amount for less money. The American public has chosen to get more light and each advance in lamp quality has resulted in increased intensity of lighting everywhere.

It is estimated that over half a billion dollars were paid in 1922 for electricity used in the United States for electric lighting. If the present day intensity of lighting were produced by using the bamboo carbon lamp of 1880, the cost of lighting in 1922 would have been increased three and one half billion dollars. This would have required about fifty-billion additional tons of coal, about ten per cent of the total coal production in the United States, to generate the amount of light actually used.

Discussion

For discussion of this paper see page 877.

The Art of Sealing Base Metals Through Glass

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Review of the Subject.—*Methods are described by which base metals may be sealed to and through glass, even though the metal and glass have different coefficients of thermal expansion. The method consists in providing a large surface of contact between the glass and the metal, and in so proportioning the metal that the stresses resulting from the difference in coefficients of expansion are less than the ultimate strength of the joint between glass and metal.*

Four different types of seals are discussed:

First, the flattened wire seal for small electrical conductors.

Second, the ribbon seal for special purposes.

Third, the disk seal for commercial manufacture of seals for carrying currents of the order of 100 amperes.

Fourth, the tube seal in which metal and glass tubing are joined together.

BOTH incandescent lamps and thermionic tubes consist of certain electrical elements enclosed in glass containing vessels. These vessels are exhausted to extremely low pressures and are then sealed up so that the vacuum may be maintained. It is necessary for leads to be provided which will make electrical contact with the electrodes within the exhausted vessel and which will permit of energizing these electrodes by means external to the vessel.

In the incandescent lamp, the electrode consists of a fine wire which is heated to a high temperature by passing current through it. For many years platinum was used as that part of the electrical conductor, passing through the walls of the glass enclosing vessel, which carried current to and from the filament. There are two reasons why platinum was used. First, it does not oxidize while the glass is being applied; consequently, the glass comes in contact with a clean surface of platinum and this was thought to be a desirable feature. Second, of the metals readily available, ten years ago, platinum was the only one which had a coefficient of expansion approximately the same as that of the lead glass in use at that time. Both lead glass and platinum have a coefficient of expansion approximately 9×10^{-6} per deg. cent. Other metals, such as gold, silver, copper, iron, nickel, etc., have coefficients of expansion appreciably greater than that of glass. Consequently when attempts are made to cover round wires of these metals with glass, while good contact may be made with the glass hot, yet when the glass and wire cool down to room temperature, the metal contracts further than the glass, and separates from the glass, leaving very small openings between the wire and the glass, through which air readily enters the vacuum container. Consequently, it became axiomatic, in the incandescent lamp manufacturing industry, that the seal wire, as that portion of the conductor coming directly in contact with the glass was called, must have the same coefficient of expansion as that of the glass through which it passed. In consequence, we find that when the price of platinum increased enormously several years ago, platinum substitutes were offered for use, which had approximately the same coefficient of expansion as the platinum which they replaced.

Alloys of iron and nickel have the property of a varying coefficient of expansion, depending upon the relative proportions of the two component parts. An alloy may be obtained having practically any coefficient of expansion from zero to 14×10^{-6} per deg. cent. One of the earliest platinum substitutes consisted of a core of a nickel iron alloy sheathed with platinum. Another substitute at present in use in the lamp manufacturing industry consists of an alloy core sheathed with copper and usually coated with dehydrated borax. In the substitution of either of these alloys for platinum, a larger diameter of the substitute wire is usually required. The alloy core is of considerably higher resistance than the platinum which it replaces. The copper sheathed wire in this respect is better than the platinum sheathed wire in that the copper is of lower resistance than the platinum. The high resistance is objectionable because, carrying the normal current, the wire heats and of course expands. If this expansion is sudden, that is, if the wire heats up before the surrounding glass, it is quite likely to split the glass from its internal wedging action. Consequently, it has been found advisable to

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use only a short length of the platinum substitute and to weld copper wire to each end of the short length. The solid copper being a better heat conductor than the alloy wire itself, serves to take heat away from the wire and thus keep the resulting expansion at a minimum. Welding the copper wire to the substitute also serves to close up any small openings which may occur between the copper sheath and the alloy core which otherwise would give rise to very small leaks, developing after several days' or weeks' use. Thus we have the practically universal use of a round cylindrical wire which has approximately the same coefficient of expansion as that of glass, passing through the glass.

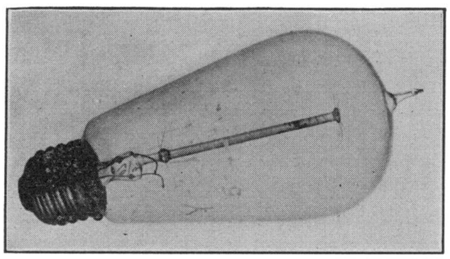

Fig. 1

Measurements made upon tungsten and molybdenum showed that they had coefficients of expansion approximately 1/3 that of the ordinary lead glass. The well-known Pyrex glass has approximately the same coefficient of expansion as that of tungsten. Thus satisfactory seals are made between tungsten and Pyrex glass through the intermediate use, however, of a second glass which seals satisfactorily to the tungsten and to which the Pyrex glass is, in turn, attached.

