BIOGRAPHICAL MEMOIRS

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DENNIS GABOR

5 June 1900 — 9 February 1979

Elected F.R.S. 1956

BY T. E. ALLIBONE, F.R.S.

DENNIS GABOR, originally in Hungarian Gábor Dénes, scientist, engineer, inventor, humanist, Nobel Prize winner, was born in Hungary on 5 June 1900, came to England in 1934, married Marjorie Louise Butler in 1936 and, after a life of brilliant scientific and philosophical achievement coupled with great happiness, died in London on 9 February 1979. To use his own words he was "one of the lucky physicists who have been able to see one of their ideas grow into a sizeable chapter of physics", a chapter he continued to enlarge up to the onset of illness in 1974, and in addition he applied his penetrating intellect to some of the problems of man's survival, problems created by the advance of technology: in a series of books and discourses he—to use again his own words—"invented a future,—and a good one,—one that preserves the values of civilization and yet is in harmony with man's nature—based on hope and the love of life". Few scientists are masters of the 'two cultures', but this, Dennis Gabor certainly was.

Early life

He was the oldest of a family of three boys; he was followed by George who died in 1935 from pancytopaenia. and by André born in 1903 who also came to England and is in the Economics Department of the University of Nottingham; André too has earned international recognition in his own field, and collaborated with Dennis in two papers to which reference will be made later. He has given me very great help in correcting some details in the excellent personal account left by Dennis with the Royal Society and by adding many other interesting facets of his brother's life. In what follows, direct quotations from Dennis's own writings are always given between double inverted commas.

Their father, Bertalan (or Bartholomew) was born at Eger in Hungary in 1867 with the name of Günsberg and changed his name to Gábor in 1899. Dennis knew his paternal grandfather who was born in 1832 of parents who had settled in Hungary at the end of the 18th century having come from Russia. The family were tall, fair, blue-eyed people, presumably descendants of one of the Russian tribes, the Cerims or the Kuzri who took up the Jewish faith centuries earlier.
Their mother, Adrienne, née Kálmán, born in 1879 was originally an actress but gave up the stage at 20 when she married. She lived through the terrible siege of Budapest in World War II and shortly afterwards came in 1946 to England living first with Dennis and later with André; she died in 1967. Her father was a highly skilled watchmaker, the son of an excellent tailor, but Dennis knew very little of his mother’s remote ancestry; they were probably descendants of Spanish Jews who settled in Hungary in the 18th century.

Latent talent in the Gábor family came out in engineering. Bertalan was a gifted and ambitious child who hoped to go to university and qualify as an engineer. One of Dennis’s uncles was a mechanical engineer, one cousin was a civil engineer, one an architect, and brother George became an excellent inventive engineer. Unfortunately Bertalan’s father’s business failed when Bertalan was only 17 years old and he had to leave school and take a job as a clerk: he prospered well enough to marry at 31 and then rose to be the director of the largest industrial enterprise in Hungary, the ‘MÁK’, the Hungarian General Coalmines.

Probably because Bertalan’s scholastic career had been broken he always considered himself a frustrated engineer and inventor (though neither Dennis nor his father could differentiate between those two for many years). He read Jules Verne to the boys and was an admirer of the great inventor Thomas Edison whose life story he read to Dennis at the age of 6. He took Dennis to the Deutsches Museum in Munich at the age of 11 and his interest in science was unabated throughout his life; he died in 1942. His son’s early desire to be an engineer afforded him great happiness.

The Gábor home provided the perfect background for a family of three boys. Both parents had excellent taste, collected books, fine pictures and objets d’art; both parents spoke German fluently and the children had German, French and English governesses in succession “so there was no need to listen to the poor language courses in school”. In addition, in their early teens the boys had a highly gifted tutor who stimulated their intellects. “But perhaps the most powerful influence in my general education was that of two highly educated friends of my father, a doctor and a lawyer. In Hungary, as also elsewhere on the Continent, there was no need for an educated man to be quiet if he finds himself in a less educated company. My parents, our friends, and we children listened avidly to the conversations of these two learned men on history, literature, the future of society, etc. and whenever an author or a book was mentioned which I did not know, I ran to read it.” Dennis was a voracious reader (indeed he was throughout the whole of his life) and had a prodigious memory. At about 12 his father offered him a prize if he could memorize Schiller’s long (430 lines) epic poem ‘Das Lied von der Glocke’; he won the prize and remembered the whole poem for many years. He amused himself by translating Hungarian poems into very good German, using the same meter as the original.

After 4 years in the elementary school Dennis went to the ‘Realiskola’ Toldi Miklós Állami Föreáliskola or grammar school in which modern languages were taught and scope was given to mathematics and the sciences. After some months
the form master complained that he had a neurotic child on his hands and suggested that Dennis be sent to a special institution catering for unmanageable children;—"The influence of my family was so strong, that in comparison, the teachers had little influence on my development. Besides I was almost always ahead of the curriculum as I was a voracious reader and had not overmuch respect for my teachers." Father Bertalan recognized that his son's fidgetiness was due to impatience with the low standard in the form and persuaded the master to keep him. The master had the pleasure of seeing Dennis gain top marks throughout his school life, and in due course master and pupil were elected to the Hungarian Academy of Sciences.

The physics master was an extremely conscientious man who constructed teaching aids not provided by the school. Dennis irritated him too, since Dennis's knowledge of physics even at that early age was superior to that of his teacher, but later in life they became good friends. His superior knowledge was due to the fact that his father allowed him to buy almost any book he desired; he found German textbooks of advanced mathematics and physics and "before I went to the University I knew all about the mathematics I was to learn there, and more electromagnetic theory than I ever learned at the Technische Hochschule in Berlin". By the age of 16 he had mastered the two subjects up to degree standard. "I remember how fascinated I was by Abbé's theory of the microscope and by Gabriel Lippmann's method of colour photography which played such a great part in my work 30 years later". Although he never took a degree in mathematics he was an extremely competent mathematician as is obvious from even a casual study of his life's work and all his inventive ideas were based on full mathematical analyses of the details they embraced.

André provides a story about his brothers: 'In 1915 the Gabor family moved to a large flat, the spare room of which became a laboratory. We had a carpenter's bench and a woodlathe, and father allowed us to buy whatever we needed. Dennis and George started serious experiments in physics and built intricate apparatus partly for their school and partly for their own amusement and edification. The former included a clever device for the demonstration of the law of falling bodies, and an epidiascope',—already, then, Dennis was turning his interest to optics—'and the latter included a large induction coil which produced sparks 12 inches (30 cm) long: they also built a Tesla coil and these items evoked the admiration of many experts. Father obtained an old X-ray tube and we took X-ray pictures; they also had a glass-blowing equipment'.

Throughout school days Bertalan subscribed to the popular scientific journals; the family were together at lunch and at dinner and, especially in later years, mealtimes were like the meetings of a discussion society. His interest in science went hand in hand with his appreciation of the arts. Again André contributes: 'In our home we had a fine selection of histories of the visual arts, with coloured reproductions of the greatest masterpieces and these we knew long before our visits to the galleries of Vienna, Dresden, Berlin, Paris and London brought us face to face with the originals. Dennis also liked music, and, having a marvellous memory and an unerring instinct for style, he could at once identify the com-
poser of a piece of music and also the artist of practically any item in a
gallery.

Physically Dennis was a delicate child but later he developed a good physique
becoming one of the best jumpers and runners in his class, and in later life
played a very good game of tennis. In 1917 he passed the medical examination
preparatory to being called up for military service on 15 March 1918. (The very
moment that Hindenberg launched his offensive on the Western Front.) He was
allowed to take the Matura examination, the qualification necessary for entry
into University, in February 1918 and then joined the O.T.C., training in
artillery and horsemanship in Lugos (now Lugoj in Romania). Here he met
Tiber Reiter, a nephew of his father's friend, and they became friends, and later
collaborators, in Berlin—of this, more anon. In the early autumn of 1918 he
was transferred for the final part of his military training to Northern Italy, then
occupied by the Hungarian forces. After his return to Budapest he took lessons
in Italian, memorizing 200 words a day and thus, all his life, he had command
of four foreign languages.

At the end of the war the whole Gábor family adopted the Lutheran faith,
the Church of which is in communion with the Church of England and Dennis
remained in that faith all his life.

**College life**

With the collapse of the Central Powers he returned home on the last day of
October 1918 and at once registered into the Magyar Királyi József Műegyetem
(the Technical University in Budapest) as a student of a 4-year course in
mechanical engineering (Dennis had an engineering drawing-board in his
office all his life). André explains his brother's choice of subject as follows: 'As
regards the attitude in Hungary to pure science and engineering, the people who
studied pure science at the University had only two outlets, one of which was to
go into schoolteaching, the other to emigrate, and it was engineering rather than
pure science that attracted people of talent and ambition'. Von Karman noted
'The scientist describes what is; the engineer creates what never was.' At the
end of his first year, Dennis won the Prize in Mechanics (Theory of the spherical
pendulum) but during his third year he received an order to register for military
service; as he disagreed with the policies of the reactionary government he left
to continue his studies in Berlin and registered in the electrical engineering
department of the Technische Hochschule, Charlottenburg. He noted: 'Though
still at its height at the time, I could not call the T.H. Berlin an ideal institution.
There were far too many students and there was hardly any personal contact
between students and teachers. It was a sort of slot machine into which one had
to throw no end of machine designs, essays and papers and out came a diploma
(1924) in the end. But it certainly made one get used to hard work! My real
education, and the memory which I cherish most at that time, was the Physical
Colloquium at the University, every Tuesday, and the unforgettable Seminar on
Statistical Mechanics which I had under Einstein's guidance in 1921–22.'
options were open, heavy currents and electronics but the latter was not available to foreign students.

The great German inflation of this period forced many impoverished people to let rooms, preferably to foreign students; thanks to his father's generosity Dennis was never short of money but he considered it a moral duty to share the deprivations and live modestly.

**RESEARCH IN GERMANY AND HUNGARY**

“When at last I had my Diploma I asked my father for permission to live on his money for another 2–3 years to get my Dr.-Ing., and—he thanked me for it! (This veneration of learning in the Jewish middle-class of Budapest is probably the main reason why there are now so many Hungarians in science.) My professor, Orlich, was a gentleman of whom I have the kindest memory but he had no scientific imagination and could give no worthwhile problem. Fortunately I found one myself. Electrical transients were a serious problem in high voltage networks; looking for methods of recording them I came upon the Braun tube and I was one of the first to turn it into a high-speed oscillograph with internal photography. (Professor Rogowski and his pupils in Aachen worked independently of me and he recorded the first rapid transient actually a few weeks before me in 1925.) I was the first to make transients photograph themselves with what is now known as a bistable system, which I called a Kipprelais.”

This work is fully described in his thesis Kathodenoszillographie, [5],* which was preceded by three papers in the *Archiv für Elektrotechnik*, [1–3]. The distinguishing feature of this work in Berlin and in Aachen was that the voltage on the oscillograph was far higher than on the Braun tube, that the oscillograph was continuously pumped, and that the photographic plate was actually introduced into the oscillograph to record the transients, so the sensitivity was increased by orders of magnitude. But Gabor was the first to shroud with iron the short solenoids used to focus the electron beams and thus concentrate their lens-effect. His kipprelais held the beam to one side until the arrival of the transient. Oscillographs all over the world copied the Aachen–Berlin models.

