method of manufacture had to be developed.



67082

Left: two pick-up tubes for television (an iconoscope and an image iconoscope). Right: a picture tube for projection television.

Of course attention had also to be paid to direct-view reception. One of the most important results of the work done in this connection was a considerable improvement in regard to flicker of the image by employing phosphors having a long persistence.

As regards TV transmission the most important advance made was in the construction of new pick-up tubes based on the principle of the image iconoscope. Further improvements lay in the television cameras and in the studio lighting.

Except for some short interruptions there have been regular experimental television transmissions from Eindhoven ever since 1946, for which purpose a studio, a control room and dressing rooms for artists were fitted out in the laboratory building. These experimental transmissions have helped much towards arousing the interest now being shown in this youngest branch of technical development both in the Netherlands and in adjoining countries.

Next in order to radio and television is the work done in the field of telecommunications. Ever since 1935 there has existed a department in the laboratory (organically not belonging to it but as part of the A.F. telephony department of the works) where apparatus for carrier telephony, i.a. a 17-channel system, and for A.F. telegraphy have been developed. About 1940, in cooperation with the laboratory, a modern carrier-telephony system for 48 channels was developed, in which the new core material for coils, "Ferroxcube", plays an important part. This system is already being used on an extensive scale in the Netherlands and in Switzerland, whilst it is to be installed also in Denmark in the near future. In this connection a word of grateful recognition is due to the Netherlands P.T.T. officials for their close cooperation. In 1945 the carrier-wave department was transferred from Eindhoven to the Philips' Telecommunication Industry at Hilversum, whilst a research group for telecommunications was established in the laboratory. Development work in Hilversum is proceeding further in the direction of the improvement and reduction in size of electrical and mechanical parts, with the aid of results reached in the laboratory.

Special carrier systems have been developed which are suitable also for short distances. Further, by developing such things as repeaters, a super-group through-filter and other filters, the laboratory has already contributed much towards a system now in course of development at Hilversum for incorporating some hundreds of channels in a coaxial cable.

In this laboratory work is continuing on new methods of modulation; for instance, a simplified form of pulse-code modulation has been studied, the quantum modulation, which makes it possible for conversations to be carried satisfactorily over long distances in spite of a high noise level. In addition, the possibilities of applying new materials and components for telecommunication apparatus are being studied.

In this connection mention is to be made of the new switching tubes with ribbon-shaped electron beam, which promise interesting applications in the field of telecommunications and electric computers.

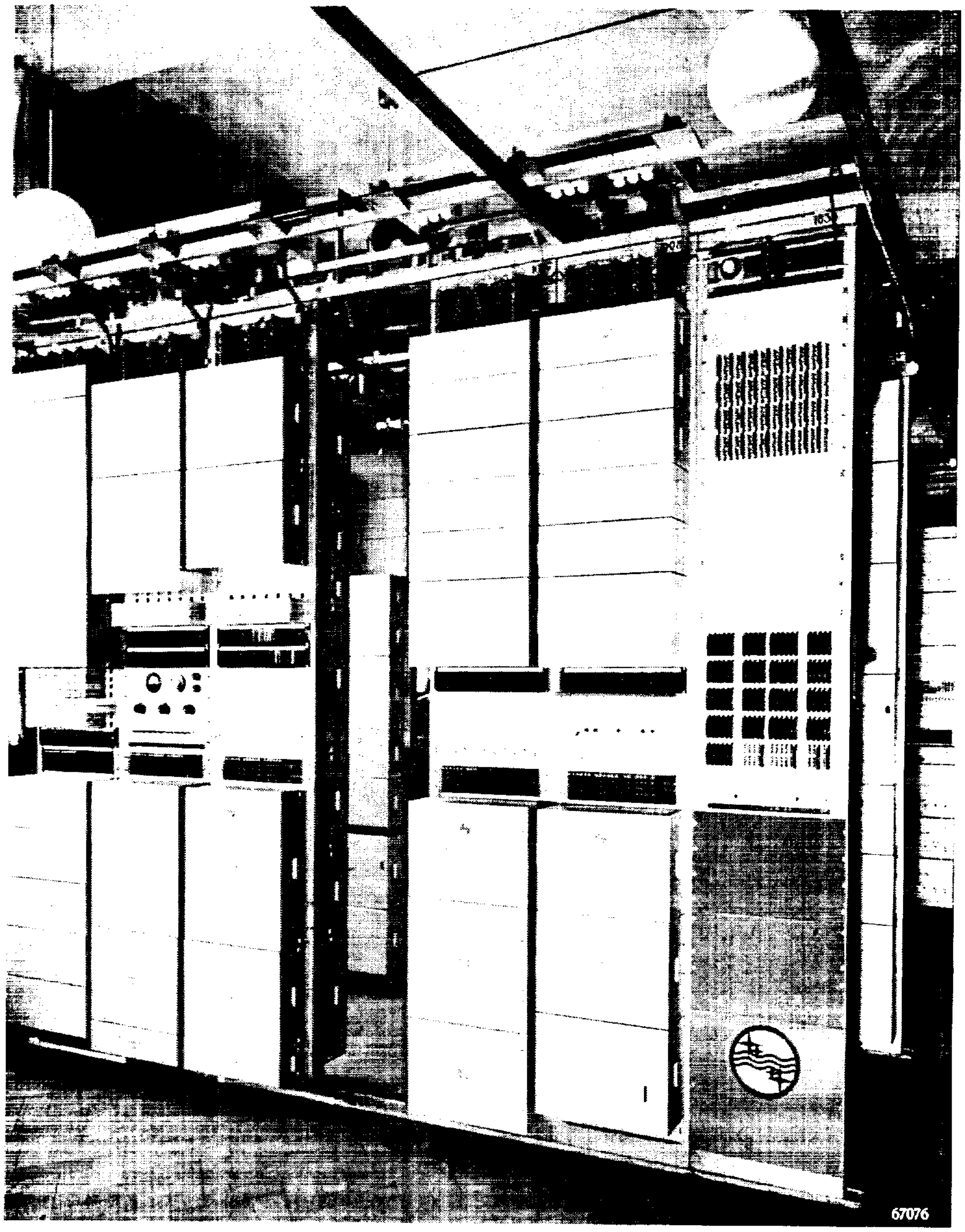
Special mention is to be made of the system of facsimile transmission worked out in the laboratory, by means of which documents can be transmitted and photographically recorded at the rate of 5000 cm^2/minute.

