STUDY OF ARCS IN MERCURY VAPOR BETWEEN TUNGSTEN
AND ACTIVATED TUNGSTEN ELECTRODES, 1947

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STUDY OF ARCS IN MERCURY VAPOR BETWEEN TUNGSTEN AND ACTIVATED TUNGSTEN ELECTRODES

BY: W. B. NOTTINGHAM

INTRODUCTION: The program of study that was formulated some time ago was planned in order to investigate the behaviour of electric arcs maintained in mercury vapor between various electrodes. As a preliminary, some data were taken on a standard CH-5 lamp produced by the Westinghouse Company. This lamp was preheated by a short period of operation on alternating current and then it was operated on direct current in order to obtain data that represented the performance of a standard CH-5 lamp. After a short period of operation with the glass envelope attached to the lamp as is normally the case, the glass cover was removed and the lamp was again operated with the ambient temperature as a controllable parameter perimeter of the experiment. These studies ~~were~~ made on the standard Westinghouse lamp to ~~in order to~~ serve as a representative sample of standard performance so that ~~we would~~ have quantitative electrical characteristics to compare with the special lamps described later. ~~as Tube I~~.

Altogether three experimental tubes have been constructed and studied for the operational characteristics including a determination of the operational voltage as a function of the current and the temperature. It is to be noted that the temperature of the coolest part of the bulb determines the vapor pressure ~~pressume~~ of the mercury and therefore the gas pressure in the arc under investigation.

Approximately 80 experimental runs have been carried out and it is one of the purposes of this report to present a complete chronological record of the experiments. The various curve ~~tariff~~ sheets contained ~~presented~~ in this report represent data that fall into ~~approximately four general~~ categories of which the following four are the most important. These are: (1.) Time curves. (2), Arc characteristic curves. (3) Probe ~~Bulb~~ characteristic curves. and (4) Pressure curves.

~~In~~

The curves present the observed variations in such quantities as the following; (a) Overall arc voltage, "Arc voltage" will represent this observation; (b) Probe voltage for the floating potential, which is defined by the determination of the probe voltage relative either to the anode or the cathode that results in zero current to the probe from the arc; ~~so called~~ (c) Tube and oven temperatures are plotted since the true temperature of the coolest part of the bulb is never greater than the measured bulb temperature and never less than the oven temperature; (d) The mercury pressure is computed from the temperature on the assumption that the mercury vapor is in equilibrium with liquid mercury and therefore determined by the vapor pressure data available in table form in ~~the~~ "Hand book of Chemistry and Physics". Since the amount of mercury used in the experimental tubes was limited, the true vapor pressure of the mercury at the highest temperatures at which experiments were carried out is probably not as high as the computed value. The limiting temperature at which the computations are likely to fail will be stated in the description of each of the experimental tubes. The above described time curves are presented whenever it seems desirable to show the chronological performance of a given tube during a time of rising or falling temperature or during the time that the arc performance is influenced by variations in the cathode surface conditions and time of operation.

It will become evident from the data to be shown that a large ~~function~~ fraction of all the experimental observations were made with a direct current of 1/2 ampere flowing in the arc. In order to assist in the evaluation of performance that would have been obtained had the arc current been higher, a great many arc characteristic curves were taken in which the operating characteristics of the arc were maintained as nearly constant as possible and the current through the arc varied from 0.5 amp. to 2.0 amp. The characteristic curves present the arc drop as a function of the arc current and in many cases the probe voltage as a function of the arc current.

~~The theories of~~ Irving Langnurr and others have developed the theoretical background by which much valuable information concerning the properties of a gas discharge can be obtained by observing the current that flows ~~flows~~ to an auxiliary electrode as a function of the voltage applied to this electrode relative to either the cathode or the anode. This auxiliary electrode is generally known as ~~a~~ "Probe". In the tubes that were constructed, a tungsten wire was stretched across the bulb in the manner shown in both the photograph ~~paragraphs~~ and the diagrams so that the arc stream ~~strain~~ would flow around the wire with approximately half of the stream ~~strain~~ on one side and half on the other. Since the arc stream is circular in cross section, the probe wire could be said to ~~be~~ lie diametrically across the arc stream. ~~and~~ The probe wire was located along the arc stream at a point approximately half way between the cathode and the anode. A detailed and literal examination of the probe current characteristic as a function of the probe voltage according to the elementary theories of Langmuir ~~Lang~~ can be made ~~on the~~ subject to certain reservations, because the theory has not been developed in all of its details as it applies to high pressure arcs. There can be no doubt, however, that in the broader aspects, the characteristic probe curves can be interpreted for high pressure arcs in a manner similar to that used for low pressure arcs.

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The main points to be considered are the following:

1. If the probe is maintained at a potential, ~~a~~ distinctly negative with respect to the space potential of the arc in its immediate neighborhood then no electrons are able to penetrate against this negative retarding potential and therefore the current to the probe must remain practically independent of a potential applied. ~~and this~~ The current that is observed will be largely dominated by the arrival and nutralization of positive ions from the arc stream As the potential of the probe becomes more positive and yet while it is negative with respect to the space potential of the arc, some of the high velocity electrons have ~~pro~~ trajectories that intersect the probe surface and therefore ~~enter~~ the measured current ~~in the direction to~~ decreases in ~~its~~ magnitude. ~~This as a~~ The potential ~~that is easy to identify and~~ observed when the net current to the probe is zero ~~This potential~~ is known as the "floating" ~~Putch~~ potential and represents the voltage that must be applied to the probe so that ~~at each instant of time,~~ the number of positive ions arriving at the probe is exactly equal to the number of electrons. Owing to the well known fact that the average velocity of the electrons is much higher than the average velocity of the ions, the floating potential must be slightly negative with respect to the true space potential in the arc. The amount that the floating potential is negative with respect to the true space potential, is dependent on the energy distribution of the electrons and the ions and on their relative densities. The latter factor is of small consequence because of the fact that in the region of the arc discharge ~~of~~ where the probe is located, the average density of positive ions must be very close to the average density of electrons. ~~Some of the works~~ On the arcs under investigation, the floating potential of the probe is probably between 3 and 4 volts negative with respect to the true arc space potential at that region of the arc.

Another factor that must be conssidered in the discussion of the measured value of the space potential, is the phenomenon known as "Contact Potential Difference". The point to be borne in mind in this respect is that in every case the voltmeters used to measure voltages give information concerning the potentials inside of the metals to which they are connected, and therefore if two different metals or surface conditions are involved, such that the so-called "work-functions" are different, then the potential in the space outside of the metals will be different from the potentials on the inside by the amount of the work function. Thus, if the probe is a pure tungsten electrode with an average work-function of approximately 4.5 volts, and the electrode to which it is connected by means of external batteries and controls is an activated anode, having an average work function of perhaps 2 volts or less, then there will be a contact difference in potential of approximately 2.5 volts. ~~If~~ The true drop~~p~~in~~g~~ potential between the external surface of the anode and the region in which the probe is located will differ from the apparent value in the direction that it will be ~~2 1/2~~ 2.5 volts less than the value measured when consideration is not given to the difference in the work functions of the materials. All of this boils down to the statement that a correction for the contact ~~in~~ difference in potential is comparable and therefore almost equal to the difference in potential between the floating potential and the actual space potential. Thus, when floating potentials are quoted relative to an activated anode, these potentials in reality are probably very close to the space potential difference between the point and the arc and the anode surface. If the anode used for reference happens to be ~~the~~ a tungsten filament in a completely clean condition, then there should be no contact difference in potential between that anode and the clean tungsten probe. Under these circumstances then for perfectly anologous operating conditions the measured potential between the anode and the floating point will be higher than the space potential ~~value~~ difference by the amount already mentioned which is thought to be of the order of 3 volts.

