Physics in Relation to Wireless.*

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THE preparatory research work for the transmitting station, that is, for generating electromagnetic waves, was done by Hertz in the years 1885-88, and appears to have been prompted by the rivalry between the extant theories of electricity and magnetism. The laboratory work for the receiving station was done by Lodge in 1889, by Minchin and by Branly in 1890. Lodge's work on the reception of electric waves arose from observing that two metal knobs nearly in contact cohered when a spark occurred near them; Minchin's work was on light sensitive cells and his observations of the effects of electric waves was a side issue, but was duly recorded; Branly's investigations were on the diminution of the electrical resistance of contacts between oxidised metals and in masses of filings when sparks were made near by.

Without asking which physicist we are to thank for each of the items needed for making a complete sending and receiving equipment for wireless telegraphy, we know that Oliver Lodge demonstrated the transmission of signals across a space of 30 yards and through several walls at the Royal Institution, London, on June 1, 1894. On this occasion a filings coherer was used, and the necessity of screening various portions of the receiver and its leads, which later became part of early wireless engineering, was emphasised. Later in 1894, during the summer meeting of the British Association at Oxford, Lodge demonstrated the sending and recording of Morse code signals. He used a Hertzian oscillator with large copper plates as capacity areas, an induction coil with the usual vibrating interrupter and a Morse telegraphic key in the primary of the coil. As receiver he used a filings coherer with attached aerial wires for picking up the waves, a trembler of electric bell type operated by the coherer current and serving to shake the filings back to their non-conductive condition, and a Morse inker for recording the dots and dashes on tape. Other telegraphic instruments were employed as alternatives. The following year Popoff, a Russian physicist, added to the recording apparatus a long earthed vertical antenna for catching natural electric waves produced by distant lightning discharges; he had possibly adopted the vertical wire from the patents of Dolbear and other American inventors.

By 1895, therefore, every item was ready for the attention of the engineer; some parts of Lodge's apparatus had to be made more powerful, other parts more sensitive, and all of it more trustworthy and robust before it could be put into the hands of telegraphists for everyday use. Improvements came rapidly, and the range of action was gradually increased, but progress was limited by the use of highly damped trains of waves. At this date the spark gap at the sending station was situated in a long vertical wire, possibly surmounted by a

large metal plate, and the coherer was in another similar antenna at the receiving station. Such an arrangement had a high decrement and therefore *any* transmitting station affected *every* receiving station within range, and only one pair could work at a time.

In Europe, so far as printed records can tell us, the earliest use of 'tuning' coils in open oscillating circuits was due to Lodge, who appears to have satisfied himself by laboratory experiments in 1896 and 1897 not only that inductance coils were useful in a Hertzian oscillator for adjusting frequency, but also that their employment brought certain advantages over the method of adding capacity areas. The main advantage of inductance over capacity in an open oscillator is that the former prolongs, the latter shortens, a strain of oscillations produced by a spark. In consequence, if straight Hertzian oscillators be used as sending antenna and receiving antenna, and they be tuned to each other by inductance coils, the damping of each is made low and sharp resonance may be attained.

Lodge's patent in 1897 embodying this principle produced a revolution in both thought and practice. Hitherto it had been imagined that the electrical oscillations produced by the spark gap in the aerial possessed a very short wave-length of the same order as the dimensions of the spark balls, just as in the case of the Righi oscillator; and the function of the transmitting antenna had been explained by supposing that the Righi waves ran up the wire and squirted out at the top. This seemed to explain why high wires were needed for long ranges. But now it was seen that the high wire vibrated as a Hertzian oscillator with a wave-length of the same order of magnitude as the length of antenna, and that range of signalling was related to length of wave. Moreover, Lodge's patent specification disclosed a scheme for exciting a metallic continuous antenna from a spark in a branch circuit, thus contradicting the accepted idea that radiation was impossible unless the spark was formed in the antenna. Stranger still, the receiving antenna was shown as a continuous straight oscillator with its tuning coil acting as the primary of a high frequency transformer, the coherer being connected into the secondary circuit. Being, in fact, a mine of scientific information and suggestion, Lodge's specification furnished during several succeeding years all the fundamental ideas employed by the engineers who developed commercial signalling plant of the spark type.

In illustration of the last statement and to put on record another triumph of the laboratory, I may cite the important development known as the quenched spark transmitter. The germ of this appears in Lodge's patent, where it is explained that an antenna would become a more persistent oscillator if it were excited by a short-lived spark in a side circuit. The cessation of the spark automatically frees the antenna from the branch circuit

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and from the dissipation of energy in it. The idea was improved upon by Max Wein in 1906, who, for the purpose of his laboratory measurements, invented a form of gap that ensured rapid quenching. This was developed by the Telefunken engineers into a type of transmitter that has seen world-wide service.