Of importance for meteorology is a newly developed radio sonde, in which extremely small radio valves with low current consumption are employed and with which experiments are now being carried out in conjunction with the Royal Netherlands Meteorological Institute at De Bilt.

Dr. A.F. Philips in front of the camera of the Eindhoven television transmitter.

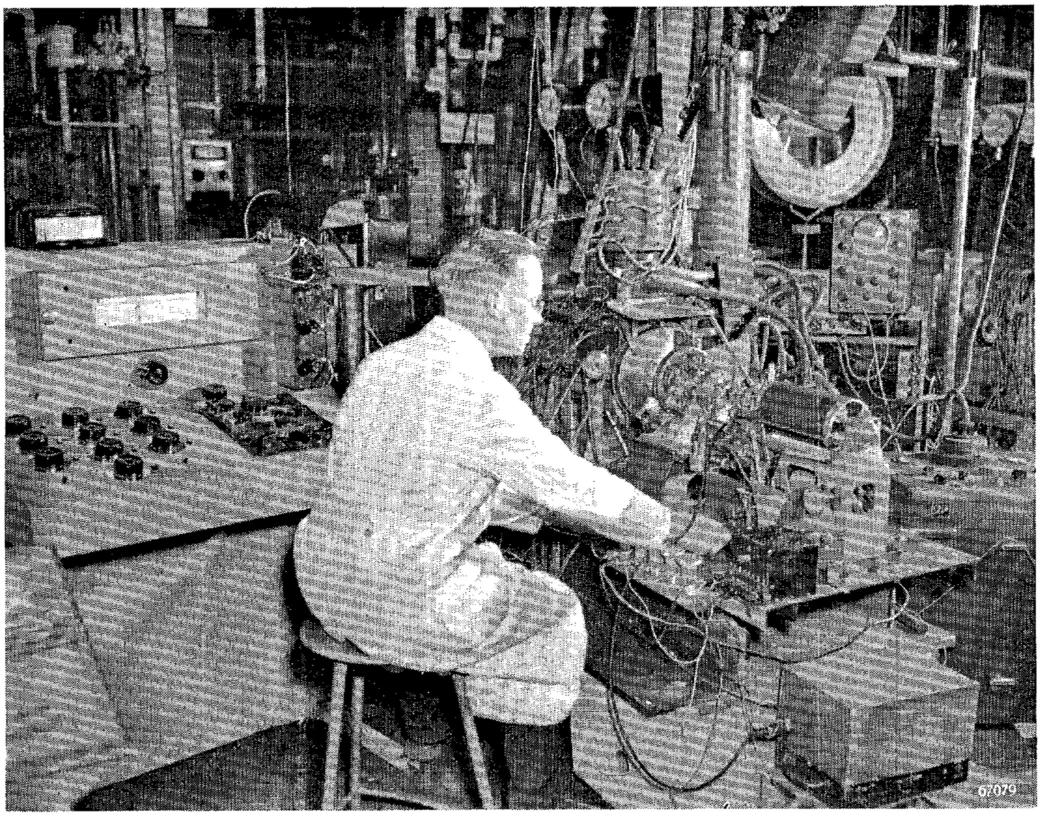
Approved For Release 1999/09/24 : CIA-RDP83-00423R002000130013-1

