The attached notes were taken of the lecture delivered at the I.T.E. in April. The secretary wishes to publish this talk and has sent it for correction. This is a verbatim transcription of the talk as recorded on a tape recorder with some minor modifications.

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IETE

Institution of Electronics
and Telecommunication
Engineers
founded in 1953

Friends;

I must thank you and the ~~association~~ Institution once again for electing me as an Honorary Member. Probably it is a reminder to me that I have not joined till now as an ordinary member which I should have. My contact with tele-communication is rather oblique. I am interested in some problems on electronics which may be of interest to some of the tele-communication engineers. In any case, since that is the only subject on which I can speak with confidence, which has any relation at all to tele-communications, I thought I might choose it as the subject of this afternoon's lecture.

Sometime back, we celebrated the invention of the thermionic tube. That was 4/5 months ago and practically every instrument in electronics ultimately involves the use of thermionic emission, somewhere in its component parts; ~~and~~ the major problem and the fundamental problem is first to know what is the rate at which electrons are emitted from the heated surface of the filament and, secondly, what is the actual distribution of temperature along the filament, because the two ends which are the leads are nearly at room temperature ~~and~~ we send a current and ~~at~~ the centre naturally the temperature will be much higher than at the ends and what is the actual distribution of temperature, since it is the temperature that will ~~xxx~~ ultimately determine the thermionic emission. Those are the two major problems, fundamental on which I thought I might be able to say something significant.

Now we know ~~this~~, that there is a directional variation in the rate ~~xxxxxxxxxx~~ of emission. That is, it the emission is a maximum per unit solid angle from unit area of the surface, then it is a maximum along the normal to the surface and drops down as you move away from the normal, almost in proportion to the cosine of the angle. Since we know that, the problem can be still further reduced to this. What is the actual rate of emission, i.e., the number of electrons emitted per unit area of the surface, per unit solid angle along the normal to the surface. Now, the problem becomes slightly complicated when we deal with actual surfaces, because you do not know what is the

effective area because we are dealing with electrons, and the forces that are involved are the forces between the electrons and the rest of the medium, and therefore, as the electron is leaving the surface, any corrugation in the surface will naturally affect very much the number of electrons emitted so that, what we call the effective area of the surface may be very different from the actual area, because the surface is not an ideal plane and we are concerned with properties very close to the surface, - that is, of the order of the inter-atomic distances- close to the surface and therefore there will be large deviations from ideal plane surface. The expression for thermionic emission, therefore, can be put in a fairly simple form.

$$i/T^2 = A(1-r)e^{-\phi/kT}$$

$$= A(1-\rho)\cdot e^{-\phi/kT}$$

$$\varphi = \varphi_0 \times \alpha T$$

$$A \cdot e^{-\alpha/kt}\left(-\alpha/RT\right)$$

where 'i' is the current corresponding to emission, saturation current corresponding to the emission, T is the temperature, and A is a certain Universal constant which is called the 'A' co-efficient in the Richardson Equation. This equation is called the Richardson Equation and I shall come to the quantity within the brackets. ' ϕ ' is the work function, thermionic work function. That is the energy that is needed in order to pull out the electron from the surface, but that is not quite a precise description of the quantity. Any electron in order that it might be able to cross the barrier, get out of the metal, should have a component of momentum along the normal to the surface which exceeds a certain critical value, and this energy ϕ is the energy corresponding to that critical value, of the momentum, because the momentum squared divided by the Mass gives you the energy, and therefore, this is also a measure of the energy that would be required in order that the corresponding momentum may exceed a certain critical value, because it is the momentum ultimately the determines whether it can cross the barrier or not cross the barrier.