In the telephone plant, thousands of tiny incandescent lamps are used for indicating the condition of subscribers' lines. These lamps are approximately ¼ in. in diameter (6 mm.) and 1¾ in. long (4½ cm.). Several years ago, experiments were made to determine

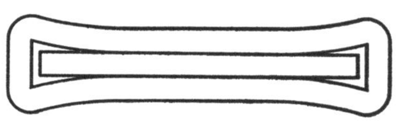

Fig. 2

upon a practicable substitute if any, for the platinum used in these lamps. Trial lots of lamps were made up using various sizes of platinum and platinum substitutes at that time available. Exceedingly fine wires of copper and iron were tried, also copper wire covered with dehydrated borax was tried. As was expected, these showed slight leaks. No. 34 B & S gage copper wire was then prepared in a different way. Placed on an anvil, it was struck at right angles with the sharp edge of a hammer, thus flattening the wire locally to a section approximately 0.001 in. thick (0.025 mm.) and 0.030 in. wide (0.75 mm.). This wire was covered with dehydrated borax and the flattened portion placed within the glass. Tests showed that a seal made in this way was vacuum tight. An experimental machine was soon put together, using a cam-actuated hammer to flatten the wire, after which the wire was drawn by motor-driven rolls through a borax coating bath and then through a dehydrating oven. Repeated tests showed that wire thus made sealed with lead glass without leaks. Larger sizes of wire were tried. Fig. 1 shows a 40-watt, 110-volt incandescent lamp made with the flattened copper. With the use of larger sizes of wire it became more and more difficult to flatten the wire by a single hammer blow. It was found that several successive blows were necessary. If the copper was not flattened sufficiently, separation occurred between the copper and glass. This separation could be seen easily, since it gave rise to interference fringes between the surface of the copper and the inner surface of the glass which had separated from the copper. Consequently, when it was found that wire, flattened to 0.002 in. (0.050 mm.) thick, 1/8 in. wide (3 mm.) made a tight seal with glass, it was reasoned that copper foil having these same dimensions should also make a satisfactory seal. This was tried and found to be so. Sheet copper, 0.002 in. thick (0.050 mm.) and 1/8 in. wide (3 mm.) covered with borax, made a tight seal with lead glass. Ribbons of copper foil 0.002 in. thick (0.050 mm.) and ¼ in. wide (6 mm.) were covered with

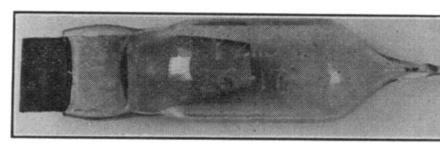

Fig. 3

borax and found to be tight. This thin ribbon, however, was mechanically weakened by oxidation outside of the seal. Consequently, ribbons were made from 0.004 in. (0.1 mm.) and 0.008 in. (0.2 mm.) sheet copper, ¼ in. wide (6 mm.), the ribbon being flattened locally at the sealing-in point, the increased thickness outside the seal making the ribbon mechanically stronger. All of these seals were covered with dehydrated borax.

The question arose as to the part played by the borax in the seal manufacture. Consequently, a seal was made with 0.002 in. (0.050 mm.) copper ribbon without borax. It was found that such a seal was tight, although the ribbon outside of the seal was exceedingly weak, due to oxidation. 0.004 in. ribbon (0.1 mm.), ¼ in. wide (6 mm.) apparently sealed in satisfactorily, though showing a slight leak under test. Ribbon 0.008 in. thick (0.2 mm.) by ¼ in. wide (6 mm.) when sealed in showed visible leaks along the edges of the ribbon, but not at the center. Fig. 2 shows a cross-section, not to scale, of such a seal. As previously explained, the leak is shown by interference rings produced in the small space between the glass and metal which are separated. We found that by tapering off the two edges of the strip by filing to a knife edge, tight seals could be obtained between glass and 0.008 in. (0.2 mm.) copper ribbon, that is, the cross-section of the ribbon instead of being a rectangle, was made a parallelogram having two rather acute angles. Tight seals, using larger and larger sizes of copper were rapidly made in succession, until a ribbon 0.015 in. thick (0.38 mm.) and 1 in. wide (25.4 mm.) was sealed through glass without the use of borax, and without leaking. As before, the edges of the ribbon were filed to a knife edge. Such a seal is shown in Fig. 3 and a cross-section in Fig. 4.

The results of these preliminary experiments were so much at variance with belief and previous experience as to be open to considerable doubt as to the reliability of methods of test. Vacuum tight seals were, however, produced by different operators using material from different sources. As a result of these experiments and tests, a complete chemical and mathematical investigation was inaugurated as well as further experimental work either to prove or disprove the results of the initial experiments which have just been recorded.