A product which certainly has some connection with radio, considering the need of a supply source in places where no electricity is available, but which represents the outcome of a development of its own, is the air engine already referred to in this review. From a close study of the heat exchange between flowing gases and metallic walls and of materials suitable therefor, and further of the thermo-dynamics of the cycle, it has become possible to build a light high-speed motor with good thermal efficiency. A new principle of application for systems with more than one cylinder, according to which the piston of one cylinder is caused to act as the transfer piston for another, is of importance in connection with future possibilities the consequences of which cannot yet be fully predicted.

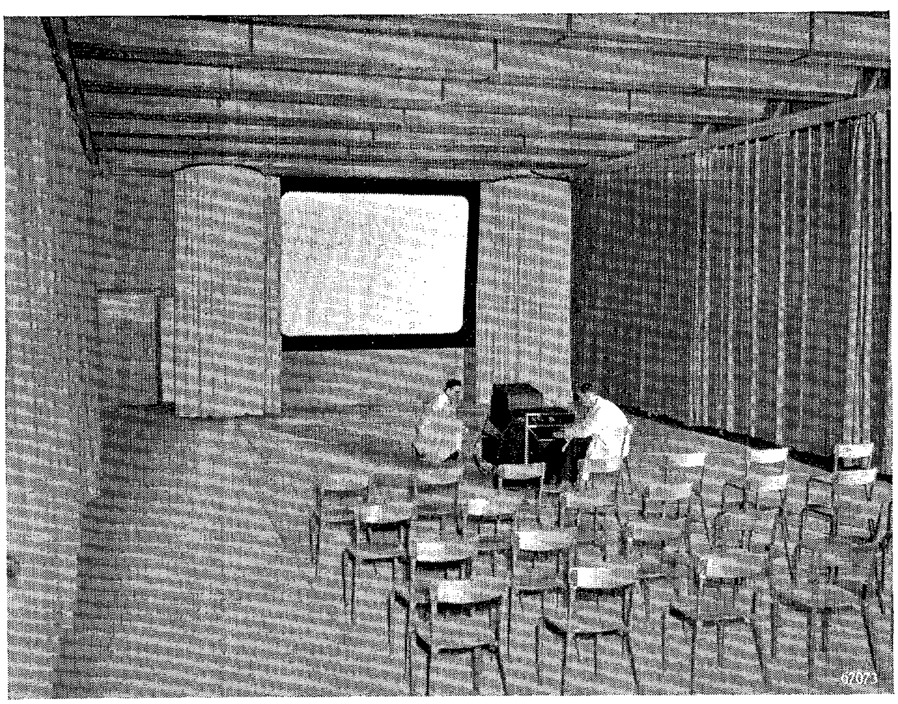


Experimental installation for carrier telephony.

In the field of acoustics there are quite a number of new products to be mentioned. First of all the improved sound reproduction by means of stereophony, which has led also to the construction of small microphones. The ideal microphone, with small dimensions compared with the wavelength, also for high audio-frequencies, appeared to be most closely approximated by the condenser microphone,



Taking measurements in the testing of an experimental air engine. Energy input by electric heating, energy output via a loaded dynamo. Connected to the desk on the left are thermo couples measuring the temperature at various points (inside and outside). A *Farnboro* pressure indicator records the pressure in the cylinder as a function of time; the phase of this diagram is checked with the aid of a capacitive pressure indicator (connected to an oscillograph) and a stroboscope.



Hall for acoustical investigations (i.a. stereophony) and large-screen television (almost 3 m × 4 m).

which can now be made in a size of about 20 mm. and for special purposes even as small as 7 mm.