The next characteristic curves that are of interest have to do with plots in which the abscissa is the computed vapor pressure of mercury and the ~~ardnent~~ ordinate is the overall arc crop or in some cases the floating potential. These curves show the influence of increased pressure ~~and~~ on the arc drop and on the distribution in potential along the arc. They also serve to give a reasonable order of magnitude of the pressure required for the arc drop to increase by a factor of two. From an inspection of such curves, it is reasonable to redefine the range in pressure that is considered to be in the class of "high pressure" arcs compared with intermediate pressure and low pressure. Evidently the high pressure arc conditions are satisfied for vapor pressures of 200 mm. and up. Pressures of the order of 5 or 10 mm and lower, to even including such small fractions of a millimeter as a thousandth of a millimeter all fall in the class of low and moderately low pressure arcs. The range between 10 mm and 200 mm is in the transition region and such arcs are probably more similar to the high pressure arcs than they are to the low pressure arcs and yet fall below that range for which the arc drop doubles with the increase in pressure. ~~For an~~ In cases where the ~~in~~complete history of the arc operation is not available, it will be assumed that the establishment of the 200 mm pressure is sufficient to warrant the classification of the arc as a truly high pressure arc.

In addition to the curves already described, there are a few that show something of the time history and emission properties of activated electrodes purely from the point of view of the electron emission in the absence of a high intensity of ionization of the kind associated with the arc discharge.

In the treatment of the data to be presented immediately, the figures will be identified by their figure number. In some cases a single figure will represent more than one "run". In other cases, a single "run" with respect to time may involve a subsidiary run in which the current is changed. Complete consistency with the regard to the identification of these "runs" has not been followed but in many cases the introduction of the letters A, B, C and the like serve to identify the subsidiary "runs". For all of these data, the data book serves as the master source of information and in this ~~data~~ book there are many remarks recorded that represent physical observations made in the progress of the "runs". The description that goes with each of the figures and will be given below, ~~records~~ Includes a ~~large pro~~portion of these descriptive remarks, but does not necessarily record them all. An attempt will be made to minimize the attention given the "runs" that prove to be of little significance and to give more extended detail and discussion concerning the runs that are of first order importance. An attempt will be made to formulate a system of identification titles so that this report will serve as a useful guide to the graphically presented numerical data.

STANDARD WESTINGHOUSE LAMP CH-5

General Remarks. The standard Westinghouse CH-5 Lamp was put in a circuit ~~and~~ that allowed ~~the~~ a control of the current to range from a few tenths of an ampere to 3 amperes. An AC line of 230 volts was available, and also ~~the~~ a DC source of the same voltage. The arc was first operated on alternating current with a value of 1.3 amps. In the course of about fifty minutes of operation the R.M.S. arc ~~initial~~ voltage ~~dropped~~ ~~dropped~~ rose from its initial value of 20 volts to 27 volts. This operation was in the nature of a preliminary run to put the arc lamp in a "normal" operating condition. Following the AC operation, eight runs were carried through, the details of which are shown in Figs. 1, ~~to~~ 4 inclusive. The outside envelope of the tube was then removed and additional runs up through 20 shown by Figs. through and including 15 were made with the standard Westinghouse tube in an oven which permitted the external control of the temperature surrounding the ~~bulb.~~ ~~globe~~ ~~tube~~ lamp.

~~Fig. 1. Runs 1, 2 and 3. Lower electrode Cathode.~~ Of th

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Fig. 1. Runs 1, 2 and 3. Lower Electrode Cathode. Std. CH-5

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Run 1 started at a current of 1.3 amps. DC and a voltage drop of 53.5. The current was reduced ~~in steps~~ to 1.1 amps and held there for two minutes. During that time the arc drop increased very noticeably from 66 to 77 volts. A part of this change in voltage is undoubtedly due to an increase in pressure with arc operation and part of it may have been due to the relocation of the arc stream on the cathode. The curve that represents run 1 shows the expected increase in voltage as the current decreases to come to its highest value at the lowest current of 0.3 ~~of an~~ amp. The drop in potential at a half an ampere is normal for an arc operated with a mercury pressure ~~casher~~ of ~~[illegible]~~ 300 to 500 mm. Runs 2 and 3 that follow show the variations in arc characteristic to be associated largely with changes in pressure.

Fig. 2. Runs 4, 5 and 6. Lower Electrode Cathode. Standard CH-5.
Arc Characteristics.

Single

Runs 4, 5 and 6 show additional characteristic curves that are typical of operation at different vapor pressures. Superimposed on the variations in these curves is probably some change in the overall characteristic that resulted from the shifting of the arc spot on ~~apparation of~~ the cathode. ~~in the actual operation.~~

Fig. 3. Run 7. Standard CH-5 Lamp. Upper Electrode Cathode.
Time variation in arc drop current 1/2 amp.

Note that for 3-1/2 minutes after the starting of the arc the arc drop increased in a reasonably normal manner consistent with the power input to the arc. Very suddenly the arc drop decreased and associated with that decrease was a shift in the location of the cathode spot. This observation indicates ~~indicating at once~~ the importance of having the cathode spot seated on a region that is in a suitably high state of activation. The lower arc drop is associated with the lower power input requirements needed to get the necessary electron admission. The lower power input resulted in a gradual lowering of the temperature and therefore a lowering of the arc drop. All this can be noted from Fig. 3.

Fig. 4. Run 8. Westinghouse CH-5 Lamp. Arc Characteristic. ~~Top~~ Upper electrode cathode.

The arc characteristic is normal and a comparison between runs 8 and runs 6 show that the arc characteristic is independent of whether or not the upper or lower electrode is used as cathode, so long as the cathode is in a suitable state of activation.

Fig. 5. Run 9. Standard CH-5 Lamp. Outside Envelope Removed.
Time run, current 1 Amp.

The outside envelope of the standard CH-5 Lamp was removed, the tube inserted in the oven, but the oven temperature continued low. Within two minutes of the starting time of the arc, the voltage stabilized at 40 volts, and remained there. This is a typically moderately low pressure arc operation.

Fig. 6. Run 10. Cold Oven, ~~Low~~ Lower Electrode Cathode; Arc Characteristic.

The arc characteristics shown in Fig. 6 was made with a current being maintained at 1 amp. between readings. It is evident from the experiment that it is necessary to make arc characteristics using a specified return point and adjusting the current to the desired value as rapidly as possible before the conditions of the arc have a chance to change. Otherwise the points of arc characteristics have relatively little significance.

~~Fig. 8. Run 11. Low Electrode Cathode. Oven cold. Return point for arc~~
chara~~cteristic 0.5 amp.~~

~~A comparison between run and~~

Fig. 7. Run 11. Oven cold. Time run at 0.5 amps.

After operation for some time at 1 amp. the current was reduced to 1/2 amp. and the voltage drop observed. ~~and~~ It is evident from the figure that the overall drop changes in six minutes' time to correspond to an arc running at a lower vapor pressure.

[redacted]

Fig. 8 Run 12. ~~Lor~~ Lower Electrode Cathode; Oven cold; Return point for arc characteristic 0.5 amp.

A comparison between run 10 and run 12 shows the influence of the change in the stabilization current of the return point.

Fig. 9 Run 13. Upper Electrode Cathode. Oven cold. Return point for arc characteristic 0.5 amp.

This figure shows the comparison between the arc characteristic run with the upper electrode as cathode compared with the lower electrode as cathode. The differences between these two curves can be accounted for either by ~~the~~ a difference in the temperature of the coolest part of the probe or by a difference in the activation of the cathode.

Fig. 10 Run 14. Oven temperature increased; ~~Timed~~ Constant 0.5 amps; Time run. ~~Time run~~.

The oven temperature was allowed to increase in ten minutes' time from room temperature to approximately 180°C. The corresponding increase in voltage drop is evident.

Fig. 11 Run 15. Oven at 176° C. Upper Electrode Cathode.

A comparison of runs 15 and 13 shows the increase in arc drop with an increase in temperature. The pressure at the high temperature is probably in the intermediate range between 50 and 100 mm. The indications seem to be that the standard Westinghouse tube requires slightly higher voltages than the tubes produced in this laboratory as will be shown later. The possible explanation for this is that high cathode efficiency is more likely to obtain when extra care is taken concerning the ~~darkroom~~ vacuum conditions used in the processing.

Fig. 12 Run 16. Lower Electrode Cathode. Oven 185° C. Tube wall 350 to 450° C.