Now even if the electron inside the medium has the requisite momentum, that normally should enable it to cross the barrier and come out of the metal, it does not necessarily follow that it will actually do that because it is not all of them which have the requisite momentum that can cross. They are reflected back at the surface and, therefore, there is a certain fraction that is lost by reflection and it is the only the rest of it that can cross over. 'r' is the reflection co-efficient and (1-r) is the fraction that is transmitted, that is, the transmission co-efficient. Usually, 'r' is taken to be a small quantity in comparison with unity. Generally, for a well de-gased surface of a metal the estimate 'r' to be of the order of 5%, certainly, less than 10%. But it is a very difficult quantity to estimate either from theoretical considerations or to determine experimentally. Now this work function 'ϕ' may also be a function of the temperature. We know that it might vary with temperature, but the variation normally should be expected to be small and therefore we generally regard it as independent of temperature, but we have no reason to believe that it is actually so. But just because the variation is small, you can take the variation with temperature, the small variation with temperature, as almost linear.

'ϕ' can be put in the form of $\phi_0 + \alpha T$, . Where T is the absolute temperature and α is the small co-efficient of thermal variation of the work function. Now, there are too many variables here. What is measured experimentally is A/T^2. A is a universal constant and it is related to what is called the chemical constant for a monotomic gas which is associated with the spin of the electron except for a factor, not present in the case of any other monotomic gas that we know in the laboratory and therefore, except for that factor (2) 'A' is the same as the chemical co-efficient, and therefore we know the value of 'A'. This 'r' is uncertain and we do not even know with this α is finite. Experimentally, we cannot discriminate between a value of A(1-r), which is different from the theoritical value, and a variation of 'ϕ' with temperature, because as you can see if we express ϕ as $\phi_0 + \alpha T$, that αT divided by

KT that part of it can be taken outside e^{-} will correspond to $A(1-r)\, e^{-\frac{\alpha}{KT}}$, that is a constant and therefore, we cannot at any given temperature we cannot distinguish between a small linear temperature variation of the work function from an actual deviation, from the co-efficient A. That is why, experimentally unless we know something we cannot make much headway, we cannot separate out this (1-r) definite about A, about factor (1-r) from $e^{-\frac{\alpha}{KT}}$ which is also constant multiplying factor and unless we can separate out, we cannot move much further in our interpretation of the actual experimental data in terms of the quantity, parameters that we need. There is an extremely elegant method of eliminating this (1-r). Many years ago, while discussing some problems in black body radiation, I noticed a certain close analogy between thermionic emission on the one side and the emission of electro-magnetic radiation from hot bodies on the other. It is like this. If you take any hot surface, it gives out electro magnetic radiations and that is the same as the radiation for an ideal black body, except for an emissivity factor which is different from unity, which is smaller than unity. You say it is not an ideal black body its emissivity is not unity, in which case it is ideal black body. It is something less than 0.8, 0.7. Even tungsten or even carbon is not a black body. It has a certain finite deviation of the emissivity value from unity and we can get rid of this finite emissivity which will affect the direct radiation from the surface by taking out the radiation through a small hole in a large cavity which is kept at constant temperature irrespective of the material of which the walls of the cavity are made, the radiation that comes out per unit area through this small hole in a thin wall of the cavity that will be the same and identical with the radiation from a black body. Today, in Radiology, that is, in theory of radiation, whenever we talk about a black body, it is a certain ideal body which does not exist, but a radiation which will be identical with the black body radiation from such a body can be produced by merely taking out the radiation through a hole in a thin wall of a chamber. It makes no difference what is the material of the wall of the chamber, whether it has an emissivity 0.1 or actually 1, any value is good enough. Only if emissivity is very small, then the total area of the walls of the surface from which radiations come in to replace the radiations that

