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NOTE ON A NEW METHOD OF JOINING GLASS.*

BY

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Introduction.—The need for flat glass windows for incandescent lamp bulbs led the writer to seek a new method for accomplishing the fusion of glass joints without appreciable deformation of the surfaces. Such lamps were desirable for studying the effects of diffraction caused by the lamp filament in an optical pyrometer of the so-called disappearing filament, or Morse, type, because the diffraction effect was obscured by the imperfect surfaces of lamp bulbs of blown glass. Lamps have been constructed by the new method, as shown in Fig. 3, C having two flat windows, the transmission of which can be easily measured and which give an undistorted telescopic image of the filament.

Parker and Dalladay [1] have developed a precision method of uniting optical glass which depends upon optical contact and pressure, the glass being raised to a temperature well below its annealing range. Their method is particularly suitable for the construction of flat-sided cells in case most precise flatness is required. Its disadvantages lie in the necessity of obtaining perfect fit of the parts to be joined, by careful polishing and cleansing, and the time required (about one hour) for junction to be completed. Its application is restricted to glasses having annealing points which differ by not more than about 50°. The method devised by the writer fails only for glasses which have too widely different coefficients of thermal expansion.

Method.—Briefly the process consists in maintaining the glass at a temperature sufficiently high to avoid cracking while applying heat locally, the temperature of the main body of the glass being one at which undue distortion will not occur. The body temperature necessary is always near the annealing temperature and this depends, of course, primarily upon the kind of glass, but is also dependent to some extent upon the dimensions of the

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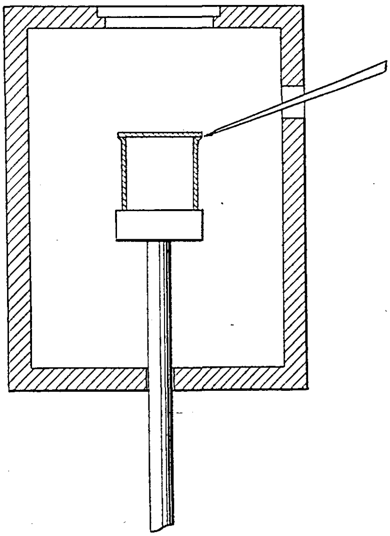
[1] Parker and Dalladay: *Faraday Soc. Trans.*, 12, pp. 305–312. For short bibliography on thermal and other properties of glass see Tool and Valasek, *B. S. Sci. Papers,* No. 358, 1920.

article. By this method complete fusion of the junction can be accomplished without propagating beyond a restricted portion near the joint the stresses occasioned by local heating; hence it is applicable where a slight deformation at the junction does not impair the usefulness of the article.

For the purpose of maintaining the body of the glass at the proper temperature during local fusion of a joint an electric furnace was constructed, as shown in Fig. 1, having a mica

FIG. 1.



Cross section of furnace and glass tube and disc supported within on a pedestal.

window [2] above and a small hole in the side for introduction of a blowpipe. It is provided with a centrally located pedestal, which extends through a closely fitting hole in the bottom, upon which glass objects can be placed and rotated about a vertical axis. A sodium flame backed by an incandescent lamp is used for illuminating the interior—the sodium flame furnishing monochromatic illumination for interference fringes between polished surfaces nearly in contact and the white light furnishing the general illumination of the object. For measuring the furnace temperature a small platinum-rhodium thermocouple is inserted through

[2] Pyrex glass or fused quartz would be better because mica soon splits and becomes more opaque with continued heating.

the furnace cover and arranged so as to place its hot junction in contact either with the furnace wall or with the glass being treated. A blowpipe having a millimeter orifice is used with an oxy-gas flame about 1 cm long.

The furnace can be quickly heated to a required temperature and held there, so that a small glass article can be raised to temperatures above the annealing temperature, the junction completed by application of the flame, and cooling initiated, before the glass has sufficient time to appreciably change its shape.

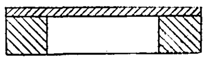
Because the writer's primary interest lay in construction of incandescent lamps, as stated above, the first experiments were performed on short tubes ground and polished on one end and topped by a flat disc as shown in Fig. 1. The tube with the disc was placed on the pedestal, the temperature was rapidly raised to slightly above the annealing temperature, the flame inserted into the furnace so that it touched the edges of the disc and tube as the pedestal slowly rotated. The completion of the joint was thus accomplished in but a few seconds after inserting the blowpipe.

