Sir Owen Richardson, F.R.S.

Nobel Prizewinner in Physics 1928

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SUMMARY

O. W. Richardson was a prolific scientist who published the first of his 133 papers, on the mechanism of thermionic emission, when he was only 22 and the last at the age of 74. This essay traces his development of the science of thermionics.

Nowadays every schoolboy knows that if a refractory metal, such as tungsten, is heated sufficiently in a vacuum or in an inert gas then a stream of electrons is emitted from the surface. The laws governing this emission are well understood, for a pure metal at least, and the effect has been of almost incalculable technological importance for the past sixty years. This came about because, in studying the production of electrons by a heated wire filament in a vacuum, Fleming discovered the principle of rectification in the thermionic valve which rapidly gave rise to the development first of radio and then electronics, both of which have had a profound effect on the development of civilization as we know it. Electron formation by hot surfaces, like many other scientific discoveries, was put to practical use long before it was properly understood and to Sir Owen Richardson goes the credit for his ingenuity and persistence in unravelling an exceedingly difficult problem.

As early as 1901 he proposed a theory which is still accepted, in only slightly modified form, today. A metal consists of an assembly of relatively immobile atoms which have each lost one or more outer electrons. The atoms are therefore positively charged and the released electrons are free to move about in the lattice formed by the atoms. The metal as a whole is stable and has no net charge. The cloud of mobile electrons cannot escape from the surface of the metal at normal temperatures because of a potential barrier at the surface. Put in simple terms this means that if an electron were to leave the metal an unneutralized positive charge would remain which would, in fact, attract the electron back again. The mobile electrons move throughout the metal lattice with random velocities just like the molecules of a gas but the number which have a high energy and therefore a high velocity, increases as the temperature is raised. Richardson postulated that at a sufficiently high temperature a measurable number of electrons acquire sufficient energy to overcome the potential barrier and thus escape from the surface of the metal and he deduced that the emitted current I is related to the temperature T by

$$I = AT^{\frac{1}{2}} \exp\left[-\frac{\phi}{kT}\right] \qquad (1)$$

where A, ϕ are constants characteristic of the emitting surface and k is Boltzmann's constant.

Ten years later he modified the formula to

$$I = AT^2 \exp\left[-\frac{\phi}{kT}\right] \qquad (2)$$

which is the form still accepted today. Although the second equation looks rather different from the first, with $T^{\frac{1}{2}}$ replaced by T^2, it is nevertheless very difficult to distinguish between the two experimentally because of the overriding effect of the exponential term.

With present-day technology it is easy to demonstrate that the current of electrons emitted by a body raised to a sufficiently high temperature is due to thermionic emission and in order to appreciate the very considerable difficulties which had to be overcome at the turn of the century it is necessary to recall that the vacuum techniques of that time were very rudimentary. The pumps, for example, were hand operated and outgassing methods hardly existed. The hot wire used for observing emission would heat the walls of the vessel thus producing copious emission of gas which continued almost indefinitely. As Richardson himself[1] stated, 'I have often heated a wire in a tube for weeks in succession in order to make sure that the currents observed were stable and not coming from residual gas'. Furthermore the materials available were often insufficiently pure and, as the above equations indicate, the emission depends in a very sensitive manner on the work function so that quite small amounts of impurity can have a considerable effect on the experimental results obtained. Nowadays the thermionic emission of electrons has been so long accepted, and is of such technological importance, that students do not often appreciate the many other processes which can and did occur in Richardson's experiments, and also those which were thought to exist.

The problem which faced Richardson, and his contemporaries, was as follows. It had been shown in the early eighteenth century that a hot body could produce electricity, for example an iron ball at red heat in air can retain a negative but not a positive charge. In the late nineteenth century it was found that many effects were

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observed when hot wires of various materials were placed near an insulated plate in different gases. However there was a tendency for the plate to acquire a positive charge at low temperatures and high pressures and a negative charge at high temperatures and low pressures, and this charge came from, or was at least produced by, the hot wire. At the time, also, considerable advances had been made in the understanding of the conduction of electricity through gases which was attributed to minute, electrically charged particles, or ions. The concept of ions, which is a term now applied to charged atoms or molecules, and their movement under the influence of electric fields, had been brilliantly used to explain the many complicated phenomena of electrical discharges in gases by J. J. Thomson. It was natural, therefore, for it to be thought that the emission from hot bodies could be explained in the same way. There seemed to be every likelihood that, in some way, the hot metal ionized the surrounding gas and that a difference either in the velocities of the positive and negative ions, or in their chemical affinity for the metal, gave rise to the positive or negative currents observed. The results obtained in an evacuated chamber were attributed to residual gases left behind by the relatively crude vacuum equipment available at the time. An alternative possibility was that the heat of radiation by the hot body was somehow involved.

