The Balsam Problem



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## The Balsam Problem.


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THERE is a remarkable absence of any reference in nineteenth century optical literature to the very important subject of the cementing together of optical parts. Probably the reason is that until recently the problem hardly existed. Complex instruments involving intricate prism combinations capable of satisfying stringent light and endurance tests are a comparatively modern development.

Such prolific optical writers as Sir John F. W. Herschel and Sir David Brewster remain practically silent on the subject. Fish glue as a cementing material has received in the past more consideration than Canada balsam. It is only in the case of Nicol prisms that the use of the latter is seriously discussed. Even then, however, the feature of interest is not the cementing properties of the balsam, but the fact that its refractive index lies between those of Iceland spar for the ordinary and minimum extraordinary rays.

Although Canada balsam is still the best all round medium at present known for the joining of optical parts, it is far from satisfactory. Its inherent disadvantages are well known to all practical opticians engaged in the production of complex instruments. Improved methods of cementing or a better medium are much desired. Possibly there are individual investigators or workers who have special information concerning this most important subject. If they can be induced by discussion of the difficulties to add to the general knowledge of the problem, the purpose of this paper will have been served.

The components of an optical system may be assembled in several ways.

I. The parts may be held mechanically with an air space between their contiguous faces.

The disadvantages of this method are as follows :—

(*a*) There is a serious loss of light at each transmission face. From theoretical considerations, discussed in his article on "Chromatics" in the Encyclopedia Britannica, Dr. Thomas Young calculated that in the case of normal rays incident at a refracting interface, the expression

$$\left(\frac{n-1}{n+1}\right)^2$$

represents the proportion of the original light reflected backwards and consequently lost. At a later date Fresnel, then quite a young engineer, independently deduced the general expression of which Young's is a special case. Assuming the refractive index $n$ of the glass to be 1·5, the loss at each transmission will be 4 per cent. of the incident light at each particular transmission. If the number of surfaces is $s$, the proportion of the light leaving the system will be

$$\left[\frac{4n}{(n+1)^2}\right]^s$$

If, as before, $n=1{\cdot}5$, then the light transmitted,

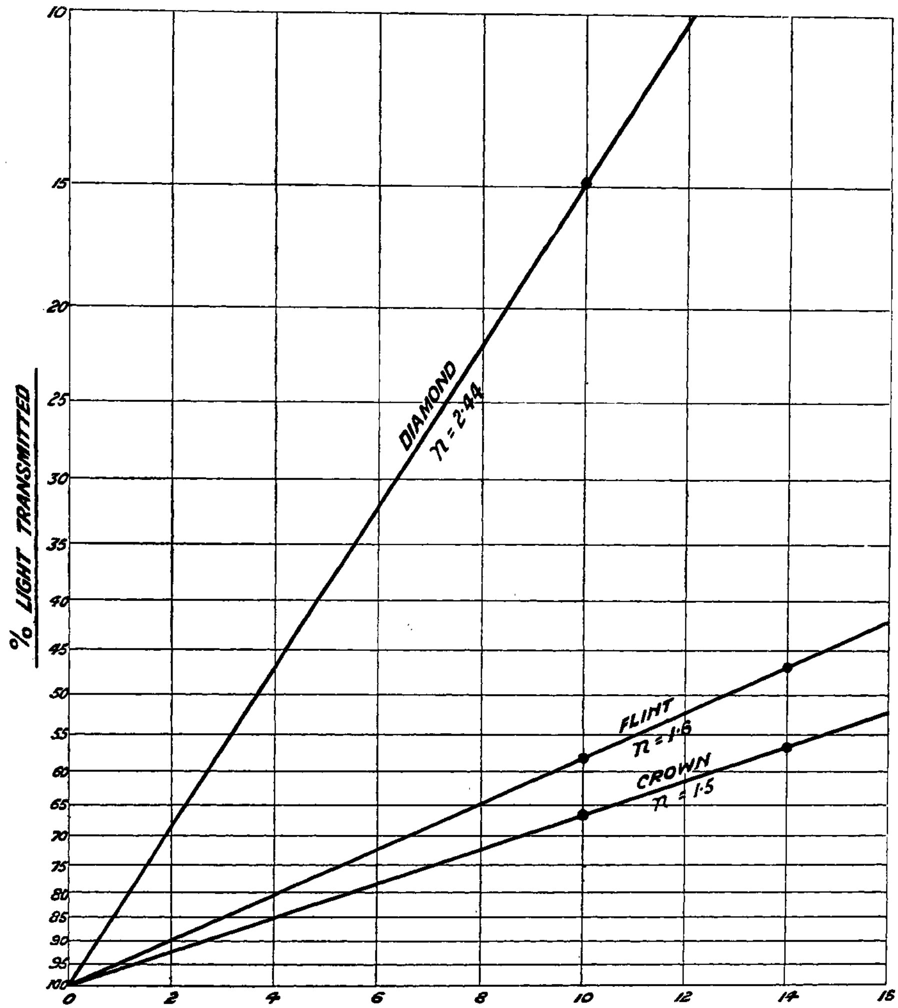
$$\left[\frac{4n}{(n+1)^2}\right]^s = \left[\frac{24}{25}\right]^s$$