Gabor once asked Professor Orlich if it was possible to learn how to invent, to which Orlich replied ‘don’t waste your time trying to invent, because in these days, all inventions are useless; either they will not work, or someone else has already made the invention’; Dennis in fact took out more than 100 patents and sold some at good profit! During his third and last year at college his research concerning the recording of transients on a 100 kV transmission line was supported by the German High-Voltage Research Association, [4, 5].

Gabor again met Reiter, now a medical student, who had come across the publication by A. Gurwitsch who claimed† that growing onion roots emitted a radiation which enhanced mitosis in roots very close to them,—mitogenetic

* A list of all his publications that I have been able to trace is appended; they are numbered in square brackets.
† Das Problem der Zellteilung physiologisch betrachtet, 1926, Berlin (in German).
rays. In spare time Reiter and Dennis worked on this subject and found there
was a radiation of $\lambda = 3400$ Å. They established that mitosis was indeed ‘induced'
in an onion shoot by a close-spaced growing tip of another onion root (a mature
root did not emit a radiation), that the radiation, although very weak, could
affect a photographic emulsion, and that sunlight of this same wavelength could
cause mutations, i.e. had an ‘induction effect’, though an excess of the radiation
had a deleterious effect. André Gabor joined them in conducting these ex-
periments which were done in a room just above the morgue of the Charité
Hospital where Reiter was a student, and André reports that ‘the room was full
of human specimens and smelled to heaven’! By 1927, Reiter had taken his
medical degree and Dennis his senior research degree: Dennis described some
of the work to the Director of one of the Siemens group of companies and he in
turn introduced Dennis to the head of the Physics Laboratory of Siemens and
Halske Co. at Siemensstadt. Both graduates were offered employment and
continued some further experiments on the phenomenon, publishing a paper,
[6a], and a book, [6b], in 1928.

Over 100 experiments were described and from a moderately careful study of
the book one would conclude that the work was authentic. In his autobio-
ographical Notes Dennis wrote: “The results . . . seemed to support . . . the
hypothesis of some radiating agency; on the other hand all experiments for
proving the radiation by physical means have failed. To this day (1956) nobody
knows what these experiments really mean.” This was not quite his attitude
at the time. Clearly a mystery surrounds this work and although I asked Dennis
about it on several occasions I never penetrated the mystery.

There was some indication that a health lamp strong in the part of the
spectrum needed for mitosis might be more effective than a mercury lamp and
Dennis found that the addition of cadmium enriched the mercury vapour
spectrum in the u.v. but the life of these lamps was short and he spent time
trying to find a way to eliminate this shortcoming. In so doing he came up
against the Langmuir paradox—of which more anon—and published papers,
[8–10]. It was in the course of this work that he invented a thin molybdenum
strip seal to carry high currents into the quartz vessel, a seal in general use even
today. Concerning paper [8], Professor Franke formerly of Siemens writes
‘Gabor was not a member of our section of the laboratory but he stepped in at
least once a day. . . . We were developing loudspeakers and microphones . . . all
problems of our work were discussed with him especially the theoretical and
mathematical ones; he did all the design of magnetic fields and coils and trans-
formers for us. When I next met him 25 years later, he immediately recognized
me and gave proof of his marvellous memory by telling me the title of my
doctor’s paper.’ In later years the Gabors, visiting Berlin, always went to see
Dr Franke.

A few weeks after Hitler came to power Dennis’s contract of service ran out
and Siemens did not renew it, so he returned to Hungary and approached Mr
Aschner the Chairman of the Tungsram Electron Tube Research Institute in
Budapest, asking if he could work on his new invention, the plasma lamp,
without a salary. This lamp contained a perforated disk through which strands of mercury discharge plasma emerged. He developed a close link with Dr Andov Budincevits, who has written to me ‘Gabor at that time was not only an eminent theoretician but also an experimental physicist, determined to develop the practical application of his concept... We produced a plasma lamp conforming to Gabor’s original idea and it had a life span of some hundreds of hours... but the yellow light emitted would probably restrict its applicability.’ Gabor demonstrated the lamp to Mr Aschner offering the patent to the Company but the Chairman did not like to create a precedent by paying for an invention and, instead, offered Gabor a position on the staff. Gabor refused this offer and decided to try to sell his patent in England. He might have been influenced by the fact that, owing to the deteriorating political situation other members of the staff (including Dr E. Orowan—later F.R.S.) ‘also intended to emigrate to England’. Paper [11], written in Budapest, is the first exhaustive analysis of the Langmuir plasma. Dr Budincevits adds that ‘our friendship was renewed in 1962 when Dennis first returned to Hungary: he became a faithful citizen of his new country but he never denied the ties which connected him with Hungary: he liked to sing Hungarian songs, he never cut his roots’.

In the summer of 1928 I went to Germany to discuss oscillographs with Professor Rogowski and Dr Gabor, and benefited greatly from these meetings, I was the first British scientist he had met. Thus it came about that Dennis wrote to me (1934), in the High Voltage Laboratory of the Metropolitan-Vickers Co., Manchester, asking if M.-V. could offer him employment. The M.-V. Company was the heavy-current half of the parent A.E.I. Company, the B.T.H. being primarily the light-current half of the A.E.I. My research director suggested that I wrote to the B.T.H. research director, Mr H. Warren, recommending Gabor. This I did and Dennis was duly invited to Rugby where he spent some 15 years, 1934–48.

Some time in 1934 Dennis wrote to ask me whether his name should be spelt with one n or two. I replied that both forms were in use in England and as his Hungarian name had contained only one he could Anglicize it into Denis. This he used for a while but later added the second n.

Research in the British Thomson-Houston Company, 1934–48

England was very sympathetic to the refugees from Nazism, and Dennis must have been given a friendly welcome in Rugby (indeed Mr Warren was a very kind man), for his brother André writes: ‘After our experiences in Germany we were most agreeably surprised by the fact that the English, who had a reputation for being insular, cold and inaccessible, were exactly the opposite. Soon after Dennis came to this country he said in his letters that he had already made a number of friends, had been the guest of several families, and that he had only just realized how unfriendly the Germans were: after 12 years in their country Dennis had made fewer friends than in England after a few weeks.’ And within two years he had found a wife. Marjorie was the eldest daughter of
Mr J. K. Butler and his wife Louise, and was at that time working in the B.T.H. Co. She had great musical interests and the Amateur Dramatic Society (with Gilbert and Sullivan operas) made a good meeting ground. Dennis played no instrument but he sang well, and all his life—with his fine memory—he could entertain with songs from very many operas. They were married on 8 August 1936 (and late in life, Dennis wrote "and lived happily ever after". They did).

Gabor’s appointment with B.T.H. began as a patent agreement to develop further the plasma lamp on which he had worked in Hungary. B.T.H. were the part of A.E.I. dealing with the lamp and lighting business so a fluorescent lamp needing no choke would be a great asset, but two further years of work failed to overcome the low life of the lamp, no material then available could withstand the ion bombardment of the cathode, and work finally ceased, and he was then given a staff appointment.

Dennis dismisses the following years spent in Rugby, 1937–48, as very sterile, comparing badly with his postgraduate work in Berlin and with his research after leaving industry but I and his few colleagues now alive would not accept this verdict. It is true that, had he not been an ‘enemy alien’ he would have been more fully engaged on war work and might well have contributed some brilliant ideas to radar research, but his scientific output was considerable, was excellent, and has stood the test of time, and at the end of this phase he invented holography and thereby won a Nobel Prize—hardly ‘sterile.’

Unfortunately we do not have a record of all the reports he may have written, but a few of his colleagues (Emeritus Professor G. Carter of Leeds, Emeritus Professor C. J. Milner of Sydney, N.S.W., Dr J. Dyson F.R.S. and Mr Ivor Williams who made most of the apparatus) have provided contributions from which a history of those years can be roughly reconstructed.

Electron optics dominated his attention though he was given other tasks to do. It will be recalled that he left the Technische Hochschule, Berlin in 1927 to work on transient electrical phenomena for a year and then went to Siemens. Just after he left the Hochschule, Busch* proved, in an important theoretical paper, that the magnetic field of a short cylindrical coil of the type Gabor had used in his oscillograph acted as a lens, obeying the lens law of optics relating object/image distances to focal length: this at once meant that magnification could be achieved. “The paper was more than an eye-opener; it was a spark in an explosive mixture,” and even with parts of Dennis’s old oscillograph, Knoll & Ruska in the Hochschule began work on the world’s first electron microscope. Dennis “could have kicked myself”, but his mind was set on electron optics and remained so for the rest of his life.

His first task was to try to increase the angle of scan of a cathode-ray tube by shaping the electrostatic field by means of high-resistance deflecting electrodes which gave more freedom in defining the boundary conditions (Dr Dyson recalls this). He first built an electrolytic-tank model of the electrode system and, with probes mounted on a tricycle carriage, measured the potential and field, [12]. This was to be shown at the Physical Society’s Exhibition and Dr

* H. Busch Arch für Electrotechnik 1S, 583–591, 1927.
Milner (as he then was) was selected by Mr Warren to be the alternate demonstrator, Milner being selected as he was a physicist. Dennis never liked being called a physicist. "No, Mr Warren" he retorted "I am an engineer. I insist, I show you my Diploma!" An almost identical electrolytic tank was independently developed in America, and Dennis showed the account of it to Dr Milner "You see it shows the American passion for the automobile, it has four wheels, not three, and is motor-propelled." Experimental tubes were made with wide-angle deflexion but work on these ceased because electrostatic deflexion became replaced by magnetic deflexion.

The advent of television in 1937 sent shock-waves through the cinema industry and in 1938 Oscar Deutsch (of the Odeon Cinemas chain which purchased sound-film projectors from B.T.H.) sought to encourage B.T.H. to develop a system for cinemas in which the viewers would see three-dimensional images without the aid of any special spectacles or other appliances. Dennis reflected on this and conceived an ingenious solution of the problem, taking out two lengthy patents on 3 May 1940 (541,751 and 541,752), the first containing rigid mathematical formulations of the conditions to be fulfilled. No experiments could, however, be made as, by now, the B.T.H. Research Laboratory was actively engaged on war work; the experimental work done with Mr Ivor Williams after the war will be reported later.

He gave an excellent lecture to the Rugby Engineering Society in 1938, on the many discharge devices which operated at low gas pressure and concluded "the theory of gas discharges has, up to now, only been able to give a lead in a few cases; in most instances it has lagged behind invention and the best it could do was to help to improve the devices invented by experimenters" (Lord Rutherford would have enjoyed this).

Professor Carter recalls an article Dennis wrote, on the menacing situation of 1938–39. Gabor commented on President Wilson's 1919 'Doctrine of national self-determination'; this idealism had a wide appeal in those days and the rightness of the President's ideas was taken too much for granted until Gabor pungently described them as "universal principles so evidently right that people do not see what nonsense they are"; at a time when barriers between nations were being lowered, it was nonsense to invoke the principle of self-determination to erect new ones, not least between the component parts of the Austro-Hungarian empire.