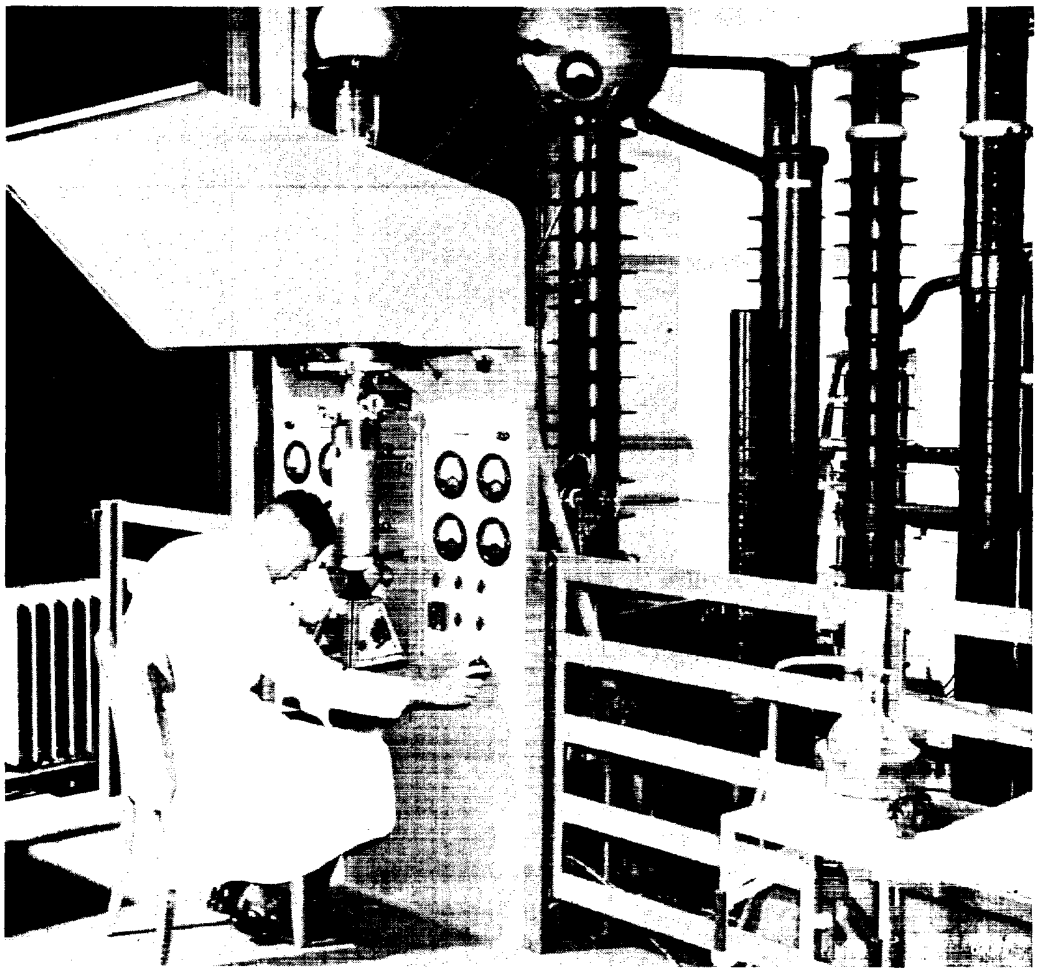
In the Philips laboratory the necessary attention has also been paid to the development, started in Denmark, of the magnetophone for recording and reproducing sound. This development obliged the manufacturers of gramophone records at last to relinquish the demand that it should be possible to play their records both electrically and mechanically, as a result of which considerable improvements became possible in the field of electrical gramophone reproduction by means of microgroove records. Thus the gramophone record may retain its position as an instrument of reproduction.

Physiological study and the resultant connection with the medical world led to the construction of hearing aids.

Experience gained in the amplification of signals of very low frequency, close to the limit of audibility, led further to the designing of a vector cardiograph, some specimens of which have been given to medical experts for testing.

Miscellaneous

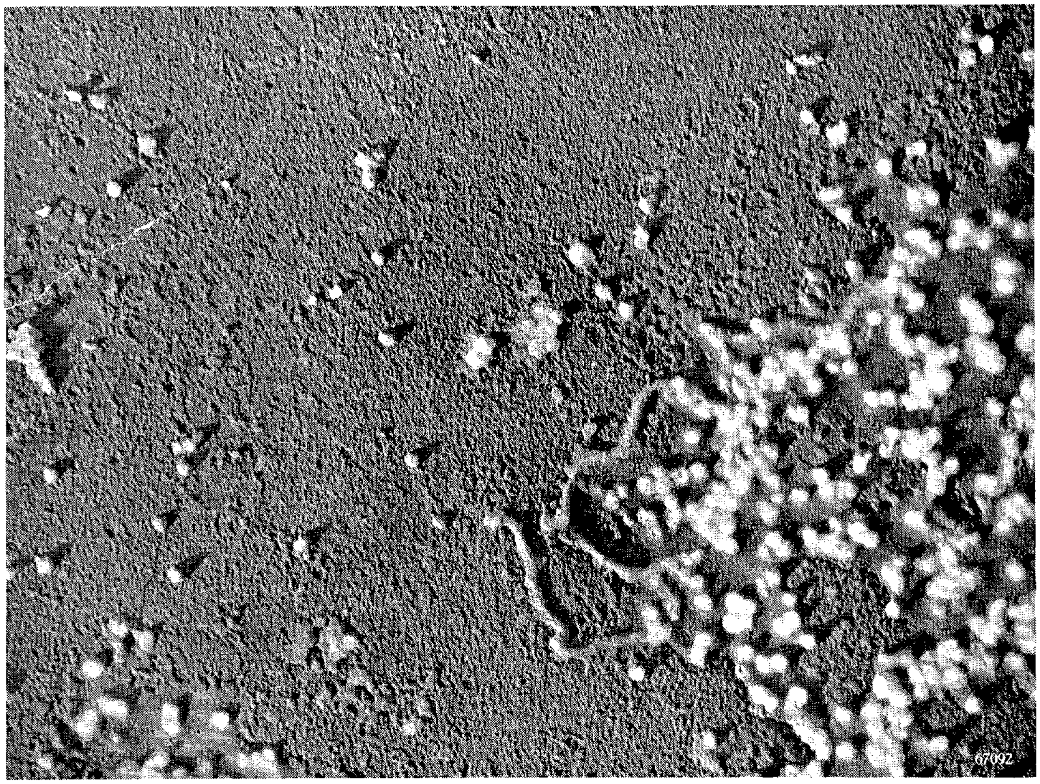
Among the X-ray tubes there is a new one for contact therapy and, further, new high-powered tubes for X-ray diffraction with accessory apparatus.



