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Rutherford, radio and opto-electronics

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The paper contains some personal reflections on Rutherford as a scientist and as a person.

It describes his remarkable initial work on radio in Canterbury College, Christchurch, New Zealand, after the work of Hertz, which was then continued in the Cavendish Laboratory, Cambridge. It is likely that Rutherford was ahead of Marconi in 1895. Here also he used the photo-emissive effect (discovered by Hertz) in his work with J. J. Thomson. He then switched in 1897 to X-rays and radioactivity.

The paper then returns to the origin of opto-electronics by the discovery of the electrical effect of light by E. Becquerel in 1839 (C.r. hebdom. Séanc. Acad. Sci., Paris 9, 145; 561).

The development of transmission of information by electrical signals over wires which led to Bell’s telephone in 1876 is outlined, and the discovery of the photo-conductive effect in 1873, which led to an outburst of ideas for television and the first real demonstration by Ayrton & Perry in 1880 (Jl R. Soc. Arts 29, 468).

Hertz’s two discoveries (used by Rutherford), the discovery of the electron by J. J. Thomson, and the invention of the Braun tube in 1897 gave a great boost to the idea of television. The major idea that came from A. A. Campbell Swinton in about 1903 was that the cathode ray tube was the key to successful television. This was published in the epoch-making note in Nature, Lond. in 1908 which laid the foundation for modern television.

The idea was repeated and up-dated in papers published in 1911 and 1924, and persistently advocated until Campbell Swinton’s death in 1930, the era when technology had progressed sufficiently to allow his proposals to be put into practice.

The first all-electronic systems of t.v. are described with reference to parallel advances in electron circuitry, photo-electricity, electron optics, phosphors, image intensifiers; all stimulated by the work on television, which would not have been possible without them.
I consider it a great honour to have been invited by the Royal Societies of London and New Zealand to deliver this lecture to honour the memory of Lord Rutherford of Nelson (here in his native country, in this city and in the university that can proudly claim to have been his alma mater). I hope it will also be taken as a small token of thanks from me for the privilege of having been a pupil of such a great master. As such, it is not surprising that I am frequently asked, 'What manner of man was Rutherford?' Figure 1, plate 1, is a reproduction of the fine portrait of Rutherford painted by Oswald Birley which hangs in pride of place in the Royal Society's rooms in London. The subject is depicted by the artist in a characteristic pose, just as he appeared when he lectured to us, his students. To add a touch of verisimilitude to the scene a typical piece of physical apparatus of that era, a McLeod gauge, is seen on the bench in front of him.

To help the illusion I shall now also reproduce a short but characteristic speech he made after receiving an honorary doctorate at Göttingen University in Germany in 1932–1933:

'I did not know that I had the right to lecture to you on this occasion but I also am greatly surprised to know the honour that the Dean of the Faculty has done me. I was very proud to be a Foreign Member of the Göttingen Academy and my pride is still more increased by being made an honorary doctor of this great University. I thank you and your colleagues for your very great kindness and also the very great honour you have done me, an unexpected honour on this occasion.

You have referred, Mr Dean, to the fact that the Royal Society of Göttingen was founded by an English King – I think King George II – King of England and Elector of Hanover. It is of some interest to recall the connection of the English Royal Family with science and particularly with the Royal Society. In the year that Newton died, in 1727, King George I of England and King George II were made members, or patrons, of the Royal Society of London and under the influence I think largely of the great fame of Newton one could understand that the King would be interested in founding associations to carry on the work of science.

I believe I am right in saying that the University of Göttingen was founded in 1737 and personally as President a few years ago of the Royal Society (of London), I have been very interested to follow the connection of this University with English Science.

It has been a great pleasure to me to send more than one of my students to learn wisdom with Professor Born and Professor Franck here. And I myself, although this is the first time that I have visited this town of Göttingen, I have known well the great reputation of this great University. I may be allowed to thank you again for this very great honour you have done me.

I must apologise for speaking to you in English but I have the excuse
Figure 1. Portrait of Rutherford. See: Notes and Records of the Royal Society of London, vol. 27 part 1, 1972, facing p. 5.

(Facing p. 194)
that I was born at the other end of the world, in New Zealand, and I have not had time since my arrival in Europe to learn your language. But I think if you heard me speak in German you would be grateful that I am addressing you in English.'

I often answered the question by saying that Rutherford was very like a reasonably prosperous New Zealand farmer, and I mean that comparison as complimentary to both Rutherford and the New Zealand farmer. To back up my slightly facetious comparison I must relate an incident that is supposed to have occurred one evening when Rutherford was dining at High Table in his college, Trinity, in Cambridge. He happened to be seated next to a very distinguished American journalist. They hit it off very well and had an animated conversation ranging from nuclear physics to farming. After dinner as they returned to the Fellows' combination room for coffee and port the American drew aside his host and asked, 'By the way, what was the name of that remarkable Australian farmer that I sat next to at dinner?' Fortunately perhaps the American's host was not a New Zealander!

Rutherford was a simple, kindly, unpretentious man and all of those qualities came through to us as we then were: young, unsophisticated, often naive students. I never remember feeling scared of him. The 'Professor', as he was known to us, at his own request, even after he became 'Lord', was very much an avuncular figure and we probably were not properly conscious of his real greatness. He, par excellence, was one who, to quote from Kipling 'could walk with Kings nor lose the common touch'.