A great stimulus was provided by J. J. Thomson in 1899 who showed that the discharge from a white-hot carbon filament in vacuum (so-called) was carried by tiny negatively-charged particles, very much smaller than the lightest atom, called electrons. At about the same time theories of conduction of electricity in metals had been proposed which involved the free movement of negative charges within the metal. These developments led Richardson to believe that the electrons, and possibly the positive ions as well, which were observed near hot bodies came from the bodies themselves and that any gases present were only of minor importance. As a result he derived the first of the formulae given above. The next, and far more difficult task, was to verify it experimentally.

With the impure materials and simple apparatus available to Richardson various kinds of emission were normally observed. When a metal is first heated it often gives a large emission of positive ions due to impurities, which can sometimes be completely driven off by prolonged heating so that eventually the effect may be eliminated. Particles of the metal being investigated may also be released in ionized form giving rise to another type of positive current. It is also possible for atoms or molecules of any gas present to become ionized on collision with the hot metal. The amount of energy required to release an electron from a surface is denoted by the constant ϕ, the work function, and the emission of electrons from a surface is very strongly dependent on this quantity. Some metals melt, and even boil, at temperatures lower than those necessary to give adequate amounts of electron emission and these are, of course, not suitable for experimentation. Despite these difficulties Richardson showed, first for platinum in 1901 and soon after for carbon and sodium, that equation (1) was

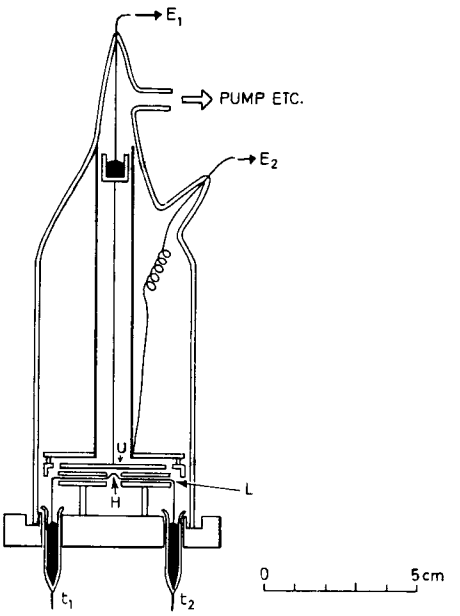

Fig. 1. Apparatus used to measure the velocity distribution of electrons emitted from a hot surface.

The small piece of thin platinum foil H at the centre of the metal plate L is heated electrically through terminals t_1 and t_2. The current collected by the platinum-coated electrode U is measured as a function of the (negative) potential applied to it.

obeyed. Similar results were then obtained with a wide range of other materials by other investigators. Thus the theory that electrons in effect, 'boil off' a metal when it is heated, in a similar way to molecules boiling off as steam when water is heated, was verified.

As with all scientific advances this was not the end of the matter, for new theories must always be tested to their limits and they can also be used to predict further new knowledge. For example there is the well-known effect that when one end of a metal wire is joined to a wire of a different material then an electrical voltage appears at the free ends. This is because the free electrons in the two metals have slightly different average energies and Richardson was able to show that this 'contact voltage', as it is called, is equal to the difference of the work functions of the two metals and he confirmed this by experiment.

Furthermore, according to the theory some of the electrons which are released during thermionic emission leave the metal with almost zero velocity whereas others leave with quite high velocities—in fact the emission velocities range from zero to high values although the number of fast electrons is small. Thus even if the collecting electrode is at a small negative potential, thereby exerting a repelling force on the electrons, the faster electrons can overcome this opposition and are still collected. Indeed if the current flowing at different repelling voltages is measured then the number of electrons emitted in different velocity ranges can be found. In this way Richardson found that the distribution of velocities among the emitted electrons was just that predicted by Maxwell, 50 years earlier, for a gas of the same molecular weight at the temperature of the metal.

This result was remarkable as the first experimental demonstration of the Maxwellian velocity distribution (Figs. 1 and 2).

