The Perfection of the Thermionic Valve

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THE past twenty-five years have seen the coming of a great change, both in human society and in the individual human life. Man has become able to speak to man, and man to mankind, directly and without obstacle of distance. Next week, King George will speak, not for the first time, to all his people wherever they may be, and his hearers may well ponder this new aspect of the many-sided relation between Crown and people.

For the ordinary man the change is that he is now in ready touch with his fellows, whether actively and personally through the long-distance telephone, or passively and with others through broadcasting. As His Majesty has implied in his broadcast words, this means that the tragedies of enforced loneliness and anxiety will soon be erased from the lot of man. Music is now within reach of all who will, and whatever there be between learning and laughter that the spoken word can bring to our ears.

The principal instrument that has enlarged on this vast scale, and yet without artificiality, the scope of our most natural mode of communication —by voice and ear—is the thermionic valve. The attainment by this instrument of its present large measure of perfection—so much even those who best know its faults can allow it—falls easily within the period under review, but springs from the efforts of so many workers in so many countries that it can here be presented only in the briefest of outlines.

To begin with, making our start from somewhat less than thirty years ago, there were then two well-recognised and eagerly pursued problems in the art of communication. The first quarry in the hunt was a delicate device capable of controlling energy from a local source in faithful response to an incoming signal, such as the attenuated speech-waves on a telephone line the length of which it was desired to extend, or alternatively a weak wireless signal. The second aim was a means of generating continuous high-frequency oscillations adaptable to similar faithful control by a microphone for wireless telephony. It was already realised that whatever should solve the first of these would also, when allowed to react on itself, go a long way towards solving the second. There was also in existence a device, the simplest, or diode, form of thermionic valve, in which current passed between electrodes in an evacuated glass bulb ; this offered a means of detecting high-frequency signals by regular rectification, but it was biding its time in face of other temporarily approved alternatives.

Ideas had arisen too, in more minds than one, of making such devices more responsive to an incoming signal, but these ideas were as yet vague in the extreme.

To complete this outline of the conditions of incubation of the valve as we now know it, we should note the technical position at the time. Amongst makers of electric lamps the production of high vacua in glass vessels, already well advanced as an art in daily practice, was being raised to the higher pitch demanded by the tungsten filament, and was ahead of corresponding practice in the laboratory in some respects at least. Acquaintance with pumps in great variety, and the use of many of them, the choice of suitable glass, its fabrication in conjunction with small metal parts, the method of outgassing by 'baking' under vacuum, the use of phosphorus as 'getter' for improvement and maintenance of vacuum, the choice again of suitable metals in addition to tungsten, all these alike were well understood, so that when the need came, any well-equipped lamp works could launch out into valve-making.

About the opening of our period, valves, thus incubated, hatched out in various places, and the excitement attending the demonstration of their working was proportionate to the interest of the double problem which they solved. A clear explanation of what was going on in them did not, however, come at once. The little that was known was reflected in their construction. The addition of the third or intermediate electrode left a controlled stream of moving particles as the obvious main connexion between input and the output circuits, but much time was spent, by some at least, before the essential simplicity of the valve and the comparative unimportance of the differences between early types were realised. It is interesting that, before these fascinating devices were turned into reliable tools, a blind eye had to be turned on those factors which need not be taken into account in explaining their action. The first of these inessentials was gas ionisation ; it had to be realised that, since even the simple diode would work at voltages below the ionisation point, some other agency must be sought. Once this was appreciated a newly-fledged graduate in physics could acquire sound ideas of the main current-voltage relation by working out the solution of a

Poisson's 'space-charge' equation. Given this luxuriously simple basis, or even still simpler qualitative ideas on the same lines, the other less important factors could be viewed in proper perspective, and the inherent limitations of the valve could be defined, even thus early, in terms of natural constants. In the triode, again, the main point to be appreciated was that one was not required to trace out the motions of particles in transit through the intermediate grid, but only to regard this member as behaving chiefly as a somewhat leaky Faraday screening cage which defined for the region near the cathode a residual field controlling the strength of the current of escaping electrons. The German term *Durchgriff* survives as a happy illustration of this point.

So much for the valve itself. Its action in the circuit had to be deduced by the application of alternating current theory to the relative variations of the voltages applied to the various electrodes and the currents led to or from them. Here, contrariwise, the range of relevant premises had to be enlarged by including the displacement currents in minute and at first disregarded stray capacities before laborious algebra bore full fruit in explaining the observed phenomena of amplification and spontaneous oscillation. From this work arose, as a kind of shorthand, the array of technical terms such as 'amplification constant' (as compared with its reciprocal synonym *Durchgriff*), 'anode impedance', 'reaction' and so forth now heard out of the mouths of schoolboys.

All this work was spread out, with much duplication and overlapping, over the first quarter of the period. The effect of the War, sometimes spoken of as a time of great advance, is dubious. It seems in retrospect that intrinsic development may actually have been retarded by the isolation and distraction of those who would in any event have carried on that work. The real benefits of this period were indirect; improvement of technique was stimulated by the making of large numbers of valves, and the number of those conversant with the use of them increased with abnormal rapidity. After the War, however, the expansion thus made possible did not come at once. The valve as a perfected tool had to establish its position, and that on a world-wide scale, by the resumption of the normal exchanges of scientific and technical intercourse, and by further demonstrations arising from free experimental activity. In regions outside the United States, preparations had to be made for the insertion of valve amplifiers or 'repeaters' in telephone lines, and over the oceans the extension of direct wireless telegraphy and the introduction of telephony had to be arranged.