André Gabor paid a visit to England in December 1938 with the intention of staying for a fortnight but Dennis, being convinced that war was imminent, would not let him return and supported him financially until he found employment in the service of the Ministry of Agriculture. In August 1939 Dennis arranged for his parents to come to England and tried to persuade them to remain but they returned home just before Hitler assaulted Poland. He wrote a monthly letter to them via the Red Cross or the Apostolic Delegation; his father died in 1942 but, as already mentioned, his mother survived the war and came to the Gabor's home in 1946. When war was declared Dennis volunteered for military service but was rejected and his name was placed on the Register of
Aliens with Special Qualifications and it was left to B.T.H. to see that he had no access to classified information. For part of the time he worked at home, and later a capacious hut was erected for him outside the security fence of the Company. He invented an improved version of the Schmidt lens system, an objective for photography or for projection, with large apertures and good chromatic properties, consisting of a spherical mirror in combination with one or more lenses having spherical surfaces: the original Schmidt system employed non-spherical surfaces not readily made in those days. Patent 544,694 of January 1941 gives full details.

Since Dennis was not informed of the secret work aimed at detecting aeroplanes at night by radar he invented his own solution, detecting a plane by the heat from its engines. To render the infrared of the spectrum visible he devised what he called a "relay screen" consisting of a transparent plate with optically smooth surfaces on one face of which were cemented parallel rows of thin strips. Over these ridges was a thin clear plastic film incorporating a fluorescent dye, and coated with a very thin infrared absorbing layer. When an infrared real image was focused on the absorbent layer the film expanded and, between each ridge, it sagged closer to the baseplate. Light striking the remote side of the transparent plate at 45° was totally internally reflected except at the parallel rows of thin strips and at the mid-span of the thin plastic film wherever it had been heated by the infrared: here the light passed into the thin film causing fluorescence. News of this relay screen reached military ears and experimental work was requested by Government. Professor Milner writes 'As Gabor was still proscribed from the Laboratory, engineer W. D. Sinclair, who had superb manipulative skill, and I visited Gabor at home once weekly to discuss progress, Sinclair being the experimenter. He made screens 1 inch square, using microscopic-interferometry inspection techniques based on Newton's rings, but, though thermal sensitivity was observed, it was never more than 1% of theoretical. Perforated films were developed to facilitate motion of the thin plastic films. By mid-1943, security regulations were eased and Gabor continued the experiments with Sinclair in the hut. In spite of poor conversion efficiency the device reached a stage when it could detect a soldering iron on the other side of the room.'

Professor Milner writes about another aspect of Dennis's activities of those days, an aspect which is a foretaste of the great concern for the future of the human race which he showed in his books and lectures after retirement. He and Dr Milner were members of the Branch Committee of the Association of Scientific Workers in the 1939-41 period and were concerned that science should be used and not abused, but at that moment in our history they were convinced of the over-riding importance of all scientists working together to win the war. In 1941, before Hitler attacked Russia, the Central Executive of the A.Sc.W. (containing to my knowledge several avowed Communists—T.E.A.) completely opposed the Rugby views and the Branch Committee resigned en bloc. Dennis had prepared for them "a kind of Hippocratic Oath", a fascinating document which, as far as I am aware, has never been published. He believed
that the new world must contain a stronger element of reason in the management of human affairs and here the scientist would come into his own: "We represent the greatest body of men and women schooled in thinking... in a field in which lies do not exist, no amount of shouting will make an incorrect mathematical error right. We are accustomed to be critical of ourselves as we work under an unbribable critic, unmoved by any flow of eloquence, but this very fact is also our greatest weakness. We may be masters of all kinds of engineering and yet ignorant in regard to the engineering of human consent." He offered a 10-point advice to scientists as to how best to equip themselves to play a full part in society. Space does not permit me to deal with these, but, writing to Milner in 1966, Gabor added: "I well remember writing those 10 points and I still subscribe to them; we anticipated by 5 years the shock-wave which hit physicists after Hiroshima when they felt they had to take a stand in a world which had become too dangerous by their own work."

In 1942 he gave a lecture on Electron Optics, [15, 16], in which the question behind his Nobel Prize is asked: "Can we make electron-lenses as perfect as the highly corrected lenses of modern optics?" The answer in 1942, 15 years after Busch, was "No"; for Scherzer had shown that neither spherical nor chromatic aberrations could be eliminated, though by using high accelerating voltages the RCA microscope produced electrons constant in velocity to 0.004% and with high intensities the numerical aperture of the electromagnet could be cut down to 1/1000 thus reducing aberrations to very low values. But Dennis was a perfectionist, he wanted to know how to arrive at ideal stigmatic lenses even if they could never be produced: he had laboured for years on this, but now he had solved the problem using Hamilton's century-old analogy of mechanics and optics; "for 3 years during which time I have not worked in electron-optics I must have been unconsciously digesting Hamiltonian methods and now, effortlessly, I have solved the trajectories and want my experience to benefit others". (He even won the Nobel 'effortlessly' as we shall see.) The full paper, [16], is a joy to read and a portent of the future.

He continued to report the applications of Hamilton's formulations of dynamics to dynamical problems in electronic devices such as magnetrons in another lecture in 1944, [18], "It may be added that their usefulness probably does not extend much further, as they seem to give little help in the problems of space-charge and noise, but the field they cover is an important one and their applications may save the specialist many hours of headaches."

In the midst of this work he found time in 1943 to write an I.E.E. paper, [17], on the fundamental processes by which steady electromagnetic oscillations can be produced in electronic devices. Regarding an oscillator as a machine for converting d.c. to a.c. with electrons as the moving parts he listed the only six possible processes and gave examples of each. Professor Carter, a colleague in B.T.H. at the time who contributed to the I.E.E. Discussions, writes of this classification and of his work on the theory of communication, [22], that 'one could not but be amazed at the brilliance of the analyses; he was gifted in identifying a seminal idea, whether from the writings of others or from his own
mind; and when he transmitted such an idea to someone else the effect on the recipient's mind was permanent'. He was awarded the Duddell Prize of the I.E.E. for his paper, [17], and of paper [22] he wrote "This theory was little understood at the time but it received wide recognition when American workers, a few years later, put communication theory on the map"; further reference will be made to this.

That he was still pondering on the problem of the perfect electron-lens is shown by the next paper—to the Royal Society, [20], written in 1944—"The theory of the motion of electron assemblies in electric and magnetic fields is of interest in the theory of the magnetron and in electron-optics where lens correction is impossible in the absence of space-charge". He produced a complete theory of stationary swarms of electrons around an axially symmetrical magnetic field, and showed that electrons injected with small velocities would distribute themselves with a density inversely proportional to their radial distance from the axis, thus offering the possibility of realizing a dispersing electron lens. In 1946 he offered practical details of how such a zonally corrected lens might be made, [21]. The electron beam would have to be fired off-axis by tilting the gun to miss the supports of the central wire supplying the electron-swarm and he calculated that spherical aberration would then be corrected in a zone of about twice the wire diameter. Dr M. E. Haine who was responsible for the investigations on electron microscopes, first in the Metropolitan-Vickers part of A.E.I. and later in the A.E.I. Research Laboratory, has reported that he discussed this space-charge correcting lens system with Gabor and expressed anxiety about the extreme accuracy required for positioning of the central wire electrode. As a result of this, Dennis carried out extensive computations on the permissible tolerances and found them to be impractically tight so this correcting system was never developed. He considered that the theory of electron swarms provided a better basis for magnetron theory than the official theory held during the war.

Two more short notes, [24, 25], deal with focusing of positive ions of very high energy.

Dennis has said that his paper on Communication Theory, [22], was one of the few he ever wrote as a scientist interested in understanding things rather than using them to a purpose, and the analyses he made so impressed his friends that, more than once, they advised him to do analytical work rather than to continue trying to invent. But his collaborator, Ivor Williams, puts a different complexion on the matter: he wrote to me ‘The Transatlantic cable was running out of space and the Post Office was working on the American 1939 Vocoder', so Dennis's analyses of the signals necessary to convey the information (part I the I.E.E. paper [22]), and of the minimum requirements of the ear for intelligibility (part II), were really essential preliminaries to the building by Mr. I Williams of simple apparatus described in part III of this paper to compress speech into a narrow frequency band without losing its intelligibility. Paper [26] written in 1946 is a sequel to this, describing a device also made by Mr Williams, to compress and then to re-expand speech, and the paper includes an extensive analysis of possible variants. Demonstration of the device was not
very satisfactory but it had only reached the early stages of development when the project was abandoned.

The penultimate activity of this B.T.H. phase of his life was the development of the 3-D projection system which he had patented in 1940; a Russian named Ivanov had, independently, patented a similar 3-D system. Mr Ivor Williams did the experimental work with him. It was based on Lippmann’s lenticular screen of 1896, but by now there were Perspex lenticular plates available. Work started after the war with the use of two projectors correctly spaced, focused on to the back plane of the screen which had a diffusely reflecting surface. Reflected light passing through the lenticular front face forms a pair of beams nearly parallel, so that a person in a row of specified positions will see the left picture with the left eye and the right with the right eye. But the viewer must not move his head. In Moscow a small stereo-theatre was built but, said Dennis, “only the Russians could be so disciplined to sit so still”. Work was abandoned in 1948 and no account was written. However by 1960 Dennis had had further thoughts embracing ways to avoid the necessity of keeping still, [74], but he realized that the scheme was practicable only with small screens and the advent of the large cinema would, in all probability, have killed it.

The foregoing account shows how his mind was constantly returning to the problem of aberrations in magnetic lenses. In his personal account he wrote "I realized that I ought to have stuck to my original line in 1927 when electron optics was just discovered, but I hoped it was not yet too late to make a come-back by improving the electron microscope beyond the limits set by aberrations". His book *The electron microscope*, [19], published in 1944 re-analysed the problems and concluded with a chapter on The Ultimate Limit of Electron Microscopy, searching hopefully to ‘see’ single atoms. He gave an illustration of Bragg’s ‘indirect’ method of structure analysis obtained by interference of diffracted beams from millions of unit cells and he also had admired Zernike’s use of a coherent background of waves to show up aberrations in optical lenses. It is therefore not surprising that while awaiting his turn for a game of tennis during the 1947 Easter holiday his subliminal ego presented him with the solution to this over-riding problem *effortlessly*, “Why not take an electron picture, one which contains the whole information and correct it by optical means. To capture the whole information, including the phase, the coherent background must be supplied by the same electron beam, which will therefore produce interference fringes: photograph these, and then illuminate this photograph with light and focus it onto a photographic plate.” He called the electron diffraction pattern a hologram, because it contained the whole information, amplitude and phase, and the magnification gain would be the ratio of the optical to the electron wavelength. To try out his idea he decided to produce first an optical hologram and reconstruct the object optically. Once again his assistant was Mr Ivor Williams: they produced an extremely fine beam of light by illuminating a pinhole of 3 μm diameter with monochromatic light: this light fell upon a microphotograph 1 mm diameter, and at a distance, a photographic plate recorded the interference patterns produced by waves from the details on the
micrograph and waves by-passing them. Williams recalls the secrecy in which this idea was tested, and the interminable exposures on account of the very feeble illumination, but between Easter 1947 and May 1948 a beautiful reconstruction had been produced, [28], followed up a year later, [29], by a full account of 'microscopy by reconstructed wave-fronts', and a forecast was made that by this method a resolution of 1 Å might be achieved.