A corollary of the theory was that since energy is required to cause the emission of electrons then because this energy is provided by the emitting body it must therefore be cooled in the process. Richardson calculated the magnitude of this effect and, with collaborators, confirmed it experimentally. In the same way if a stream of electrons flows into a metal from outside then they give up an amount of energy depending on the work function which should be independent of the temperature of the metal and the attracting voltage. This was also confirmed (Fig. 3).

Scientific progress is rarely simple and straightforward and in a brief article it is not possible to give any details of the experimental difficulties or of the results obtained. Although the emission equation was verified by many different workers the values obtained for the constants in the equation, especially the work function ϕ, sometimes differed considerably. This was undoubtedly due to the different methods of preparation of the materials, the effects of impurities and the large and unpredictable influence of residual gases present. The experimental results were therefore not universally accepted as proving the theory of thermionic emission. Some people still held the view that the explanation lay in chemical interaction between the hot metal and surrounding gas. This hypothesis was very elegantly shown by Richardson to

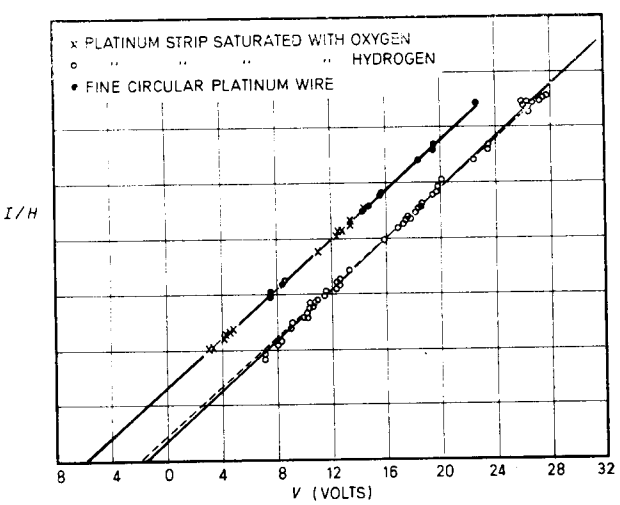

Fig. 3. Determination of the heat liberated during electron absorption on a surface.

A very thin strip of the metal to be tested was mounted in a vacuum between two high-temperature filaments. The metal strip formed one arm of a very sensitive Wheatstone bridge, so that the change in resistance, and thus in temperature, experienced by the strip as electrons were absorbed could be derived. The quantity of heat absorbed H as a function of the voltage V between strip and filaments, and the current I, was then measured as V was varied. The graph shows the observed dependence of H/I on V and the intercept of the extrapolated line with the V axis gives the heat liberated per electron in (negative) equivalent electron volts, ~ 6 V in this case.

The points which fall on the right-hand full and dashed lines have been arbitrarily moved a distance corresponding to 4 V in this direction to avoid confusion.

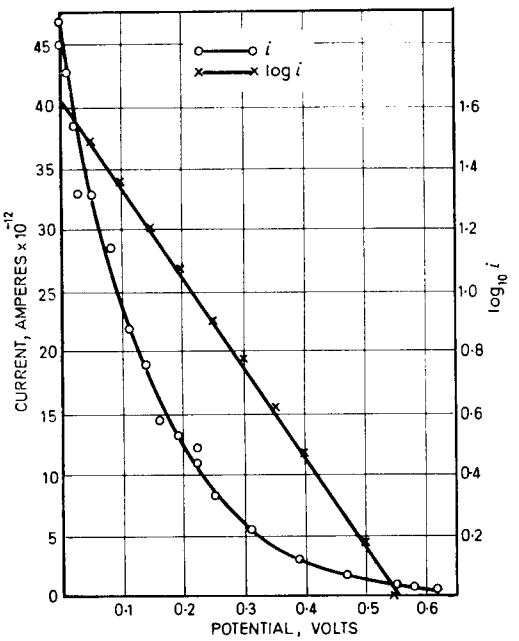

Fig. 2. Typical results obtained with the apparatus shown in Fig. 1.

The variations of the logarithm of the current collected by electrode U with retarding voltage is linear as predicted by theory. From the slope of the line obtained for a range of conditions Richardson deduced a mean value $R = 3{\cdot}719 \times 10^3$ for the universal gas constant compared with the theoretical value, accepted at the time, of $3{\cdot}711 \times 10^3$. He observed that this excellent agreement was partly fortuitous.

be untenable when ductile tungsten wire became available in 1913. With this he was able to obtain much larger emission currents which enabled him to prove that the total mass of the electrons emitted far exceeded that of any of the materials which could have been chemically consumed.