Experimental electron microscope with an accelerating voltage of 100,000 V.

With the experience gained in the field of television it has been possible to construct an X-ray picture intensifier, by means of which the intensity of the screen picture can be increased to such an extent as to allow of screening patients in a room not blacked out. A number of these intensifiers are now being tried out in Philips' Medical Department.

As an offshoot, so to speak, of the development of cathode-ray tubes, aided by the experience acquired with high tensions and in collaboration



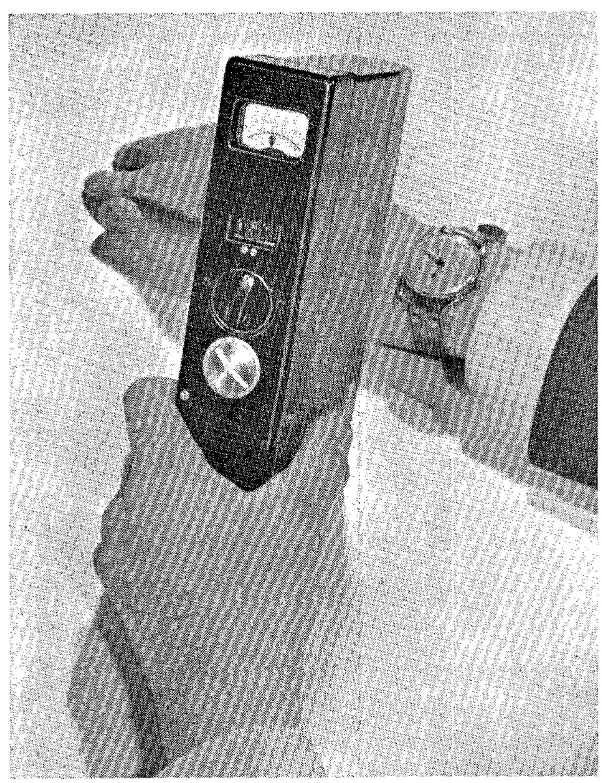
Microgram of influenza virus (specimen not entirely purified) magnified 21,000 times by the electron microscope. This virus occurs in the shape of small pellets as well as in a thread-like form.

with the Technical-Physical Laboratory of the Technical University at Delft, an electron microscope with a magnetic electron-optical system was constructed. An apparatus for 100 kV has been marketed, and in the laboratory an experimental apparatus for 400 kV has also been built. Recently, following upon previous experiments by Burgers, an emission-electron microscope has been developed, with which phenomena at the surface of metals (recrystallization) can be observed with a magnification of 1000.

For the detection and measurement of X-rays and other kinds of rays, radiation counter tubes with accessory apparatus have been made, and a special electrometer with vibrating capacitor has been developed, which can be connected, for instance, to a dosimeter for X-rays.