go out of the hole, ~~xxxxxxx~~ - that total area - must be large in comparison with the ~~xxxxxxx~~ size of the hole, because when the radiations move out of the hole at a certain rate which corresponds to an emissivity of unity, the radiations which replace them, had to be naturally comparable with the radiation much larger than the radiation that comes out. Otherwise, equilibrium will be disturbed and in order that equilibrium may be maintained, if the walls consist of a material whose emissivity is small, correspondingly the total area of the wall has to be made large in order that the radiation that goes out through the small apperture can be more than replaced by the radiation that can come in from the walls of the chamber. That is a small precaution as long as you make the hole small in comparison with the total area, the area of the hole small in comparison with the total area of the walls of the chamber, how small depending upon, how small is the emissivity of the walls, then the radiation that comes out is ideal black body radiation and we use that in all experiments in black body. To-day we know what ~~xxxxx~~ we call black body is just the hole in a thin wall of a chamber of a cavity which is kept at a large temperature. One can do exactly the same thing with thermionic emission. This factor (1-r) that appears here is analogous to the emissivity. What we call emissivity in black body radiation from a hot body, electromagnetic radiation from a black body, is just what can cross the surface and only we call it emissivity there due to historic reasons. We call it the transmission co-efficient; It is a matter of small detail how we have come to define that body, define that quantity, but it makes no difference actually how we define it. The quantity (1-r) here which represents the fraction that is transmitted by the surface is very similar to the emissivity which occurs in radiation of electromagnetic waves from the surface of a hot body. Just as we eliminate that Crasilon by taking radiation ~~from~~ thro' a ~~the~~ a hole in ~~the~~ cavity, we can eliminate this factor (1-r) by this simple procedure. Instead of pulling out the electrons directly from the surface, you make a chamber of the material and make a small hole in a thin wall of the chamber. You take out the electrons that come out of that small hole. The radiation that comes out will now have all the characteristics of the radiation from the surface except for the fact that this (1-r) which is such an uncertain factor is now completely eliminated. So, instead of taking the emission

directly from the surface of the hot body, we take it through a hole in a chamber, the walls of which are constituted by the ~~body~~ material which we are studying. There is a further advantage. Now when we measure the area of the hole, there is no uncertainty about the ~~planners~~ plane of the surface because it is a certain area which is not occupied by the material and therefore you can measure the area quite, at least you can define that area quite precisely, you can also measure the area of the hole quite precisely, ~~xxxxxxxxxxxxxxxxxx~~ and therefore the old difficulty about what was the effective area responsible for emission, also gets automatically eliminated, because we now have a precise area which is the actual area and there is no need for correction for any corrugation of the surface and this factor (1-r) is eliminated. You know ~~in all thermionic we use to~~ - Anyone who has experience with vacuum technique would have realised that it takes repeated heating at very high temperatures in order that the surface may be effectively de-gased, because often times it is of the order of several hundred hours at a very high temperature. Otherwise any absorbed gases on the surface are not quite easily removed and the effect of the absorbed gases is almost wholly through influencing this factor (1-r), because when we you talk about a reflection co-efficient at the surface, how diffused is the surface will be wholly determine by whether the reflection co-efficient whether is large or small. If it is a short surface then the reflection co-efficient can be expected to be large. If it is a very diffused surface, the reflection co-efficient will be small and there is an uncertainty and Most of our trouble with undegassed surfaces in thermionic emission is due to the this factor (1-r) being so greatly influenced by the nature of the absorbed gases on the surface of the material. When once you get rid of this factor it, there is no need actually to degas the surface at all. You can start with the surface as it is. As long as the bulk of the material is pure, any surface contamination with gases, which is unavoidable-even a casual exposure to the atmosphere would give those absorbed layers - that will not affect the factor (1-r). Absorption can also affect the magnitude of the work function but, in effect, that also gets eliminated this way. You can treat the substance whose surface is contaminated with gas, as consisting of two materials -- one the bulk of the substance and the other a layer of a different substance, that is the absorbed layer. As long as this