In a standard prismatic monocular there are fourteen transmission surfaces, neglecting the graticule or light filter. If all are unbalsamed, the light transmitted will be not more than 56·5 per cent., neglecting questions of absorption. If the objective and eye lens are cemented, the number of surfaces will be reduced to ten. The light transmitted, neglecting absorption, will then be about 66·5 per cent.; that is, a saving of 10 per cent. of the initial light resulting from the cementing of four of the fourteen surfaces, and an increased brightness of over 17 per cent.

If the exit pupil is of maximum size, the illumination cannot be improved by increasing the objective diameter. Greater light can then only be obtained by reducing the absorption if that is possible; by reducing the number of transmission faces, or by reducing the refractive index.

Fig. 1 is a diagram which shows how the light lost by normal reflection varies with the number of surfaces and with the value of $n$. Ordinates denote the percentage of the initial light transmitted by the system, neglecting absorption, and abscissæ the number of transmitting surfaces. The ordinates are plotted on a logarithmic scale in order to obtain straight line curves.

Considering the monocular with ten transmitting surfaces: If crown glass of refractive index $n = 1{\cdot}5$ were used, the light transmitted would be 66·5 per cent. If flint glass of refractive index $n = 1{\cdot}6$ were used,




Number of Transmission Surfaces.

Fig. 1.

the light transmitted would be 58 per cent. If diamond were used, only 14·7 per cent. of the initial light would be transmitted. Through fourteen surfaces diamond would transmit only 6·8 per cent. To make optical instruments of this material is not advisable.

It is not easy to understand why light flint should be used for binocular prisms. Hovestadt states that the absorption of flint is less than that of crown. If so, the difference is in practice negligible. In any case the statement is indefinite, as so much depends on glass manufacturing conditions.

The loss by absorption is roughly about 5 per cent. per inch of length. For 2 ins. of glass the loss is about equal to that resulting from two normal flint surface reflections.

(*b*) The reflected light by subsequent reflection may ultimately emerge from the system. Usually the secondary images will not coincide with the main image. If their intensity were appreciable, the definition would be affected, but in general they will be so weak as to be invisible. But in the case of deeply curved uncemented surfaces, total reflection of oblique rays at glass-air interfaces may occur, giving rise ultimately to flare spots.

(*c*) There is danger of fogging. If the air space is small, say 1/100″, moisture arising from dampness may condense in globular form on the confined surfaces. It is not easy to promote air circulation in so confined a space, and the removal of the moisture by desiccation is accordingly difficult.

(*d*) Astigmatism of the images may result. If the air space is traversed obliquely by a convergent beam, as is quite frequently the case in prism combinations, there may be very considerable errors of astigmatism, the amount of which can easily be computed for any particular case. An error of a fraction of a degree in the parallelism of the surfaces may largely increase the error. Defective definition in prism combinations may often be traced to these sources.

(*e*) There may be distortion of the surfaces. If the air space is very small, portions of the intermediate space may become filled with water sucked in from the periphery. The surface tension forces brought into play may be such as to affect the definition appreciably by actual distortion of the glass.