After operation with the upper electrode as the cathode, the polarity was reversed and the arc drop ~~was~~ observed as a function of the time. Although the oven was kept constant, the increased power put in at the cathode caused the wall of the tube at that point to increase in temperature. from 350° to 450°. For the previous run it is likely that the lower end of the tube was the coolest part and therefore the part that determined the vapor pressure. Now with the lower end as cathode, the vapor pressure increases and the reaction on the arc drop is evident. The vapor pressure for this run is probably high enough ~~xxxthatxxthe~~ to be well into the high pressure range, that is well above 200 mm.

Fig. 13 Run 17. Lower Electrode Cathode. Oven 200° C. Arc Characteristic at high pressure.

Comparison between run ~~18~~ 17 and 15 shows the upward displacement of the arc characteristic almost parallel to itself and largely determined in its shift by the ~~thought~~ fact that the vapor pressure is undoubtedly higher for run ~~18~~ 17.

Fig. 14 Run 18. Upper Electrode ~~Positive~~ Cathode. Oven Temperature 190°.

After operation at the very high pressure, the polarity was reversed and an attempt was made to start the arc. As a result of the high pressure, it was very difficult to start and it was only after the arc had a chance to cool off that the pressure was suitable for starting. The time run shows the new change in arc voltage with a change in pressure. The influence of the short period of operation at a higher than the standard 1/2 amp. current resulted in additional changes in pressure.

Fig. 15 Run ~~20~~ 19. Lower Electrode Cathode. Current 1/2 ampere. Time run immediately after reversal.

The time run covering 36 minutes of operation shows the increase in voltage that accompanies operation at 1/2 amp. and associated with this is a measured increase in wall temperature.

CONCLUSIONS FROM STUDY OF STANDARD CH-5 LAMP:

The study of the standard CH-5 lamp yielded quantitative information concerning the important factors of mercury vapor pressure, ~~and~~ cathode activity and the influence of these on the arc characteristic. It is evident that the performance of the CH -5 lamp is not dependent on the presence of the external bulb if provision is made for supplying an ambient temperature that is sufficiently high so that the lowest temperature at any part of the bulb is equal to 300° C or higher. Operation with the cathode at the top or bottom of the tube is in itself unimportant. Such differences in operation that do exist can well be explained by accidental differences in the cathode activation and the definite differences in the temperature distribution that exist~~s~~ under ~~specified~~ operating conditions.

EXPERIMENTS WITH SPECIAL ARC LAMP NO: 1

Description of the Tube

(To be continued on Page 10)

[Descriptxion of ~~xhe~~ the Tube)

~~The Tube one is shown in Photo 1 P~~

It is evident from the photograph that ~~the~~ a standard Westinghouse electrode is mounted ~~in~~ on the two lead press at the top of the tube. Halfway down is a ~~ten~~ 10 mil~~s~~ tungsten wire stretched diametrically across the tube. On the left hand/end of this wire as one views the picture of Photo 1, the wire passes through a small opening in the glass wall and is connected to a ~~moleticum sprain~~ molybdenum spring which is supported on a single lead press, and shielded from the electric discharge by the ~~press with the hole through which the tungsten wire passes each point small~~ glass. At the lower end of the tube is a three lead press of which two leads support a coil of tungsten ~~the~~ with its axis ~~of which is~~ concentric with the axis of the tube. This tungsten coil is made with ~~twelve~~ 12 mil pure tungsten wire by winding ten ~~kim tongs~~ turns on to a fifty mil mandrel with a separation between ~~xinks turnsxxwx~~ turns ~~was~~ of approximately ~~seven~~ 7.0 mils. The scale drawing of Tube 1 is so near like that of Tube 2 that the reader is referred ~~txx~~ to ~~figure blank~~ Fig. 64 for a cross sectional diagram of the tube.

~~xan~~ In addition ~~to~~ to the above mentioned tungsten coil the lower end of the tube contains a piece of ~~folium~~ thorium five mils in thickness and ~~one more meter~~ ~~millimeter~~ 1.0 mm by 6.0 mm ~~by six milimeters~~ in area. This ~~form~~ thorium is mounted by welding to a very small ~~txlium~~ piece of ~~tolium~~ ~~thorium~~ tantanlum which in turn~~ed~~ is welded to a tungsten rod. The entire assembly was arranged in such a manner that the ~~folium~~ thorium strip could be inserted along the axis of the filament and caused to take up a position there in which although ~~the folium~~ ~~thorium~~ it was inside/of the tungsten coil ~~it~~ the thorium was not in physical contact with the coil. In addition to this possible position the axis of rotation of the ~~tungsten~~ thorium strip was so planned that by rotating the strip it was possible/for it to make ~~ecclesical~~ ~~electrical~~ physical contact with the tungsten coil. The reason for this elaborate structure was that it was the original ~~attentn~~ intention

$$w = \frac{Pv}{T}\, 3.22 \times 10^{-3} \text{ gms.} \qquad (1)$$

E(q) 1 Eq. 1. 10^{-8} mm (1.)

②

to operate the arc to the tungsten coil and ~~to~~ determine whether or not an appreciable amount of arc stream current would flow~~xaxis~~ to the thorium in preference to the tungsten. Provision ~~is~~ was made for the establishment of physical contact between the thorium and the tungsten, in order to permit the tungsten to be activated by thorium which ~~it is known~~ will migrate over a tungsten surface rather than evaporate from the surface if the temperature is below 2000°K.

After the tube was constructed so that its volume could be computed, preparations were made for the introduction of a specific quantity of mercury The volume of Tube 1 was computed to be 72 cubic centimeters. Plans were made to put in at least enough mercury to bring the pressure up to 145 millimeters at a temperature of 550°K (277°C). Later experience showed that this operating temperature and pressure was not as high as would be desirable for the arc to be operated under truly "high pressure" conditions. The data reported concerning our experiments with Tube 1 however indicate many of the fundamental properties of the high-pressure arc ~~despite~~ in spite of the fact that in all probability the pressure did not exceed 200 millimeters by any very large margin .

(2)

The formula given as Eq. 1 , ~~xxxxx~~ ~~Pvxx~~ ~~w =~~ ~~PV~~

$$W = \frac{Pv}{T}\ 3.22 \times 10^{-3} \text{ gms} \qquad [1]$$

Type out as shown

has been derived and used to compute the weight W of mercury expressed in grams required to give the pressure P in millimeters of mercury in a volume of ~~M~~ v cubic centimeters when the last ~~bit~~ trace of liquid mercury has been evaporated into the vapor phase at the absolute temperature ~~t~~ T expressed in degrees Kelvin. The method of using this formula is first to compute the volume, then ~~and~~ ~~to~~ determine the maximum operating temperature and find from the published tables of mercury vapor pressure the equilibrium pressure found at the specified temperature . When these qualities, all of which are easily determined, are used in the formula the weight of mercury required is known ~~to the required accuracy~~. The computed value of weight for Tube 1 was 68 milligrams. A capillary tube was prepared and a determination made of the extent to which this capillary needed to be filled in order that it contain 68 milligrams . In the actual preparation of the capsule it turned out that slightly more mercury was put ~~it~~ in than the 68 milligrams and therefore the maximim temperature ~~at~~ at which the tube could be operated and still have liquid mercury present was slightly higher than the 550°K used in the formula.

The mercury was prepared by attaching it to a high vacuum system capable of pumping down to 10^{-8} millimeters pressure. A small amount of clean mercury was put in and attached mercury still ~~adn~~ and after the system was baked thoroughly, including the liquid air ~~cap~~ trap and all the pumping ways back to the pump, the mercury was distilled into the capillary to slightly higher than the theoretically required depth. The reason for this deviation was simply that it was not easy to obtain exactly the required amount of mercury and after two or three tries the capsule was sealed off under very high vacuum with a little more than 68 milligrams.