layer is thin enough to transmit electrons, even it has a work function which is very different from the work function of the main material, what is called the contact potential between the two materials, theoretically is exactly the same as the difference between the work functions of the two. Since we apply the potential to the lower medium, it does not matter really whether the surface contamination affects in addition to affecting (1-r), whether it also affects materially the work function because if it did affect, that will be automatically compensated by the corresponding contact potential which is precisely the difference between the two work functions. It is a very satisfactory situation because in trying to eliminate this uncertain factor (1-r) we have eliminated automatically not only the effect of the surface contamination on (1-r), but also its effect on the work function. So all that we have to do is to take a chamber, make a thin wall and make a hole and collect the electrons that come out. The study of the electrons which effuse out of that hole is exactly the same as in the case of emission; the technique is very much similar. Only you put a small apperture in order to restrict the solid angle to a small core, so that the uncertainities about even the thinnest of the walls - because if it is a thick wall there are difficulties if the emission is at large angle - that can be eliminated if you make an apperture which restricts the cone of measurement to a small solid angle. Then it is the cone which comes into forward direction. It has no chance of meeting the walls even if the walls are not ideally thin.

One can get a precise measure of the number of electrons that effuse out of the hole. This again bears a very close analogy to the rate of evaporation from a surface. Originally, Langmuir who developed the theory of thermionic emission, also developed the theory of evaporation from a surface. The two phenomena are very similar. Evaporation, here is the evaporation of electrons. You have a certain latent heat of evaporation which is called the work function. Unfortunately, the different branches of Physics have developed independantly of one another so that we use slightly different notations and slightly different nomenclature when we deal with different branches. On the other hand, if we started de-novo, we would have used exactly the same phraseology whether it is

evaporation of the electrons from the surface ~~ex~~ or evaporation of the material of a liquid or a solid. What is the latent heat of evaporation there will correspond to the work function here. There again, in latent heat of evaporation if we started afresh, I would define the latent heat of evaporation at absolute zero as the latent heat and then throw the extra on to the specific heat of the solid or the liquid and the specific heat in the vapour phase. The differences accounting for variation with temperature. It is a very fascinating point of view because I have been able to derive the expression for the well known Clayperon equation by treating an ordinary liquid as consisting of molecules, which have kinetic energies and you can find the fraction of the molecules whose momentum exceeds a certain critical momentum so that it can cross the surface and get into the vapour phase and that against the energy barrier. That energy barrier is the latent heat of evaporation and there are many phenomena in evaporation which bear a close resemblance to thermionic emission. I thought I might mention that in passing. In evaporation what is called the accomodation co-efficient or the condensation co-efficient, i.e. what condenses back or what is held back by reflection, they call it accommodation co-efficient there which is percisely the factor (1-r) here, which is again the same as the emissivity - all of them are identical quantities, only in one case we deal with electromagnetic radiation, in the other case electrons and in the third case with the emission of with the emission of the molecules of the medium. But the theory is identical in all the three cases and you know the well-known method of Knudson by which he determined the rate of evaporation because it is very difficult to determine the rate of evaporation directly from the surface. So he took a chamber and put a hole and he found the rate at which the molecules effuse out. Effusion is very different from flow. Effusion is into vacuum and from a pressure which is sufficiently low that the mean free path of the molecules is much larger than the linear dimensions of the aperture, so that is just what would come out, it is like calculating the number of molecules in the medium which will cross unit area. It is precisely that it has nothing to do with any difference in preasures on the two sides of the aperture. One calls this effusion, the other flow. In order to verify the rate of evaporation, he merly

found the rate at which the substance effuses out through the aperture. That ~~which~~ again he determined by merely finding out the rate of loss in mass. In course of time, i.e., he keeps it for a long time and so due to evaporation inside and effusion through the hole is continuously losing mass.