(*f*) A higher degree of perfection is necessary in uncemented surfaces than in cemented, but in practice this is of minor importance, as the production in one shop of two qualities of surfaces is hardly advisable or even practicable.

II. The parts may be placed in optical contact.

If the surfaces are optically true to one another and if they are thoroughly clean, they may be placed in direct optical contact by simple pressure. It is not necessary to perform the operation in a vacuum. So far as adhesion is concerned, the method is generally quite satisfactory. Sooner or later, however, separation of such surfaces is sure to take place. It may be due to the entrance of moisture at the periphery or to forces arising from differential expansion. When the combination is heated, the parts usually separate, especially when they are of different materials, such as flint and crown, as in the case of an object glass.

Recently I had occasion to examine a large prism combination from a captured German instrument. The prisms of the combination were held together by simple optical contact. To prevent the entrance of moisture, the chamfered edges were sealed with Canada balsam. Although this arrangement is by no means novel, it is not frequently adopted. This specimen was interesting as indicating that at least one large German firm preferred such a method to the ordinary use of Canada balsam.

Similar specimens tested in comparison with balsamed specimens proved to be of inferior resistance when subjected to temperature and shock tests.

III. The pieces may be actually joined together by the Parker and Halliday method.

The parts of the combination are held in optical contact and are heated until they become one. There is good reason to believe that the polished surface layer of glass softens at a temperature of at least 100°C below the softening point of the unmodified glass. If, therefore, the parts are heated to a temperature considerably below the softening point of the body of the glass, the surface layers in optical contact may actually weld together. Such welding appears to take place since the surfaces thus joined together cannot be separated again.

In the case of many optical arrangements, this permanency of connection is a serious disadvantage, since once the parts are joined, it is impossible to readjust them, as is so often desirable. Further, the process necessitates the heating of the parts to quite a considerable temperature. Where definition is of importance, such extreme heating of finished optical work is often objectionable, especially when there is any doubt as to the homogeneity of the glass.

Whatever the respective merits of the above-mentioned methods may be, there is none of them that appears to be entirely free from objections of a serious kind. There remains to be considered the fourth and by far the commonest method of cementing the parts together by means of Canada balsam, which forms the subject of this paper.

As is well known, the commonest troubles experienced in the case of cemented parts are due to starring of the balsam and possible separation of the parts in the course of time, or as the result of shock, and to distortion of the surfaces sufficient to cause defects of definition.

From an examination of early optical records, it would appear that the cementing of optical parts was introduced by Alexis Marie de Rochon, generally known as Abbot Rochon. He was born at Brest in 1741, and his life of seventy-six years is an astonishing record of pioneer work and discovery in many branches of science, including optics.

The following description is an extract I have translated from that portion of Montucla's "History of Mathematics," written by M. de la Lande, who is said to share with Dr. Bevis the honour of having originated that most indispensable word "achromatic." The translation is as follows :—

"Rochon thought objectives might be perfected by the interposition of fluid. If, for instance, in the case of a triple objective, there is a thousandth of error, that is, if there are differences of a thousandth of a line in the curvature from centre to edge of each surface, there may result an appreciable defect in the definition of the objective. (NOTE : A line is one-twelfth of an inch.)

"Further, when it is remembered that in giving the last polish, the heat of the hand alone is sufficient to expand the glass being operated upon even when it is very thin, it will be realised how difficult it is to avoid quite appreciable irregularities of surface in the case of large pieces of glass.

"These errors may possibly be avoidable. Rochon, however, sought to remedy them. From his Collected Papers of 1783, it will be seen that, by introducing a diaphanous fluid between the surfaces of an achromatic objective, he reduced very considerably the effects of imperfections of the four internal surfaces of the triple objective.

"These experiments were repeated and the results confirmed by a Committee comprising Borda, Le Gentil, and the brothers Cassini. 'We have taken,' they said, 'a telescope having an achromatic doublet objective of three feet focus and about three inches aperture. The two lenses of the objective were separated by an interval of about six lines (0·5 inch). Into the space we introduced a thin plate of Bohemian glass, not optically worked. As was expected, the telescope was then very bad. When directed towards certain hand-writing, the telescope had to be advanced to within five and three-quarter fathoms (34·5 feet) of the words before the characters could be read.