In order that the explanation of the action of this seal, known as the ribbon seal, may be clear, the various steps in the manufacture will be explained somewhat in detail. A piece of 0.015 in. (0.37 mm.) sheet

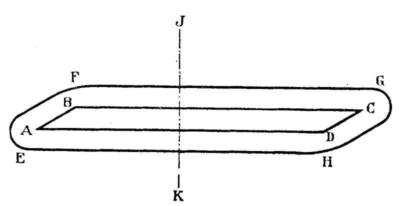

FIG. 4

copper is cut approximately 1 in. wide (25.4 mm.) by 4 in. long (10.1 cm.). The edges of the sheet copper for a length of approximately 1 in. (25.4 mm.) at the center are filed away so that the angle at the edge is approximately 8 deg. or 10 deg. A glass tube is provided, into the end of which it is desired to seal the ribbon. The end is flattened to provide an opening approximately 1 1/8 in. (28 mm.) by 1/8 in. (3 mm.). The sheet copper is then heated in the glass working fires for several seconds to a good red heat. It is then so placed within the end of the glass tube that the glass will come in contact with that section provided with the sharpened edges. The glass is pressed in contact with the ribbon and melted in place at as high a temperature as can be maintained without injury to the glass or the copper. It is then annealed and finally allowed to cool off. It will readily be seen that this operation is the exact parallel to that employed in sealing in platinum or platinum substitute wires.

In previous attempts to seal base metals through glass, in practically every instance round or nearly round wires were used, that is, wires were used in which the perimeter of the cross-section was the minimum possible for the area of cross-section. In the case of the copper ribbon seal, with a ribbon width of 1 in. (25.4 mm.) and thickness of 0.015 in. (0.37 mm.), the perimeter of the cross-section is very great compared to the perimeter of a circle of equal cross-section. In other words, for a given cross-section of metal, the ribbon affords a great deal more surface of contact between metal and glass than if a cylindrical conductor were used. Due to this great surface of contact, the stresses produced between metal and glass due to the difference in coefficients of expansion never become large enough to fracture either the joint between metal and glass or the glass itself.

In Fig. 4, *A, B, C, D,* is the cross-section of the copper ribbon, not to scale, and *E, F, G, H* is the enclosing glass. We find that the copper ribbon is actually stretched in the direction *A C*. The cubical contraction of the copper is practically the same as that of an unrestrained piece. Consequently, copper contracts in thickness in the direction of the line *J K* by that amount required by the cubical contraction of the copper. A few approximate figures may in this connection be interesting.

Assuming 525 deg. cent. as that temperature at which the glass commences to stretch the copper, room temperature of 25 deg. cent. coefficient of expansion for copper of 17×10^{-6} per deg. cent., and coefficient of 9.1×10^{-6} for glass, then the strain in a 1 in. length of copper will be approximately $(17.2 - 9.1) \times 10^{-6} \times 500 = 0.00405$ in. (0.1 mm.) Tests on soft copper show that this elongation corresponds approximately to a stress of 8700 pounds per square inch (612 kilograms per sq. cm.). The thickness of ribbon in the direction *J K* of Fig. 4, being approximately 0.015 in. (0.37 mm.), the force necessary to stretch a 1 in. length of the seal will be approximately 131 lb. (59.4 kg.). This stress may be assumed to be carried as shear between the glass and the copper along planes *A B* and *C D*. *A B* and *C D* are both approximately 5/32 in. (4 mm.) so that the shearing stress per square inch necessary to stretch the copper the required amount is approximately 840 pounds per square inch (59.1 kg. per sq. cm.). These figures are approximate only, since they neglect complications caused by the fact that the copper is in tension in three directions, in the directions *A C* and *J K*, and also in a direction at right angles to the cross-section of the figure. However, the figures indicate the order of magnitude of the stresses involved.

The stretching of the copper has been directly measured on a somewhat different type of seal, the disk seal, which will be described later. There can be no doubt that the glass is sucked in by the copper in the direction *J K*. Two parallel spots were lapped on the glass surrounding such a seal and the distance, *J K*, on Fig. 3, carefully measured with a micrometer. The copper was then dissolved in nitric acid, leaving only the surrounding glass shell. Subsequent measurements showed that the glass had sprung outwardly a measurable amount.