He finds the rate at which altogether it loses mass and so he can determine that he found it agreed very well with the rate of evaporation calculated theroetically. That is the well known Knudson method. Later on he used it for determining the vapour pressures which means the same thing because if we know the rate at which it gives out you know vapour pressure ~~xxxxxxxxxx~~ inside, the vapour pressures of metals which are very low, which normally cannot be determined by any of the known methods. He merely found for example, lead or tungsten or any of the metal you may merely keep it inside the ~~xxx~~ chamber and you find the rate at which it loses the mass, by keeping it at a constant temperature for a long time. We do exactly that now. Only for the chamber we use a long tube, thin walled cylinderical tube of graphite. You can put it inside a inverted belljar, double walled belljar, that is actually a large size thermos flask. You can grind the edges and then fit it on the base plate and you can connect it up to a diffusion pump and you can reduce the pressure to 10^{-6} to 10^{-7} of a millimeter quite easily because it is all glass part and you send the heavy current through the tube, that is, you have the terminals, you take the current from a generator which gives it a low voltage, about 2 to 4 volts ~~xxx~~ but the current can be heavy, of the order of 200 or 300 amperes. Then what we do is this.

(Projecting a slide and explaining it) This is a thin walled

tube of graphite. The section gives the section of the walls. It is not uniformly thick. We make the thickness here slightly smaller than the thickness near the centre so that the temperature can remain uniform over a large part of the length. If the thickness is uniform, the temperature is maximum near the centre and then remains nearly constant over a certain distance and drops down. Here by making it thinner you keep it uniform over a much longer range than would be possible otherwise. The tube is really worked on the lathe. It is from Acheson graphite rod thick rod which he used for electrodes. You can work it on the lathe. You leave a thin wall here. This part is detachable and so the tube with a partition at that place and a hole in the centre, that is, what is worked out on the lathe and this is a hallow plug, which is insulated from this part of the tube by a ring of mica, There is a thin sheet of mica coming this is the section of the cylinder so that this part is insulated and the temperature distribution is not affected by the presence of this insulated thermally. This is a sheet of mica in which there is a small hole because when we want to take the effusion from hole, we should be careful to avoid the emmission from the the adjoining surface and so just to avoid ~~the emission from the~~ that, you put a small sheet of mica and the effusion hole is really a hole in a mica sheet. backed by a bigger hole in the medium that is graphite here, and at this end it is shaped this way. That is the rod and it can be clamped. i.e., this is the section of the cylindrical tube and it is clamped by two blocks of graphite which can be worked on the lathe and fitted to the ..... This is the clamp, and that is the electrodes through which you take the heavy current. That is to say, these electrodes ~~through wh~~. This is merely a convenient way of leading the current through the tube because the current is fairly heavy, 200 amps, sometimes 400 amps., and one has to be careful to work it on the lathe sufficiently smoothly for a fit so that there is no arcing between, otherwise, especially when we are working at a high vacuum it is desirable that the contacts are very good. This is all the experimental set-up. What we do is this. At this end is a metal diaphragm. This is merely a plate with a circular hole in the centre. This is a Faraday cylinder and you connect the Faraday cylinder to the positive terminals and the negative terminals are connected to the tube and then you can get the current collected. You can vary the voltage and you can calculate the current corresponding to zero space

charge.

(Projecting the other slide and explaining it)

You change the potential 1, 2, and 3,. You know, in ordinary emission from a surface, as you vary the voltage, the variation of the current is rather complicated. It follows a $V^{3/2}$ x law

I forget the actual variation, something complicated like that. One can work it out theoretically because the electrons are pulled out from the surface, with a field and so it becomes complicated. Here the electrons which come out through that apperture, they are pulled out by the extra field, the field can sightly penetrate if the potential is large and so they pull out a little more if the voltage is larger. One can work theoretically if the solid angle is small then the variation of the current with voltage after the early stages should be linear. Therefore the extrapolation from, that is, this is with one setting at a particular temperature. We merely vary the applied voltage and you can see that it follows a linear law after the voltage has exceeded a certain small voltage of the order of 4 volts and one can readily extrapolate to zero space charge and the variation, that is 100, that 120 and that is 140 in some arbitrary units, so that the slope is not much. One can get more or less precisely the magnitude of the saturation current corresponding to zero space charge. That is for one temperature and we can plot the values of $\log I/T^2$ against $\frac{1}{T}$ and you get a straight line curve and the slope of this straight line i.e., the tangent of the angle gives you immediatley the ϕ_0 in this expression and the point of contact here i.e., the intercept on this axis gives you immediately A $e^{-\frac{\alpha}{KT}}$ and since you know A theoretically any deviation of the observed value of that intercept from the theoretical value of A can be taken to give you a measure of α so that we now have precise measurement of the temperature independent part of the work function and we have also a measure of the temperature coefficient of the work function. Both of them can be measured precisely. Just because we have managed to eliminate the factor, the transmission coefficient which is such a suspicious and very undependable factor and we have no need actually to..... as long as we make the apperture small, to degas the surface. Actually we find it more convenient to work with an undegased surface because you know there is an extension of the tube and we don't want electrons from there. They are shielded by a mica