Tube No. 1 was sealed onto the vacuum system described above along with the sealed capillary filled with mercury. The mounting arrangement was one in which the tube proper could be baked at a higher temperature than the mercury capsule and after a sufficient amount of baking, Argon at a pressure of 10 millimeters was introduced into the system. Over a period of approximately ~~of~~ 35 minutes, the arc was started and stopped a number of times. ~~using~~ The standard ~~electrode~~ "electrode" was used as cathode part of the time and ~~using it~~ as anode the rest of the time. When the standard electrode was used as anode, the tungsten coil was used as the cathode. ~~In all cases~~ With a current ~~the count~~ of one ampere flowing in the arc, the electrodes appeared very hot although the ~~details of~~ measurement ~~concerning~~ of temperature was ~~were~~ not followed very closely. ~~The~~ When the tungsten coil was ~~as~~ cathode it was ~~unquestionably~~ very much hotter than the standard electrode and under this condition of operation the surface was freed of all activating material. ~~due both~~ . Under these operating conditions the arc drop was high and therefore the tungsten coil was operating very hot and was under very severe bombardment. As a result of this bombardment all activating material was removed and an appreciable amount of pure tungsten was ~~scattered~~ sputtered off onto the glass wall of the ~~Tube No. 1.~~ tube.

After this period of operation the argon was pumped out and a new supply of argon introduced after a vacuum close to a 10^{-8} mm. was attained for the second time. Following the final introduction of argon ~~xf~~ to a pressure of 10 mm the ~~xxxx~~ arc was again operated for a very short period of time and the tube was sealed off ~~xt~~ of the vacuum system in such a manner that the unbroken capsule of mercury was still connected to Tube No. 1 .

Subsequent to the sealing off from the vacuum system, a magnetically controlled hammer was used to break the mercury capsule and that part of the assembly containing the mercury was inserted in an oven while the tube proper was maintained cold. After a sufficient period of time all the mercury passed from the hot portion of the assembly into the cold tube, ~~and again~~ The glass connection was sealed off so as to confine the mercury to the tube proper. The precautions ~~portions~~ with regard to vacuum and sealing off ~~circumstances for~~ were controlled in such a manner as to give the best obtainable ~~faster turnabout~~ vacuum and to minimize the effect of impurities that might arise and interfere with the operation of the cathodes.

After the tube was finished nickel leads were attached and the tube was mounted as is shown for the case of Tube 2 in Photo. 4. Following this operation, an oven was put into place as is shown in Photo. 5 and insulation ~~information~~ applied as shown in Photos. 6 and 7. Thermocouples were used to determine the temperature at various points on the bulb of Tube 1 and also a thermocouple was used to determine the oven temperature. The report on the runs that follow is based on the recorded experimental data as indicated:

(5)

Fig. 16. Run 20. First Run on Tube 1; Standard Electrode Cathode; Low Pressure Arc.

Single space

¶ This run represents the first operation of Tube No. 1. The oven temperature was low and therefore the vapor pressure was probably not more than about 6×10^{-3} mm. Initially the cathode was not in a good state of activation and the voltage drop over the tube was abnormally high considering the low pressure condition. This high voltage drop resulted in heating of the cathode ~~enough~~ enough to improve the activation, ~~and~~ As the cathode spot found better and more activated region for operation the voltage dropped from 66 volts to 40 and then finally experienced a sharp fluctuation and a final voltage as low as 33 volts as observed. Associated with this change in voltage the temperature of the glass in the immediate neighborhood of the cathode showed a very measurable decrease. Also the appearance of the cathode showed the effect of the decreasing temperature, associated with the increase in operation efficiency because of the more favorable ~~admission~~ emission at the cathode. This run shows the importance of the cathode activation even though the pressure in the arc is so low that this arc operation can not ~~hardly~~ be classified as a "high pressure" arc. ~~at all.~~

Fig. 18. Run 22 ~~and 23~~. Low Pressure, Standard Electrode, Arc Characteristic. The arc characteristic curve shown here can be compared with Run 12, Figure 8, Results indicate that under low pressure conditions ~~group~~ tube 1 is very similar to the Standard Westinghouse ~~tube~~ CH-5 tube.

Fig. 18. Run 23. Special Cathode: First Operation: Low Pressure Arc: Time Run. After reversing the potential on the tube it was possible to start ~~out~~ the arc fairly easily with the tungsten coil as the cathode. For about four minutes of operation, the drop in potential over the arc was low, the temperature of the cathode very moderate and the arc stream concentrated on a region near the coils ~~near~~ of tungsten where cold contact with

the thorium had taken place during the time after the tube was completed that a check was made to find out whether or not the movable thorium electrode was operating satisfactorily. The operating conditions at the time of the first striking of the arc to the tungsten electrode was with the thorium completely removed from the coil and not connected to the conducting circuit. After about four minutes of operation the arc suddenly shifted and the current went down and the ~~xxx~~ voltage up with the result that all of the activating thorium was sputtered off of the filament and operation became that characterized by a pure tungsten surface being the cathode. It was obviously necessary for the temperature to increase very considerably and the overall drop in potential rose as is indicated. After a total of 12 minutes of operation the arc was turned off because the tungsten was sputtering over onto the glass wall severely and it was desired to find out whether or not the operation in the reverse direction had changed from normal. (See Run 24.)

Fig. 18,. Run 24. Standard Electric Cathode: Time Run at 0.5 amps : Immediately after the operation described as Run 23 the polarity was reversed the arc started to the standard electrode as cathode. ~~and~~ It turned out that the operation of the arc was still normal.

Fig. 19. Run 23A. Special Cathode Deactivated: Low Pressure Conditions: Arc Characteristics.

Only a few points on the arc characteristics were obtained on this run. A comparison with the single point before the deactivation described above took place, shows the big change in the overall voltage. ~~That all it is.~~

Fig. 20. Run 24A. Standard Electrode. Arc Characteristic. ~~PowerxRunx23A~~ After Power run 23A, 24A was undertaken ~~but~~ to show that the arc characteristic using the standard electrode had not changed appreciably.

Fig. 21. Run 25. Special Electrode Cathode: Low Pressure Conditions: Arc Characteristics.

An arc characteristic taken at this time shows that the activation of the tungsten did not come from the standard ~~electrode~~ electrode, but must have come from the ~~[illegible]~~ cold contact with the ~~strip of thorium~~. movable thorium electrode. Cathode operating temperatures are shown and the indications are that the cathode ~~is~~ was very hot. The brightness temperature was ~~that is~~ in the neighborhood of 2000° C or higher.

Fig. 22. Run 30. Special Electrode Cathode: Variable heating current used to determine influence.

At various arc current values from 0.5 amps to 1.5 amps. the heating current through the tungsten coil was varied. The indications are that with the higher heating current the overall drop in voltage ~~is~~ was less, Since the operation ~~is~~ was still at low pressure, this is relatively unimportant, ~~although at that it shows up at any time that it is investigated.~~

Fig. 23. Run 31. ~~Stand~~ Special Electrode: Low Pressure: Arc Characteristic: Four amp. heating current.

The arc characteristic taken with a 4 amp. heating current shows that the voltage drop is definitely less, but the actual observed cathode temperature is still higher. The maximum value recorded was brightness temperature ~~was~~ 2270° C. The actual temperature was probably at least 2400° C showing the very high temperature necessary to give the current when the tungsten is not activated in any way.

Fig. 24. Run 32. Studies On Influence of Heating Currents ~~for~~ on Arc Drop.

Note is made in the data book of a development of a hot spot which finally resulted in the break of the filament.

Fig. 25. Run 33. Special Electrode CAthode: Pressure Low: ~~Laying Your~~ Langmuir Probe Charactistic.

The probe wire was connected into the circuit in such a manner as

(8)

to record ~~correctly~~ directly the voltage of the probe wire relative to the cathode and the observed current was ~~recorded~~ observed. The probe characteristic obtained could be considered tobe normal with a relativley constant current to the probe when ~~the probe~~ it was ~~definitely~~ definitely negative with respect to the space. ~~When~~ near space potential there was a rapid ~~increase~~ change in probe current that indicat~~ing~~ed ~~was~~ the presence of electrons. During the time of the operation, the tungsten cathode ~~xx~~ sputtered away and the ~~cathode~~ ~~circuit~~ ~~cathode heating~~ circuit opened up leaving just a small amount of tungsten coil ~~cathode~~ at the top, and about seven or eight turns below. ~~Ax~~ A detailed analysis of the ~~study~~ ~~leure~~ Langmuir probe characteristic was hardly warranted, ~~but~~ and yet it is fairly evident that with an overall arc drop of approximately 62 volts, 51 volts of the arc drop occured between the cathode and the probe ~~was~~ whereas approximately 11 volts. ~~with~~ was the arc drop between the probe and the anode. This result indicates that something ~~that something~~ of the order of ten or eleven volts is the probable arc stream drop in potential, for half the ~~leng~~ length of the arc. A rough computation of the electron temperature gave it as 15,000°K.