By 1948 the new A.E.I. Research Laboratory at Aldermaston had been created, one section of which was to include the study of the long-term problems of electron microscopy to back up the development of the electron microscope in the Metropolitan-Vickers Co. (the B.T.H. Co., the other half of A.E.I., was not engaged in this subject). Dennis asked me if he could join us and pursue his proposal in Aldermaston but he had other commitments in the B.T.H. Co. and they were not willing to share his time on a 50 : 50 basis. We did, however, decide to work on the subject with his help and guidance from a distance, and I applied to D.S.I.R. for financial assistance because, if we were successful in resolving atomic lattice spacings many of the sciences would benefit, but A.E.I. might not necessarily increase its sales of microscopes: D.S.I.R. accepted this argument and gave what, I believe, was the first-ever grant to an industrial laboratory. We ran into scientific difficulties which do not directly concern this biography, except in so far as they reacted upon Dennis. Again, Dr Haine says 'Probably our main contribution was to push Dennis repeatedly into thinking about the practical aspects of the method and to express himself in terms understandable to us and relevant to the practicabilities.' This in turn reacted upon Dr Haine and his team 'I remember how my understanding took a sudden jump forward and inspired me to realize the fact that this point-projection method was unnecessary and that a transmission method . . . was free of the chromatic defects which made the point projection method impracticable'. As a result Gabor re-examined and also extended his theory, [36], but to cut out unwanted interference, a Zernicke phase-plate was needed and this was too difficult to make: the attempt to produce micrograms by his process was abandoned, but the effort had been of great value in focusing attention on other features of the electron microscope, and, as a result, resolving powers of 5 Å were obtained. Later in 1948 he was appointed Reader in Electron Physics in Imperial College and left the B.T.H. Co.

MULLARD READERSHIP IN ELECTRONICS: IMPERIAL COLLEGE 1949–58

In his 'personal account' he wrote in 1956 that the preceding 6–7 years had been the happiest in his scientific career: 'at last I was my own master and could work with young research students on problems of my own'. Academics seldom realise that for those of us whose lives have been spent in industry the majority of our activities have been set by the requirements of our employers and only, almost as a side-line, have we been able to pursue ideas of a more academic character. Dennis had spent many months in 1947 on paper [28] but had the Metropolitan-Vickers Co. not been making electron microscopes it is very
doubtful whether he would have been allowed the time in B.T.H. to proceed to paper [29]. Now he could please himself. I asked him immediately if he would consent to be a consultant of A.E.I. and we enjoyed his visits to Aldermaston for many years: he was a great favourite with the staff, always provocative, always inspiring. He was also a consultant to the Post Office.

In a lecture he gave at Delft, [31], he revealed some of the difficulties being encountered in the A.E.I. Research Laboratory and in [34] he proposed a complicated electron-optical system to avoid chromatic aberrations of electron lenses: as already stated, he also fully analysed, [36], a proposal made by the Aldermaston group which had advantages over his original scheme for making electron holograms, but with the closure of this work his concentration on holography almost ceased, and apart from reviews contributed in French, [41, 42], and German, [43], and a final review of theoretical and experimental work completed in the A.E.I. Laboratory, [46], he left the subject until it was dramatically revived in 1963* when a laser beam was used to produce an optical hologram.

Although the experiments on electron microscopy by holography were not forging ahead rapidly, he realized from the optical holography done in Rugby that the optical microscope might benefit "by superimposing two strong coherent backgrounds on the images of an object having a phase shift of 90° between them; one can obtain a complete optical record of an object, containing amplitude and phase". His design for such an interference microscope was described in 1954, [46], after a research student, W. P. Goss, had begun to work on it and it was supported by the Paul Instrument Fund of the Royal Society for five years. However an account of the work done did not appear till 1966, [102]. It had achieved its goal; with it, three-dimensional objects could be seen though the separation in depth was not as good as had been anticipated. But by 1966 the laser was available and with such illumination it was hoped that the concept would be revitalized.

Dennis's interest in plasmas continued; he reviewed the experimental work and the theories of plasma oscillations, [37], produced a classical wave-theory of plasmas, [38], which upset his Budapest theory given in [11], and he suggested that there must exist strong internal oscillations in the arc plasma far exceeding what had been assumed. With two research assistants E. A. Ash and D. Dracott a very elegant piece of apparatus was devised with which they succeeded in 1955 in measuring such oscillations, [53], and thus solved what Gabor had recognized, 25 years earlier, to have been a paradox in Langmuir's first observations on plasmas. A fuller account of this work is given in [62], and Ash's work on electron interactions in [54].

He continued also to pursue his very erudite considerations of Communication Theory: since he had written paper [22] in 1944 his ideas had received wide recognition—as already stated—and he was invited to present a general report to the Symposium on Electronics and Television in Milan in 1954, [45], on

'communication theory and cybernetics'. He said he feared there was a danger that the subject would become abstract, even sterile and it was his "object to show that, far from being sterile, the theory is likely to become a powerful driving force in the future development of the techniques of communication and control". He dealt in great detail with two aspects of the theory, the analysis and use of all the prior information available—the structural part of the theory—and the part which probability plays in the sending and receiving of information—the statistical part of the theory. He went on to propose a "learning filter for noise elimination, prediction, or recognition"; he considered such a filter could be made but at that time was not prepared to forecast its practicability: we shall see how just such a device came into being a few years later. With his brother he read "An essay on the mathematical theory of freedom", [47], to the Royal Statistical Society; they "wanted to show that in the vast domain covered by this powerful but vague idea there exists a field, large and important in itself, which is amenable to quantitative discussion, the approach being based on the statistical concept of communication" already referred to. The mathematics of this is extremely complex to the layman, but, from the discussion it provoked, it had clearly been well appreciated by the statisticians present. The Gabors had been encouraged to attempt this formulation by the success of communication theory which enabled them "to make comparisons between different systems which otherwise would remain incommensurable". Four years later they presented a further paper on freedom, [67], confining themselves to statistical, and not to the philosophical, ideas of freedom. They laid down a number of axioms and then derived diversity and dependence coefficients of the variables. As an example they applied their results to the "choice of a profession", based on some Swedish statistics of (a) the occupation, and class, of the parent and (b) the IQ and the occupation of the son at age 24.

In the post-war years, applied electron-physics was becoming very popular, Ordinary and Higher National Certificate courses were being organized and in 1952 the British valve industry offered financial support to Imperial College to establish a post-graduate course in the subject and the U.G.C. gave help to re-equip the electronics laboratory. An account of the splendid new equipment was written in 1955, [56], equipment sufficient for making up almost any type of vacuum apparatus, glass lathes, hydrogen and muffle furnaces, induction coil heating, and exhaust pump stands, etc. The stage was thus set for Dennis to develop his inventive flair, and make working models. "In 1952 I had the idea of a flat, thin television tube for monochrome and for colour... I am now busily engaged on its development with three young assistants and I hope that this will at last satisfy my life-long craving to make a useful and successful invention in the field of electronics" (this was written in 1956). The thin flat tube hanging on the wall like a picture had been for years a standing feature of imaginative American advertisements and these gave Gabor the idea. He sought assistance from the National Research and Development Corporation and I was asked by them for an opinion. It was a very complicated device on paper, involving very wide angle sideways deflection, the bending of the beam first
through 180° and then back through 90°, though the design for colour appeared to be less demanding than the colour concepts then being proposed. I, in turn, discussed the design with the specialists in the A.E.I. (Woolwich) who were making t.v. tubes, and finally gave qualified support, with a warning about putting so many complications inside the glass envelope, itself a very difficult thing to make in large sizes. The first description of its construction and operation was in 1958, [68, 69], Dr P. R. Stuart and Dr P. G. Kalman being co-authors, Ph.D. students at that time. The many difficult design features were calculated and developed with Dennis's usual brilliance. Dr Kalman, a fellow Hungarian, has given a fascinating insight into the way Dennis worked: 'He was, as you know, a very kind man but a hard taskmaster. Demanding the utmost from himself, he simply could not see how others could do otherwise, . . . Because he had an uncommon insight into complex mechanics he could not see that lesser mortals found his example hard to follow. He would juggle with various would-be solutions bending the rules as he went and straightening out the mathematics afterwards; being apparently unmethodical, using no perceptible logic, but somehow he knew the answer and was designing the hard-ware in the matter of a few breathless minutes. Once, seeing that I had been taken aback by his methods he burst out laughing, "Do you really think anything was ever invented in any other way? First you have to know the answer, logic comes afterwards." This was indeed his way of working which I have seen on many occasions but I knew that he had wrestled with a concept for perhaps days or even years, as with holography, and what Kalman was describing was the outpouring of Gabor's subconscious mind which had already provided the answers. Kalman consulted him on the desirable length of the Ph.D. thesis he was about to write: "Well Kalman, that depends: Fermi wrote his on the back of a postcard but in your case I should make it a little longer."

Dennis had no lecturing duties but gave many specialist lectures. As he got more excited his speech became slurred and sibilant, losing intelligibility, though his style improved in later years. He disliked administrative duties and fortunately he was relieved of them. Dr Kalman thought that people like Gabor ought to live in a world where he would never have to think about money: that is precisely how General Electric of America treated Langmuir—he was given an open cheque account.

By 1958 the flat t.v. tube had reached the stage when all the electron-optical problems had been resolved; "a development of this sort cannot be wholly completed in an academic laboratory, but really in industry". But by this date the conventional cathode-ray tube had been greatly reduced in length and industry was not interested in a thin tube. "If I live long enough I may still be able to see some of my inventions through to success; my motto is that of G. de Taciturne: Il n'est pas nécessaire d'espérer pour entreprendre, ni de réussir pour persévérer!" Two other students, H. A. W. Tothill and J. E. Smith-Whittington spent more years on the flat tube, taking out some of the complications and in 1968 paper [112] reports "We have now realized, in vacuum-tank experiments, a thin tube . . . have indicated how parts could be further
improved—but a full development would have exceeded our time and resources.” A patent only last 16 years, and 16 years had elapsed since work began. By a quirk of fate, even as I prepare this memoir a very small, flat television tube probably ready for the market has been announced, within 4 months of the death of the inventor of the original flat t.v. tube.

Two other inventions in this (1958) period might be mentioned. In a review of the theory of electron interference experiments, [63], he showed that two new instruments could be constructed, a phase-marking diffraction camera, and an electron interference microscope. The other concerned a Wilson cloud chamber, [66]; he proposed turning it into a microwave cavity operating so near to breakdown that multiplication of secondary electrons would take place on the α-particle tracks at each antinode, thus giving time-markings at, say, every $10^{-10}$ s. With B. Hampton the chamber was made and the marks were well recorded; the Royal Society had again provided help from the Paul Instrument Fund.

**Professorship at Imperial College, 1958–67**

He was appointed to a personal Chair of Applied Electron Physics in 1958, his Inaugural Address, [70], being on “Electronic Inventions and their Impact on Civilization”. He reviewed in part I the work on three projects in the laboratory, on the t.v. tube, on an early attempt to raise the temperature of a plasma, aimed at thermonuclear fusion, and on the ‘learning filter’, to which I have already referred, Paper [45]. Then in part II, Inventions and Civilization, he speculated on the part which sophisticated electronic machines might be expected to play and asked “Do we need inventors; do we need more inventions?” Sir George Thomson’s *The foreseeable future* had just been published and Dennis concluded “for the first time in history we are faced with the possibility of a world in which only a minority need work to keep the great majority in idle luxury—a nightmare of a leisured world for which we are socially and psychologically unprepared”. “Who has left Mankind without a Vision? The predictable part of the future may be a job for technology but for the part which is a matter of free human choice, it ought to be, as it was in the great epochs of the past, the prerogative of the inspired humanists”. And this is what Dennis set about to be for the rest of his valuable life. An abridged version, [70a], was printed by *Encounter* in 1960 under the title “Inventing the Future”; a title proposed by the Editor. The German Merkur printed part II of the lecture, [81], and it also formed the basis for his Joseph Wunsch Lecture delivered in Haifa on 30 May 1965, [87].