At the same time as these researches were being carried out other methods of obtaining the emission of electrons from solids were being studied. Perhaps the most important of these was photoelectric emission. It was known empirically that light of frequency greater than a critical value, which was characteristic of the material, would cause the emission of electrons from its surface. Light of longer wavelength, no matter how great its intensity, was unable to cause such emission. No satisfactory explanation of this effect was available until, in 1905, Einstein made the daring and epoch-making suggestion that light, and indeed all electromagnetic radiation, is not continuous but consists of discrete wavelets which fly through space like a hail of shot with the velocity of light. He deduced the elegantly simple relation that the energy E of each wavelet or quantum of radiation is related to its frequency by $E = hf$ where h is Planck's constant. The explanation of photoelectric emission now became almost childishly easy. Since a fixed amount of energy is required to release an electron from a metal, then light of low frequency, containing photons of low energy, cannot cause emission. Photons having more than this minimum amount of energy on the other hand, corresponding to light of higher frequency, can cause emission.

The amount of energy required to release an electron from a surface, as expressed by the work function ϕ, can thus be determined by measurements of thermionic emission and of photoelectric emission. Richardson, together with the famous American scientist K. T. Compton, showed that the two methods give the same results so providing further evidence in favour of the thermionic theory and of Einstein's postulate.

Photoelectric emission was also important for another reason, as it had been suggested as another alternative to thermionic emission and provided, as it were, a further rival theory. Any hot body in equilibrium with its surroundings produces electromagnetic radiation extending over all frequencies, the so-called black-body radiation. It follows that the portion of this radiation which has a frequency greater than the critical value is capable of causing the emission of electrons by the photoelectric effect, and moreover the resulting emission will increase very rapidly with temperature as does thermionic emission. Indeed Richardson's analysis indicated that the formula describing the integrated photoelectric effect is of the same form as equation (1) and it is therefore not easy to differentiate between the two processes experimentally. Following some fairly sophisticated measurements of photoelectric constants, however, he was able to show that the electron currents produced by any black body radiation which might be present were considerably smaller than those actually measured. That thermionic emission was the dominant process had thus, at last, been clearly and unambiguously established.

As a result of further study Richardson subsequently modified his expression for the emitted current density to that of equation (2). As remarked above it was not possible to differentiate between the two equations (1) and (2) experimentally even though measurements were made, for example, on tungsten over such a wide range of temperature that the current changed in the colossal ratio of 10^{12} : 1. Both equations could be made to fit the results, within the experimental error, but with different values of A and ϕ of course (Fig. 4).

Nevertheless many problems remained. We know that Richardson had correctly deduced the mechanism of emission and had produced a theory which agreed with the experimental observations. On the other hand the equation relating the magnitude of the current to the temperature was not unambiguous and, as we have seen, fitted the 'integrated photoelectric' theory as well as the thermionic theory. At the same time the quantum theory of radiation and matter was being rapidly developed and in a sense it was fortuitous, and perhaps fortunate, that the form of equation deduced has turned out to be the correct one. It is interesting to consider the reasons for this since they also illustrate the effect which Richardson's work had on the electron theory of metals. The latter theory was invoked in order to explain the high electrical conductivity of metals and it was supposed that the outermost electrons of the constituent atoms were free to move about at will and were limited only by reflexions at the boundaries. It was natural to take the analogy with a gas further and to assume that the velocities of the electrons were the same as those of an ideal