Glass may be regarded as a more or less viscous liquid. It has no definite melting point such as simple materials have. Upon heating it becomes more and more fluid until at the temperature at which it is applied to copper, it has the consistency of rather thin molasses. Glass at this temperature wets the copper, just as at room temperature, water will wet glass. Apparently as the hot glass and copper cool off, the adhesion of the glass to the copper is stronger than the cohesion within the glass, since in every case of a seal properly made, fracture will occur, not between the glass and copper, but in the glass itself, a thin film of glass being left adhering to the copper. Consequently the shearing strength of the joint between the glass and copper may be taken as equal to the shearing strength of the glass itself. Now the adhesion of the glass to the copper is entirely independent of the thickness of the copper or the thickness of the glass. The stresses, however, which the joint may be called upon to resist, are directly dependent upon the thickness of the glass or the copper or both. It is not possible to seal a heavy block of copper to a heavy block of glass since the stresses which the joint will be called upon to resist will be greater than the strength of the glass near the joint. However, it is entirely possible to seal a very thin section of either substance directly to the other; for example, a circular microscope cover glass may be melted to and will adhere to a large block of copper and a disk of sheet copper of approximately the same dimensions may be melted to a large block of glass. In both of these cases the stress which the joint between glass and copper is called upon to resist is less than the strength of the joint. Consequently, again referring to Fig. 4, we are led to the conclusion, which is amply sustained by experiment, that no matter what the metal, the angle $B\ A\ D$ may always be made sufficiently acute so that the stress between the metal and glass is always less than the shearing strength of the joint; that is, it is entirely possible to seal any metal through glass, provided that the glass wets the metal when hot and further provided that the metal does not melt at the temperature necessary for it to be wetted by the glass. Seals have been made between lead glass and base metals, such as, iron, brass, and silver. Copper is peculiarly satisfactory for this service, since soft copper passes its elastic limit at a comparatively low stress per square inch. Consequently, for a given width of ribbon, thicker copper may be used than if other metals are used. This is fortunate, because copper has good electrical and heat conductivity.

Referring again to Fig. 4, attempts have been made to determine the most desirable cross-section of the copper ribbon. The various methods of considering the stresses indicate approximately the same most desirable cross-section. It has been previously stated that the copper ribbon is stretched in the direction $A\ C$. This occasions a compressional stress in the glass $A\ F\ C$ and under compression this glass may be assumed a column, or, again, it has been stated that the glass $F\ C$ is drawn towards the glass $E\ D$ in the direction $J\ K$, by contraction of the copper ribbon in thickness. The glass $A\ F\ C$ then may be considered as a beam rigidly supported at both ends and deflected downwards under the load applied by the copper. In this case the deflection of the beam at each point throughout its length would be proportional to the thickness of the copper ribbon at that point. Under such conditions bending stresses will occur in the glass beam opposite points A and B at which points there is a change in rate of deflection. Preliminary consideration thus indicates the desirability of avoiding all corners on the cross-section of the ribbon.

Mr. T. C. Fry has made a very complete mathematical analysis of the stresses and strains occurring in a ribbon seal, in order to determine the best section of the copper, the "best section" being that having the maximum cross-section for a given width of ribbon. The curve indicated by Mr. Fry for cross-section of ribbon lies between the cosine curve of the glass considered as a column in compression and the curve of deflection of a beam rigidly fixed at both ends such that maximum fiber stress is nowhere exceeded. Thus in Fig. 4, the surface $A\ B$ should be curved and be approached by surface $A\ D$ tangentially, and surface $A\ B\ C$ should be a smooth curve without any sudden change in direction. The calculations, however, cannot be made with as great precision as might be desirable because of unknown factors in the calculation. We do not know the exact temperature at which solidification of the glass may be said to commence on cooling, nor do we know the elastic constants of glass and metals under various conditions of temperature and stress. Practically, if a ribbon seal fails, the angle at the edge is made sharper and a new seal made, rather than attempting to calculate the exact dimensions.

In the introductory paragraphs an advantage for platinum was claimed in that it did not oxidize and thus permitted closer contact between glass and metal. In the description of the seal manufacture it was stated that the copper ribbon was heated red hot before covering with glass. This heating of the copper ribbon of course oxidizes it and this oxide is not removed before being brought into contact with the glass. These two statements are at variance. As a matter of fact, perfectly good seals result when the copper has been oxidized as stated. If care is used to work in a reducing atmosphere and to use glass which does not reduce, as lead glass will, it is quite possible to make entirely satisfactory seals between glass and clean copper. Apparently, a reasonably thin coating of oxide does no harm, whatever, to the seal. When hot, this oxide is black, but as the seal cools off, the cupric oxide changes to cuprous oxide and it is this latter oxide which gives rise to the crimson color of the seal.

Fig. 5 shows a microphotograph of a section of the seal between copper and glass. The copper may be recognized from its etched surface. The black line immediately next to the copper is a thin layer of cuprous oxide approximately 0.0003 in. in thickness (0.007 mm.) Immediately next to the thin layer of oxide will be seen a section of glass. This photograph is given to show the exceedingly close adhesion of the glass to the copper.

So far as we can find from consideration of the various factors entering the copper-lead glass seal, chemical reactions play a small and unimportant part. While certain reactions do occur, these are relatively slow and minute in comparison with the physical phenomena which make the seal possible.