Though he was the acknowledged primus inter pares of experimental scientists of his generation he seems to have been accorded that primacy without the jealousy that is usually aroused by great achievement leading to great fame. This was probably because he never tried to grab the credit for another scientist's, or even a student's, work and he was most generous and punctilious in giving credit to others where credit was due. It has been said with truth that he never lost a friend and never made an enemy. In the fifty odd years during which I worked in scientific circles in London I heard not a single word of criticism of Rutherford. And yet he could be guilty at times of what in most people would be regarded as 'skiting' (to use an antipodean expression), as once when his friend (and later biographer) Dr A. S. Eve, when congratulating him on some recent discovery, commented: 'You're a lucky man, Rutherford, always on the crest of the wave.' To which, after the usual chuckle, Rutherford replied, 'Well I made the wave didn't I!', and then added disarmingly: 'at least to some extent.'

There is much evidence that I could quote from my own experiences and from that of others to support my view that he was a man of very refined, cultured and kindly nature even if it was somewhat disguised by a bucolic exterior. I must restrict myself to the comments of a great lady from 'the other culture' who lived as a neighbour of the Rutherfords in Cambridge and knew them well. She was Madame de Navarro who, as a young American actress, Mary Anderson, had been probably the greatest dramatic artiste at the turn of the century. She wrote in her
autobiography (de Navarro 1936), 'Wherever he is, Lord Rutherford seems to radiate brightness. His zest for good stories, his recounting of boyhood experiences in New Zealand are refreshing... There is something arresting about Lord Rutherford's appearance, whether it is the piercing expression of his eyes or the natural energy of the man. His voice is resonant, his conversation animated and vivid. An unselfconscious victorious personality. He takes his greatness in his stride and leaves it at that. That is how Lord Rutherford impresses me.'

Now a few words about the place that I think Rutherford should occupy in the scientific Hall of Fame. This must be of course, an entirely personal opinion. In the field of experimental physical science he certainly ranks with Galileo, Newton and Faraday. Other scientific greats, such as Einstein, Pasteur, Copernicus, worked in sufficiently different fields to make any comparison difficult. However, from the perspective of half a century, I would vote for Rutherford as the greatest in that galaxy even making allowances for the very different eras in which they worked, because I believe that his discoveries altered and enlarged the human understanding of the physical Universe more than those of any other man. When one adds that he (with Michael Faraday) was a man of such a fine nature whereas some of the others certainly were not, it places him very high in the ranks of great human beings.

Now I must begin my digression from Rutherford and his work to my own interest – opto-electronics – but am led there by Rutherford's early work on electromagnetic radiation, begun when he was only a student in Canterbury College, New Zealand in the early 1890s. This was only 6 or 7 years after the discovery of this new form of radiation by Heinrich Hertz (1887), predicted by Maxwell a few years previously. It says a great deal, not only for Rutherford's ingenuity and scientific acumen but also for that of his teachers here, that he was able to carry his experimental work on radiotelegraphy to such a high standard that when he took his apparatus with him to the Cavendish Laboratory, Cambridge, to work under the already world famous J. J. Thomson† (or 'J. J.' as he was known world-wide in scientific circles) in 1895 it soon became the talk of the town. People like Lord Kelvin, Sir Oliver Lodge, Sir Robert Ball were almost queuing up to see, and to hear about, this remarkable work, which he continued in the Cavendish. It seems to me certain that in those few years he was more advanced in radiotelegraphy than Marconi, who of course was still in Italy. It is worth remembering and emphasizing that Rutherford (with J. S. Townsend) and his remarkable work may be considered to have established the status of this new type of student in Cambridge: the post-graduate research student from the colonies. Many of us who followed in his footsteps benefited greatly. Much later, on 10 February 1909, J. J., in a great tribute to Rutherford in Manchester on the occasion of his award of the Nobel prize (for chemistry), commented: 'Professor Rutherford has never received the credit that he should have had for his work at Cambridge in connection with

† 'J. J.', Professor Sir J. J. Thomson, O.M., F.R.S., Cavendish Professor of Physics Cambridge, immediately preceding Rutherford.
radiotelegraphy in 1895. His success was so great that I have since felt some misgivings that I persuaded him to devote himself to Röntgen rays and radioactivity. J. J. was at the relevant time Rutherford's research supervisor.

During those years in the Cavendish, 1895–1898, working under J. J., Rutherford spent much of his time helping him in his researches into the passage of electricity through gases, J. J.'s main research interest, which eventually led to his discovery of the electron in 1897 (Thomson 1897). In the course of this work Rutherford used that other major discovery by Heinrich Hertz (1887): the release of electrons from metal surfaces by violet light: the external photoelectric effect. Rutherford measured the speed of these negatively charged particles in gases. Thus we have Rutherford actively experimenting in his Cavendish days on the two phenomena, electromagnetic radiation and photoelectricity, which were ultimately to lead to radio, television and opto-electronics.

It has often been said that J. J. opened the door to the world of electronics but never passed through it himself. Hovering around that same door, and even helping to open it, was the youthful Rutherford but he also did not enter. Instead, he followed that unerring instinct that was to remain with him all his life, that guided him to the most significant line of investigation. He found another door, just opened by Henri Bacquerel (1896) in Paris by his discovery of the radioactivity of uranium, which was to be Rutherford's life's work.