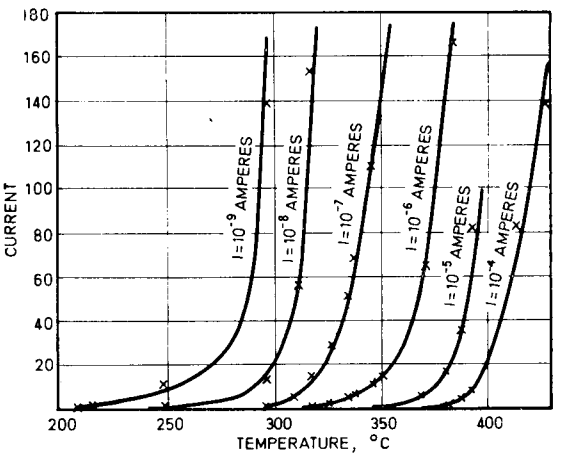

Fig. 4. If the material experimented on is in a condition which does not change with lapse of time the rate of emission of electrons increases with enormous rapidity as the temperature is raised. This is true whether the substance under investigation is in a good vacuum or is surrounded by various gases. The extreme rapidity of this variation is well shown in these graphs which represents the results of Richardson's early experiments with sodium. The observations recorded extended over a range of temperature from 217°C to 427°C whilst the corresponding currents increased from $1{\cdot}8\times10^{-9}$ A to $1{\cdot}4\times10^{-2}$ A. Thus with a rise of temperature of a little over 200°C the current increases by a factor of 10^7. In order conveniently to exhibit all the values on the same diagram the curve is shown by means of a number of branches, in each of which, proceeding from left to right, the scale of the ordinates is successively reduced by a factor of 10. Thus, starting from the left-hand side, in the first curve the unit of current is 10^{-9} A, in the second 10^{-8}, and so on. The various crosses which lie vertically over one another represent the same observation on different scales. It will be noticed that the successive branches are very similar to one another; so that the general character of the temperature variation is much the same at all temperatures. As the temperature is reduced the current continuously approaches the value zero but never actually reaches it. The experiments to which the Figure refers were probably affected to some extent by the presence of a surrounding gaseous atmosphere, but however carefully gaseous contamination has been avoided, it has always been found that the general character of the temperature variation is of the kind shown in the Figure. The difference between different substances lies in the temperature at which the emission becomes appreciable; and this temperature determines the whole scale of the diagram. With most substances the currents cannot be measured on a sensitive galvanometer at temperatures below 1000°C. A correspondingly larger interval of temperature is then required in order to change the current in a given proportion.

classical gas of the same mass and at the same temperature. As remarked earlier this meant that at any instant of time there would be electrons of all velocities present but most would be moving at roughly the average velocity which is determined by the temperature. Just as with a gas the number of electrons within each small range of velocity, or energy, values was to be given by the Maxwell distribution law. The fact that the measured velocities of electrons produced by thermionic emission *outside* the metal followed the same law was taken as confirmation of the Maxwellian distribution *inside* the metal. Indeed on the classical theory, which ignored quantum effects, this was a necessary corollary. However on a non-classical theory the same argument would not necessarily apply and the energy distribution of electrons in metals was in dispute for a considerable time. Richardson

himself was of the opinion that the classical theory did not apply but he was unable to deduce the correct one.

In some respects the classical theory had been perfectly satisfactory. It provided an explanation for the high electrical and thermal conductivities of metals and the fact that these properties are directly related, as well as correctly predicting the observed variation of thermionic emission with temperature. In other respects it was completely at variance with the experimental facts and particularly with the measured values of the specific heats of metals. The specific heat is simply the amount of energy required to raise the temperature of unit volume of a substance by 1 K. Any heat applied to a metal is taken up partly by the atoms, which increase in amplitude of vibration about fixed points, and partly by the free electrons. If the latter behaved like an ideal gas, as required by the classical theory, then all the electrons would have their energies increased and it can easily be shown that in this case the calculated specific heat would be 50% greater than that actually measured. It was as if with increasing temperature the electrons, in practice, did not take up very much energy from the heat source. Further evidence of the same, rather unexpected, kind came from some accurate measurements with the same tungsten filament of both the work function using the cooling effect and thermionic emission over a range of temperatures. These results again showed that the average energy of the electrons in a metal seemed to be independent of temperature and provided another nail in the coffin of the classical theory.

The explanation of this dilemma was provided by Pauli and Sommerfeld in 1927 when they pointed out that at the high concentrations in metals the electrons must obey the statistical laws of Fermi and Dirac. These are considerably different from those of the classical theory in which the energies of all the electrons decreases with falling temperature so that at a temperature of zero degrees absolute all the electrons are stationary. In the Fermi–Dirac theory, on the other hand, the electrons can only take up a certain discrete (although very large) number of energies and only one electron can have each permitted value of energy. Thus in an approximate fashion it may be said that even at zero temperature only one electron can be at rest, one can have the next smallest energy and so on, with the result that the total energy of the electrons is no longer zero but is a finite, calculable value. All the possible energies up to a given level, that is the Fermi level, are taken up and there are no electrons present with a higher energy. As the temperature is raised, only the electrons with the highest energies, i.e. those near the Fermi level, increase their energies but the bulk of the electrons, except for temperatures far above room temperature, are unaffected. The lack of electronic contribution to the specific heat was now easily explained because only a very small fraction of the electrons present are able to absorb thermal energy.