Several interesting features of the ribbon seal are evident upon consideration. The copper ribbon with-

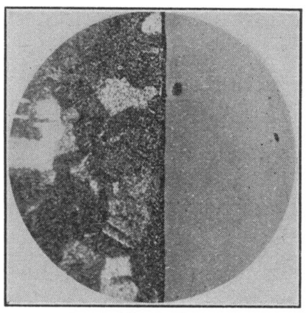

Fig. 5

in the glass, it will be remembered, is in tension in every direction. Heating the copper will thus initially reduce stresses because the copper will be expanded in the direction of the tension forces acting upon it. In other words, such a seal will not fail with sudden passage of current through the ribbon, because such heating as may occur in the ribbon actually lessens the stresses in the glass. A ribbon seal made from 0.008 in. sheet copper (0.4 mm.) and 7/16 in. wide (11 mm.) will continuously carry 40 amperes. It will, however, easily carry several hundred amperes for a short time. In fact it will carry enough current to make the ribbon visibly hot outside the seal. Again, various electrodes for

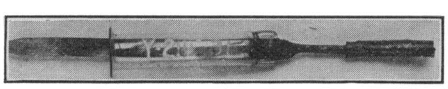

Fig. 6

use in vacuum apparatus may be formed from that portion of the ribbon within the enclosing chamber. Such an application may be seen in Fig. 6, showing the anode for a mercury rectifier tube made in one piece with the iron ribbon which passes through the glass member of the stem. Further applications may be easily imagined.

In the discussion of the ribbon seal it was assumed that the copper in Fig. 4 was stretched in the direction *A C* by the clamping effect of the glass upon the surfaces *A B* and *C D*. If this is the case, then it should be possible to construct a seal in which the glass comes only in contact with the copper ribbon at the edges of the ribbon and not along the center, that is, a seal such as that shown in Fig. 7 should be possible of construction. Next consider that Fig. 7 is a cross-section, not of a ribbon, but of a circular disk, taken at right angles to the plane of the disk along the diameter of the disk. Since, according to our assumption, glass does not touch the copper near the center of the disk, it

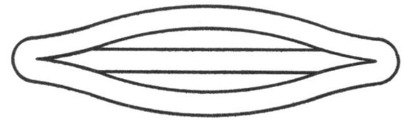

Fig. 7

makes no difference what form the glass assumes where it is not in contact with the copper; that is, it should be possible to seal a circular diaphragm into a glass tube in the manner shown in Fig. 8. It will be remembered that in the discussion of the ribbon seal, the edges of the ribbon were sharpened in order to prevent

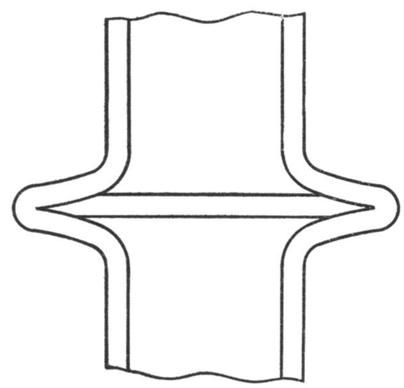

Fig. 8

separation of the ribbon and glass. If the disk has square edges, then whatever separation occurs between glass and copper will do no damage provided separation does not extend to the inside of the tube. Further, since the separation in this case is not objectionable, we might just as well leave off the glass from the edge

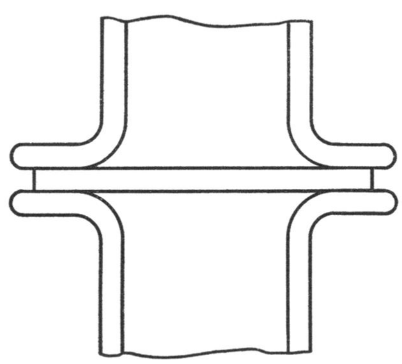

Fig. 9

of the disk and apply glass only to the two faces. This is shown in Fig. 9. This then results in two pieces of glass tubing, one end of each being flared and the two flares melted to opposite faces of a single copper disk. As a matter of fact, such a seal is entirely possible. The final step in the development of the disk seal is shown in Fig. 10. A round copper wire is passed through a centrally located hole in the disk and is soldered to the disk. Tubing on one face of the disk is almost entirely removed, leaving only a torus of glass in contact with one face. Fig. 11 shows such a disk seal. This type of seal has certain advantages over the ribbon seal. First, the electrical conductor is round and thus of a shape easily obtainable commercially. It is more rigid than a corresponding section of copper ribbon. The disk can easily be punched out on a punch press and requires no filing or machining.

In this seal the stresses are more simple than in the ribbon seal. The copper disk is stretched radially in all directions upon cooling. The glass is subjected to compression only without bending stresses such as occur in the ribbon seal. The disk contracts in thickness by an amount sufficient to compensate for the restricted radial contraction.