Figure 26. Run 33. Special Electrode. Probe Characteristic analyzed for Electron Temperature.

The analysis of the probe characteristic was quite unsatisfactory because of the changing conditions near the cathode. It ~~is~~ was ~~hard~~ possible to estimate however from ~~that~~ the data that the electron temperature ~~data~~ ~~is~~ was probably of the order of 15,000° ~~K~~.

~~Cont'd on following sheet~~

~~two lead test~~

~~It is evident from the photograph that a standard Westington is mounted inh~~

~~Tube 1 is shown is photo 1~~

~~Descrotopm pf tíe Tibe~~

~~Tibe 8 os~~

The fact that the arc ~~is~~ was operating at a relatively ~~a~~ low pressure ~~are~~ makes the importance of ~~this~~ these data small.

Fig. 27. Run 34. Special Electrode: Open Circuited; Arc to Top of Coil: Time Run With Increased Oven Temperature.

The time run over which the oven temperature rose ~~to~~ from room temperature up to approximately 300° shows that the voltage dropped instead of increasing as might have been expected. The maximum pressure was probably near 200 mm. of mercury. The floating potential of the probe is also plotted as a function of the time and shows by computation that the drop of potential between the probe and the anode increased with pressure, while the potential drop between the cathode and the probe decreased with pressure. This decrease with pressure resulted from the increased efficiency of operation and the arc became more concentrated. This is the first example of the anonymous behavior of ~~increasing~~ decreasing overall voltage as a result of increasing pressure. The explanation of this phenomena is to be associated with the operation of a ~~deactivated~~ ~~or~~ nonactivated tungsten filament as the cathode.

Fig. 28. Run 35. Pressure Approximately 250 mm. Arc Characteristic.

A short ~~xxxx~~ range in the arc characteristic was studied in this tube at the highest pressure at which it was operated. The results show the normal sort of characteristic with additional detail concerning the characteristic of the probe to anode and probe to ~~to~~ cathode potentials.

Fig. 29A. Run 36. Standard Electrode as Cathode: Pressure 60 mm: ~~Count~~ Current 0.5 amps. ~~Laneuil~~ Langmuir Probe Characteristics.

Previous experience indicated that it was best to measure probe characteristics relative to the anode rather than to the cathode because their conditions between the probe and the anode remained fairly constant while those between the probe and the cathode are very dependent on the emission properties of the cathode itself. Therefore for all probe measurements unless otherwise noted in the future the ~~xxxx~~ actual applied voltage will be relative to the anode rather than the cathode. The ~~count.~~ probe current is observed ~~then~~ as a function of that voltage.

Fig. 29. Run 36A. Conditions Same as 29A ~~Explanation as Follows~~.

This figure is an expanded portion of ~~Figure 28~~ Fig 29-A

Fig. 30. Run 36A. Conditions Given Above. Logarithmic ~~Laneur~~ Langmuir Plot to Determine Electron Temperature.

The logarithmic plot to determine the electron temperature ~~is~~ was decidely more satisfactory for the conditions found in the tube for run 36A. Pressure ~~is~~ was definitely higher ~~is~~ and near ~~er~~ 60mm. ~~and~~ The electron temperature of 7600° was ~~is~~ definitely lower. ~~in the 7600° K.~~ The drop between the tungsten probe and tungsten anode ~~seems to be~~ was approximately 8 volts. The arc drop ~~averages about~~ between the cathode and the probe seemed to be about 23 volts. On this basis the cathode fall might be estimated at 15 to 18 volts. A reasonable order of magnitude for the cathode sheath might be taken to be about ~~fourx10~~ 4 x 10^{-4} cm. Under these circumstances, ~~then~~ the average electric intensity in the neighborhood of the cathode would be 40,000 volts per centimeter. In the presence of such a strong accelerating field for electrons, there is a great intensification of ~~filed~~ field as the individual ~~irons~~ ions approach the electrode and therefore it is not at all unlikely that the electric field near the surface of the cathode could be estimated at near 1,000,000 volts per centimeter. This question concerning the electric ~~of the~~ intensity ~~at~~ the cathode will be important in all of our thinking and will be important in connection with the application of the usual thermionic ~~thermatic~~ constants usually published ~~essentially~~ for zero field conditions.

Start of p 17

Fig. 31. Run 36. ~~ASxxx A~~ Standard Electrode. Time Run for Arc Drop and Probe Potential.

Figure 31 is a composite of many curves showing observations taken as a function of the time. The principal curves of interest are the overall arc drop , the computed vapor pressure, and the probe potential. The main point start of interest might be said to be the sudden transition which is shown at ~~x746~~ 7:46 p.m. at which time the arc shifted in position on the cathode and at the same time a very noticeable change took place in the overall drop and in the drop in potential between the cathode and the probe.

Fig. 32 Run 36 b. Standard Electrode Cathode. Pressure 20 mm. Arc Characteristic.

Some arc ~~marked~~ characteristic curves are shown ~~XXXXXXXXXX those~~ which seem to be of little importance.

Fig. 33. Run 36 c. Standard Electrode. Presure 310 mm. Arc Charateristic.

The expected increase in the characteristic voltages as a result of the increased pressure are evident. One indication from the data shown seems to be that over the range of pressure from 20 to 300 mm. the cathode fall seems to remain relatively constant while the change in arc drop in a case studied involves a change in the arc stream itself. rather than a change at the cathode.

Fig. 34. Run 37. Pressure 225 mm. Standard electrode. Arc Characteristic.

Indications here again show the influence of changing pressure. Nothing unexpected.

Fig. 35. Run 37. Special electrode cathode: Thorium inside: Time Run.

At this stage of the measurement the tungsten coil ~~file~~ has become separated leaving a small piece of tungsten at the top and the main body of the tungsten at the bottom. The thorium was inserted into this tungsten coil and even though it was not possible to heat the coil by passing current through it, the contact between the thorium and the tungsten permitted activation of the lower tungsten coil. The ~~upper~~ observations shown indicate that the arc drop is very low and of the order of 27 volts when operated to the activated coil, whereas when the arc operates to the small tip of tungsten out in front of the coil which is more nearly clean tungsten, the arc drop is very noticeably higher. These points are illustrated in this figure.

Fig. 36. Run 38. Activated Tungsten. Time run during increase in pressure.

After the oven was turned on, the temperature was allowed to rise until the maximum pressure was probably near 200 mm. The arc was running to the activated part of the tungsten coil, and the arc drop shows an increase in voltage from 26 volts to 56 volts in the range from a relatively low pressure up to 200 mm, indicating that the 200 mm point is generally consistent with the definition of high pressure arc having double the initial drop. The variation in the floating potential is also shown.

Fig. 37. Plot of milligrams of mercury in capillary used for the production of tube ~~number two~~. No 2. No importance.

Fig. 38. Plot of thermocouple emf readings using the new thermocouple wire.

The thermocouple readings obtained as a function of the temperature using the new thermocouple wire ~~gotten~~ obtained from Prof. Keyes shows variations of five or six percent that are largely random and are centered reasonably well around the standard values expected from this ~~copper~~ couple material. The indication is that the standard values will be suitable for use since these fluctuation values as shown on this chart really represent deviations from the intended temperature that resulted from convexion ~~turns~~ currents and other disturbing influences.

Space

~~Fig. 39.~~ XXXX38X

CONCLUSIONS DRAWN FROM EXPERIMENTS ON TUBE NO: 1.

Space

Inspite of the difficulties encountered in the use of tube ~~number one~~ No 1, a number of conclusions were supported by these experiments. Some of the points established were as follows:

¶ (1) It is possible for us to build an arc discharge tube using a tungsten coil capable of activation by thorium and using a standard Westinghouse electrode. The operation of this tube in the direction using the standard electrode as cathode is very similar to the standard Westinghouse tube.