The first trial was satisfactory for the primary purpose in mind, the disc showing no distortion beyond two mm from the inner edge of the joint. The very slight application of the flame required in case the end of the tube was polished, indicated that fine grinding of the tube would be sufficient; also that flaring of the ends was unnecessary. After some practice quite satisfactory joints were obtained, using unflared tubes with the ends finished by grinding with wash emery. While the first experiments were tried having the disc of exactly the same glass as the tube, ordinary American plate was found quite satisfactory to use with common lead glass tubing. The annealing temperature of the plate glass used was approximately 565° C. and that of the tubing 460° C.[3] The coefficients of thermal expansion in the low range were respectively, 0.101×10^{-4} and 0.09×10^{-4}. There is quite an advantage in using glass for the disc which has a higher annealing temperature than that of the tube. Since the glass was thin, sudden application of heat to the disc at a temperature as low as 470° did not crack it and the unavoidable strains were not serious. They were probably greater than the allowable strains in a polarimeter tube, but were so slight that the incandescent lamps made could easily be heated over a bare flame during their exhaustion.

[3] Peters and Cragoe: *Jour. Opt. Soc. of Amer.*, 4, 3, pp. 105–145, 1920.

Discussion of the Principles Involved.—The combined effect of low thermal conductivity of glass and the rapid change in its mobility with temperature was the single important factor leading to the development of the simple process described. As a result of low thermal conductivity *large temperature gradients may be imposed with only slight flow of heat.* When glass is heated to its annealing temperature its mobility begins to increase at a rapid rate, *experiments showing the mobility to be approximately an exponential function of the temperature.* For example, some glasses become twice as soft for every rise in temperature of 8° or 10° C.[4] These two properties permit the attainment of such a temperature gradient that the variation in mobility in a very small distance is exceedingly great. If the relation of mobility to temperature persists over wide ranges of temperature, a gradient of 100° per mm. corresponds to a change of mobility per mm of over 1000 times. Thus a piece of glass at the anneal-

FIG. 2.



Cross section of glass ring and flat cover.

ing temperature may be suddenly heated superficially without distorting more than a small part of it. The glass being heated to its annealing temperature, or slightly above it, the application of the flame to an edge quickly raises the edge far above the temperature called by Tool[5] "upper limit of the annealing range." At this latter temperature the glass has become very nearly a true viscous substance, that is, minute stresses result in flow. It is due to this fact that union is so quickly started by the flame. The local distortion occurring under the flame does not extend far and, since the body of the glass is within its annealing range stresses cannot be propagated in any appreciable amount beyond the region overheated. In some cases it was possible by watching interference fringes during the process of joining, to observe very nicely the effect of sudden expansion of the part touched by the flame, the quick union occurring, the very rapid loss of heat by radiation, and the fairly rapid return to the original configura-

[4] See ref. 1.

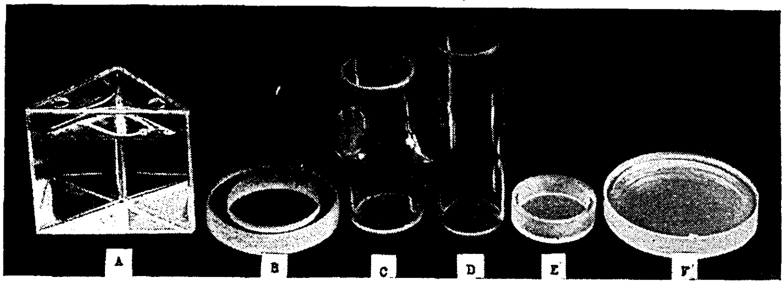
[5] Tool and Valasek: *B. S. Sci. Papers,* No. 358, 1920.

tion. Probably expansion forces the surfaces into contact before fusion and the force may be fairly large. Molecular forces are brought into play as soon as contact occurs. The surfaces become quite clean at the temperatures used because of the oxidation of organic matter (as dust) and the expulsion of occluded gases.

The change in the temperature coefficient of thermal expansion observed by Peters and Cragoe,[6] to take place at the annealing temperature, may play a part, and probably the best joints can be made above the annealing temperature; that is, above the temperature at which this coefficient changes from the value which persists from room temperature to the annealing temperature.

At the annealing temperature the flow of small glass articles

FIG. 3.



A. Hollow 45° prism; B. glass cell; C. optical pyrometer lamp; D. tube closed at both ends; E. glass cell with thin rim; F. compound lens fused at periphery. Line of fusion is visible as dark band.

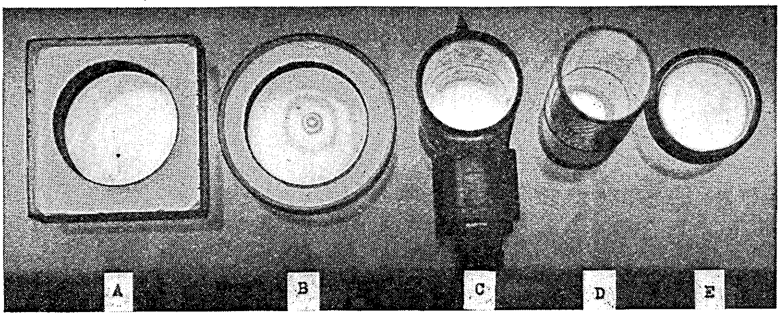
due to their own weight when unevenly supported, is exceedingly slow and the quickness with which a joint can be made by this method allows very little distortion to occur. Hence, in nearly all cases it will be best to use the annealing temperature, in which event, after completing the joint the temperature can be allowed to fall slowly without any complications for the purpose of annealing.