I must now go back a long way to give a short summary of the development of electrical communication. I think this began with the fundamental discovery by the elder E. Becquerel in 1839 in Paris of the internal photoelectric effect which of course is the fundamental link in the whole opto-electronic field, since it showed for the first time the possibility of the conversion of light to electricity, fundamental to all television systems. Little notice seems to have been taken of this significant discovery for several decades. People went on experimenting with methods of transmitting information by electrical signals over wires, but little attention was given to the problem of originating these signals from optical images. However, the idea of television, or 'district electric vision' as it was then called, had been around for a long time but mainly as a topic for science fiction. Then the invention of the telephone in 1876 by A. G. Bell and the discovery of the effect of light on the conductivity of selenium by Willoughby Smith in 1873 (Smith 1873) seemed to spark off an interest in real television and led to a series of proposals for achieving it. Most of these were seriously deficient technically in one respect or another but taken together they covered most of the requirements for simple television. Thus, the ideas of scanning an optical image in a series of lines were established, each line being a succession of points of varying brightness, now termed 'pixels'. These could be converted to corresponding electrical quantities – current, voltage or resistance – by the photoelectric effect. Also, an electrical marker signal was to be generated at the end of each line and each complete picture, or frame, to signify that the next line or frame should begin. A complete picture could be, as it were, stretched out as a series of say 100 lines each comprising 100 pixels to give a
linear electrical signal which could then be transmitted over a single line-wire, to a receiver where it could be reassembled to form the original picture. It was already known from cinema photography that this picture transmission had to be repeated at least 15 times per second to give the effect of movement, and that at

![Diagram of Ayrton & Perry's apparatus.]

Figure 2. Ayrton & Perry's apparatus.

the very least 100 lines, with 100 pixels per line, were required to give nearly acceptable picture definition. This required a top frequency response of about 100 kHz, a speed quite unheard-of at that time. Of all these proposals I shall not mention in any detail more than one which was not only proposed but was demonstrated experimentally by Ayrton & Perry at the Royal Society of Arts in London in 1881 (Ayrton & Perry 1881). This in my estimation was the first demonstration of real television in history, albeit in a simple form. Television may be regarded as just over a century old!

Ayrton & Perry's apparatus is shown diagrammatically in figure 2. A light image of the scene to be transmitted is formed by the optical lens L on the screen S where it is scanned line by line by a small light-sensitive selenium cell D moving across it in a succession of horizontal lines so that its conductivity is modulated by the varying light intensity of the image. An electric potential difference applied across this cell thus produces a varying electric current or 'picture signal' which can be transmitted over a single conductor to the picture receiver. There, those electric picture signals were used to modulate a beam of light passing through a Kerr cell, by using the Faraday effect. This beam was then scanned over a viewing screen S, in synchronism with the transmitting scanner, by two oscillating mirrors. Here we have all the essentials of a television system. A moving optical image is reduced by scanning to a linear electric picture-signal which can be transmitted over a single line and used to reproduce the scene as a moving, visible image, but given the state of technology at that time these experimenters were unable to reach the 15 pictures per second and 100 lines, of 100 pixels per line, postulated above as the very minimum required for worthwhile television. They were well
aware of the limitations of their apparatus, imposed by the mechanical inertia of its moving parts and the lack of response at the high frequencies of the selenium photo-conductive effect. Their important achievement was to point the right direction for research, but it was just about another 50 years before that goal could be reached.

Figure 3. The Nipkow disc.

A few years later Paul Nipkow (1884), a Pole working in Berlin, invented the Nipkow disc which enabled the scanning process to be done more effectively. This is shown in figure 3. The image (4) to be transmitted is focused by a lens (6) on to a rotating disc (1) which has a spiral of small, equally spaced, apertures (3) around its periphery, each aperture being spaced towards the centre by a distance equal to its own diameter, thus as the disc rotates the apertures scan across the image in turn and the light of the image passes through the apertures and falls into a photocell (7). The photoelectrons liberated are accelerated to the anode by the field from the battery (8) and pass through the resistor R across which they generate the picture signal. At the receiving end this process is reversed; a light source modulated by the picture signal takes the place of the photocell and the light from it passes through the disc apertures to be focused to form the image (5). This system, however, also suffered from the limits imposed by mechanical inertia, and slow response of the selenium photo cell, and although it, and the systems derived from it, were to be widely used in experimental television right through until the 1930s, these fatal defects finally caused its failure.