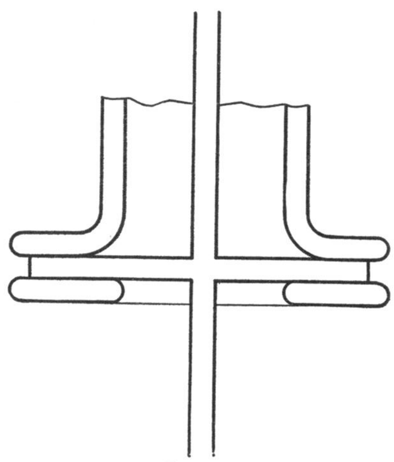

FIG. 10

Care must be taken to prevent glass on one side from running over the edge and making contact with glass on the opposite side of the disk, for if it should make contact, the seal will be broken, because the glass around the edge will not contract as far as the copper disk contracts in thickness.

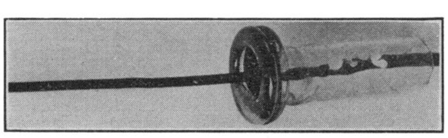

FIG. 11

As in the ribbon seal, so also in this disk seal, the copper is under tension, though in two dimensions instead of in three. In consequence, when the disk is heated by passage of current through the central conductor, the copper when first expanded reduces the tension stresses so that the corresponding stress in the glass is actually lessened and passes through zero before any possible destructive stresses are applied to the glass by the copper. For example, a certain disk seal, made with a disk 1 3/16 in. diameter (3 cm.) and No. 6 B & S gage copper wire, (0.162 in. diameter — 4.1 mm.) normally carries a current of 90 amperes. Such a seal will carry any current which the copper wire is capable of conducting short of fusing the copper wire. Such a seal will carry 1200 amperes suddenly applied, though a current of 700 amperes will fuse the wire in air if applied for several minutes. As a matter of fact, the disk seal will remain tight even with the copper conductor operating at red heat. Thus this type of seal has the very desirable feature of withstanding heavy overload. It, of course, has the further desirable feature that it has the full conductivity of the given size of copper wire, there being no intermediate portion having a higher resistance.

There seems to be no reason why disk seals of any desired conductivity cannot be made if it is found necessary to make them. 3/8 in. diameter (10 mm.) of copper conductor, is as large as we have so far found it necessary to try out. For exceedingly heavy currents, still another type of seal is available, which will be referred to a little later.

The thickness of the disk is determined by the subsequent use to which the seal is to be put. For example, it is quite possible to seal a disk 1 in. in diameter (25.4 mm.) and 3/32 in. in thickness (2.5 mm.) between two flared glass tubes. However, such a seal once cooled to room temperature will not withstand subsequent heating and cooling. The explanation seems to be that even though the copper is thoroughly annealed when red hot with application of glass yet the subsequent stretching of the copper as it cools off, hardens the copper to an appreciable degree, thus raising the elastic limit and thus increasing the stress which the copper passes through the joint to the glass. Thus in proportioning a seal which is to withstand a great number of repeated cycles of heating and cooling, it is necessary to decrease the thickness of the disk until the maximum stress which the copper can pass to the glass is less than the ultimate strength of the glass. In the case of the 1 in. diameter (25.4 mm.) disk, a convenient thickness is 0.020 in. (0.5 mm.) or 0.030 in. (0.75 mm.).

Glass may be sealed to opposite faces of a copper cent and if carefully annealed, the cent may be made a great circle of a glass sphere.

Theoretical calculations of the relation between thickness and diameter of a disk indicate dimensions of the same order of magnitude as those found by experiment, although here again, as in the case of the ribbon seal, the elastic constants of the glass and copper are not definitely known, nor is the temperature at which the glass may be assumed to solidify a definite quantity.

There are thus, three methods by which copper may be sealed through glass for use as electrical conductors; first, the borax-coated, flattened copper wire; second, the ribbon seal, and third, the disk seal.

The function of the borax in the case of the flattened wire seems to be to provide material next to the copper, which by its low melting point decreases the temperature difference over which the copper is stretched upon cooling. For example, on a certain flattened seal wire with borax the thickness of the flat was 0.0015 in. (0.037 mm.) and without borax it was found necessary to decrease the thickness to 0.0009 in. (0.023 mm.). It is necessary only on the smaller seals where the copper should be as strong mechanically as possible. For ribbon seals and disk seals, borax is not used, the dimensions of the copper being sufficiently large to withstand ordinary handling.

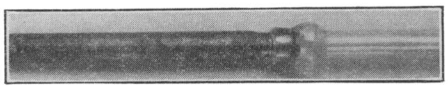

FIG. 12

With the success attending the development of the ribbon and disk seals, further experiments were made to determine the possibility of joining metal tubing to glass tubing. For example, a ½ in. diameter (13 mm.) copper tube was spun outwardly in a flange at one end and the resulting flange was sealed to glass tube in a manner similar to that employed in making disk seals. The over-all diameter of such a seal, however, is of course considerably larger than the diameter of the copper tube. Consequently the experiment shown in