Applications of the Process.—A few articles of various forms have been made to determine the applicability of the process. Some of these are shown in Figs. 3 and 4. The method can also be employed for constructing absorption cells, colorimeter tubes, glass boxes, polarimeter tubes, Nessler tubes, glass-liquid prisms, lenses, etc., hæmacytometers, and even interferometer parts. In

[6] See ref. 3.

Fig. 4 the articles have been placed on a glass plane and illuminated with a mercury lamp. The hollow 45° prism shown in Fig. 3 was not flat enough to photograph as in Fig. 4. The millimeter plate glass used had not been well annealed and merely heating to the annealing temperature distorted it. A compound lens was made by fusing the periphery with the inclusion of an air film. The joint is about 2 mm wide and the air film about 0.2 mm thick at the centre. The convex part was selected with a surface of greater radius than that of the concave. The two glasses[7] used were (1) borosilicate crown, annealing temperature

FIG. 4.



Articles placed on a glass plane and illuminated with a mercury lamp. A, B, E, glass cells. C. Optical pyrometer lamp. The end down is seen to be flat to about 1 micron.; D. simple tube. The end is seen to be flat to fraction of a wave-length within 1 mm. of edge.

530°, coefficient of expansion (below 500°) 0.090×10^{-4}, and (2) medium flint, annealing temperature 450°, coefficient of expansion 0.097×10^{-4}. The lens is about 5 cms in diameter. Possibly such a lens is of little usefulness, but so far as distortion is concerned the result was satisfactory. If such a thing were of any utility, lenses could be made by carrying the weld through only a portion of the periphery, leaving an opening for the injection of Canada balsam. It may be found that glass-liquid lenses will be useful. A seeming disadvantage is the higher temperature coefficient of refraction of liquids. This would probably limit the use of such a lens to special laboratory problems. Such a lens could be easily made by welding the parts on to the two ends of a short tube, as shown in Fig. 5.

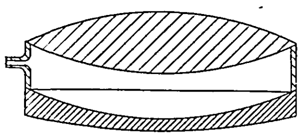
Various details of the method of making hæmacytometers

[7] See ref. 5.

have been tried but will not be described. The writer is now constructing some total reflecting glass rhombs having fused-on protecting plates for the reflecting surfaces. These are for use in a colorimeter in which the rhombs are immersed in the liquid whose transmission is being studied. A preliminary experiment has shown that the plates can be fused on very easily without distortion of more than approximately a millimetre of the surfaces at the edges of the joints.

The ordinary absorption cell with cemented sides has usually been made with a very thick rim for the purpose of cementing. This method does not require such heavy construction and for most ordinary purposes cells can be made with thin-walled tubing. Further experiments showed, however, that the thick rim was of considerable advantage in making cells with quite flat sides. It was found that a joint started by the flame at the outer edge

FIG. 5.



Cross section of suggested form of a glass-liquid lens.

in such case extended to the inner edge well beyond the parts heated above the annealing range. It became apparent that molecular attraction was brought into play, pulling the surfaces together when once molecular contact was started. In one case shown in cross section in Fig. 2, a flat disc about 5 cm in diameter and 8 mm thick, flat on one side, was bored out, affording a ring with a bearing surface 1 cm in width. The piece had not been properly annealed and cutting the hole resulted in a distortion which raised the inner edge of the ring so that a flat disc placed upon it touched only the inner edge and allowed an air film at the outer edge. Examination before the sodium flame exhibited six interference fringes. The result of joining a cover to this ring was quite unexpected. Quick fusion around the outer edge caused complete joining as far as the inner edge, pulling the periphery of the cover into contact and forcing the centre out about 10 microns. At first thought, such an effect might be assigned to fusion of the periphery and subsequent contraction.

But such action would undoubtedly have resulted in a distortion of the cover in the opposite direction. Furthermore, the amount of distortion of the cover corresponded to the original condition of the ring. In this way it is emphasized that this new method of joining glass does not require a perfect fit of the articles to be joined and that the final result is measured quantitatively by the lack of fit. Thus, in the construction of various articles the fitting may be perfected to a degree governed by the precision desired. It is particularly to be noted that examination of the piece illustrated by Fig. 2, by placing a flat test plate upon it to obtain interference fringes, gave fringes which crossed the inner edge of the joint without any displacement. There remains little doubt that had the ring been quite flat the cover would have remained undistorted. There has not been opportunity to prove this, but the action described seems fairly conclusive. We may add that only for precise work, in which case fusion by the flame is kept at a minimum, is it necessary to exercise special precautions as to particles of dust caught between surfaces. A particle of dust lodged near the outer rim is no hindrance and is entrapped, becoming invisible. A particle near the inner edge obviously prevents complete junction.

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