I shall now briefly enumerate the scientific discoveries that gradually made real television possible. As already mentioned, in 1887 Heinrich Hertz discovered not only electromagnetic radiation but also the photo-emissive effect, both phenomena which Rutherford used experimentally in the Cavendish. The importance of the latter was that it was an almost instantaneous effect, so avoiding the difficulty of the slow response of selenium to light. However, it was then a very inefficient process, and remained so until about 1930. The next important step was the discovery of the electron by J. J. Thompson in the Cavendish in 1897 (with Rutherford at his elbow). Within a few months these electrons were being used by Braun in Germany to invent the cathode ray tube. Many scientists quickly
realized the essential features of the c.r.t.: that the electrons, because of their extremely small mass but strong electric charge, could be accelerated to very high velocities; ca. 1600 km s\(^{-1}\) by a field of a few volts and also could be deflected at high speeds by transverse electric or magnetic fields. Such a device was described by Dieckmann & Glage in 1906 and a diagram of their invention is shown in figure 4. It shows a conical glass tube, evacuated to a low pressure, with a long neck in which an electron beam K can be generated. It can be scanned over the circular glass end of the tube, which is coated with a phosphor, by transverse magnetic fields produced by the two pairs of electromagnets ab and cd. The electron beam is modulated in passing through the aperture in the electrode L by the electromagnets e and f, thus visible patterns of varying brightness can be written on the screen. Dieckmann & Glage, however, did not propose this device for the display of television pictures but only used it to trace patterns, for example for the purpose of electric measurements. A few years before this, another of the great constructive inventors of that era, A. A. Campbell Swinton, F.R.S., had already realized the importance of the c.r.t. in solving the problem of television. Because of the extraordinarily high speeds of movement achievable by the scanning electron beam the high speed required to scan a television picture in adequate detail (ca. 5 km s\(^{-1}\)) could be reached. It has only recently come to my notice (Bridgewater 1982) that Campbell Swinton did in fact try, in about 1903 to operate an experimental television system with cathode ray tubes both transmitting the optical image and displaying the received television image. However, in his own account of these experiments, published some 25 years later, he commented they ‘were not very successful’. This is not surprising considering the extremely
primitive nature of all technology and especially the c.r. tubes – Braun tubes – that
he had obtained from Germany. Nevertheless, he was not deterred and a few years
later in 1908 when there was much discussion in the technical journals as to if, and
how, television could be achieved, he described his cathode ray tube system briefly
in a letter to Nature (Campbell Swinton 1908), pointing out that only the electron
beams in a c.r.t. held out any hope of reaching the high speeds of movement
necessary to scan a television image of adequate definition, because of the electrons’
high electric charge and minute inertia.

I should like to reproduce this letter verbatim because I regard it as containing
the seminal ideas of modern television. It was followed only a few weeks later by
the filing of a patent in London by Boris Rosing of St Petersburg (now Leningrad)
along the same lines but proposing the cathode ray tube for picture reception only.
For a more detailed account of Campbell Swinton’s idea I pass on three years to
his Presidential Address to the Röntgen Society in London on 7 November 1911
(Campbell Swinton 1912). (He was, incidentally, one of the pioneers of the use of
Röntgen or X-rays in England.) He illustrated his proposed television system with
the diagram shown in figure 5. It is remarkable that this diagram can be used (I
have used it) to illustrate the basic features of the electronic television system now
in general use. On the left is the image transmitting cathode ray tube A in which a
beam of electrons, originating from the cathode B, is canalized by the aperture in
C and then impinges on the mosaic of minute photocells J. Two pairs of magnetic
coils at right angles, D and E, produce varying (scanning) magnetic fields at right
angles to one another, one at low, or frame frequency, and the other at high, or
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line frequency. Thus the electron beam can be scanned over the mosaic of photocells repeatedly as a succession of frames each of a given number of lines. The optical image \( N \) to be transmitted is focused on to this two-dimensional array of minute separate photocells in each of which the light at that point of the image liberates negatively charged photoelectrons in proportion to its intensity and thus builds up a positive charge on the photocell. These charges are sequentially discharged by the negative electrons of the scanning beam. This succession of electrical discharges constitutes the picture signal which is carried over the line-wire to the picture display tube \( B' \) on the right. This is very similar to the tube \( B \) except that the electron beam impinges on, and scans over, a layer of phosphor powder \( A' \) deposited on the inside surface of the glass end \( H \) of the tube. This electron beam is modulated by the picture signal applied to the deflecting plates \( O \) to vary the beam current passing through the aperture in \( P \). The electron beam causes the phosphor to emit light approximately in proportion to its energy. Hence the scanning modulated electron beam reproduces the original picture \( N \) on the phosphor screen. The scanning magnetic coils, energized from the commutators \( G \) and \( F \), scan both the transmitting and the receiving tube electron-beams and hence the received picture is synchronized with that transmitted. It is quite extraordinary that this scheme contained almost all the essential features of a modern electronic television system while at the same time being deficient in almost all the elements of technology necessary for success. For example:

1. there was no thermionic cathode to produce the beam electrons;
2. there was no means of focusing the electron beams;
3. the vacuum would be very poor and the photoelectric cells would not survive in it;
4. the photocells proposed were rubidium metal surfaces and these would be very inefficient;
5. there was no thermionic (valve) amplifier, then known, with which to detect and amplify the very weak signals;
6. there were no saw-tooth scan generators to deflect the beams;
7. the phosphor screen would be very inefficient and even 30 years later it still was, and had to be, green or blue in colour;
8. the mechanism of charge and discharge of the photocells was very unclear and the complicating effects of secondary electron emission were not known or anticipated at that time.

Campbell Swinton was well aware of most of these obstacles to the implementation of his proposal but he up-dated his scheme as technological improvements became available from work in other fields. After World War I he revised his scheme in a paper in the journal *Wireless World* in 1924, bringing in such advances as radio transmission, thermionic cathodes for the c.r.t.s., improved photocells, thermionic amplifiers, etc. However, in essential features the scheme remained the same. What is perhaps more important is that he realized that to implement his...
scheme effectively would require the efforts of a large team of scientists and engineers working on the detailed problems that required solutions. He repeatedly urged that some large industrial laboratory should take up the problem and pointed out the fundamental weaknesses of the mechanical systems that were being experimented on and pushed by various people in England, the U.S.A. and elsewhere. Those people, like J. L. Baird and his associates in England, were committed to mechanical systems stemming from Nipkow's invention, which were doomed to failure for reasons that Campbell Swinton repeatedly emphasized and which seemed absolutely convincing to us who came fresh to the problem about 1930. Of course there could be no objection to experimenters exploring the possibilities of mechanically-based methods but what was inexcusable was the propaganda and political pressure exerted to have the mechanical system adopted by the Broadcasting Authorities (B.B.C. and P.O.) as the official broadcasting t.v. system. Anyone who saw the quality of the t.v. pictures then (as I did) would have had to be incredibly naïve to accept the system as being worthwhile for a public broadcasting service. However, behind the scenes and largely in secret, several large commercial-industrial research laboratories were beginning to take an interest in television, for example E.M.I. in England, R.C.A. and Bell Telephone Labs in the U.S.A., Telefunken A.G. in Germany, and they, consciously or unconsciously, based their research plans on Campbell Swinton's ideas.