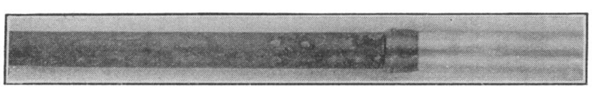

FIG. 13

Fig. 12 was tried and found to be practicable. In this case a copper tube is machined at one end to provide a thin wall of copper. Glass is melted to the outside and joined to a glass tube of suitable size. Here, again, the copper is under tension as the seal cools, yet the adhesion of the glass to the copper is sufficient to stretch the copper as it cools. Further experiments showed that if the glass accidentally ran across the end of the tube, the seal failed at that point because the glass in this case impeded the contraction in thickness of the

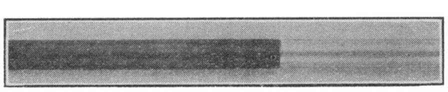

FIG. 14

copper tube. To avoid this difficulty, the expedient used on the ribbon seal was adopted and the edge of the copper tube machined to a knife edge. Then should any glass pass over the edge, failure of the seal would not occur.

Fig. 13 shows a seal of this type in which the copper tube has been reduced to a knife edge at the open end. Here the glass is applied outside of the copper and in this form is known as an external seal. Fig. 14 shows glass tubing applied to the inside of the same sort of copper tubing. This is known as an internal seal. It has been found that there is a difference in the behavior of internal and external seals made with the same dimensions of the copper tube. An internal seal will resist sudden heating much better than an external seal, while an external seal will resist sudden cooling much better than an internal seal. So far, there seems to be no limit to the size of copper tubing which can be joined to glass tubing.

Fig. 15 shows a seal between a 3½ in. diameter (9 cm.) copper tube and a 5 in. (12.8 cm.) diameter glass tube. In this seal the copper tubing is materially reduced in thickness over that portion which comes in contact with the glass.

As in the case of the other forms of seal, the tube seal

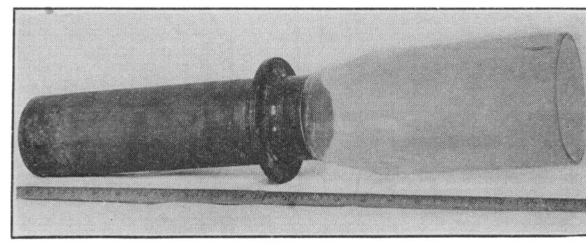

FIG. 15

is not restricted to either copper or lead glass. Fig. 16 shows a seal made between lead glass having a coefficient of expansion of 9×10^{-6}, Pyrex glass with a coefficient of expansion of 3×10^{-6}, and copper with a coefficient of expansion of 17×10^{-6}. In this case a copper tube is sealed to a Pyrex glass tube at one end and to a lead glass tube at the opposite end.

If it should ever be necessary to seal exceedingly heavy copper conductors through glass, such, for example, as a copper shaft 2 in. or 3 in. in diameter, the easy way to accomplish this would be to select a copper tube slightly flared at one end, which would slide easily over the copper shaft. To the flared end of the copper tube

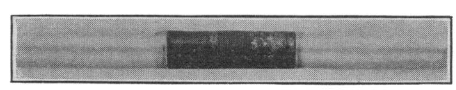

FIG. 16

the glass could be sealed and then after the seal was made, the copper tube could be brazed or welded to the copper shaft.

In conclusion, there does not seem to be any limit to the size of the seals which can be made between metal and glass, so long as the parts are properly proportioned. The practical limit is reached in the laboratory, due to the weight of the parts to be handled and the necessity for keeping the parts in the proper relative relation. This, however, is purely a matter of design of mechanical means for so supporting the weights that they may be moved into proper relative positions.

It has thus been shown that where the parts are properly proportioned the difference in coefficients of expansion of the metal and the glass may be made of no effect upon the strength of the resulting seals.

Discussion

THE QUALITY OF INCANDESCENT LAMPS

(Howell and Schroeder) and

THE ART OF SEALING BASE METALS THROUGH GLASS

(Houskeeper), Swampscott, Mass., June 29, 1923

C. F. Scott: About fifteen years ago the tungsten lamp was evolving quite rapidly. Mr. Houskeeper and I were associated in those days in the Westinghouse Lamp factory, trying to help along the progress of the lamp.

A common method of making the tungsten lamp then before the days of the present long wire was the mixing of fine powdered tungsten with carbon and some kind of glue and then squirting it through a diamond die and taking that soft thread catching it on a piece of paper which was moved back and forth, and then cutting the pieces into almost hairpin shaped filaments. These were then packed in boxes and placed in a carbonizing furnace. They went through a cycle of several hours of carbonizing to burn out the mucilage and leave a compact combination of carbon and tungsten particles.

These hairpins were then placed in some neutral gas, a mixture made of hydrogen and nitrogen, and the current was passed through the filaments, which burned out the carbon and sifted together the little tungsten particles forming a little tungsten hairpin, not very rigid, and a half dozen of these hairpins, more or less were assembled together in a lamp, each of these hairpins as an individual, individually measured, and so on.