"'Having determined this, and without disturbing the telescope, pure water was poured between the objective lenses until the intervening spaces were completely filled. The hand-writing which before was undecipherable could now be distinguished perfectly.

"'By moving the hand-writing bit by bit away from the telescope, it was found that only when a distance of 31 fathoms (186 feet) was reached, did the writing become as indistinct as it previously was when the interval was $5\frac{3}{4}$ fathoms (34·5 feet).

"'Having tested water, we then used oil and found that the hand-writing had to be brought up to a distance of 41 fathoms (246 feet) before the writing could be deciphered.

" 'We were able to test in the same way the effects of various other simple and compound fluids, but circumstances and the sudden departure of Rochon on the business of the Ministry prevented us from carrying out all the experiments proposed.' "

(NOTE: As an illustration of the versatility of these early workers, it is interesting to observe that the business in question was the survey of a proposed canal.)

" Moreover, this work could best be done by Abbot Rochon himself, who would naturally give an account of it to the Academy. The Committee were charged with the verification of the principal claim advanced by Rochon, namely, that the interposition of a fluid corrects to a large extent the defects of the lens surfaces. These experiments provided incontestible proof. The results surpassed those which Rochon announced or dared to hope for.

" Following the discovery by Rochon of the advantage arising from the interposition of water between the glasses of an objective, Grateloup, in 1785, suggested the substitution of non-liquid substances for fluids that are subject to evaporation and are difficult to retain between the surfaces of the lenses. It was only a question of finding a substance that would preserve the transparence of the glass while filling exactly all the inequalities of the surfaces.

" Mastic in the natural form of tears, as used by jewellers to unite gems with a view to increasing their brilliance, appeared to Grateloup to be more suitable than any other substance. He communicated his ideas to Putois, an intelligent optician, and with his help carried out various experiments with the greatest success.

" Putois soon constructed several achromatic objectives which attained a new order of perfection. Over the interior surface of one of the lenses he melted a layer of tear mastic by the action of fire. Upon this he laid the other portion of the objective, which, on the cooling of the resin, became so united and cemented to the first portion that it could only be separated by heating in a stove or by plunging into boiling water.

" To demonstrate the advantage of this method, they took an objective in which the interior surfaces were partially polished and cemented only over a portion of it. The cemented portion became beautifully transparent, whereas the other portion transmitted but a few rays of light.

" Grateloup inferred that the polishing of the interior surfaces could be dispensed with if they were intended to be cemented. He even believed it might be advantageous not to polish them."

Cassini, in recounting this experiment, remarks that long experience alone will suffice to prove the truth of the statement.

"Rochon has proposed objectives comprising five lenses. He states that the difficulty of forming ten surfaces is reduced by cementing the eight internal and contiguous faces. It is then only necessary to form the two outer surfaces with the same degree of regularity as is requisite for long focus lenses.

"In fact, as Rochon states, the reflection and optical ghosts that are more or less troublesome in the use of ordinary achromatic objectives do not arise in the case of cemented objectives.

"The loss of light is also much less considerable. It is also necessary to reckon among the advantages of this method the possibility of using much thinner plates of flint glass because the flexibility which is always to be feared in the working of thin glasses does not cause the same errors when the two surfaces are coated with a layer of varnish and are united and cemented by this substance to thicker plates of glass. Opticians know that thin plates of flint glass are of superior quality to thicker ones.

"At first the telescopes made in this way surpassed all others and gave surprising results. All the Paris opticians cemented their glasses. But in the course of a few years these telescopes became so bad that they had to be rejected.

"Perhaps there may be found a substance which will not be decomposed by the heat and humidity to which telescope objectives are subjected. Possibly the cement may be renewed from time to time without deforming the glasses. 'It is to be hoped,' says De la Lande, 'that greater experience will overcome these difficulties.'"