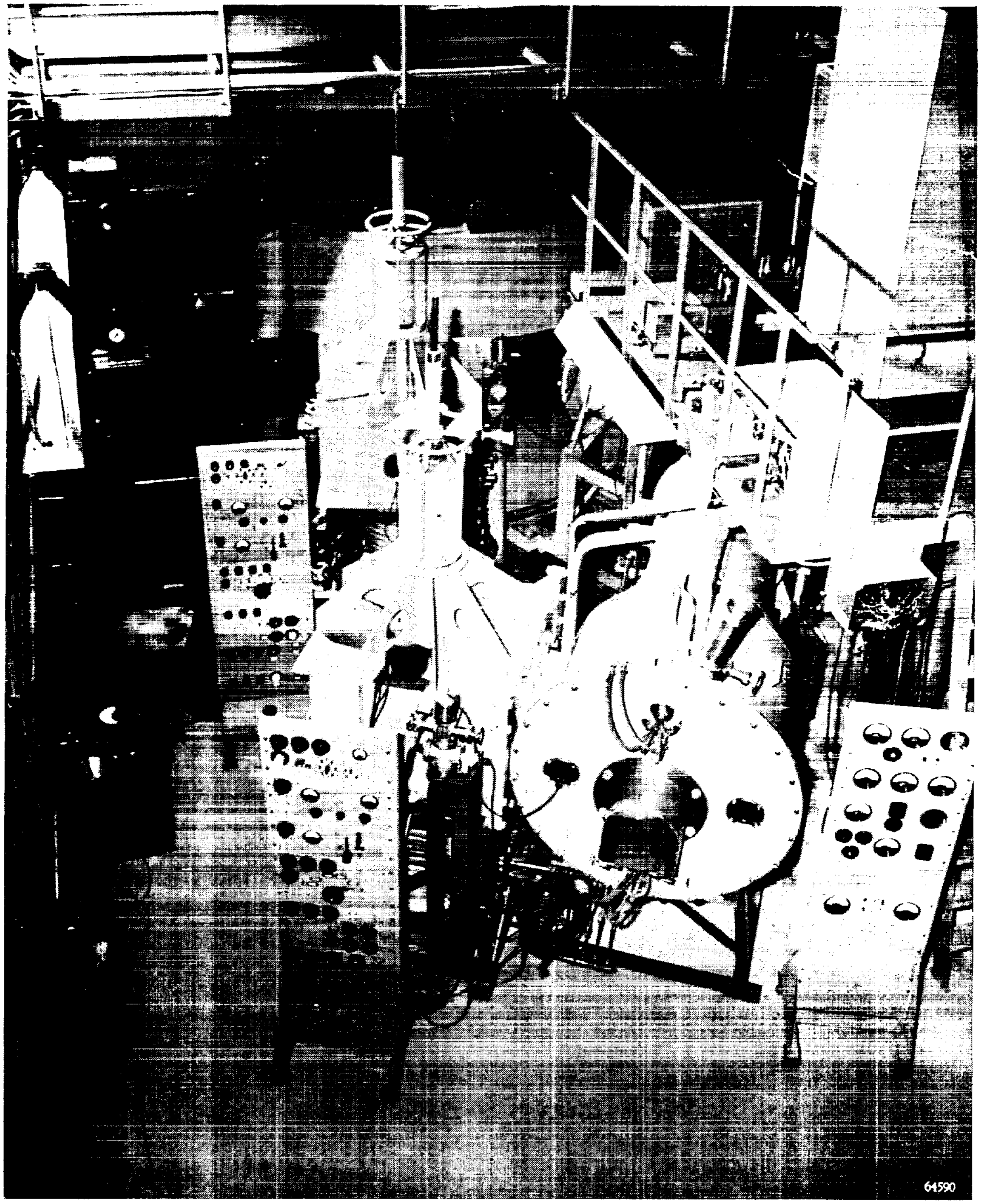
Finally, nuclear-physical research has led to the construction of neutron generators with ion-accelerating tube (maximum voltage 1.2 MV) and also a synchrocyclotron, with which, for instance, deuterons can be accelerated to an energy of 28 MeV; this synchrocyclotron has been installed at Amsterdam.

Further, an experimental betatron with air coils has been developed, with which electrons can be accelerated to an energy of 9 MeV.



67065

Portable radiation counter for detecting beta and gamma rays, fed entirely from built-in batteries. The counter reacts perceptibility to the rays from the luminescent paint on the hands of a watch.