As in the classical theory, when the temperature is raised a sufficient number of the more energetic electrons acquire enough energy to escape from the surface to give a measurable emission current and the theory predicts an equation of the form of equation (2). It also predicted

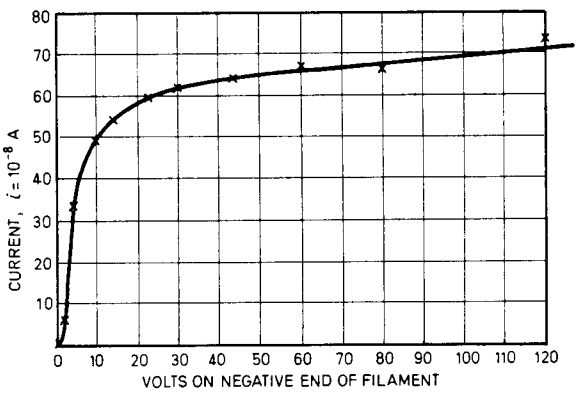

Fig. 5. The type of curve connecting the current and applied potential difference which is most frequently obtained under fairly good vacuum conditions. This represents observations made by Richardson with a U-shaped carbon filament surrounded by a cylindrical electrode, the pressure being 0·003 mm. It will be seen that approximate saturation is attained at about 30 V, although there is a further rise of about 10% of the total value on increasing the voltage to 120. This further increase is almost always, as here, proportional to the increase in the applied potential. It usually diminishes with continued use of a given tube, and it appears to be due either to the evolution of gas from the hot filament or to the presence of a layer of condensed gas on the electrode, or to both these circumstances. Richardson stated he had not observed this effect in a tube which had been well glowed out and exhausted in the vacuum furnace before testing, although a case of its appearance under these conditions had been recorded by K. K. Smith.

that the emitted electrons *outside* the surface would have a Maxwellian velocity distribution and was therefore in agreement with the experimental facts concerning thermionic emission. Here then was the theory which Richardson was seeking. The final blow had now been dealt to the classical theory of the electron energy distribution in metals and the Fermi–Dirac distribution was confirmed by some elegant experiments performed by Davisson and Germer. It had been shown by de Broglie that all matter exhibits both wave and particle properties although the wave-like behaviour is normally only observable for bodies of atomic size or smaller. We have already noted the wave and particle nature of light quanta for example. Davisson and Germer passed a beam of slow electrons into various metal crystals. The equivalent wavelength of the electrons depended on their energy in the crystal which in turn depended on the Fermi energy and the work function. The wavelength of the electrons was measured from their angle of reflection by the crystal lattice from which the Fermi energy was obtained. This showed quite clearly the correctness of the new theory.

A further consequence of the quantum theory is that it gave a numerical value for the constant A which turned out to be independent of the material. A was thus shown to be a universal constant of value 120×10^4 $\mathrm{A\,m^{-2}\,(K)^{-2}}$. Unfortunately even recent experimental determinations are not in very good agreement with this prediction and range from 4·6 to 170 and even 1380 for nickel. The reasons for the wide discrepancies are still not properly understood and in practice there are probably several causes. Richardson attributed the variation to contamination of the surface and impurities, which undoubtedly can have a considerable effect, pointing out

that even so his emission equation was still obeyed (Fig. 5). This explanation is not so easily invoked with present-day techniques in which quite pure surfaces can be prepared in conditions of very high vacuum.

One difficulty which arises is that while in Richardson's equation the work function ϕ is assumed to be constant, in practice it varies with temperature probably sufficiently to cause a significant change in A. Another is that thermionic emission measurements are normally made with polycrystalline materials. It is now known that the different faces of a crystal have different work functions and since the emission is so critically dependent on the work function most of the current comes only from those exposed faces of low work function and the effective emitting area may be much smaller than the apparent surface area. A third source of error is due to electric fields which may be present at the surface. As electrons are released into the space surrounding the emitter they form a negative space charge which tends to repel any further electrons which appear and return them to the surface. The 'space-charge limited' current measured at the collecting electrode is thus less than the emitted current and a false reading is obtained. The usual remedy is to increase the positive voltage on the collector so that the negative electric field due to space charge is always more than counteracted. Unfortunately the positive field which now exists at the surface enables more electrons to escape because the effective height of the potential barrier at the surface is reduced. The resulting increase in current and its dependence on the electric field at the surface is known as the Schottky effect. Fortunately the effect of field-enhanced emission can be corrected for and the Richardson constant A and the work function ϕ can still be obtained from measurements. It was noted earlier that the force preventing the release of low-energy electrons from a surface is assumed to be mainly due to the electrostatic attraction of the effective positive charge left behind in the surface—the so-called 'image' force. The theory of the Schottky effect takes into account this image force and the good agreement with experiment is important because it provides the most direct experimental proof, and confirmation, of the image-force concept.