From the year 1900 onwards the more alert workers in wireless sought about for a method of generating continuous waves. The hope of achieving wireless telephony was the incentive, for no one at that time foresaw that continuous wave telegraphy by the Morse code could be better than spark telegraphy. The problem was to devise a method of generating continuous waves of frequency at least 100,000 cycles per second. The physicists' solution came from an unexpected direction, namely, from the scientific investigation of the properties of an electric arc traversed by alternating currents of low frequency. In 1900, Duddell was pursuing these investigations on carbon arcs and happened to connect across the arc gap an inductance coil and condenser in series just as if the arc gap was a spark gap. He was surprised to find that the arc whistled when ignited, and soon discovered that the pitch of the note depended on the magnitudes of inductance and capacity of the shunt circuit in the same way as in a spark circuit.

The study of the oscillating arc was taken up by Poulsen in Denmark and he investigated the Duddell phenomenon when the arc burnt in various gases and between various electrodes. By 1903 he discovered that an arc burning in hydrogenous vapour between a copper anode and a carbon cathode was capable of developing currents of frequency required for radio-telephony and of considerable power. This splendid discovery led straight to practical radiotelephony.

Fessenden invented the heterodyne method of receiving telegraphic signals. The method relies upon the employment of a local source of electrical oscillations near enough in frequency to that of the incoming wave to produce in the receiving circuits regular increases and decreases of amplitude at an acoustic frequency. The conception comes straight from the storehouse of acoustic theory, and could only have arisen in the mind of a student and teacher of physics, like Fessenden. It is, in my opinion, one of the four or five universally important steps in the history of wireless technique.

The most striking example of the discontinuity of the progress of wireless is afforded by the maturing of the amplifying vacuum valve.

The first vacuum tube containing a hot filament and a separate electrode with external lead, that is, the first thermionic diode, was made by Edison in 1883. Studies of the thermionic current across the vacuum were conducted by Hittorf (1883), Preece (1884), Elster and Geitel (1887), and Fleming (1889 and 1896). Three years later J. J. Thomson's laboratory took up the problem and, in particular, O. W. Richardson during the next three years pursued his classical researches, usually employing a form of diode that has become typical, namely, a

straight filament along the axis of a cylindrical anode. Meanwhile an analogous form of diode in which the source of electrons is a photo-electric surface was being similarly studied. Many of the researches of the date were aimed at measuring the charge and the mass of the particles carrying the current across the vacuous space; and for this purpose other electrodes were sometimes introduced for deflecting the particles by an electric field. Lenard, in 1902, used an anode of wire gauze so that light could pass through it to the cathode and liberate electrons; Wulf later used a flat spiral of wire, parallel to the photoelectric cathode for the same reason; Varley in 1903 observed that when the gas pressure was below about five microns the electrons could be accelerated towards a positive grid so as to be shot through the meshes of the gauze. At higher pressures ionisation by collision occurred near the grid and gave such tubes their steep characteristic curves. Besides all this experimental work of an abstract nature, various applications of the electric discharge through gases had been made to the rectifying of alternating currents. Thus the scientific atmosphere of the first three years of the twentieth century was thick with material ready for useful applications.

The first application of vacuum tube physics which I have to notice was made by the well-known German physicist Wehnelt, who, having discovered in 1903 that filaments coated with oxides of rare earths emitted electrons copiously, patented a diode with coated filament as a rectifier in January 1904. He called this thermionic diode an electric valve. It is sometimes said that Wehnelt invented the thermionic valve—but this is a fallacy; he invented the coated filament, and he invented the name, perhaps, but thermionic tubes with two electrodes had long been commonplaces in physical laboratories. It is noteworthy that, apart from the valuable invention of the oxide coating, Wehnelt's application is widely used to-day at many transmitting stations for rectifying alternating current and in the so-called 'battery eliminators' of broadcasting sets. About eleven months after Wehnelt, Fleming patented the combination of a thermionic diode, a coil and an indicating instrument, to form a circuit in which alternating current could be produced and rectified, special stress being laid on the applicability of the circuit for detecting by rectification the feeble alternating currents experienced in wireless receivers. The diode as detector was in the field for several years as a rival to the electrolytic and contact detector. The third interesting application of vacuum tube physics was made a year later by von Lieben, who proposed to utilise the lateral deflection of a stream of electrons as an amplifier. The current to be amplified was intended to cause the deflection—either by charging an auxiliary electrode which then attracted or repelled the stream, or by producing a magnetic field. The fourth application was made a year later in America by de Forest, who, by means of an auxiliary electrode in the form of a grid, controlled the passage of the electrons to an anode by accelerating or decelerating them in their line of motion.