In the years 1925–1930 several important advances in technology occurred which finally made it possible to implement Campbell Swinton's scheme, although not without considerable difficulties. These were the following.

1. The great improvements in vacuum technique. High vacuum pumps, diffusion pumps, borosilicate glass, glass-to-metal seals, etc. became available.

2. The discovery of electron-optics (Knoll & Ruska 1932). Electrons behave in electric or magnetic fields as light does in a refractive transparent medium, e.g. glass, hence electron beams in a cathode ray tube could be focused by a suitable magnetic or electrostatic field. Up to this time the only effective means of focusing the electron beam was by gas ions. This was very inefficient as the electron beam could not be varied (modulated) nor could it be deflected (scanned) at high speeds without losing definition. Thus, these gas-focused tubes were quite unsuitable for Campbell Swinton's system.

3. The discovery of the first really efficient photo-electric surface by Koller (1930) in the U.S.A., the silver-silver oxide caesium surface. The conversion of the light of the optical image to an electrical signal is fundamental to the whole problem of television and this had to await the discovery of an efficient transducer.

4. The improvement of phosphors. Although still rather inefficient and of various colours, mostly green, they were improving rapidly.

5. The whole technique of electronic circuitry. Technology included thermionic valves, amplifiers to operate over the wide signal band-width required for t.v., of the order of at least 1 MHz (up to this time engineers were accustomed to designing
systems for the acoustic range of not more than a few kilohertz), high voltage generators to operate the cathode ray tubes, generators of the saw-tooth wave form to scan the electron beam and many other novel electronic problems.

(6) Ability to broadcast television signals of a band-width of several megahertz required a radio carrier wavelength of a few metres. This again was the new and unexplored technique of short wave radio.

As Campbell Swinton clearly saw, it required a team of physicists, chemists, electric and mechanical engineers, working in close cooperation, to cover this large problem. It was completely beyond the capacity of a one-man laboratory. It was just such a team-in-the-making that I joined in the recently formed company of E.M.I. limited at Hayes, Middlesex in England on 1 January 1932.

The overall director of this research project was Mr (later Sir) Isaac Shoenberg; the Manager of the research department was Mr G. E. Condliffe. The senior engineers were A. D. Blumlein (electronic) and C. O. Browne (mechanical) while I joined Mr W. Tedham, a physicist with the research programme, to develop the required vacuum electron tubes. Many others joined this team over the next few years and to give an account of its work over the following ten years would require many volumes. I should like to recall some of the very difficult engineering problems, electronic and mechanical, that my colleagues led by Alan Blumlein and Cecil Browne had to overcome. There were a host of general problems about television that we debated endlessly, for example how many lines to the picture would be required, how many pictures per second, what size of picture, would green pictures as they then were be acceptable, how much flicker would be tolerated, and so on. I can only give you an outline of the problems that Tedham and I were attempting to solve. I must say that Tedham was already fully aware of Campbell Swinton’s proposals and he quickly convinced me that they provided the blueprint for our work. Campbell Swinton had already been dead (in 1930) for a couple of years and I often regret that he did not live long enough to have been brought in, even as a consultant, to see his ideas being worked out.

Tedham had established a very efficient vacuum-physics laboratory and was already making experimental cathode ray tubes and S-1 type photocells, for television picture reception. The television pictures that we displayed on our crude tubes were derived from signals transmitted from cinema film by mechanical scanning from C. O. Browne’s department. Crude as they still were, with a small number of lines and hence poor definition, displayed on a small green c.r.t. screen, very dim, so that they could be seen satisfactorily only in dim light, there was soon no doubt in our minds that this was the way to provide television pictures in the home. Our task was clear: to make tubes with bigger, brighter screens. At that time we thought of 30 cm diameter as quite enormous. The phosphor screens should fluoresce near white; the electron beam had to be large enough or of high enough energy (say 5 kV) and sharply focused to give a bright, sharply focused black and white picture. A team of chemists assisted in synthesizing phosphors.
which of course had to be compatible with high vacuum conditions. They could produce phosphor compounds which fluoresced green, blue, red, yellow: any colour but white! We had to take suitable mixtures of phosphors giving the three primary colours – red, green and blue – and concoct a mixture that, when bombarded with electrons, gave a synthetic white fluorescence. This was done by trial and error though the fact that one of us was unaware of being colour blind nearly led to a complete breakdown in otherwise very good working relations. We gave the glass manufacturers many problems. We had to make glass cathode ray tubes with near-enough flat ends and large enough, say 30 cm in diameter, for a reasonable sized picture, which would not collapse under the air pressure when evacuated. After all, the air pressure on the face of your television tube is about a ton and if it collapses it makes quite a loud bang: something that our potential customers would not like to happen in their lounge room! Another problem that cropped up at that time was the possible danger from the X-ray radiation generated at the phosphor screen by the bombarding electron beams. Alarm on this score was raised in the popular press in much the same way as alarm about radiation from nuclear power generators today. I had to spend a considerable time measuring this radiation and collecting evidence to convince the powers that were that it was harmless: roughly comparable with that from a modern nuclear power station!