¶ 2. The performance of the arc depend~~ing~~s on whether or not the tungsten coil is activated. ~~is decidedly different than in the direction that~~ Activation brings about a great reduction

ok

in power input for a given current and temperature operating condition. ¶3. In the tube as constructed it was possible to activate and deactivate the coil at will depending on the cycle of operation used. ¶4. The usefulness of the Langnuir probe electrode has been established for the determination of approximate values of electron ~~electro-~~energy distribution and space potential. ¶5. Operation of this tube was so satisfactory at the relatively high oven temperatures used, that the design of tube No. 2 will be made to conform to the requirement of having a range of still higher pressure than the 200 mm provided for in tube No 1.

EXPERIMENTS WITH TUBE NO: 2

Description of Tube No. 2

For practical purposes, the constructional features for tube No. 2 were the same as those of tube No. 1. The movable thorium electrode was designed to be inserted into the tungsten coil and all essential features were the same. in these two tubes. The amount of mercury planned for use in tube no. 2 was raised to 330 mm. With this amount of mercury and a net volume of approximately 100 cu. cm. the pressure that ~~should be~~ obtained at the temperature of 347°C was 636 mm of mercury. This pressure maximum was at least three times as high as that provided for in tube No. 1. The processing of tube No. 2 was similar to that used in the processing of tube No. 1. It was evident during this processing that the operation of the arc to the deactivated tungsten coil at low pressure resulted in the sputtering of a good deal of tungsten over onto the glass wall. Care was exercised not to get any more of the tungsten deposit on the glass wall than was absolutely necessary consistentwith suitable vacuum treatment needed ~~for~~ to make the tube ~~to be~~ stable in its operation. Photographs of tube No. 2 are evident in Photo 1, 4 and 5. The following descriptions of the figures available cover the studies on tube No. 2. Fig. 64 is a scale drawing of this tube.

Fig. 39. Run 39. Tube No. 2 Standard Electrode Cathode. Time run.

The first time run of tube No. 2 is shown in this figure. The arc drop is normal for a reasonably well activated cathode when the pressure is low and as the mercury pressure increases with the temperature of the oven the arc drop increases along a curve which is more or less typical of all such operations. At about 8:03 p.m. there was a marked change in the overall potential which was observed to be definitely associated with a shift in the location of the cathode spot, and since this change was in the direction to lower the voltage it is evident that the new cathode spot was in a more favorable state of activation.

Fig. 40. Run 39 A and 39 B. Standard Electrode as cathode: Arc and probe charcateristic curves. Pressure 180 mm.

The characteristic curves of the arc operation in tube No. 2 using the standard electrode were normal.

Fig. 41 Run 40. Tungsten coil as cathode. Time run.

This figure shows the first run made with the tungsten coil of tube No. 2 as cathode. It started out at a relatively low pressure, probably near 100 mm which put the arc in the class of intermediate pressure. The arc drop was low and therefore indicated that the tungsten coil ~~is~~ started out in an activated condition. The source of this activation was the thorium which in the course of the testing of the tube made cold contact with the tungsten. Such cold contact with the tungsten released enough thorium from the sample to cause the tungsten to become activated. The thorium deposited in this way was small ~~Another flaw in there is obviously small and there~~ and therefore easily removed. The arc showed that it was concentrated and in those parts of the tungsten coil that were most easily activated by the p~~XXXXXXXXXXXXXX~~ cold contact.

In the course of time of operation, the activation of the tungsten diminished because of the migration of the thorium and the spattering of the thorium and therefore the arc moved around from coil to coil. The history of its operation is recorded ~~which is noted~~ in the data book. Some changes in arc position resulted in such a rapid evaporation of the thorium, that the arc voltage rose abnormally rapidly, but when the arc moved to a new position where the thorium present was in higher concentration, the arc voltage would suddenly decrease in overall value. The range of pressure studied went up to something over 400 mm. The plotted variation in floating potential indicated that all of the variations that were observed in overall voltage took place between the tungsten probe and the tungsten cathode.

Fig. 42. Run 40 A. Tungsten partially activated. Arc characteristic. Pressure approximately 470 mm.

The ~~two~~ points on the arc characteristic were determined that show the normal behaviour of this arc as a high pressure moderately activated cathode.

Fig. 43. Run 41. Thermionic emission from tungsten coil to thorium electrode.

A number of measurements were made concerning the thermionic emission from the tungsten coil as a function of the temperature and of the voltage difference between the coil and the thorium electrode. ~~which was~~ For these measurements the thorium was outside of the coil and serv~~ing~~ed simply as a collector of the emitted electrons. The intention was to see whether or not the history of activation could be investigated and the state of activation determined by the electron emission. In any such measurement of this kind in the presence of the gas one can expect gas discharges to alter the true thermionic emissionn observations. ~~and~~ This result was found to be true in the course of the investigation. The other figures in runs that have to do with these studies will be described only in the briefest possible way. Indications in this figure are that gas discharge phenomena become strong as the voltage is increased.

Fig. 44. Runs 42 and 43. ~~Therme.~~ Thermionic emission shown for two different heating currents.

Fig. 45 Run 42. The test for space charge effects.

In order to determine whether or not the rapid rise in current was simply due to the space charge, the current to the two-thirds power was plotted as a function of voltage. Since the ~~current~~ curve obtained was convex downward ~~may have~~ it is a direct indication that a gas discharge was taking place.

Fig. 46. Runs 42 and 43. Plot of current to the one-third power.

A plot of the current to the one-third power shows very nearly straight lines, indicating that the current in this example is going up with the cube of the voltage. Nothing of any importance can be attached to this experimental fact.

Fig. 47. Runs 42, 44 and 45. Evidence for deactivation.

The three curves in this figure show the state of filament after various heat treatments which progressively deactivated the filament and therefore caused a very large reduction in the thermionic emission at a given temperature.

(start)

Fig. 48. Runs 39, 40 and 48. Time runs convered to show pressure effect.

In the runs taken prior to this one, the time has been plotted across the abscissa and the overall voltage or probe voltage was plotted along the ordinate. It is evident that if instead of plotting the observed data as a function of the time it were plotted as a function of the computed pressure, we would eliminate the irrelevant variable, ~~mainly~~ namely the time, and express the results with respect to the important variable, the pressure. Of the three sets of data shown here, two are taken with the tungsten coil electrode and one is taken with the standard cathode. It is evident that the floating potential curves are quite reproducable.

Fig. 49. Run 46. Special cathode. Low pressure operation. Time run.

The time run shown here was for the arc in a low pressure condition. It started out with a low arc drop but increased very rapidly as the thorium was ~~spotted~~ sputtered off of the tungsten.

Fig. 50. Run 47. Time run after cold contact activation.

Following run 46 the experimental data shown on pages 20, 21 to 23 inclusive (book 2) show some scattered arc studies and an investigation of the thermionic emission from the filament. The evidence there simply points to the fact that if the filament was in a deactivated state and ~~after~~ then make cold contact with the thorium it ~~was in an~~ improved in its state of activation. Run 47 covers a time period during which the vapor pressure was still quite low. It is evident however from the data shown that the filament became activated as a result of cold contact and that shifts in the location of the arc spot show expected variations in the overall potential as the arc moves from one spot to another, depending on the activation at the spot on which the arc is operating.

Fig. 51 Run 48. Time run. ~~Short~~ arc drop with high pressure operation.

Operation of the arc ~~still~~ showed definite signs of the previous activation. The initial voltage was about what could be expected using a partially activated cathode. As the temperature increased and therefore the vapor pressure increased, the voltage drop increased ~~definitely~~.

Fig. 52. Runs 50 A, 51 and 52. Thermionic emission as a function of heating current.

Some measurements were made using a constant accelerating ~~exhilarating~~ voltage to the thorium electrode as an electron collector at a voltage ~~being~~ of 45 volts. Subsequent experiments showed that this voltage was too high to have pure thermionic ~~puritinionic~~ emission. ~~however,~~ The emission observed did depend very definitely on the heating current and the results are shown. The indications are that once the filament is activated by cold contact it holds its activation over considerable periods of time, in case it is not mistreated in terms of excess temperature and ion bombardment.

Fig. 53. Run 53. Time run with increasing vapor pressure.