More than one hundred and thirty years have passed since Rochon and Grateloup first cemented objectives, and yet the reasonable hope of De la Lande that greater experience would overcome the difficulties is unfulfilled. To-day we use the same material and the same method and face with complete complacence the same difficulties.

Mastic, which was the medium preferred by Grateloup, is a turpentine resin akin to the so-called Canada balsam of to-day. It is commonly stated that of the oleo resins, Canada balsam is chosen because its refractive index is the same as that of glass. It is true that its refractive index of 1·549 for red rays lies between those of ordinary flint and crown glasses, but actually, however, the refractive index is not of importance, unless possibly in the case of very oblique rays incident near the critical angle. Often the statement is made that Canada balsam is chosen because it has a higher refractive index than any other resin. This is not the case. Colophony is slightly lower; copal is the same as Canada balsam; but balsam of Tolu is very much higher, being about 1·628 for red rays.

For the cementing of Nicol prisms, Canada balsam was chosen because its refractive index lies between those of the ordinary and minimum extraordinary rays for Iceland spar. Copal, however, would have been equally effective, but possibly difficulty was experienced in those days in satisfactorily dissolving fossil copal, which must first be heated to a considerable temperature or be distilled.

The dispersive power of Canada balsam is nearer that of flint than crown glass, but its dispersive power is of no practical importance, considering that the layers involved are generally less than half a thousandth of an inch thick.

While referring to the uses of Canada balsam, which are not numerous, it may be of interest to observe that Sir David Brewster and others made microscope lenses from the same material. In the first instances, Sir David Brewster placed drops of balsam in minute holes pierced in thin metal plates. The drops thus formed powerful lenses. He also constructed microscopes comprising four or more plano-convex lenses consisting each of a drop of very pure and viscid turpentine varnish taken up by the point of a piece of wood and dropped upon a piece of very thin and polished glass. The lower surface of the plate was then smoked with a candle flame and the black pigment immediately below the lens removed to allow the light to pass only through the lens.

Canada balsam is an oleo-resinous exudation of the so-called Balsam Fir, *Abies-Balsamea*, and its allied species. In the lower Canadian districts, where the *Abies Canadensis* or Hemlock Spruce Fir, flourishes, it is gathered during the months of June and July. In August the cold is sufficient to prevent the balsam from exuding from the elongated tumour-like vescicles in the pine bark in which it accumulates. The balsam is collected in tin cans having sharp pointed spouts, which, when driven into the bases of the vesicles, serve to hold the cans in position as well as to direct the flow. A full grown tree yields about eight ounces of oleo-resin for the first two years. After resting for two or three years, the tapping may be continued, but the yield is less. During wet weather, the work of collecting is discontinued, as the rain makes the balsam turn milky. After the balsam is collected, it is strained to separate fragments of bark and dirt.

For optical purposes the balsam must be quite free from visible particles of foreign matter. In pre-war days it was good practice to store the balsam for at least a year, during which time foreign particles sank towards the bottom. More recently, owing to the stocks having become used up, it has been found necessary to hasten the process by thinning the balsam with benzol or turpentine and by straining to remove large particles of dirt and then to finish by settling. Thereafter the balsam is evaporated to the correct consistency. Natural settling over a long period seems, however, to give the most consistently reliable results.

Substances such as Canada balsam have very complex chemical compositions. According to Bonastre, who first investigated the subject, the chief ingredients are :—

Essential oils, about 18·6 per cent.
Resin soluble in alcohol, about 40 per cent.
Resin hardly soluble in alcohol, about 4 per cent.
Extractives and salts, about 4 per cent.

It has a bitter taste and a pleasant aromatic odour.

Strictly speaking, a balsam should contain benzoic or cinnamic acids. Canada balsam contains neither. It is really a turpentine.

So far as the optician is concerned, it is unlikely that the name " Canada balsam " will ever be changed, even though its main source may no longer be Canada.

If Canada balsam is dissolved in alcohol, a white resinous powder remains. Alcohol is therefore an unsuitable thinning medium. It is completely soluble in turpentine, benzol, ether, chloroform, and other solvents. For practical purposes the best thinning media are turpentine and benzol, which give equally good results. The resinous portion insoluble in alcohol has very poor cementing qualities. It starts very readily.