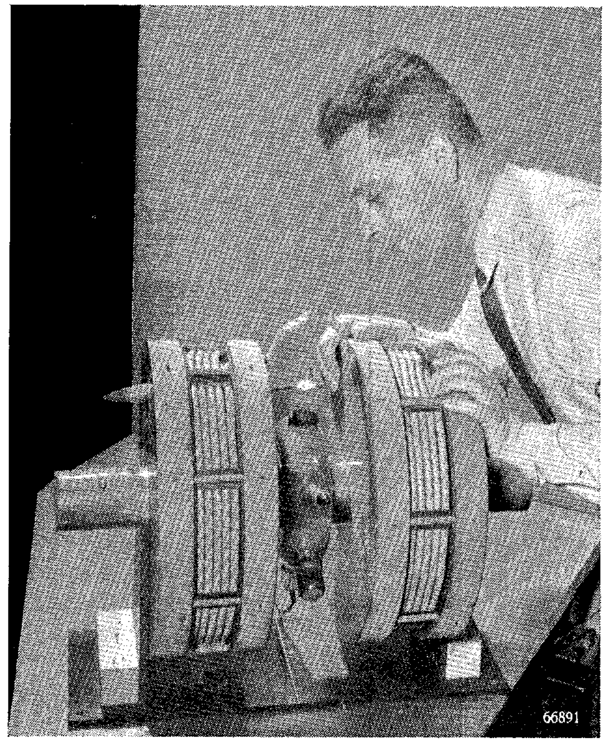
* The synchrocyclotron installed in the Institute for Nuclear Research at Amsterdam. This cyclotron produces continuously deuterons with an energy of 28 million electronvolts. In the background the electromagnet, between the poles of which, where there is a maximum flux density of 1.38 Wb/m², are the two Dees (not visible in the photograph) inside which the deuterons describe spiral orbits. Between the Dees is an alternating voltage with a peak value of 15 kV and a frequency of about 10.7 Mc/s. The modulator (in the foreground on the right) varies the frequency periodically by an amount of 4%, so as to keep at least some of the deuterons to the desired orbits.

Conclusion

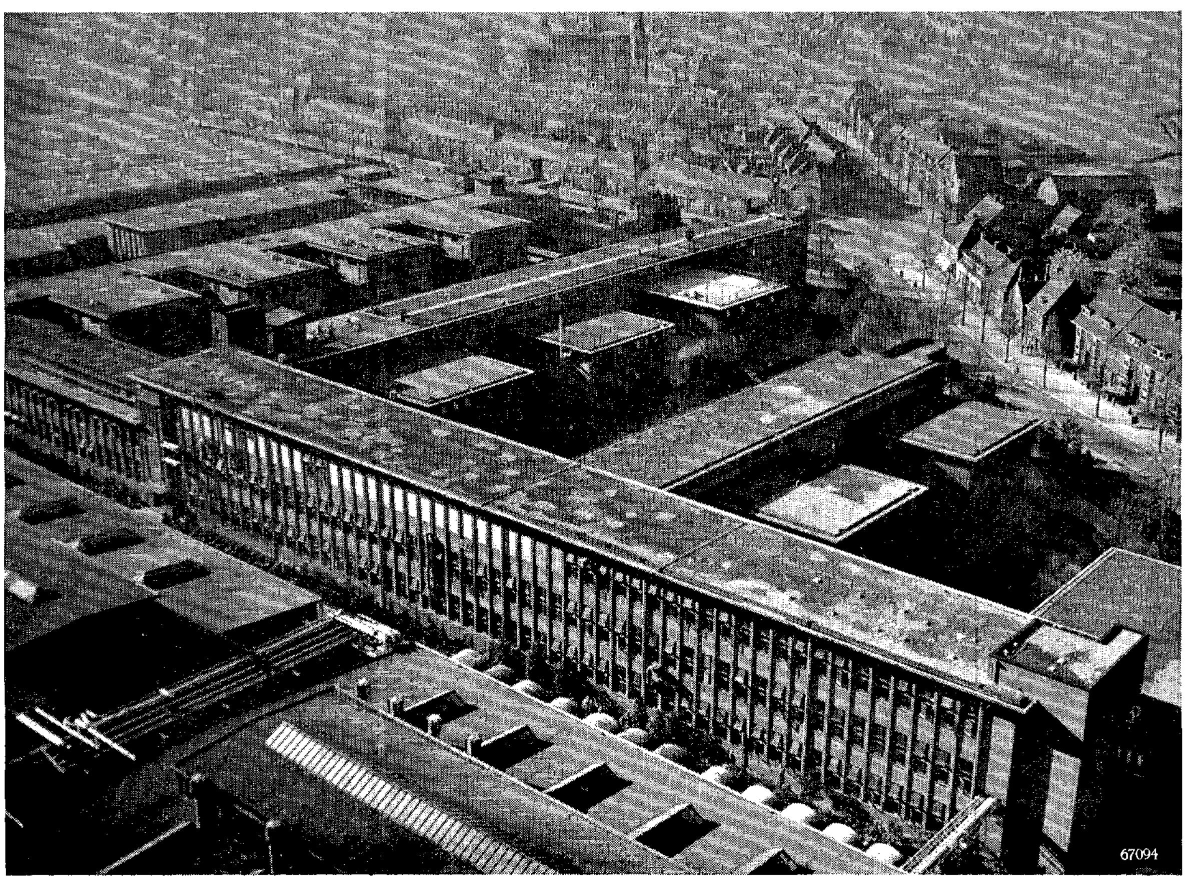
In the foregoing an attempt has been made to give a review of the activities of the Physical Research Laboratory of Philips' Industries in the course of the nearly forty years during which it has formed part of the Concern now celebrating the sixtieth anniversary of its foundation. It goes without saying that these activities could not have been achieved without the build-up of an extensive organization for the equipment of the laboratory and the workshops. In many cases these workshops have made substantial contributions to the realization of various projects.