sheet, and mica ring, a mica cylinderical screen. In spite of that we would like the emission from the surface itself to be small and if it is small naturally, the problem of screening is also much simpler and so we work with the substance as it is without taking any special precaution to degas it and we would prefer it to be undegased.

We have degased it also after repeated heating and we don't find any diffénence either in the A value or in the work function, which shows again that the major effect of the absorbed gas on thermionic emission - it may be by a factor of the order of 100, i.e., it may be depressed by a factor of the order of 100 and that is due wholly to the presence of these surface films of adsorbed gases. Now having determinéd the constance for graphite with this, what you do is this. You coat the whole of the inside of the chamber including the walls of the hollow plug which you put from behind, from below. Even the walls of the small apperture on either side, you coat it with the metal for which we study the work function. Then you can use the same technique, the same tube. Only you coat it now with the metal which you want to study, which is very easily done. You can deposit it either by thermal evaporation in vacuum or you can deposit electrolytically and we can get the constants for any metal or in some cases for alloys, but one has to be little careful that the composition of the alloy, does not vary with temperature and the composition determined and it is homogenous alloy because when you deposit, it is only some alloys which can be deposited as alloy. Electrolytically it is not every alloy that can be done - but we can coat the two in the proper composition and then raise the temperature much higher than the sintering temperature for that particular substance. Then there is a flow and they mix. Only we should be careful not to raise it too high in which case immediately it will show holes in the deposit. It should be high enough to make the two faces, diffuse into each other but not too high to give a surface tension which will immediately make them flow out into globules. One can easily manage because there is wide range between the sintering temperature and the actual melting temperature. That is why sintering is such a popular and such

a useful process because it can be done on a temperature very much below the melting, otherwise people would have melted the substance and worked with it very much more conveniently and so we can determine for almost any metal, whereas the old method of determining thermionic constants one had to prepare it in the form of a filament and it is not every metal that can be prepared that way, at least in the diede process, there are other ways by which you can determine, in which you can have a plane surface than the A co-efficient will become uncertain because of the effective area of the surface. So we can do it for every metal or alloy. We can go further. Coat the inside with any semi-conductor - say an oxide. We do not need to coat even the whole inside, you can have a large number of filaments sticking up from the back coated with oxide, that is, a large number of oxide coated cathodes which supply the electrons. In the chamber, you probably know the physics of emission of block body radiation from the cavity, because after repeated reflection if the radiation is repeatedly reflected in the walls of the chamber, what comes out per unit area is as though the reflection coefficient is unity. That is, the black body. Similarly, here, if you have a large number of these filaments sticking out and they give profusely electrons and these electrons are totally reflected repeatedly in the walls of the chamber until it emerges out through the hole, is after several reflections and therefore, it is the value characteristic of emission from the semi-conductor without the factor (1-r) Again it is interesting because formerly they used to get an A value of the 2 or 3 and a work function which is extremely low and varying with temperature. We do not find that, because now we have eliminated that factor (1-r). What we find is this. As long as we keep within the range when we activate it, we should not raise it to a temperature where the activation is spoiled. We know the rules of the game. In the manufacture you start with carbonite, for example, of either Ba. or Sr. or the mixture of the two and then you raise it to the temperature where it is reduced the oxide and then you activate it at a particular constant temperature and you should not raise it beyond that temperature, too much of that temperature, but as long as you are within the permitted range, you can increase or decrease and you can reproduce the filament without spoiling it, at least one can work with it for a few hundred hours without spoiling it. And so we find now that the A co-efficient is reasonably correct, that is, it is of the