It should be noted that other cementing substances such as copal and colophony give very different results when thinned with different solvents.

There is no need to describe here in detail the various methods of balsaming which are already well known. Speaking generally, the balsam may be applied in a liquid form at a moderate temperature and be baked for a considerable period, or it may be applied in a more solid or stick or tear form at a considerably higher temperature and be baked for a shorter period.

During the baking process, the beadings of exuded balsam that accumulate around the edges should be removed at intervals, as otherwise the procses of drying, such as it is, will be retarded. Care should be taken to leave a small final beading, as otherwise the balsam may start at the edges. That the bad conductivity of the glass has a considerable retarding effect on the baking of the balsam can easily be demonstrated by subjecting cemented metal and cemented glass plates to the same baking treatment.

It will be observed that the beading of baked balsam acquires a deep orange red colour, and in preparing stick balsam considerable trouble may be experienced owing to serious discolouration. This difficulty may be quite overcome by evaporating the balsam in a vacuum. The resultant stick balsam, when thus treated, retains its original pale yellow colour.

One of the commonest objections to the use of the usual cementing materials is the ease with which starting or starring occurs.

Fig. 2 is a typical start (magnification 27 diameters) commencing at the edge, and Fig. 3 (magnification 11 diameters) is one commencing from the centre of an object glass. In both cases the rounded edges are indicative of a viscous state. Accepting for the moment the viscous condition of the balsam, starting may be due to an increase of volume of the interspace or to contraction of the cement in a fixed space.

For example, the start, Fig. 2, was the result of a light blow sufficient to spring the parts asunder locally, thus admitting air in this particular instance. As the start continued to grow for some time, the parts were evidently constrained by the balsam. No doubt it is generally well

Fig. 2.—Magnification 27 diameters.

Fig. 3.—Magnification 11 diameters.

known that if two optically perfect surfaces are cemented together and then separated, the surfaces will be found to be permanently distorted, due no doubt to the irregular contraction of the cement, which must introduce very considerable forces.

In the case of the second specimen, Fig. 3, the concave curve was deeper than the convex; the parts accordingly bore round the edge as is customary, and the balsam thickness increased from the rim to the centre where the space was unduly great. As the balsam contracted, owing to evaporation of the volatile oils outwards through the periphery, the tension at the centre increased until the start was formed. Possibly it may have commenced at the two curved sleeks near the centre.

Given the required conditions of a suitable viscous medium contracting in a fixed space, any minor accident may commence the starring of the layer. It may be due to distortion arising from a blow or the action of heat or to a point of weakness in the balsam itself, as, for example, an air or vapour bell.

It might be argued, in the case of parallel surfaces, that, as the balsam contracted, the parts would come together and the contraction could not be resisted. But balsam in thin layers exposed to the air quickly hardens. Around the edges in the interspace there is accordingly formed a hard ring which keeps the parts asunder. This ring soon attains a width of about one millimetre, but a very considerable time may be required for the formation of a width of 4 mm.

There is no great difficulty in demonstrating that balsam does contract as it hardens, although the amount of contraction is astonishingly small.

Various media, such as balsam, colophony, copal, gums, fish glue, indiarubber, and guttapercha, were dissolved in suitable solvents, the same solvent being employed as generally as possible and the same consistency being aimed at throughout. Zapon (that is, celluloid dissolved in amyl acetate and acetone) contracted many hundredfold. When used as a cementing medium it proved to be quite unsuitable, owing to extensive starring. At the opposite small contraction end of the scale there are two substances, Canada balsam and colophony, that are outstanding. Both are remarkably good in this respect, and colophony (that is, resin) is slightly better than Canada balsam.

By means of a simple contraction test of the kind described, the unsuitability of many substances may at once be demonstrated. It is also possible to select the best solvent for a particular substance, as contraction sometimes varies with the solvent.