The time run shown here gives the voltage drop as a function of the time and also records the pressure. The performance of the arc is normal for a moderately activated filament. The pressure data are computed ~~xxxthex~~ from the temperature even though the temperature increases above the limit for which mercury would be expected to be in the liquid state. In all probability, the pressure did not reach ~~one thousand~~ 1000 mm as is indicated, but did not rise above approx. 700 mm as would be consistent with the amount of mercury inserted in the tube at the time that it was produced. (See Fig 55)

Fig. 54. Run 54. Time run with increasing pressure.

The time run shows a normal increase in overall voltage as the pressure increases.

Fig. 55. Run 53 and run 54. Plotted voltage against pressure.

This voltage pressure curve shows a normal rise in voltage as the pressure of mercury increases and also shows a rise in probe floating potential at the same time. Note the fact that at 200 mm pressure, the probe floating potential has risen by approx. a factor of two and the same is true for the overall arc voltage. The fact that runs 54 and 53 are so near alike is an indication that the data are reproducable when the condition of the cathode remains reasonably constant.

Fig. 56. Runs 57, 57 B, 57 C and 57 D. Voltages as a function of pressure.

The curves on this figure represent four runs made first with increasing pressure, then decreasing pressure then increasing again and finally decreasing. The interesting point concerning this operation is that the curves with increasing pressure lie below the curves observed with decreasing pressure. Although there are ~~the~~ possible explanations for this effect, ~~and~~ it was not feasible to establish the ~~importan~~ relative importance of the determining factors. ~~determine which of the two represents the fact~~. One explanation ~~which is the simpler but not necessarily true~~, is that the thermocouples used to determine the temperature of the coolest part~~s~~ of the bulb were not located at the point that was really the coolest. ~~but were located at a point somewhat warmer than the coolest part of the bulb. If such were the case, then it is possible that the difference in temperature between the thermocouple and the coolest part of the bulb might be different depending on the rate of change of temperature~~. An other explanation may be that the cathode actually undergoes a gradual change, as the arc becomes more and more concentrated and as a result of that change, it could become less active at the seat of the arc. ~~as the arc becomes more concentrated.~~ In this case ~~This would result in~~ a steeper increase in voltage ~~than~~ would ~~otherwise~~ take place. During the decrease in temperature, the seat of the arc spreads out and finds itself on areas that are less active ~~and~~ until it finally spreads out very considerably at the lower pressures. ~~Finally~~ ~~finds a~~ and locates on a well actived area. Another factor is that the thermocouple was on the outside of the tube and therefore while the temperature was rising the inside would be cooler than the outside while the reverse would be true while the temperature was decreasing. As a final consideration it is possible that (over) the mercury vapor does not condense out immediately and that the actual concentration of mercury remains high until some mercury starts to condense and then condenses very rapidly onto the liquid formed.

The additional fact that the probe measurement shows a systematic displacement is further evidence to indicate that the pressures computed from thermocouple readings were not exactly right. Therefore it is not like that ~~both of these~~ all of the above ~~explanations~~ factors may play some part in the determination of the results that were observed. In the data book there is a reasonably complete record of a particular ~~term or terms~~ turn or turns of the tungsten coil that seemed to be accepting the arc ~~as being~~ and therefore showed as the most favorable parts of the tungsten coil for electron ~~d~~emission. As the pressure changed the most favorable coil changed from place to place and associated with many of those changes ~~are~~ were definite changes in the overall arc drop.

Fig. 57. Run 57A. Arc Characteristic at pressure of approximately 680 mm.

The characteristic curve for the arc at this high pressure ~~is~~ was quite normal. The probe characteristic is also shown

Fig. 58. Run 61 and 63. Filament Activation Studies.

Although the activation studies shown in this figure are rather random and not as well organized as would be desirable, ~~but~~ they indicate the very definite increase in thermonic emmision observed following a systematic activation with the filament in contact with the thorium and the filament hot enough to permit thorium migration over it. A test was made that showed that the electron emission under high pressure conditions could not be measured, but that in spite of the increase to high pressure, and then the foollowing decrease, the ~~d~~emission properties remained reasonably constant. ~~and the pressure is low enough so that the electrons could pass readily from the filament to the collecting electrode, namely the thorium electrode itself, without the help of a strong gas discharge~~ The method of measurement depended on the collection of electrons on the thorium electrode when it was made positive with respect to the tungsten cathode.

Fig. 59. Runs 63 to 69 inclusive. Addition Electron emmisions.

It ~~is~~ was found by observation that at voltages above 15 volts, definite ionization effects ~~are~~ were apparent. This explanation of increased emmision in the presence of the ions is consistent with the ionization of argon, which ~~occurs~~ has ~~at~~ an ionization potential of 15.68 volts .

Fig. 60. Run 67, ~~XXX~~ 68, and 69. Electron emmision as a function of heating current

The runs shown in this Figure were taken at 12.2 volts, 13.8 volts and 6 volts. Both runs 67 and 68 show the effect of gas in the tube, when the current exceeds 10 microamperes. The generation of a very weak gas discharge is very evident and results in a very large increase in current, with a very small increase in temperature.

Fig. 61. Run 70. Activitated Tungsten Coil Run. Increasing and decreasing temperature.

The data shown are again plotted as a function of the computed mercury pressure. It is evident that the observed points are not strictly reproducible, as the current is increased and decreased. Again this lack of reproducibility can be associated with some inaccuracy in the exact determination of the ~~temperature of the coolest part of the bulb~~ vapor pressure. A comparison may be made with run 72, which shows the quality of the reproducibility on the rising characteristic. A comparison may also be made with Figures 48, 55, and 56.

Fig. 62. Run 70A. Arc to top turns of tungsten electrode, pressure 665 mm. Run 71: emission data.

The arc characteristic is shown for the high pressure operating conditions and also the variation of the floating potential with the arc current is shown. The characteristics are normal, and allow for extension of data from the one-half ampere value to the higher values of current. Also on Fig. 62 are the emmision data taken with the tube cold and the thorium electrode at 10.7 volts. The comparison with run 60 shows that some activitation has remained on the filament.

Fig. 63. Run 72. Activated Tungsten Cathode.

Run 72 was made at a very much slower rate of increase in temperature and therefore is apt to be a more accurate representation of the performance of tube No. 2, as a function of the pressure of the mercury. It is very evident that the drop ~~is~~ was lower at the higher pressures of gas, than previously observed. In most cases as the pressure ~~is~~ was increased, the arc concentrated on such a small portion of the tungsten filament that the thorium which had been caused to migrate to that point became so severly bombarded that it ~~is~~ was rather easily lost. In spite of this loss in thorium, the performance of the filament under conditions shown in this Figure, ~~is~~ was that of a reasonably well activated tungsten cathode. (notes elsewhere) (use insert ~~the~~) (on next page here)

Fig. 64. Scale Drawing of Tube No. 2

The scale drawing of tube No. 2, is shown in this figure along with most of the specification details

(more figures)

stop here ~

Insert on page 20 of draft.

Additional notes to be incorporated with Fig. 63.

The data represented in this figure were taken on the afternoon of October 3rd when the following observers were visiting the laboratory. These were Dr. Laub, Dr. Danzieger, Dr. Anderson, Dr. Huber, Mr. Johnson, and Professor Keyes. After the data were taken as shown in the figure an attempt was made to cause the arc to transfer and operate directly to the small piece of ~~XXXamenX~~ Thorium that was left on the thorium support ~~of the tube.~~ structure On the morning of October 3rd, the main body of the thorium electrode broke off leaving a tip of thorium plenty large for the operation of the arc, but too small to insert well up into the coil of tungsten. Experience now shows that even had the thorium been ~~in~~ inserted well into the tungsten, but not in contact with it, the arc would not have run to the thorium. ~~It~~ The arc was given every opportunity possible to run to the remaining piece of thorium which was near the bottom part of the coil in its position. The circuit was even changed to the extent of making ~~a~~ the piece of thorium 45 volts negative with respect to the cathode itself, and even so the arc would not transfer from the tungsten cathode over to the thorium. The first attempt to make the arc transfer over to the thorium was done while the temperature was quite high, and therefore the vapor pressure was quite high. Since those attempts were unsuccessful, the temperature was lowered by opening up the heat shield on the oven, and very vigorous efforts, including the use of strong high voltage spark all failed to cause the arc to transfer to the thorium . Finally the arc was turned off, and with the thorium connected to the cathode part of the circuit, ~~while~~ the tungsten coil, which had been previously available as cathode was connected ~~to,~~ through a ~~first~~ 1,000 ohm resistance at first, and later to a 100 ohm resistance to the anode at +230 volts. ~~With~~ The idea of ~~using it~~ this connection was to use the tungsten coil as a starting electrode. In every case, in spite of strenuous efforts it was impossible to generate more than a low pressure glow, around the thorium electrode. The experiments with tube No. 2 were finally discontinued without a successful transfer of the arc to the thorium electrode.