I have already dealt with the demise of the flat t.v. tube. The other two projects unfortunately suffered similar fates. The ‘learning filter’, [71], and [75, 76], with his students Wilby and Woodcock as collaborators, was “an analogue computer which learned to do its job: one had to teach it by putting into it a magnetic tape which had a record on it which had to be recognized or predicted, together with another tape which had the solution on it. By a feedback process the non-linear filter modified its parameters until it optimized itself and did the job. The linear
Dennis Gabor

part worked beautifully as a predictor and simulator, but in the end, after 6 years work, the project was abandoned."

The thermonuclear fusion project had to be abandoned for different reasons. Gabor had started on a most ambitious project after the thermo-nuclear work in U.S.A. and Britain had been declassified in 1958. D.S.I.R. referred the proposal to me and I had commented that the project appeared to be too difficult for a small university group to tackle, but a grant of £67 000 was given. Work went on, indifferently, for 2-3 years but illness intervened: "I am not inclined to nervous breakdowns, my nerves are tougher than my body, but the serious thrombosis-phlebitis which I got in my legs in America in 1961 was probably due to this disappointment." I visited Dennis in the St Mary Abbots Hospital on 14 December 1961 and told him to withdraw from the D.S.I.R. contract for the sake of his health; that the project might be tackled by E. O. Lawrence and the expert team in Berkeley, California, but was too much for his Electronics Laboratory. He withdrew—and recovered.

The reproduction by Encounter of the second half of the Inaugural Lecture, with its new title 'Inventing the Future' appealed to Gabor's friend, Frederic Warburg of the publishing house of Secker and Warburg and he pressed Dennis to write a book; a year of Saturdays 1961–62 was put to extremely good use, and this popular book has been translated into many languages. The new title put a different complexion on his work and "it gave direction to my thinking". The Inaugural Lecture was concerned with what the world is, and how technology might develop in the foreseeable future (as G. P. Thomson had written too): the new book dealt more exhaustively of course with all this but went much further in inventing a plan for survival: "The future cannot be predicted, but futures can be invented. It was man's ability to invent which has made human society what it is. The first step of the inventor is to visualize, by an act of imagination, a thing or a state which does not yet exist and which to him appears in some way desirable. He can then start rationally arguing backwards and forwards until a way is found from the one to the other. For the social inventor the engineering of human consent is the most essential and the most difficult step." "With Moses, I have given forty years for the education of a generation which will deserve to live in the Age of Leisure."

The last experimental work pursued in the laboratory before Gabor retired held out, for a time, great promise so I must deal with it: it concerned his very old work in Siemens, passing plasmas through perforated disks, paper [11] in Hungary, and [13, 17] in Rugby. The original plasma device failed because ionic bombardment destroyed the electrode but his student, J. Nilson, made an important discovery and Gabor realized that the dark discharge coming through the perforated disc or gauze might be used for making an inert gas-filled controlled thermionic converter (the Nilson contribution does not appear to have been written up so that its exact nature cannot be described). Work was then continued by H. A. Fatmi with N.R.D.C. support and in 1961 Gabor could envisage the physical design of a thermionic converter, [78, 90], filled with argon/mercury mixture or with caesium from which a.c. or d.c. power might be
extracted at quite low cost, the heat for the cathode being supplied at 1200–1800 °C from for example, the flames before they licked over the surfaces of the boiler tubes of a steam-generator (or even from the fuel elements of a nuclear reactor—if they could operate at such temperatures!) “Provided that these problems can be solved there is a wide field of potential applications for thermionic generators for supplying d.c. power—and for improving the efficiency of power plants”—“After 1½ years of rather disappointing research we had a stroke of luck; I had the idea that an addition of copper to the electrode—but my collaborator, Michael Albert, out of habit added zirconium hydride—and there is now good hope that we shall make—thermionic converters.” A theory was written, [83], and in 1966 Albert, Atta and Gabor described the various cathodes on which work had been done, [109], but time ran out, and in 1979 these converters are not even on the horizon. The development caused a bit of a stir. N.R.D.C. interested Unimation Inc. of America and Mr J. F. Engelberger came over hoping to secure a patent licence; ‘Well I remember my first encounter with Dennis. When I introduced myself he said, “Oh yes, I have only known one other Engelberger, that was Willy, the Austrian composer”. I replied with dignity that that was my uncle, whereupon Dennis stretched himself to full height and sang the refrain from one of my uncle’s famous songs, Wenn Die Letzte Blaue Geht’: Engelberger got his licence!—and Dennis’s friendship. Mr Engelberger concludes his 1979 letter to me ‘Thermionics is still not a practical technology, it may just be that a Gabor idea needs a quarter century of gestation before an environment exists that allows it to blossom forth in full glory! He took me round St Paul’s; he was far better than any walkie-talkie for he knew not only the statutes but even the history of the sculptors, and the peccadillos interred with the remains of famous men. The secret of being a futurist, he said, was to start predicting in your 60s and make your predictions for 50 years hence’.

The junior collaborator of [109], Dr M. J. Albert, also writes in 1979 from Israel, ‘Dennis was not only a brilliant theoretical scientist, he took an active interest in the minutest details; the work was governed by diaries and edicts—typewritten instructions handed out to collaborators—followed by memoranda of discussions, made several times daily: jigs, fixtures, apparatus, all was designed and drawn by him. But one did not feel suppressed or overpowered, one had the opportunity of exercising initiative. His starting point was the concept of the invention, then work was directed towards its realization; his attitude was that of a starry-eyed young tycoon hoping to make his first million; maybe it was good for physics that none of his inventions became ‘hits’ in the sense of making him a millionaire’. But had he become a millionaire this would not, in my opinion, have made any difference to his pursuit of knowledge. He regarded his research students as his most precious products, and his laboratory as his Heaven on Earth.

Gabor was elected an Honorary Member of the Hungarian Academy of Science in 1964, the first emigré to be elected. He was rather surprised “seeing that in my book Inventing the future I have expressed rather critical views on Communism. Welcome sign of liberalization.” He was also invited by a fellow-
countryman, Peter Goldmark, with whom he had worked in Berlin, to the laboratories of the Columbia Broadcasting System (C.B.S.). The C.B.S. had bought a number of his patents and in 1965 Goldmark, the director, offered him an appointment for life as a Staff Scientist, but he did not want to give up his Chair and instead, accepted a part-time consultancy. He gave a very challenging lecture to an Education Seminar, [98], at U.C.L.A. in April 1965 on ‘Inventing Education for the Future’, a future world which must be economically stagnant.

After Aldous Huxley died in 1963 a Memorial Volume was published containing tributes from many friends including one from Dennis, [97]. Huxley’s lifelong influence on him started in student days. The early novels “acted like a shock wave on me and on my fellow Central Europeans; we found he could discuss intellectual matters so much better than we had imagined from reading other English novelists, but the sort of Central European who could read and enjoy Aldous Huxley was destined to emigration or the gas chamber . . . . His greatness lay in the unparalleled span of his mind, in his ability to compose grand contrapuntal symphonies of human life and to put them into perfect literary form.” “I am not however concerned with his literary fame . . . but his heritage to those who really care about the future of the human race, and in this respect I hope he will be remembered with Thomas More.”

Here we see the growing concern for the future to which Dennis devoted so much of his later life. It began (so far as his published works provide the evidence) way back in the early days of the war when he framed his version of “a kind of Hippocratic Oath” to guide scientists’ behaviour. This contained thoughts which may well have been provoked by Brave new world (Huxley 1932).

I have already referred to the brilliant theme of the second part of his Inaugural Lecture, 1959, [70], from which Inventing the future, [70a], sprang and here there is a direct connection with Science, liberty and peace (Huxley, 1947) in which “Huxley gave a closely reasoned analysis of the threat to individual liberty arising from the progress of science.” His views on the possible development or invention of beneficial drugs were influenced by Doors of perception (Huxley, 1957); and finally “To me Island (Huxley, 1962) was the last great gift with which he enriched my life”, and Dennis too has enriched the lives—maybe partly on account of Aldous Huxley,—of many who care about the future of mankind.

Holography had been dramatically revived by the invention of the laser; this is not the place in which to describe the eruption which occurred except insofar as it directly involved the inventor of holography. Using a laser beam produced by a helium-neon gas operating at 6328 Å Leith and Upatnieks produced optical holograms in 1963 by Gabor’s original technique, [28, 29], with remarkable clarity. Gabor lectured at the C.B.S. Laboratories, also in April 1965, [91], reviewing the dramatic change, a change made possible because the holograms could now record 10 000 interferences and thus make full use of the information capacity of fine-grain photographic plates.

In October 1965 he described what might turn out to be one of his most important inventions ‘Character recognition by Holography’, [94], an invention
which, almost certainly, will not have to wait 16–20 years to fructify. He showed that holography could "solve one of the most urgent problems of computers and other data-processing devices; the recognition of characters with many variants. . . A single hologram may discriminate between all the numerals and the letters of the alphabet, each with 30 variants." His brilliant proposal involved the making of one hologram combining two coherent waves at an angle to one another, both falling on a photographic plate each proceeding from different objects, the first object being, say, a letter of the alphabet, written or printed, the second being a combination of point sources of that same letter arranged as a code which can be read by a machine. When light from the handwritten letter is presented to the hologram, the coded version flashes out and can be read by the data-processing device.

Lensless holography also appeared in December 1965 and with American colleagues, [96], he reverted to work done (with Goss, see [102]) in London in 1951–56 but not, as yet, published on the reconstruction of phase objects by holography. All this was reviewed in January 1966, [99]; "lensless holography has an intrinsic advantage over ordinary photography because there is no lens which can fully exploit the information of the photographic plate,—it has been put to good use in the photography of explosive waves" (shown in [101]), "it has been applied to the optical testing of surfaces and their deformations, and holography with X-rays is particularly attractive."

His last major paper, [111], before retirement was written with an American, Professor G. W. Stroke of the University of Michigan, who had made many contributions to holography using lasers. In Gabor's pioneer work the light wave from the object was frozen onto the photographic plate by the superposition of the 'background' or 'reference' wave which might, or might not, be the original wave or even a wave of the original wave-length. But with lasers, the Americans had shown that the reference wave can be transmitted at an angle to the wave striking the object, that it can even be a diffuse illumination so that a three-dimensional image may even be seen with two eyes, that the technique can be used with a modification of Lippmann's (1894) method of colour photography (that is to say by letting the reference wave fall on the emulsion from the opposite side to the object wave, thus giving a deep or volume hologram), and finally that volume holograms could be made to reconstruct multi-colour images upon illumination with ordinary white light. Gabor and Stroke wrote a comprehensive theory covering all these variants.