This method of control proved, in the course of a few years' development, more effective for amplifying purposes than the method of control by lateral deflection.

The introduction of the von Lieben and the de Forest tubes is specially notable because these instruments were not alternatives to existing ones but were novel in purpose as well as in principle. Von Lieben at any rate—de Forest seemed to be rather vague—clearly appreciated that an inertialess magnifying device was in his hands—the first distortionless repeater in history. Unfortunately, neither form of instrument became an immediate practical success, perhaps because evacuation was not pushed far enough. Von Baeyer was probably nearer success than either; for independently of de Forest, in 1907 he constructed a triode of ideal modern form containing a cylindrical anode two centimetres in diameter, a coaxial gauze cylinder one centimetre in diameter, and a filament in the common axis of the cylinders, and more highly evacuated than de Forest's tubes appear to have been. But von Baeyer was engaged on the study of the motion of the electrons from the incandescent filament, and never applied the excellent amplifying functions which it undoubtedly possessed.

The key to the situation was really lying all the time in Varley's remark in his 1903 paper, that electrons did not pass through the grid in quantity until the vacuum was below five microns. However, during these years the physical laboratories intent upon the study of electricity at extreme exhaustions developed several methods of producing and retaining very high vacua. In the years 1912 and 1913, Langmuir, working in the laboratory which also evolved the Coolidge X-ray tube, gave the triode a more stable behaviour by resorting to extreme rarefaction.

The technical value of the high vacuum triode rests upon its ability to magnify very small and very rapid electrical changes with close fidelity. An electromotive force applied to the grid causes inappreciable current flow but liberates a magnified electromotive force in the anode circuit where relatively large currents are possible. The development in size of triodic oscillation generators made them feasible for the transmission of signals, while small sizes improved reception—a remarkably happy concatenation.

After this last revolution in wireless technique, later developments in the apparatus and methods of radio communication seem relatively undramatic. For my present purpose I need only give one or two examples, with which I am very familiar, of the influence of the physical laboratory. There are two methods of generating electrical oscillations for transmitting stations which have appeared as alternatives to the back coupled valve method, and have been adopted in large short wave stations all over the world. The first is the crossed valve method, which was devised in the physical research laboratories of Finsbury Technical College in 1916–17 at the request of the Signal Experimental Establishment of our War Office. It was intended for

use over short distances behind the trenches on wave-lengths of 50 metres and less.

The second method aims at generating electrical oscillations of very constant frequency by aid of massive bodies sustained in mechanical vibration by triodes. The earlier apparatus for this purpose was the tuning-fork alternator, which was developed in 1918 for delivering fundamental and harmonic frequencies for the purposes of measurement in the physical laboratory. A later apparatus arose out of the growth of supersonic under-water signalling in 1917. In the autumn of that year Langevin in France and Rutherford in England independently suggested that the piezoelectric qualities of quartz might be utilised for perceiving the arrival at a receiving station of pressure waves in water and for producing such waves at a transmitting station. Langevin's work at Toulon was supplemented by his collaborators at Finsbury Technical College and Harwich, and at Finsbury this led, first, to an appreciation of the fact that quartz vibrating under the stimulus of a feedback circuit steadied the electrical oscillator, and, later, to a triode circuit for automatically sustaining quartz in vibration at its natural frequency in water without the use of back coupling. At about the same time, we learned later, Nicholson in the New York laboratory of the Western Electric Company, devised an equivalent method of vibrating piezoelectric crystals such as Rochelle salt in air by aid of a triode. Thus came about what may be called the marriage of mechanical and electrical oscillations, the so-called 'stabilisation of frequency', which plays so large a part to-day in wireless stations, large and small.

My account of the contributions of physicists to wireless omits all reference to the great engineers who have adorned the industry, as otherwise this address would become a complete history of wireless, but I must refer to the effect upon practical wireless of the study of the electrical properties of our atmosphere—a branch of geophysics—which has already assisted practical operation of telegraphic circuits. In Great Britain the study has been pursued under the auspices of the Radio Research Board and independently by T. L. Eckersley. In my opinion the cumulative effects on radio communications of these researches will disclose itself in the near future.