When the field at the surface becomes very high, of the order 10^9 V/cm, the potential barrier not only becomes lower but its thickness is decreased and electrons which are not energetic enough to surmount the barrier are enabled to tunnel through it thus causing an appreciable emission even at low temperatures. This phenomenon does not come under the heading of thermionic emission and will therefore not be considered further but interestingly enough it is used in a technique to measure the work function of the different faces of a metal crystal.

It will be clear from this brief account of Richardson's work that the correct interpretation of the phenomena of thermionic emission had to await the development of the quantum theory and was closely bound up with it. Indeed his work contributed in no small measure to a better understanding of quantum concepts as well as providing a correct understanding of 'thermionics', to use a term which he himself coined.

The technological importance of thermionic emission cannot be over-estimated because from it and the electron tube grew first radio, then radar and eventually electronics, or information engineering, as we know it today. It is probably true to say that all this would have come about even without a proper understanding of the fundamental processes, by using an empirical approach, so that we remember Richardson for his contribution to physics rather than to technology. With the rapid growth of solid-state devices the applications of thermionic emission are decreasing, in electronics at least, but it has provided an enormous and varied base on which to build the future. It has certainly had a profound effect on all our lives.

Considering the importance of his work and the remarkable way in which it has stood the test of time it seems incredible that Richardson should have read his first classic paper explaining the mechanism of thermionic emission at the age of 22 (in 1901) to the Cambridge Philosophical Society. This was only one year after graduating with first-class honours in Natural Science at the University of Cambridge. When 24 he was elected Fellow of Trinity College, Cambridge and when 25 he was awarded a D.Sc. by the University of London. Besides his researches in thermionics Richardson made contributions to many branches of physics. For example in his early days in Cambridge he studied, among other topics, diffusion of hydrogen through palladium and platinum, ionic recombination, and the diffusion of dissociated gases in solution. In 1906 he was appointed a Professor of Physics at Princeton University where his research activities ranged over the gyromagnetic effect, pressure shift of spectral lines, ratio of charge to mass of positive ions, gravitation, theory of dispersion and many others. His work on thermionics continued, of course, and his measurements on the velocity distribution of the emitted electrons were made at Princeton, as well as those on the heating and cooling effects and the theory of contact voltages. He and K. T. Compton together played a large part in the verification of Einstein's theory of photoelectric emission. As well as the emission of electrons he investigated the emission of positive ions from hot metals and other materials.

In 1913 he was elected Fellow of the Royal Society and returned to England the following year to become Professor of Physics at King's College, London, when his first book[2] 'The Electron Theory of Matter' was published. Two years later followed[3] 'The Emission of Electricity from Hot Bodies' which gives an excellent account of the subject up to, and including, that time. At King's College his publications embraced metallic conduction, spectroscopy, conduction in metals and photoelectric emission. From 1924 onwards he was able to devote more time to the activity which he loved best on his appointment as Yarrow Research Professor by the Royal Society. An important new phase of his work then began with a detailed study of the spectrum of molecular hydrogen to which he made further important contributions and a book on this topic appeared in 1934. Other work included X-ray spectroscopy, the structure of

the Hα and Dα lines and further research on the emission of charges, and the interaction of charges with surfaces.

In addition to the honours already mentioned and the award of the Nobel Prize for Physics in 1928 he received honorary degrees and two honorary Fellowships. The Royal Society presented him with the Hughes Medal (1920) and he was elected a President (1921) of the British Association (Section A) and President of the Physical Society (1926–1928) of which he acted as its honorary Foreign Secretary (1928–1945). He was knighted in 1939.

Sir Owen Richardson was a brilliant and prolific scientist (his last paper was published at the age of 74) as well as being a quiet, kindly and generous person.[4,5] He died in 1959.

Acknowledgments

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