The first book on holography had been published by Professor Stroke in 1966 Coherent optics and holography and in its preface he wrote 'Because of the uniquely important place held by Professor Gabor's three original "wavefront-reconstruction" papers which laid the ground-work for the principles of wavefront reconstruction imaging in optics, and more particularly for the retrievable recording of phase and amplitude information in imaging light fields, the three original Gabor papers, [28, 29, 36], are reprinted in their entirety in an Appendix'. No greater testimony to the value of this work done 18 years ago could have been paid, and this by one of the leading authorities in the world.
"I am no longer afraid of retirement because I have acquired a new hobby, writing on social matters. Now that ‘my future is mostly behind me’ I am passionately interested in the future which I shall never see, but I hope that my writings will contribute to a smooth passage into a very new epoch." This was the last entry he made in his ‘personal record’. He retired in September 1967 and was made a Research Fellow of Imperial College and Professor Emeritus.

André writes ‘In 1921 Dennis spent part of his holiday at Igls in the Tyrol and part travelling in Italy. From Rome he travelled along the coast south of Rome and it was then his wish to have a villa there sometime.’ Now he purchased land at Lavinio Lido, a pleasant holiday resort near Anzio, and built a beautiful villa named after his wife, where he and his wife subsequently spent all of their summers.

**Retirement**

Gabor was immediately offered a Senior Professorial Fellowship which would have left him in command of his research laboratory but there had been very few graduates wanting to work on his special subjects, the students who had last worked on the flat television tube had completed their theses and had left College, he had never worked in collaboration with a more junior member of the staff, and he had had the invitation from the C.B.S. to devote more time to work in America than he had been able to spare during his active professorship. So he declined the College offer and accepted, instead, a Professorial Fellowship which gave him the use of secretarial services and allowed him to keep his old office.

The Italian house had been built and was ready for occupation in the summer of 1968 and the Gabors spent the Michaelmas and Lent terms of 1967–68 in Stamford, Connecticut.

The first year of retirement was exceptionally busy. The Americans, Kahn and Wiener*, had published a list of one hundred inventions and innovations placed in possible chronological order which might materialize before the year 2000 A.D. and abstained from all judgements about their value. Dennis was stirred to think more deeply; he took the list as a basis for analysis, discarded some of them and added many of his own; he consulted specialists in the various fields of endeavour and also expressed his own view of the desirability or otherwise of the 137 inventions listed. In two lectures to the Science of Science Foundation in January–February 1968 he presented these reflections (they are to be found in French translation in [114]) and then prepared an extensive review of them for his next book, *Inventions*, [127]. Since writing his earlier book *Inventing the future*, [84], he had become more and more anxious for the distant future he would never live to see: "The most important and urgent problems of the technology of today are no longer the satisfactions of primary needs nor of archetypal wishes, but the reparation of the evils and damages wrought by the technology of yesterday . . . Fossil fuels are threatened

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by exhaustion, so we must have nuclear power; death control has upset the balance of population so we must have the pill; mechanization, rationalization, and automation have upset the balance of employment: what is it we must have? For the time being we have nothing better than Parkinson's Law and restrictive practices.” So many of the most profitable advances carry inherent penalties, for example some of the new remarkably strong materials of extreme value to industry “might be used to produce the poor man’s hydrogen bomb . . . innovation must work towards a new harmony otherwise it will lead to an explosion,” and the author’s intention was to make us think. The book was published in 1970 and in the same year a German tract, “Prognosen des technischen Fortschrittes”, [128], summarized the main theme.

The 60th birthday celebrations of Professor Scherzer gave Dennis an opportunity of dedicating to him an “Outlook for holography”, [113], recalling that it was Scherzer’s brilliant proof in 1936 of the theorem that the spherical aberrations can never be eliminated in any axially symmetrical electron-optical lens system “that induced me, in 1947, to look for a way around this fundamental difficulty”. He repeated the story of the Aldermaston experiments of 1948–53 which ended in disappointment owing to a combination of defects; “I wish we could start now when the patient work of German and Japanese electron microscopists has eliminated these defects and has reduced the resolving power to the ‘Scherzer limit’ of 3.6 Å”. “There are now many ways in which holography is developing, and more speculatively it may record wave phenomena for which good imaging systems are not available, such as X-rays, radio waves, sound waves and earth waves.”

In his ‘Fifty-eighth May Lecture’ to the Institute of Metals, [115], “The prospects of industrial civilization” he strongly attacked our present way of industrial life concentrating mainly on Britain’s malaise. His central theme was the problem of ‘mismatch”, to use an electrical engineering term; the mismatch of the I.Q. of most of the population and the I.Q. demanded by industry of the future, the relatively few people needed, for example, in the earth-moving industry, the containerized freight industry, etc., the mismatch between the military arms we need, and the huge size of the armament industry which (even in U.S.S.R.) exports to all and sundry, and many other similar examples of mismatch, culminating between life and economics,—life being now so safe and rich we could do so many good things like improving education, clearing slums, etc., but we don’t do these things because we are up against economics of balance of payments, of insoluble unemployment, just bogged down in day-to-day politics. Of the potentially greatest mismatch of the future, between Man’s nature and the Age of Plenty; he asks “the huge increasing crime rate, the drug taking, the restlessness, etc., are these all the portents of the Age of Leisure?” Here, as he saw it, is the challenge of our times; it epitomized his pleading to every thinking man and woman, to the students who heard him in Japan (The World in 2000 A.D. [116]) and in due course it became the theme of his next book The mature society, [135]. He reflected “Because I shudder at the thought of brain washing or pacifying drugs I would rather take a leaf out of the book of
the successful elites of the past, such as the English aristocracy and the religious orders. I don't expect you to like it. It is Hardship. The calculated discomfort of the English public school (cold water tubs and the like) may look like the modern version of the savage's initiation ceremony, but actually there is wisdom here in the recognition that man does not appreciate what he gets for nothing. The permissive society is approaching a dead end. Despite the lunatic fringe, rebellious youth also contains a potential elite. For those with a fighting spirit among them let life be hard and competitive. Everybody must be made aware that a civilization achieved by a hundred thousand years of hard work and human sacrifice is worth preserving."

Professor Stroke, now Head of Electro-Optical Center in the State University of New York at Stony Brook, had invited Dennis to be a Visiting Professor, and there they gave an account of the successes, to date, of holography [118]. Most of the basic features have already been mentioned in this Memoir. Some of the new applications were the taking of shock-wave pictures, the examination below a water surface of microfauna, of aerosol and jets emerging at high velocities, of faults below the surface,—of, for example,—motorcar tyres, and then, just ahead, maybe, lay the prospect of holographic portraiture.

Returning home from America and going on to his Italian home he went to a meeting of the Accademia dei Lincei in April 1968 where the 'Club of Rome' was founded. The members of the Club belonged to the world of culture, industry, art, and science and had most diverse backgrounds, but, whether economists, philosophers, scientists, technologists, humanists, or artists, they were a group interested in studying problems of natural resources, nutrition, environment, climate, the Third World, income distribution, etc. Dennis had been invited as a founder-member in consideration of his broad vision of the problems of the world which he was able to set out from both the scientific and the humanistic viewpoints. In due course he made great contributions to the Club's activities as will later be recounted.

In the autumn he joined the O.E.C.D. Working Party on long-range forecasting and planning convened at Bellagio in October and there presented his views on "Open-ended planning", [117], the sort of planning which does not unduly restrict the freedom of other, later, planners. He admitted, of course, that he spoke as an amateur though he backed his proposals for safety and freedom of action with mathematical analogues. In essence he proposed that, since potential productivity was so much greater than actual, certain vital parts of state planning could be financed on the stock market with bonds redeemable at a future date at the current industrial index value at that date, so that the investor would be safeguarded from inflation and the bonds would have an anti-inflationary effect on the Exchange (a proposal anticipating the present—though greatly restricted—'Granny Bonds'). Gabor gave some reflections at the end of the Symposium; "The main dangers which threaten our civilization are the decline of the Gospel of Work—and the meaninglessness of a world in which rational thought (modern science and technology) has brought to the fore the irrationality of Man": "the new planners must modify the social structure to
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provide a component of self-interest of individuals and of corporations towards long-term stability”, quoting Abraham Lincoln’s words, “like the Patent System, adding the fuel of self-interest to the fire of genius”—words aptly quoted by an inventor of the highest calibre.

Earlier in the year at Florence he had presented to the Symposium on Applications of Coherent Light some thoughts on prospective applications of holography, [119], holographic panoramas, three-dimensional pictures in monochrome and colour, and information coding and storage which for the moment were held up by ‘laser speckle’. Some were probably for the next century, but transmission and storage by holographic means he regarded as likely to be successful if speckle could be eliminated. A further goal he envisaged would be the translation of the information received by the radio-astronomers into the optical domain by optical means. At another Symposium, the first on Acoustical Holography he summarized the proceedings, [123], “... how thrilled I have been, I am sure this is the beginning of greater things. The acoustic reconstructions are in the stage my optical were in 1947 and it took me 15 years before optical holograms gave good pictures; we shall not have to wait 15 years before you get good results—ultra-sound for medical purposes and (non-destructive testing), and underwater imaging for oceanography.” As for using holography for seismic waves, “use coherent oscillations, measure the field at the earth’s surface and conclude what is below; holography for this type of problem is complementary to sonar, sonar and radar are wonderful for looking sideways, the only thing that they cannot do is to look forward. And holography can do exactly that.”

It had been suggested* in 1968 that the remarkable property of the human memory of recognizing and recalling long sequences of which, at first, only a small fraction is consciously remembered, could be simulated by a mathematical model which had been called a temporal analogue of holography. Gabor devised another mathematical model, [110a, b], which he considered produced a closer analogue of holography though he did not wish to suggest that it corresponded to the reality of the nervous system. Later in the year 1969 in America he showed in “Associative Holographic Memories”, [124], that in holography a mere part of the hologram suffices to recall the whole object and commented on the interest shown by the neurophysiologists; the fact that large parts of the brain can be destroyed without wiping out a learned pattern of behaviour has suggested that the brain might contain a holographic mechanism. “I do not suggest that such processes are present in the nervous system—but the possibility cannot be excluded and the hypothesis deserves careful examination.”

He wrote, with H. Hartley, the Royal Society’s Biographical Memoir, [131], on Sir Thomas Merton during 1969. Merton was a man after Dennis’s own heart, a wonderfully able inventor who worked by inner compulsion rather than under economic necessity, a man for whom inventing was a creative joy; Merton had said that the research laboratory was the only place where one swallow can make a summer. Like Dennis, Merton had been an art connoisseur

and, apparently like Dennis who spent the six winter months in America and most of the summer in Italy, would quote with relish a saying by J. M. Keynes, "The avoidance of taxes is the only intellectual pursuit that still carries any reward."