Although we were by this time confident that the cathode ray tube could be made an effective television picture receiver there was much doubt and confusion as to how the television programmes could be originated. After all, receivers were quite useless without transmitters. There were roughly three schools of thought:

(1) the television programmes would be derived entirely from cinema films by mechanical scanning;

(2) all additional material would be provided from mechanical scanning systems, such as Nipkow discs, restricted to studios where intense lighting could be used;

(3) that for television to be successful required portable electronic cameras which would be used in studios or outside where the light was not always predictable.

Tedham and I belonged to this third group and we believed that Campbell Swinton’s proposed cathode-ray-tube picture-transmitter was the only practicable solution. Strangely enough we could not convince our higher management of this and we were instructed not to do any work on the problem. This irked us considerably and eventually we decided to ignore instructions and try a few quick experiments on the quiet. We already had most of the components and techniques required for our experiment and we had submitted an invention for patent cover in August 1932 of a simple device that we believed might work.

The diagrams as published in our patent specification (Tedham & McGee 1932) are shown in figure 6 and this formed the basis for our experiment. We used the components of one of our high vacuum cathode ray tubes, as shown in figure 6a with the usual electron gun (6) with electrostatic focusing of the electron beam. The beam was scanned by magnetic coils, but in place of the usual phosphor screen,
we constructed a target (2) consisting of a large number of small photocells (5). These were minute platelets of silver formed by evaporation of silver through a stencil mesh (4) on to an insulating layer of aluminium oxide which in turn was formed on an aluminium plate (3). The minute silver plates were activated to form S.1 type photocathode surfaces (Ag–Ag₂O–Cs). This was done successfully and is described fully in McGee (1979). For those of you who are electronically minded

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Figure 6. Patent Specification. Figures of experimental tube.
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the equivalent circuit is shown in section (figure 6c). The aluminium plate (3) is connected to the input of the valve amplifier (10). The complete tube was set up with the necessary high voltage supplies for the electron gun, scanning fields to scan the electron beam over the target and we projected a simple light image, a draught-board pattern, on to the photoelectric mosaic. The output of the amplifier was applied to one of our primitive cathode ray tubes to reproduce, we hoped, the picture. It is quite impossible to describe our astonishment when, within a few minutes and after making a few adjustments, the device was working as planned. The effect seemed to us then, and still does to me, almost magical. To see the optical image projected on to the target of the transmitting tube reappearing, on the screen of the receiving tube on the other side of the room, with only a wire connecting the two, seemed quite strange. We spent a few hours investigating the behaviour of the tube – image definition, time lag, colour response, spurious signals, sensitivity etc. – and then, to our chagrin, suddenly realized that the tube was dying. We had, however, learned two important things:
Figure 7. Photograph of first experimental tube. (This photograph is reproduced with permission from the Science Museum, London; Crown copyright.)
Figure 10. Emitron camera without cover. (Reproduced with permission from Thorn E.M.I. Central Research Laboratories.)
Figure 11. Outside broadcast: D. Birkinshaw with first Emitron camera. (Reproduced with permission from the B.B.C.)
Figure 12. Complete camera. (Reproduced with permission from the E.M.I. Central Research Laboratories.)
(1) that Campbell Swinton's idea was not only possible but practicable;
(2) that it would require a lot of detailed careful work to make a worthwhile, feasible device.

What is strange is that we did not then make a very strong démarche to the management to be allowed to continue urgently this line of work which we were convinced was the most essential link in the whole technology of television. Instead we meekly put the defunct tube away in a cupboard where it lay for twenty years or so when it was brought out, dusted off and presented to the Science Museum in London where it is now displayed in the History of Television exhibit. The next illustration, figure 7, plate 2, shows a photograph of the tube as it exists today.

We continued our work on cathode ray tubes, as already described until July of the following year (1933) when to our chagrin Dr V. K. Zworykin of the Radio Corporation of America (R.C.A.) came to London and described to the Institution of Electrical Engineers a television picture-transmitting tube of the same type as we had made. This is shown in figure 8, and although the details of construction, etc. were not given there was no doubt that it was essentially the same device. Dr Zworykin, before escaping from Russia during the revolution, had been a pupil of Boris Rosing of St Petersburg who, as I mentioned earlier, had made proposals similar to those of Campbell Swinton. This device, named the Iconoscope by the R.C.A., was the first to be described publicly and hence the credit of inventing the first electronic television camera must go to Zworykin and the R.C.A. The Iconoscope is a high vacuum cathode ray tube with an electron gun A which fires a beam of electrons on to a target. This consists of a large number of small elements of
photoelectric material disposed on an insulating surface which in turn lies on a conducting metal plate: the signal plate. This metal plate is connected to the input of an electronic amplifier. The target is mounted at an angle to the incident electron beam so as to allow the optical image to be projected normally on to the photosensitive mosaic. The light of the optical image liberates electrons from the photosensitive elements of the mosaic and when these are removed a distribution of positive electrical charges is built up on the mosaic. As the electron beam is scanned over this surface the electrons neutralize these charges and electrical impulses are thus induced in the supporting metal plate and so conveyed to the amplifier.