It was, then, at about the middle of our period that the valve came into its own. For the specialised conditions of long-distance telephony on land-lines the necessary requirement of reliability was early satisfied. In wireless the word 'system' dropped out of common parlance; the time for alternative methods was past. The discovery of the peculiar transmission possibilities of 'short' waves, for the generation of which valves were uniquely adaptable, brought world-wide range almost as a gift. At the same time came broadcasting, with, on the technical side, the need of new standards of faithfulness imposed by the nature of the matter transmitted, particularly music, and of reliability at both ends of the unilateral transmission. The waste of energy by thermal radiation from the cathode was progressively reduced. The implicit possibility of using free electronic projectiles as the sole connexion between circuit elements was exploited in 'screen-grid' tetrodes and later more complicated types. Amplification was carried to the limit set by those disturbances, the 'Shot effect' and the like, arising from the discontinuous structure of matter itself, a real limitation at present. The power handled by valves has, however, since the conversion of the anode into a water-cooled metal portion of the envelope, no near upper limit, even without resort to continuous evacuation. Uses have also at length been found for thermionic devices employing ionisation in the forms of heavy-current rectifiers of great efficiency, occupying a position midway between the high-vacuum rectifier and the rectifying arc, and of trigger devices which make a virtue of the formerly troublesome discontinuity in current-control in presence of a lavish supply of ionisable material.

In the field of communication, the second half of our period has thus been a time of technical consolidation and expansion and of the rise of great social implications. During this time also the valve has influenced the course of scientific research as an instrument generally adaptable for use wherever there is a need for delicacy and nimbleness beyond what is conveniently possible for purely mechanical devices. Thus, physiologists have been using valve amplifiers for the study of nerve action as revealed by minute electrical changes; valves, sometimes of special design, have replaced sensitive voltmeters and electrometers; thermionic relays have come into use for counting the minute discontinuous occurrences of atomic disintegration; metallurgists have used valve-generated high-frequency currents in furnaces for melting experimental specimens.

The position at the present day and the immediate prospect have now to be outlined. One point of arrest is to be noted. The deliberate design of valves by calculation has progressed but little, although the physical principles being known this work might be held to have passed into the province of the engineer. However, the mathematical functions are generally intractable, and engineers may be excused for their reliance on methods of trial and error. As valves get larger, however, such methods are becoming expensive. The evolution of the valve is not yet by any means complete, although sometimes, as in television, the valve is an accepted tool and interest centres on other devices at either end of the train of valves.

There is still, however, the new field where the periods of electrical oscillation are so short that electron inertia is no longer negligible, but has itself to be brought into service as a main principle of action. Here early history has been repeating itself, but the period of groping is now past; theoretical study is difficult but is well advanced. Indeed, in contrast to the early days, development has been somewhat in advance of demand. There are also novel devices using free electrons which are not of thermionic origin but are ingeniously obtained by photo-electric or secondary emission.

Other new developments may be expected now that valves have made their appearance in the laboratory as appliances built and operated by continuous evacuation in the laboratory for the purposes of research without recourse to the valve maker, for example, for obtaining continuous high-voltage supplies by rectification and very recently also by short-wave oscillation. It is not in general to be supposed that valves manufactured by the thousand for engineering purposes or by the million for domestic use are really those best suited for special problems, and it is well that the experimental physicist should take the initiative in meeting his own needs.

Finally, new prospects are beginning to open in yet other directions associated rather with the material needs of the human body than with man as an intelligent and social being. For some few years high-frequency electrical oscillations of wave-lengths from a few metres downwards generated by valves have been coming into use for purposes as yet perhaps of practical medicine rather than of physiological study, first for surgery, and later for the reinforcement of the *vis medicatrix naturæ*, in part, it would seem, by some kind of inward fomentation, and in part, perhaps, by some more specific action dependent on the existence of natural frequencies in molecules of various sizes or in small bodies of greater than molecular size. The achievement of direct specific action on such structural elements would open up wide fields of application to chemical and biological processes far removed from the problems of communication from which the development of the essential instrument took its origin.

Developments in Aeronautical Science

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THERE can be few applied sciences able to compare with aviation in the rate at which purely academic physical conceptions have been first translated into actual accomplishments and then industrialised, to the extent of the aircraft industry in the short space of a quarter of a century. Although the mechanics of flight have been investigated by certain mathematicians practically since the Middle Ages, continuous sustained flight for heavier-than-air machines, or even a useful degree of controlled flight in lighter-than-air craft, was not possible until some device capable of giving out power in the form of a propeller thrust was available, with reasonable weight. The internal combustion engine made this possible, and in 1903 the first power-driven flight in a heavier-than-air machine was made by one of the Wright brothers in the United States. The dirigible balloon antedated this achievement by a few years for lighter-than-air craft, although it is not possible to be precise about the date of the first flight owing to the difficulty of specifying exactly what constituted a power-driven flight, as distinct from having merely floated from one spot to another. It is certain, however, that at the commencement of the period under review, achievement in either school did not consist of much more than having succeeded in flying for a reasonable period of time, with a very small margin of safety. Little attention had been paid to progress towards any severely utilitarian aspects of the problem of flight.

In the spring of 1910, Cody, Dunne, Roe and Short were flying aeroplanes of their own design and building in Great Britain. Mr. J. T. C. Moore-Brabazon (now Lieut.-Col. and at present president of the Royal Aeronautical Society) was granted