Several universities conferred honorary degrees on Gabor, the first being Southampton 1970, followed in a few months by Delft (1971) where the Oration was given by Professor Le Poole who had first heard Dennis at the electron microscope conference in Manchester in 1946 and had been in close contact with him ever afterwards. He told a little-known anecdote about the Graduand;—‘walking in the streets of Berlin with your friend Leo Szilard and discussing the wave-nature of electrons advanced by de Broglie;—summing up, you both agreed that here was an ultra-short-wave radiation readily available with lenses to go with it, so why not build an electron microscope which should be capable of giving much better resolution than the light microscope. But you both agreed it would serve no purpose’. In his reply, [131a], Gabor spoke of Delft as the premier technical university of Europe and told how he had missed making the first electron microscope ‘out of the pieces of the cathode-ray oscillograph with which I had made my doctorate in Berlin and this never ceased to annoy me. I spent much of my spare time thinking of ways and means to perfect the instrument I had failed to invent. The super-resolution I aimed at in 1948—and failed to achieve—could be achieved today if somebody went at it with sufficient determination.” He spoke of his failure also to invent the laser: “In 1921 I attended a seminar by Einstein on Statistical Mechanics and shall never forget his brilliant derivation of Planck’s Law in which ‘simulated emission’ occurred for the first time, presented with unforgettable gusto. When, in 1950, I realized that holography could be interesting in light optics if one had a strong source of coherent light, I had the idea of the pulsed laser and proposed it to a student, but he thought it too risky and I agreed with him.” It is interesting to note here that Dennis never contemplated doing the experimental research himself; although, as has been here recorded, he gave much time and attention to the planning of an experiment he was not a real experimenter, Ivor Williams on B.T.H. and my Aldermaston staff did the experiments: Dennis was, as he told me in 1934, an “ideas man”. Mr R. H. McMann, a colleague in the C.B.S. Laboratories where Dennis worked for most of the Michaelmas and Lent terms, contributes a similar assessment: ‘Dennis did all his own typing by the hunt and peck method and consequently, since he was a very prolific writer, he seemed to spend all his time out of the laboratory in front of a typewriter. He did all his own drawings despite the fact that we had a large Drafting Department at his disposal! He was a good experimentalist but he liked others to actually do the experiments. He would go into the lab., observe what was going on for 10 minutes, make a few suggestions, then go back to his office where he would hunt and peck several pages of ideas on how to properly conduct the experiment.’ Mr McMann also provided another nice touch: ‘Dennis was a very hard worker but he worked strictly at his own pace.’ (The reader might remember that at this time Dennis had retired, supposedly.) 'If he felt like taking a nap at 2 in the
afternoon, and he frequently did, he would simply sit at his desk and go to sleep. At one time he shared an office with a colleague and their desks faced each other. Every afternoon the two of them could be found facing each other, quietly asleep. But of course they could also be found in the laboratory on almost every Saturday and Sunday and if need be, on any day of the week till midnight.

Laser speckle “is a direct consequence of the high coherence of laser light and has long been recognized as Enemy Number One,” wrote Dennis as he worked in America in 1969, [130]. The reconstructed image is marred by interference fringes set up by every particle of dust, etc. He distinguished between objective speckle, due to uneven illumination of the object, and subjective speckle caused by imperfections in the optical reproduction. He then showed that the former could be eliminated by a special type of illumination of the hologram through two phase-plates of great complexity “The realisation of these may require considerable experimental skill,” the subjective speckle presented even greater difficulties which were not resolved in this paper.

In April 1970 he spoke at the Engineering Conference at Chicago, [127a], on the ‘Scientific and technological trends for future television’. First he referred to the start of British t.v. when the picture was scanned at 405 lines and now with 625 lines; he suggested that the Americans would jump to the front with 750 or even 1000 lines, though high-quality pictures in the homes might be better provided at 1000 lines from video cassettes. Looking further ahead he thought the large screen, say 3 ft x 4 ft (0.9 m x 1.2 m) might be served with 1000 lines; this should suffice for such screens, as viewers would not be sitting very close to them. He dismissed the ‘solid-state’ t.v. screen; little progress has been made in 20 years. As for three-dimensional t.v. which could even then actually be achieved, using perhaps holographic techniques, the complications at the receiving end would be stupendous and he did not think “to my regret, that full 3-D. t.v. will arrive except in the remote and rather unlikely future post-economic society.”

Throughout the year 1970 he was immersed in writing The mature society, [135], which he sent to the printers early in 1971. It was a sequel to his earlier (1963) book, [84]; “in the intervening 8 years more and more thinking people have realised that our free industrial civilisation is not likely to survive another generation without fundamental institutional changes.” We had seen Soviet expansion in the occupations of Czechoslovakia and interference in the Middle East, and we have witnessed moral erosion manifested by rebellious university youth. Added to this, growth of the National Product which had brought such affluence had slowed down, and though there would be ups and downs of prosperity, Gabor thought that a crisis of saturation was almost upon us. He argued for improved scientific forecasting of socio-economic matters (especially in a lecture ‘Cybernetics and the future of our industrial civilisation’, [132]) and set out to sketch a mature society which accepts zero growth in materialistic matters while preserving growth in the quality of life. The retreat from material growth is going to be difficult. Hundreds of government and other bodies exist to make forecasts and long-term plans and many of these concern themselves
with material possibilities, but Gabor suggested that it is the psychological reactions which will be the most threatening to the change which has to occur, and he considered that a new science *The new anthropology* will be needed. He advocated, as before, a change in state financing, a different approach to education, first at an early age and then at university level where there could be two branches, one for the gifted minority, the other to prepare the less-gifted majority for entrance into the permissive society. He advocated that everyone should have a chance to change occupation in middle life, and that everyone ought to spend some time in some service occupation. “The programme for the future must not become a platform for political parties,” and he offered suggestions for the way it might be put across to the people. With two American colleagues he gave a general review of holography to the American Association for the Advancement of Science, [133].

Gabor had been on the Nobel Prize list for some time. Indeed he had always recognized that the original invention of holography might one day be so rewarded; he and I hoped in Aldermaston years that if a resolution of 1–2 Å were ever achieved, he and the team producing the electron hologram and the optical reconstruction might share a Prize. After the explosion of holography in the 1960s the recognition of his basic work and of the brilliant inventions which followed appeared to be well justified. However, the atomists seemed to win the day and in 1968 in a mood of depression he said that the days of awards for inventions were passed. Now, in December 1971, ‘the Winter of his discontent’ was ended by the award of the Nobel Prize in Physics and his delight was shared by his friends and the many scientists for whom holography had become a way of life. Several thousand papers had now been written on holography and its applications.

His Nobel Lecture, [134], embraced the foundations of wave theory and the invention of holography, and then he reviewed the wonderful achievements of holographic scientists, concluding with a brief mention of two of his favourite holographic brainchildren, Panoramic Holography or Holographic Art, and three-dimensional holography without viewing aids (the old basic concept of 1932 mentioned by Oscar Deutsch). So far, holograms could extend to a depth of a few meters; if they could be extended to infinity a ‘picture’ on a wall could look like a window through which a distant vista could be seen. Work on both these concepts was proceeding but “I am not sure whether the difficulties will be overcome in this century. Ambitious schemes, for which I have a congenital inclination, take a long time for their realization. I shall be lucky if I shall be able to see in my life-time the realization of holographic electron microscopy on which I started 24 years ago”—we shall see soon the sequel to this reflection—“but I am one of the few lucky physicists who could see an idea of theirs grow into a sizeable chapter of physics. I am deeply aware that this has been achieved by an army of young, talented and enthusiastic researchers and I want to express my heartfelt thanks to them, for having helped me, by their work, to this greatest of scientific honours.” To a German friend he wrote “Ich schäme mich beinahe, das ich für eine so einfache Erfindung den Nobel-Preis erhalten habe”.
The City University had invited Gabor to give the second Edwards Memorial Lecture early in 1972 and for this he chose to give the Nobel Lecture, [137]; this was followed in December of that year by an Hon.D.Sc. of the University conferred in Guildhall by the Chancellor, the Lord Mayor of London, this being the first occasion on which a Nobel Prizeman had received a degree in this famous Hall in which, over the centuries, so many distinguished men had been honoured. The Orator on this occasion, Professor C. W. Miller, spoke of Gabor’s mixture of invention and discovery; ‘he has never let himself be restricted by existing technology, and his far-reaching, perhaps futuristic thinking has been directed to fundamental reasoning; some of his contributions at present dormant, will, no doubt, make their full impact at a future date’. Surrey University and the Engineering College, Bridgeport, Conn., likewise honoured him, and at his own university, London, he received the LL.D. from the hands of H.M. The Queen Mother in 1973.

The two years 1972, 1973 were greatly occupied with giving lectures, the Tykociner Memorial at the University of Illinois, [139], the eighth Annual Science Policy Foundation, [140], one to a Government and Public Affairs group at U.C.L.A., [142], two in Japan, the Fawley lecture in Southampton, [143], one in Budapest, one in 1972 at the Institute for Medical Optics in the university in Munich where a memorial plaque to the naming of the research laboratory after him was unveiled, the street leading to the laboratory being Die Gaborstrasse (there is a Nobel Avenue in Nottingham with one side-street named after Gabor), and a second visit to Munich to the Siemens Foundation, [146.]

Some of these lectures were on holography, others on variants of The mature society, [135], but all are so different and so brilliantly expounded. He gave a great amount of time also to the Club of Rome: its first report on ‘The limits to growth’ published in 1972 had been criticized on the grounds that it had neglected the help which science and technology might be able to give in overcoming threatened scarcity of world resources. Early in 1973 Dennis, with Sr Umberto Colombo, proposed that a Study group should be asked to identify those areas of scientific endeavour which could increase man’s capacity to exploit and regenerate natural resources. They co-chaired this Working Party, meeting in Rome, Tokyo and Milan and completed their task in 1976, publishing Beyond the age of waste, [155], in 1978.

In the Spring of 1973 the Gabors were guests of the Young Presidents’ Organization, an organization comprising only men who, before they are 40 years of age, have become Presidents of their respective Companies, and they must leave the Organization before their 50th birthday. They hold an annual event called the ‘International University’ and in 1973 took over the Queen Elizabeth II for a 6-day cruise from Southampton into the Mediterranean and invited academics and people prominent in public life. He gave two formal lectures, as a futurist; they were well received as were his rejoinders to queries from his audience. Mr J. F. Engelberger writes ‘Dennis was confronted with an assemblage of aggressive and self-confident middle-aged executives from the
United States, Europe and Japan. He revelled in this student body, so different from his students in electron physics where classes were heavily loaded with Hindus and Pakistanis whose educational motives distressed him; he deplored their fascination with scientific exotica when their home countries so dearly needed basic engineering contributions.

He was elected, for four years, a Trustee of the International Federation of Institutes for Advanced Studies. This Federation had been studying problems of the type mentioned in Gabor’s books and the October 1979 Seminar, ‘From vision to action’ will be in memory of him. The Director, Dr S. Nilsson, recalls Dennis saying “The so-called Western civilisation is built on extraordinary successful technology, but spiritually on practically nothing”.

He prepared several papers for conferences in 1974 but was unable to present them in person as he suffered a severe cerebral haemorrhage when in Lavinio in the summer. To the International Meeting of Communications and Transports (Geneva) he dealt with the energy crises precipitated by the fourfold rise in the price of oil, [153], and at the International Institute for Peace, meeting in Vienna, he dealt with the impact of this crisis on power politics, [152]. He sent two papers to the International Conference on Electron Microscopy meeting in Canberra, [150, 151]: one was an extremely detailed review of the history of the electron microscope, one of the best ever written: in it he repeated more accurately the story Professor Le Poole has told of the 1928 Szilard/Gabor conversation in the Cafe Wien, Berlin. Gabor had replied to Szilard “But one cannot put living matter into a vacuum, and everything would burn anyway to a cinder under the electron beam”. It would, of course, but, as he wrote, “who would have dared to believe that the cinder would preserve not only the structure of microscopic bodies but even the shape of organic molecules!” Then he looked ahead; he was still waiting for his 1948 electron holograms, but in the intervening 25 years alternate approaches had been very successful, “holography entering into electron microscopy through the back door”, he stated the immediate goal without giving detailed advice, “I do not want to spoil the pleasure of investigators as to how to achieve it.”