Although there had been no direct exchange of information on this problem between the R.C.A. and E.M.I. laboratories, the physical features of this tube and our experimental tube were very similar. This was because in the state of technology at that time this was the only way in which the required device could be made. Later, when we came to have close collaboration with the R.C.A. laboratories we found that there were many details of technique in which we differed. As a result of the visit by Dr Zworykin, our management became convinced that we should, after all, follow suit and I was given the responsibility of directing the work. We simply took up the work where we had dropped it 18 months previously and with increased staff and facilities we were soon able to make tubes that were reliable and gave a very promising performance. There were naturally many detailed problems to be solved: described in McGee & Lubszynski (1939). This was complicated by the fact that we soon came to realize that we did not know exactly how the device worked, nor had Zworykin given any plausible theory of this in his paper. Certainly in our case we have relied on a simplistic theory, already mentioned above, but we soon found that it was quite inadequate to explain what we found to be happening in practice. The main complicating factor was the release of large numbers of secondary electrons from the target surface by the electrons of the scanning beam. These spread around the tube and produced many strange effects, good and bad, but it took us several man-years of experiment to sort out the puzzle. After much trial and error we eventually arrived at the design of tube shown in figure 9. The essential features are the same as those shown in figures 6 and 7 which show the first experimental tube. In a high vacuum glass tube an electron gun is mounted in a side tube and fires a beam of electrons at a target. This consists of an insulating mica dielectric, on one side of which is formed a mosaic of minute separate photocathodes, and on the other side is a continuous conducting metal coating, the signal plate, from which the video signal is taken to the first stage of a thermionic amplifier. The optical image to be transmitted is formed on the mosaic of photocells by a lens. Photoelectrons are liberated, charges built up and then discharged by the scanning beam to produce the picture signal.

After a time, our engineering colleagues, Blumlein & Browne, also became convinced that the electronic transmitting tube might possibly be made to work, but I well remember Cecil Browne's explosion when he saw for the first time the crude
pictures and picture-signals we were producing from our tube, 'What the... do you expect me to do with that mess!' he exclaimed. It was a measure of the extraordinary electronic genius of those men, A. D. Blumlein, C. O. Browne, E. L. C. White et al., that they were able to tidy up the Emitron signals into a form that could be used in practice. The Emitron tube mounted in a camera was required to operate at some distance — perhaps 100 m — from the main control apparatus. So, for reasons that will be obvious to electronic engineers it was necessary to build the output stages of the control gear operating the tube and the input stage of the amplifier which received the signal, as close to the tube as possible. This is shown in figure 10, plate 3, which shows the tube mounted on its operating base. As soon as it became clear that the cathode-ray image-transmitting tube could be made to work we envisaged the possibility of operating at 25 pictures per second and about 400 lines per picture: a standard of definition that seemed quite extraordinary at that time. This, of course, was for the reasons that Campbell Swinton has been patiently advocating for several decades. Thus in about 1935, our Director, Mr I. Shoenberg, greatly daring, undertook a contract on behalf of E.M.I. to supply an electronic television system on these standards to the B.B.C. for the first television station in the World to give a regular public service. Figure 11, plate 4, shows one of the original cameras supplied to the B.B.C. in November 1936 being operated by the Chief B.B.C. t.v. Engineer, Mr Douglas Birkinshaw, outside in the grounds of
Alexandra Palace – the London transmitting station of the B.B.C. – in what must have been one of the earliest outside broadcasts ever done. You will notice that this camera has only one lens – the one focusing the optical image on to the tube mosaic – and the operator has no means of focusing or view-finding except on instructions through his head-phones from the control room. It was primitive but it worked! In figure 12, plate 5, is shown a somewhat improved camera which has now a view-finding–focusing lens coupled to the main camera lens.

For comparison purposes a second system designed by the Baird Company was installed at Alexandra Palace and the two systems were used alternately. It soon became apparent that this Baird system, which was largely based on the mechanical processes, could not compete with the E.M.I. system and was closed down after a few months. Thus the E.M.I. equipment continued in operation but with many improvements which arose from continuing research and experience in operation. It was closed down on the outbreak of World War II in September 1939 and was reactivated in 1946 and continued for about ten more years. Even so the changes that then took place were merely improvements in the components of the basic system. For example more sensitive camera tubes with better picture quality, better electronic components throughout the system, available because of better valves, etc. that had become available after the War, better film-scanning systems partly because of the advent of effective photo-multipliers, micro-wave and cable links to connect up with transmitters covering the whole country, etc.

The immediate problem confronting my group was to devise or invent better television cameras and this meant understanding the mechanism of the existing Emitron tube and so, we hoped, seeing ways to improve it, and also inventing new methods of doing the same thing better. There were a host of problems which were time-consuming and difficult. I shall mention only one: the colour response, that is the relative strengths at which areas of different colours in the scene are reproduced by the camera. This depends on the sensitivity of the photoelectric mosaic surface to light of different colours. It so happened that the only efficient photoelectric material known to us at that time was strongly sensitive to red, and even more sensitive to infrared, light which the eye cannot see. Hence, the first cameras gave black and white pictures that were very distorted in colour contrast. This gave some strange and undesirable effects and necessitated very heavy and unnatural make-up on the artists’ faces. This was the problem posed to my colleague, the late Dr Leonard Klatzow: to try to discover a photoelectric material with a better colour response. This he was able to do but owing to Klatzow’s premature death the details were never published. They are described in British patents (Klatzow 1935). This discovery gave our cameras a considerable advantage over our competitors for several years because of the improved aesthetic quality of the pictures.