order of 60, 70 The theoretical values are 120 and the difference between the two is due to this exponential $\frac{-\phi}{kT}$ that is of the same order of magnitude as for metals. The only difference between semi-conductor and the metal lies in its very low work function. Everything else is comparable with that of the metal except the work function which is very low, of the order of 1.5, 1.4. It depends upon the nature of the material but that is ϕ_0 It is of the order of that as compared with 3, 4, and when it appears in exponential factor you can work at sufficiently low temperature and still get a profusion of current and that part also gets nicely cleared up. We have used the same method also for determining what may be called the ionisation potential of some of molecules, large molecules like anthrancine phenontharine because it is really thermionic emission from the molecules or from the vapour and it is identical. The technique is the same. What is called the ionisation potential there is just the work function for the individual molecule and we are able to determine that, only as the positive ions accumulate, there is a space charge inside the chamber and one has to do it very quickly i.e., before any accumulation of charge takes place and you can extrapulate ions backwards to 0 positive space charge present and it is not difficult and we have now devised a method, magnetically, by which the positive ions are moved of the field and they are forced to go to the walls of the chamber in which case it automatically becomes the samething as thermionic emmission. When I mentioned about distribution of temperature, it looks a little surprising. When we started this measurement, we wanted to know how long our tube should be in order that a certain length, say of the order of 3 centimeters of the chamber would be of constant temperature, that is where the temperature variation is less than three or four degrees centigrade which is the limit of accuracy of measurement of our temperature with the pyrometers. By the way, for measuring temperature since we are doing the measurement through the walls of the thermos flask, one has to correct for reflection and transmission and there are various other corrections involved and we have detailed measurements for the total emissivity and the spectural emissivity for the surface. Again we use black body radiation. You take a long tube of graphite. You make a small hole in the wall, you can view through the hole inside which is the black body radiation and so you can get the correct temperature of the cavity inside. You can get the small variation in temperature between the inside wall

and the outside wall quite easily and you knowing that you know the actual temperature of the outside surface and the temperature as given by the optical pyrometer. That is what is called the pyrometer temperature and one can calculate backwards the emissivity and from the spectral emissivity for that particular region, knowing emissivity later on, you can have a chart, correlating the temperature with the temperature as viewed by pyrometer for that particular substance and so you can precisely measure the temperature also. We can measure the temperature, we can reduce the temperature to any degree. The actual position will also be the same, but we don't want to make the dimension of the pyrometer long and so we have to determine the temperature distribution. It is a straightforward problem which must have been tackled and so I looked through the literature and found that this is a simple problem, namely, the distribution of temperature along filament molecule, electrolytically hot, has not been done. They have extensive experimental data and Genl. Electric, Philips and many other companies have very extensive data particularly for filament platinum and some of the other molecules and they have innumerable formulae and some graphical methods of computation.