Dennis had been invited to be the Chairman of this Conference, paper [150] was to have been his opening address, and his inability to attend had been a bitter blow. His old friend of Aldermaston days, Professor Tom Mulvey, read the Address and also spoke about the content of the second paper, [151]. This had been hastily prepared and was not typed in the Conference standard format so it was not published, and indeed has never been published. However, this second paper concerned such an important milestone that its origin must be given here, however briefly. Professor Bartell of the University of Michigan had written to Dennis in April about having achieved direct views of electron clouds in atoms by means of the two-stage holographic microscope based on the original 1948 principle; with his collaborator, Dr Ritz, he had achieved a theoretical resolving power of 0.08 Å. Professor Bartell has kindly presented me with the correspondence which followed. Dennis was delighted with the news (10 April 1974) but thought he saw a flaw: he asked for a slide of the atom picture to show
at Canberra where he was to give the opening address, [150]. Professor Bartell was able to satisfy his doubts and Dennis replied (22 April) that he could “see a good chance that your idea will revolutionise electron microscopy; it is not difficult to build a few heavy atoms into complicated molecules such as DNA and these ought to give enough coherent background to make visible light atoms nearby”. He indicated how this should be done and wrote a paper, [151], in which he suggested that heavy atoms should be evaporated as a widespread lattice onto the object; his calculations indicated that with this technique carbon atoms may be made visible by the ordinary process of electron microscopy. To Bartell he wrote (31 May) “your work has started me thinking and I have worked out an approximate theory of heavy atom holography: it is complicated but it can be done”. In his next letter, written by an amanuensis, he had to report his severe illness, but it is so gratifying to note from the above correspondence that he lived to see the realization of his early dream and was able to write about it, and calculate afresh the outline of a new chapter in microscopy.

His final paper, in three parts, [154], dealt with the transmission of information by coherent light, as in the experiments done by Goss 20 years earlier, [102], and with suggested ways to reduce speckle, as previously studied, [130].

An account of Gabor’s scientific work would not be complete without some reference, however brief, to his many patents. Mention has already been made to a few of the early patents but Gabor did not compile a list and I regret I have not had time to trace them all. Those of later years were mostly assigned to the C.B.S. and I am grateful to the C.B.S. Counsel for sending me copies of the American versions; all of them are erudite in the extreme. Two concern the magnetization of plastic filaments and tapes of the kind used in sound reproducing machines; these date back to 1957, ten years before retirement. The first (U.S.A. 2 911 317) describes a novel way of aligning magnetic particles so that their direction of easy magnetization lies at 45° to the axis of the plastic filament and thus there is less interference magnetically between adjacent turns. The second (U.S.A. 3 064 087) concerns a very clever way to magnetize a tape from both sides. Two years later he invented (U.S.A. 3 108 383) for the C.B.S., apparatus to decode into pictorial form information encoded in a t.v. video tape; it was based on the diffraction patterns produced when monochromatic light traversed the tape and then fell on a mask having as many graded transparent lines in it as the scanning lines of the t.v. signal; the emergent light, focused, produced a recognizable image good enough for the purpose of editing a video film strip.

Then Gabor returned to his early love of 1939-40, a three-dimensional projection for a cinema (a partial version of some new thinking had been written up in 1960, [74]), but now he had two aids not available in 1940, holography and laser beams. The essence of the 1966 patent (U.S.A. 3 479 111) was the creation of a ‘deep hologram’ on a cinema screen, (for theory of the deep hologram, see [111] published two years later). The screen, or segments of it in turn, was to be coated on the reverse side with a photosensitive medium and then processed to produce the deep hologram, the process starting with a laser beam split into two halves, one half being reflected onto the reverse of the emulsion, the other
onto the front surface of the emulsion, the direction of the two beams coinciding with the direction of light from one cine projector, say the left-eye view, and with the direction of light to the left eye of the viewer. Both these light sources had then to be made to transverse the whole of the emulsion and then the process repeated for beams of light from the right-eye projector to the viewer’s right eye; finally, for colour cine films the whole process had to be repeated with lasers of two more different colours. At the time of writing I am not aware that this patent has been developed.

In the previous year, 1965, he had invented an ultrasonic camera (assigned to C.B.S. May 1966, U.S.A. 3 869 904) employing holographic principles based on laser beam illumination; sound waves in a fluid, modified by the object to be ‘photographed’, fell on a thin silvered membrane and thus distorted it, its position was registered by being illuminated by part of a laser beam, the other part of which bypassed the vessel and interfered with the reflected wave and thus produced a hologram of the object. Some years later he developed this idea further (1971, U.S.A. 3 745 814), replacing the ultrasonic generator by a short sharp pressure wave; prior to this wave the membrane had been illuminated with a laser and a hologram taken of it, thus recording any imperfections it may have had, and then the hologram was combined with the reflection from the membrane distorted by the pulsed wave modified by the object.

Another patent taken out before retirement and made over to C.B.S. (U.S.A. 3 506 952) concerns a sonar system employing holography; it is referred to in 1969, [123]. A narrow acoustic wave scans an object and each one of an array of small hydrophones collects reflected waves from all parts of the object field. Each hydrophone is also fed with a modulating signal of the same frequency as the acoustic wave but 30° out of phase, this constitutes the ‘reference wave’, as used in the generation of optical holograms. The combined joint intensity signals are then converted into modified light signals by an ingenious set of micro-shutters which are moved by the electrical signals and they then fall on a photographic film. Also early in 1967 he laid down the principles of holographic imaging (U.S.A. 3 561 838) and later in the year the principles of picture making (U.S.A. 3 545 836) both of which were beautifully portrayed in his Friday Evening Discourse at the Royal Institution in February 1969, [120].

Mr McMann also informed me that Dennis analysed the ideas of other members of the staff, at the request of the Director, and frequently contributed ideas of his own; he was never caught up in the ‘not invented here’ syndrome and would help with someone else’s invention as much as his own. One electrical printing system had been devised in the Laboratories of C.B.S. and Dennis did a great amount of work analysing the electron optics of the image dissector pick-up tube and c.t.r. display. Even today, the performance of this system is far above anything else that has ever been done with electron beams. All American patents are printed by this system.

The succeeding years must have been most frustrating for Dennis; he could neither read nor write, and later almost lost the power of speech. Fortunately his keen intellect and hearing were unimpaired so that he could enjoy company
and conversation, and the tape recordings of lectures and scientific papers sent to him by his friends. His physique remained good and with Marjorie he was able to travel far and wide, thus unconsciously inspiring many with his grit and determination to overcome the human physical difficulties just as, all his life, he had overcome the difficulties of science.

He observed with great pleasure the invasion of holography into the field of art and of advertising; his friend, Salvador Dali, was most impressed with the possibilities of 3-D since holography provides the third dimension far surpassing any of the conventional tricks based on illusions. Instead of lasers, ordinary lamps, even candles, could now be used to illuminate the hologram and the art museums were quick to seize upon this new medium. The Gabors in March 1977 visited the newly created Museum of Holography in New York of which Dennis's Membership was no. 1; in the winter of that year they were honoured at the holography exhibition staged at the Royal Academy and in the following March they paid their second visit to the New York Museum and Dennis was invited to become the Honorary Chairman of the Board of Trustees. Here he sat for his holographic portrait by Hart Perry, a form of art destined to become very popular.

At his home in Italy Dennis swam frequently and they entertained numerous friends. Indeed his friends will always treasure memories of the Gabors’ happy life and generous hospitality; for 25 years we ’let the New Year in’ with a party at which Dennis was the leading spirit. Though not blessed with children he was always fond of young people and little ones, who responded with affection.

After a happy summer in Italy, in 1978 he became bed-ridden and died peacefully in a nursing home. At the funeral service, the Reverend Ian Robson echoed all our thoughts: ‘We do indeed give thanks for Dennis’s interests in the small things of life, his love of children, of people, of music and of subjects which deeply concern mankind.’ We knew him as an extremely genial, warm-hearted man who knew how to listen especially when talking to younger folk whom he encouraged by his manifest interest in their work. As Professor McGee wrote ‘He walked with kings, yet kept the common touch’.

Pericles provides me with my last thought; ‘Famous men have the whole Earth as their memorial; it is not only the inscription on their graves that mark them out; no, in foreign lands and in peoples’ hearts their memory abides and grows’. So will it be with Dennis Gabor.

Honours
Commander of the Order of the British Empire, 1970
Honorary membership of the Hungarian Academy of Sciences, 1964
The Cristoforo Colombo Prize of Genoa, International Institute of Communications, 1967
The Thomas Young Medal of the Physical Society, 1967
The Michelson Medal of the Franklin Institute, 1968
The Rumford Medal of the Royal Society, 1968
The Medal of Honor of the I.E.E.E., 1970
The Semmelweiss Medal, American Hungarian Medical Association, 1970
Holweck Prize of the French Physical Society, 1971
Dennis Gabor

Nobel Prize in Physics, 1971
Foreign Associate Nat. Acad. of Sciences, U.S.A., 1973
George Washington Award, Amer-Hungarian Studies Foundation, 1973
Hon.D.Sc. University of Southampton, 1970
Hon.D.Sc. Delft University of Technology, 1971
Hon.D.Sc. University of Surrey, 1972
Hon.D.Sc. The City University, 1972
Hon.LL.D. London University, 1973

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(b) In B.T.H. and A.E.I. Professor G. C. Carter, Dr J. Dyson, Mr C. E. Fenwick, Dr M. E. Haine, Professor C. J. Milner, Professor T. Mulvey, Mr R. L. Rouse, Mr L. Rushforth, Mr K. J. R. Wilkinson and Mr W. I. Williams.

(c) In Imperial College years Dr M. J. Albert, Professor E. A. Ash, Professor C. Cherry, Professor W. A. Gambling, Professor M. A. Jaswon, Dr P. Kalman, Professor N. Kurti, Mrs E. Moffatt, Professor J. D. McGee, Professor C. W. Miller, Mrs J. Pingree, and Professor J. Brown.

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The photograph reproduced was taken by Novotta Ferenc, Budapest, Hungary, about 1970.

BIBLIOGRAPHY

German Period, 1925–33

Biographical Memoirs


In Britain, 1934–48 at B.T.H. Co.


At Imperial College of Science and Technology, 1940–67


[52] What have we learned so far from Cybernetics? (A talk in the Third Programme of the R.A.I.) (Italian Radio.)


[58] Collective oscillations and characteristic energy losses in solids. Phil. Mag. (8), 1, 1–18.


Biographical Memoirs


[80] 1961 Machines and prediction. Chapter 13 of La Scuola in Azione San Donato


[92] Imaging with coherent light. Summary of C.B.S. Laboratories Seminar, 8 April.

Dennis Gabor


[103] Holography and communications (Symp. on Generalized Networks. Polytechnic Institute of Brooklyn, April 12–14 vol. xvi in the Microwave Research Institute Symposia Series, Polytechnic Press, Brooklyn.


1971b Wavefront reconstruction, pp. 15–21.

1971c Information theory in holography, pp. 23–40.


1971g L’Holographie. Prix Holweck. Société Française de Physique.


1973a Social control through communication. Chapter 7 of *Understanding the new cultural revolution*. John Wiley & Son.


1973g Thoughts on the future. (Bowra Memorial Lecture, Cheltenham College 6 October 1973.)


1974d Wissenschaft und Frieden; Der Frieden und die Erdölkrise Inst. für der Frieden, pp. 73–76. Wien, 1974.


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