By mid-summer of 1937 we had overcome most of the teething troubles of our equipment and the public reaction to television was so favourable that the B.B.C.
ordered another set of 3 Cameras especially for outside broadcasts. These were to be ready for the celebrations of the Coronation of King George VI and Queen Elizabeth on 12 May 1937. It was an exhilarating race against time but it was done successfully and the broadcast of the Coronation procession from Hyde Park Corner was one of the most memorable and successful in the history of television.

We were still using the original type camera and they had performed well that day even compared with conventional cinematograph cameras. However, it was obvious that we would not always have nice bright summer days on which to operate and that cameras which would operate at much lower illumination were very necessary.

In parallel with the work I have been describing we had been exploring, in my group, the possibilities of image intensification. This was stimulated by the idea of electron-optics first spelled out by M. Knoll and E. Ruska who showed that suitable arrangements of either electrostatic or electromagnetic fields could operate to focus a stream of electrons in much the same way that a glass lens focuses light (Knoll & Ruska 1932). A simple device of this kind is shown in figure 13. It shows a cylindrical glass tube (1) with flat glass windows (2) and (3) at either end. It is highly evacuated and a transparent photocathode (7) is formed on one window while a fluorescent screen (8) is deposited on the other. A uniform, high electric field is maintained by a potential of say 10 kV between the surfaces (7) and (8) and a uniform, axial magnetic field is established by a current in a solenoid (5). If an optical image is formed on the photocathode by the lens (10), photoelectrons will be released which will be accelerated to the phosphor screen (8) and with a suitable relation between the magnetic and electric fields these electrons can be brought to a focus on the phosphor screen. There they give up their energy to produce a fluorescent image which can be viewed, or recorded on a plate (9). Now the important feature of this device is that if we operate it so that the photoelectrons are accelerated to a high energy in the electric field—say 10–15 kV—they can produce a fluorescent image on the output phosphor screen which is brighter than the input light image. And this can be done without serious loss of

Figure 13. Simple image intensifier.
image quality. This led to a large family of image intensifiers that have become very important in many fields, but we are at the moment concerned only with its first use in television.

![Diagram](image.png)

**Figure 14.** The Super Emitron with magnetic screening.

My colleagues, H. G. Lubszynski and S. Rodda realized that this type of device could be coupled with a tube like the Emitron to give a tube of greatly increased light-sensitivity. The outcome of this idea is shown in figure 14. Disregard the outer shell which is electric and magnetic screening, and inside this you see what looks like an Emitron but with a cylindrical tube added on to it in place of the optical window. At the extreme left end of this tube is a flat glass window inside which is another glass plate on which we formed a transparent conducting photo-cathode on to which the optical image is focused by the lens. The photoelectrons produced by this light are accelerated by an axial electric field and focused by a magnetic lens, produced by the focusing coil, to form an electron image on the surface of the target. This is now not photosensitive, as in the Emitron, but is formed by a material which is an efficient source of secondary electrons when struck by fast primary electrons. Each primary electron can liberate 5–10 secondary electrons from this surface. Also the continuous conducting photo-cathode now used, can be at least twice as efficient as the mosaic photocathode. Hence each photon can liberate about 10 times as many electrons from the mosaic target as it would do from the photoelectric mosaic of the Emitron. These secondary electrons play almost the same role in generating the picture signal as the photoelectrons. There are some minor differences which need not concern us here, but the overall
result is that this tube was approximately ten times as sensitive to light as the original Emitron. This was the first big step forward in improving the light-sensitivity of the television camera and it was quickly used by the B.B.C. to extend the scope of outside broadcasts where the light could be pretty dim. Thus, cameras of this type were used for the first time for the broadcast of the memorial service from the Cenotaph in Whitehall on 11 November 1937. Those of you who know London will know how dim the light can be even at 11 a.m. in winter. The B.B.C. went on to use this type of camera (named the Super-Emitron) for outside broadcasts and so were able to extend greatly the range of events that could be broadcast. For example, sport events on winter afternoons, city theatres, etc. Up to the outbreak of war in September 1939 the B.B.C.'s London television service was carried on by using the Emitron tube for studio programmes and the Super Emitron for outside broadcasts.

When the work described above was well advanced (in late 1936) Rutherford visited our (E.M.I.) research laboratories. His programme was to spend the forenoon looking at the work in the laboratories and then, after lunch with the Directors, to return to Cambridge. However, he became so interested in what he was seeing that he asked if he might continue his visit into the afternoon. We, of course, were flattered and he continued to look at everything with that mixture of critical appreciation and enthusiasm that was so characteristic of him. His visit went on so late that he had to be rushed back to the London railway station by car to enable him to catch his train back to Cambridge. But what was most memorable, and instructive to us, was to see this legendary, world famous man come in to our laboratory, sit down on a stool beside a quite junior scientist or technician and ask him to explain what he was doing. He would then ask questions and listen attentively to the explanations given without the slightest suggestion of being patronising. The impression he created was profound. It was an unforgettable lesson to us of both nobility of character and the natural ability to inspire the loyalty, respect and, yes, affection, of a team of research scientists.

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