The writer is fully aware that many sides of the development of the research work have been inadequately treated in this review. Due to lack of space, several subjects have received but scanty attention or have not been mentioned at all. However, the reader will be able to supplement this summary by referring to the Abstracts of Scientific Publications regularly appearing in Philips Technical Review and to the subject index given with the last number of each volume.

W. de Groot.



A betatron, with which electrons can be given an energy of 9 million electronvolts. The electrons travel round in the annular glass tube seen in the middle. The particular feature about the rest of the construction is that no iron yoke is used for the magnetic field.



BOOKS WRITTEN BY SCIENTISTS OF THE PHILIPS' RESEARCH LABORATORY *)

G. Holst. Electrische lichtbronnen en hare eigenschappen (Electric sources of light and their properties; in Dutch only). Haarlem, de Erven Boon, 1920.

A. Bouwers. Physica en techniek der Röntgenstralen (Physics and technics of X-rays; in Dutch only), Deventer, Kluwer, 1927.

A. E. van Arkel and J. H. de Boer. Chemische binding als electrostatisch verschijnsel (Chemical binding as electrostatic phenomenon; in Dutch). Amsterdam, Centen, 1930 (Supplement 1937).
id. id. Chemische Bindung als elektrostatische Erscheinung. Leipzig, Hirzel, 1931.
id. id. La valence et l'électrostatique. Paris, Alcan, 1936.

J. H. de Boer. Electron emission and adsorption phenomena. Oxford, University Press, 1935.
id. Elektronenemission und Adsorptionserscheinungen. Leipzig, Barth, 1937.

W. Uyterhoeven. Elektrische Gasentladungslampen. Berlin, Springer, 1938.

A. Bouwers. Elektrische Höchstspannungen. Berlin, Springer, 1938.

A. E. van Arkel. Moleculen en kristallen (Molecules and crystals; in Dutch). The Hague, Van Stockum, 1941.

W. G. Burgers. Rekristallisation, verformter Zustand und Erholung. Handbuch der Metallphysik III, Leipzig, Akademische Verlagsgesellschaft, 1941.

H. Bruining. Die Sekundär-elektronenemission fester Körper. Berlin, Springer, 1942.

P. J. Bouma. Physical aspects of colour. 1947 (also in Dutch, French and German) edited by N.V. Philips' Gloeilampenfabrieken, Technical & Scientific Literature Department.

E. J. W. Verwey and J. Th. G. Overbeek. Theory of the stability of lyophobic colloids. Amsterdam, Elsevier Publishing Co., 1948.

J. L. Snoek. New developments in ferromagnetic materials. Amsterdam, Elsevier Publishing Co., 1948.

F. A. Kröger. Some aspects of the luminescence of solids. Amsterdam, Elsevier Publishing Co., 1948.

J. M. Stevels. Progress in the theory of the physical properties of glass. Amsterdam, Elsevier Publishing Co., 1948.

H. Bremmer. Terrestrial radio waves. Amsterdam, Elsevier Publishing Co., 1949.

Balth. van der Pol and H. Bremmer. Operational Calculus, based on the two-sided Laplace integral, Cambridge, University Press, 1950.

W. Elenbaas. The high-pressure mercury vapour discharge. Amsterdam, Noord-Hollandse Uitgeversmaatschappij, 1951.

*) This list does not include books the contents of which are not directly related to the laboratory work, a number of contributions to manuals, and suchlike.

CONTENTS OF THE LAST TWO NUMBERS OF PHILIPS RESEARCH REPORTS

Vol. 6, No. 2, 1951

Vol. 6, No. 3, 1951

Readers interested in any of the above-mentioned articles may apply to the Administration of the Philips Research Laboratory, Kastanjelaan, Eindhoven, Netherlands, where a limited number of copies are available for distribution.

Philips Techn. Rev. Vol. 13, No. 1-2 July-August 1951

Contents

PHILIPS TECHNICAL REVIEW IS PUBLISHED MONTHLY IN FOUR EDITIONS, IN ENGLISH, DUTCH, FRENCH AND GERMAN ALL IDENTICAL IN CONTENTS.

SEND SUBSCRIPTION ORDERS AND SUBSCRIPTION CORRESPONDENCE TO

N.V. PHILIPS' GLOEILAMPENFABRIEKEN
Technical and Scientific Literature Department
Eindhoven (Netherlands)