A valuable geophysical discovery made neither by physicists nor engineers was the phenomenon that short waves could travel long distances. Short wave transmitting and receiving apparatus was much used during the War, for example, 50 metres for trench sets and less than 20 metres for aeroplanes, in several of the belligerent countries; short waves had been tried for telephony across a hundred miles of the North Sea and between London and Birmingham overland, but were not suspected of shooting aloft and coming down thousands of miles away. We now know that trials made within the skip distance were inevitably misleading. However, before 1920 all the technique of short wave telegraphy and telephony was common a.e. As a mere chance, amateur wireless enthusiasts were officially relegated in most countries

to transmission experiments on waves shorter than 300 metres. Gradually widely scattered amateurs began to overhear signals exchanged between two very distant colleagues. In 1921, American amateurs transmitted to British amateurs on wavelengths of 200 metres; this was reciprocated in 1922. Meanwhile the American amateurs had found shorter waves better, and in 1923 were

communicating easily with other amateurs across world-wide ranges. The first commercial application was made in the autumn of 1923 and has been followed by universal adoption of short-wave signalling. It is a remarkable example of a revolution in method which was not due to, and did not require, any change of technique—a revolution effected by pure discovery.

The Concept of Space.

ON Friday, June 6, Nottingham was honoured by a visit from Prof. A. Einstein, who delivered a lecture (in German) in the Great Hall of the University College. After each section an English translation was given by Dr. H. L. Brose. The chair was taken by Prof. H. H. Turner. The lecture was an account of the history of the concept of space, and was addressed to a general audience. At the end questions were invited: those received were all concerned with the present position of the unitary field theory. For the following impression of the lecture I am deeply indebted to Miss Dallas and Miss Lieber for their help, but for any inaccuracies I alone am responsible.

At the outset Prof. Einstein emphasised that he was not making an authoritative pronouncement, but merely stating his own personal opinions. He believed that the fundamental concept of physics was that of the rigid body. The idea of space was not acquired until a much later date, and was not known to the ancient Greeks. Euclid's geometry, in particular the part dealing with the congruence of triangles, was based upon notions of rigid bodies, such as measuring rods which could be moved about as a standard of comparison. Motion appeared first, not as in space, but as that of one body relative to another. The concept of space was introduced by Descartes, the founder of co-ordinate geometry. This was a purely mathematical notion, without any physical implications, and concerned only with the geometrical aspect of the relative position of two or more bodies. The other aspect of space was due to Newton, who considered the bodies, not at rest, but in motion. To deal with the problem of acceleration he introduced the idea of an absolute space, forming a framework by which the motion of the bodies could be measured, but itself quite unaffected by those bodies. It was a wonderful thing that Newton's genius enabled him to realise the definitely physical reality of space. This reality has been neglected or misunderstood by many of his successors, including the philosopher Kant.

However, in Prof. Einstein's opinion, the really decisive change from the geometrical to the physical conception of space was due to Faraday and Maxwell, who considered electromagnetic phenomena to have their seat in the ether, and spoke of the field or the state of this ether as affected by electromagnetic action. Why did they think it necessary to use a new word ether, when the old one space

was already available? The reason, no doubt, was that they were fettered by the ideas prevailing in their day, and had not realised the connexion between the space of geometry and the space of physics. As material bodies were the first objects to be considered in physics, they introduced the idea of a material ether to replace what was formerly considered as empty space, through which electromagnetic action took place. This idea was developed by Lorentz, in whose view all electromagnetic action, even that in the interior of material bodies, really took place in the ether. Thus he deprived matter of all its electromagnetic properties, but to compensate for this he deprived ether of all its mechanical properties, and attributed a capacity for motion only to the elementary particles of matter.

The next modification was the special theory of relativity. Classical physics used three co-ordinates in space and one in time. It was now found necessary to unite these into the four co-ordinates of space-time, and to give up the belief that events could be divided into categories of 'before', 'simultaneous', and 'after'. This prepared the way for the general theory of relativity, which dealt with the phenomena of inertia and derived the laws of motion from the geometrical structure of space, or rather of space-time, thus uniting geometry and physics in a new intimacy. The experimental verification of this theory is well known. We have now come to the conclusion that space is the primary thing and matter only secondary; we may say that space, in revenge for its former inferior position, is now eating up matter.

With regard to the unitary field theory, the purpose of which was to derive all physical phenomena, electromagnetic as well as gravitation, from the properties of space, Prof. Einstein confessed that his colleagues did not agree with him. In fact, he added with a smile, they think that I am crazy on this subject. However, he himself had faith that the idea (which came to him during a severe illness two years ago) of attributing direction as well as metrical structure to space would ultimately lead to success in obtaining a single theory to embrace all phenomena. He regarded this as a true physical theory, not as a mere mathematical curiosity. It was best to leave aside the difficulties of the quantum theory for the present, but he hoped that when the simpler problem of