Mr. Houskeeper devised a method by which that process which usually took several days, passing through many hands, was reduced to a process of five minutes in which the squirted filament passing down through a few feet of tubing was carbonized by high temperature. Then a current passed through the filament and it came forth this continuous so-called wire of tungsten, which might be a thousand feet long with a uniformity which was otherwise, previously impossible. That led to a wire formed lamp, one filament wound continuously as they are wound now. I think Mr. Houskeeper's name would have been widely known in connection with that process which would have been a very important thing if the rate of progress had been less rapid. The wired lamp of the General Electric came at about the same time and was commercially developed at the same time that this was being developed, so that this stage of the tungsten filament lamp was shortlived on account of the progress.

Another important problem in this old incandescent lamp field has been the problem of getting the current from the outside to the inside of the enclosed lamp or bulb. It seems to me that many of the research processes which Houskeeper used in that earlier work have characterized this next development. There is no phenomenally new discovery. He takes the metals, the common metals, not platinum or some other particular thing, but the common metals and any kind of glass apparently, and by a little physical study of the way of combining, and the form, and the strength, and coefficient of expansion, he forms a new combination which is remarkable. The ability to take the things that we are familiar with, and get some new and almost startling outcome is to me as remarkable or possibly more remarkable than discoveries in new fields.

H. Lemp: In 1885 while connected with the Schuyler Electric Light Company of Hartford, Conn. Mr. Merle J. Wightman and myself were engaged in developing what we called the "Series Incandescent Lamp" for arc light circuits. The plan used before the advent of the series incandescent lamp was to use a number of the regular 100-volt lamps in multiple to absorb the current used in connection with arcs, and we then conceived the idea that it would be much better if a lamp could be made with a filament large enough to take the whole ten amperes of a commercial arc light circuit and be connected in series with arc lamps, instead of in groups of lamps in multiple requiring complicated compensating devices.

As all the early incandescent lamps were limited to something like a one-ampere current, to go from one ampere to ten amperes at that time required some research work as to the manner of passing these relatively big currents through the glass sealing, and if one cares to look at past records one will find an early patent to Mr. Wightman and myself for the use of a platinum ribbon in place of the platinum wire, then commercially used for leading in conductors for incandescent lamps.

We thought that if we could make the conductor in such a form that its surface of contact with the glass would be very large in proportion to its thickness, any heat developed would be more easily absorbed by the glass without cracking and the relative expansion by heat of the metal and glass would be less, and so we started out to make these platinum ribbons to conduct the current through the seal for these series incandescent lamps. Many hundreds of these lamps were commercially exploited.

When we found that we were successful in that attempt we grew bolder. We said "Now, if the platinum in the sheet form will carry those heavier currents and not crack the glass seal, why not take some other metals, iron and copper," and then we tried thin copper ribbons and sealed them in the manner shown by Mr. Houskeeper this morning, without however thinning the edge, and we were very much astonished to see that the seals did not crack; they seemed all right, but after a while the air leaked in and destroyed the vacuum.

Mr. Houskeeper has told me this morning why we failed and I want to pay my tribute to him for this lesson.

I think that the method of sealing he has shown us today is a great step ahead in the art, particularly as it will enable us to manufacture larger electron tubes for the purpose of rectifying alternating currents of magnitude.

C. H. Sharp: With reference to the paper of Messrs. Howell and Schroeder I wish to call attention to one statement which I think should be added, and that is that 500-hour test criteria apply to, I believe, the Lamp Works and not necessarily to other lamp testing organizations which may use a different basic life value for determining the efficiency at which lamps are to be operated on life test.

Mr. Howell has been connected with the manufacture of incandescent lamps longer than almost any other man in the world. He has a familiarity with the history of lamp manufacture, with the romantic history of that art which few, if any, other men possess. It would be very desirable if we could have a record of Mr. Howell's knowledge and recollection of the circumstances of the evolution of the lamp; of the troubles, of the successes which the incandescent lamp manufacturers have experienced in the course of all the years of the development of this art.

A. L. Atherton: The very important work that Mr. Houskeeper has described opens up many possibilities. In thinking over the possibilities, a question comes up which I would like to ask. Some applications for this type of seal will doubtless require materials other than copper on account of chemical limitations. In trying to bond other metals to glass there has been some experience with what seems like an electrolytic action by which gas bubbles are evolved at the contacts. This is particularly true with metals like nickel which have other advantages over copper. I would like to ask Mr. Houskeeper if this sort of thing has been encountered in the work which he has referred to with metals other than copper, and if some preventive methods have been devised.

W. G. Houskeeper: In answer to the last question as to the sealing of other metals than copper into glass, if I understood the question correctly it was a question of the evolution of gas bubbles between the metal and the glass. That can be very satisfactorily taken care of by giving the metal a heating in vacuum before the glass is applied. If sheet nickel, for example, be maintained at approximately 800 deg. cent. for ten or twenty minutes in vacuum you can apply the glass to the surface any time in several weeks without bubbles between the glass and the nickel.