Differential equation, that is, the characteristic equation, defining the distribution of temperature can be formulated, has been formulated..... it is given in Carslaw and Jaeger, the standard book on Heat Conduction. When you come to solution of the differential equation, for some reason they fought shy of facing this equation and they always resorted to a graphical method. We now find.....it is interesting..... you can find the two particular solutions very easily. But in order that the two particular solutions can be combined in order to give the general solution, which is what we want as the solution of the differential equation, certain conditions have to be satisfied and those conditions are satisfied only in a very narrow region near the centre and therefore it looks as though it is a trivial result because if we can be satisfied only in a narrow region and if in that narrow region you can get a complete solution. It is just the solution we could have obtained even otherwise, because near the centre there is no difficulty. We want the distribution over the whole length of the filament. Curiously, one of these solutions, particularly solutions, increases exponentially as we move out from the centre. The other decreases exponentially. The ratio of the two, naturally, first to the second, increases much more rapidly than the increase or decrease either of them and it so happens before you have moved out of the narrow region, one of the solutions has decreased almost negligibly in comparison with the other. When once it has decreased, you don't need to satisfy the condition for combining the two, because after all we have only one solution and you don't need to combine the two and therefore you can keep combination and make it applicable over the whole length of the fialment, though mathematically if you give that as a solution and if you differentiate it twice and if you get the second differential co-efficient and you would not get the original equation. That is true and therefore the mathematician would not recognise it directly as a solution, but, experimentally, that is, practically, you will find that one of the solutions has dropped down to a negligible value and therefore it will give you precisely the result which you would have obtained by a very detailed mathematical calculation and got the - if you had obtained - the solution and the solution become extremely simple and we have a series of ..... I shall describe presently this..... The solution now can be put in extremely elegant form. All the

various empirical formuae which had been given by particularly the Bell Telephone co. people, there is a big monograph on tungsten which is written by Worthing. All the properties of tungsten including temperature distribution, distribution of various other quantities what are called the end losses with which one is deeply concerned in all power tubes which are short and therefore the temperature variation does not correspond to uniform temperature. All the empirical formulae came out as ~~x~~ special cases. There I mentioned just one..... result. They say if you want to attain a temperature to with 1/1,000th of the temperature in the centxre, you take this and this combination and multiply by 7.0 and if you want to ..... I am sorry for 1/100... if you want 1/1000th, you add to $\frac{7.07}{3}$. All that $\frac{7}{3}$ comes out as a natural number. It is one of the logarithm to the base E and that is how it fits in perfectly. That 7.0 comes out theoretically and $\frac{7}{3}$ comes out theoretically and all the expressions are verified. We have a series of six papers. Five of them have appeared in the proceedings of the Royal Society and the sixth one is in course of publication. I sent back the proofs sometime ago. When we started I thought if you could give the solution in a paper and the experimental verification of the results, in a second paper that would be complete , but as we proceeded we got such exciting results. It all shows that there is no problem ~~and how ixxshap~~ which is too tirivial. It depends upon the natue of the problem and how it shapes. We found it led on to the third part, in the 4 th part, and a fifth part and now I am almost tired of putting them all, because the original title, the distribution of temperature along a thin rod--I should have said the filament now,--electrically heated in vacuum does not fit in with some of the things we say now. We have moved out so much, I have decided to cut short at this stage because now I would not talk about the thin rod. Originally I wrote it for the mathematician, thin cylinderical rod. Now I would call it the filament because it deals essentially with the distribution of temperature in filaments, in lamps and similar instruments and there are many other anachronosims now which all started with out treating the paper as a mathematical paper for a mathematical audience. There is ultimiately -- it comes out as a verification of many of the empirical results. The original paper about the thermionic constants - it has gone to the fourth part. That is also in the proceedings of the Royal Society. There is 5th and a 6th which will be shortly out about the semi-conductors and meanwhile we have some interesting results

about monovalent metals which, from the theoretical side, bring in the small finite specific heat of the electrons in the metal which formerly we thought was negligible and one can determine that one need to take into account in order to explain some of the observations and so we feel extremely gratified at the way the subject has taken shape. Meanwhile, I find that hollow oxide coated cathodes, - hollow in two different senses - are becoming popular in the industry. Hollow, first, when you take out through the cavity, that is one. That is not so important industrially but where you heat from inside, you put your filament inside and the cathode is a layer and you condition the cathode by heating from inside and the diffusion of the proper, because especially when we are dealing with semi-conductor, it is what diffuses to the surface that gives electrons that is responsible and they have numerous new applications of this hollow cathodes.