CONCLUSIONS DRAWN BASED ON THE EXPERIMENTS OF TUBE NO: 2

The experiments with tube No. 2 contributed much in the way of additional infomation to support observations previously made in connection with tube No. 1. The results of experiments up to this point might be summarized as follows. 1. Operation of the arc to the activated tungsten electrode is far more efficient and very much more closer to the performance of the standard electrode than ~~is~~ the case when pure tungsten is used. 2. ~~We thought that the activated tungsten electrode always operated at a higher temperature than the standard Westinghouse electrode makes it very definitely out of the question as to whether or not the simple activation ofpure thorium on tungsten is as efficient as the standard electrode that can involve not only tungsten and thorium , but also thorium oxide and tungsten.~~

2). The experiments showed that the standard electrode operated at a lower temperature than the simple mono-layer activated tungsten. It is possible to argue that the very low temperature is the result of higher heat conductivity to the main bulk of the electrode. whereas when the arc is running to the isolated coil of activated tungsten, the heat absorbed under the ~~iron~~ ion bombardment raises the temperature of the coil to a higher value in order to dissipate the heat.

3 For equal conditions etc →

(see page 21A)

4) Auxiliary experiments in which the tube was operated with the standard electrode in the upper position and compared with its operation with the standard electrode in the lower position shows that the conditions are the same within the accuracy with which one can measure. Therefore the fact that most of the experiments described have been with the special electrode in the lower position and the standard electrode in the upper position is of no consequence.

(insert for page 21)

3. For equal conditions concerning mercury pressure and tube geometry, the higher the efficiency of the emmision process at the cathode, the lower the overall arc voltage. Thus it is generaly true that at a given pressure the arc voltage XXXXXXg when the standard electrode is cathode, is likely to be slightly less than that found when the activitated tungsten is used as a cathode. The difference is small and the main evidence for believing that the standard electrode does not operate as a simple activated tungsten electrode, ~~but it is possible to put up the argument that the apparently very low temperature is the result ---~~

is that it operates at such a very low temperature.

5. In order to establish rather more clearly the question as to whether or not the interface between tungsten and thorium and thorium oxide plays the dominating part as seems to be indicated from these experiments. Tube No. 3 which involved radical changes in the design of the test electrode ~~has been~~ was planned.

~~TEST~~ INVESTIGATION OF THE PROPERTIES OF TUBE NO: 3 MADE WITH A SOLID THORIUM ELECTRODE ATTACHED TO TUNGSTEN:

Description of tube. Tube No. 3 will be described with the help of the photographs shown as Photo ~~two~~ 2 and Photo ~~three~~ 3. It is very clear from these photographs that the upper electrode is a standard Westinghouse cathode and associated with it there is ~~there~~ a starting electrode. ~~In the middle~~ Half way along the length of the tube there is the tungsten filament wire probe used for the determination of the floating potential and the space potential in the neighborhood of the middle of the arc. At the lower end of the tube a coiled filament shows and in this case the filament is at right angles to the axis of the tube instead of being parallel to it. Just over the top of this filament as is very clear in photo 3, is a strip of tungsten foil. This foil is in two parts, of which only one side shows in the photograph, since it is ~~somewhat~~ in the form of a "sandwich" with a piece of thorium welded between the two pieces of tungsten. The thorium piece is not quite as wide as the tungsten and shows in the picture as a piece of metal just above the tungsten support. This piece of thorium ~~was~~ is 5 mils in thickness and 4 mm wide, & extends about 3 mm up above the tungsten support. The tungsten foil was welded to a tungsten rod and this in turn is supported on the metal conductor that comes through the glass press at the base of the tube. The spacing at the press was made as large as possible so that the filament could be used to bombard the thorium electrode and its support in order to ~~outguess~~ outgas it in the vacuum processing. During ~~the~~ one stage of the processing of this tube, the thorium was maintained 7000 V positive with respect to the filament, and a bombarding current of as much as 25 ~~million amp~~ milliamperes was used for short periods of time in order to heat up the ~~test~~ thorium electrode. The glass surface also received a considerable bombardment and therefore it was not safe to attempt to bombard the thorium for long periods of time. The bombardment given, however, was sufficient to drive off all the gas that was likely to come off in the final operation of the electrode as a cathode in the arc.

It was anticipated that after the tube was put in service it might be necessary to again bombard this electrode very severely in order to get it in a state of surface condition that would allow the arc to play to it. In view of this possibility, the tube was finally pumped in such a manner as to leave out the 10 mm of argon conventionally put into these tubes to assist in ~~stocking~~ starting. The thought was that in case it was necessary to give the electrode~~s~~ a severe bombardment, and perhaps even try to melt the thorium down, ~~that~~ the tube could be immersed in dry ice, and high voltage applied, along with a high bombarding current in order to deliver sufficient heat to the electrode to melt it. Later experience showed that it was unnecessary to ~~make~~ follow this plan and it would have been desirable to have used argon in order to make the starting somewhat easier than turned out to be the case.

The structure thus as planned ~~omitted~~ Permitted the use of the tungsten coil filament as a means of operating the arc with ~~that of~~ it as the cathode. The arc was ~~also~~ operated while on the vaccumm system, with the standard electrode as cathode. After sealing off, however, without the presence of the argon, it was difficult although perhaps not impossible to run the arc with the standard electrode as cathode. In the experiments carried out in this tube, we did not persevere sufficently to bring about that kind of operation.

Plans were made in advance to have a movie camera available to ~~show~~ take movies ~~concerning~~ of the actual behavior of the cathode spot as it plays over the surface of the thorium-tungsten electrode. In anticipation of these experiments some movie shots were taken of the operation of tube No. 2. Some of these shots showed the operation of the standard electrode in a beautifully clear manner, and especially when viewed in ~~crotocrome~~ Kodachrome. After the experience with that tube it was evidently desirable to use the ~~crotocrome~~ Kodachrome for photographing tube No. 3. Some photographs were taken with "black-and-white", simply in order to be sure that pictures would be available, althought it ~~is~~ was anticipated that the ~~crotocrome~~ Kodachrome pictures will be far easier to understand and interpret. Some of the pictures were taken without the tungsten filament being heated, while others were taken with the tungsten filament turned on in order to illuminate the electrode as a whole. When this was done the tungsten filament was not connected to the circuit, but was essentially floating, and none of the arc current flowed to the tungsten filament. It was used simply as a means of illuminating the electrode so that it would be very clear as to just where the arc stream was originating.

(Additionalreport information elsewhere)

after that, continue next page.

CONCLUSIONS DRAWN FROM EXPERIMENTS ON TUBE 3

The experiments on tube 3 yielded extremely valuable and interesting information. It was possible to cause the arc to transfer from the tungsten electrode over to the thorium electrode, but it was very evident that the arc chose to operate almost entirely at the junction line between the thorium and the tungsten in spite of the fact that thorium in bulk was available for the arc stream to operate to, and would have given an arc stream path that was shorter than the one that was actually taken. These observations serve in a convincing manner to show that the junction between the thorium and the tungsten is the seat of maximum thermionic or field emmision activity. In the actual operation of this electrode the temperature of the electrode was very low. In fact, it was so low that the electrode showed no visible color of its own. Thus it was actually operating at a temperature which in all probability was lower than that of the standard electrode. ~~and yet in operating the electrode~~, It seemed as though the conditions here ~~are~~ were far more similar to those of the standard electrode than was the case for the simple mono-molecular activation of the tungsten.

Electron emmision in the presence of a very strong field is known to increase enormously following the activation of a clean metal surface by an electro- positive material or is its oxide. Experiments with high pressure arc in air and other gases show that un-oxidized electrodes are very poor cathodes for the high pressure arcs.