For the investigation of the hardening of Canada balsam, numerous specimens of cemented optical parts of various ages were opened out. Some of the parts had been cemented for ten years, and of these old specimens there was good reason to believe that a few had been cemented with stick, that is hard, balsam, the others having been cemented with dissolved balsam. At the moment of opening there was perceived in all cases a strong aromatic odour. In the recently balsamed specimens the strong odour lasted for half-an-hour or more, whereas in the five to ten year old specimens the odour disappeared in a minute or so, or even in a few seconds. The duration of the odour may thus afford a rough indication of the age of a specimen. Several flat surface specimens of various ages were separated and over the surface there was drawn a needle point under a constant load. The width of the furrow thus produced was then measured under the microscope. There appeared to be an outer hard ring of from one to four millimetres width. Thereafter, in the case of even the oldest specimen cemented with dissolved balsam, the substance was definitely soft. Not only so, but, contrary to expectation, there was no very appreciable difference in hardness from the centre to the outer rim. Evidently the hardened rim acts as a seal that greatly retards evaporation of the solvent. It is probable, however, that some of the essences may evaporate more quickly, thus accounting for the loss of odour.

Natural drying of balsam layers after the hard outer ring has been formed is evidently an extremely slow process and quite negligible in practice.

When a balsamed objective is bound up very tightly in its holder, the definition is generally impaired. If for the balsam there is substituted a liquid such as oil, glycerine, or water, the result is the same. If, however, the parts are separated by air, the same treatment will not affect the definition. This evidently suggests that the balsam layer is viscous.

Old specimens that originally were cemented with melted, as distinguished from dissolved, balsam, proved to be of special interest. On opening such specimens the strong aromatic odour disappeared in a few minutes. The hardened continuous layer of about one-tenth millimetre thickness was as brittle as glass. It was observed, however, that isolated pieces had no adhesion to the surface of the glass, over which they could be glided with ease. Closer microscopic investigation showed that there was an extremely thin and continuous layer of oil between the hardened plate and the glass surfaces. This is illustrated in Fig. 4.

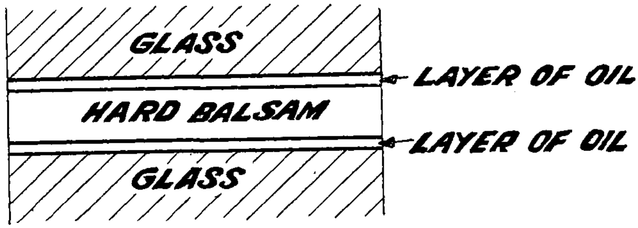



Fig. 4.

Thus, in all the specimens examined, the action was that of a liquid, the parts being held together by atmospheric pressure and by the cohesive forces of a very thin layer of an oily or viscous substance. The actual adhesion of the hardened balsam to the glass was comparatively small.

The hardening process may be accelerated by continued baking, which keeps the balsam soft and increases the vapour tension, thus facilitating the evaporation. In general, such specially prepared specimens confirmed the observations made with the specimens of various ages.

Fig. 5 is an unbaked specimen (magnification 27 diameters). The surface tension forces evidently exceeded the adhesion to the glass and consequently the balsam gathered into strings.

Fig. 6 is another unbaked specimen, of somewhat less viscous balsam. In this case the surface tension greatly exceeds the cohesion, with the result that the balsam has separated into cords and then further subdivided into globules. The regularity of portions of this specimen was such that quite a good surface spectrum was obtained from it.

Fig. 7 is a specimen (magnification 27 diameters) baked for 11 hours, and Fig. 8 is one (magnification 27 diameters) baked for 40 hours. Many beautiful and characteristic figures are obtainable in this way.

Fig. 5.—Magnification 27 diameters.

Fig. 6.—Magnification 27 diameters.

When stiffer balsam is used and the baking is continued far enough, the specimens present new features. The harder layer becomes more continuous and there are evidences of the less viscous surface layers.

Thus Figs. 9 and 10 (magnification 45 diameters) are specimens baked for 40 hours. The hard layer has been lifted away by the upper glass, but the fluid layer has been left on the lower portion, and, under the action of surface tension, has contracted into strings and globules in the curious manner indicated. It is evident that the actual adhesion to the glass is very poor.

The clear spaces are glass quite free from balsam.

Fig. 11 (magnification 27 diameters) is a similar specimen showing portions of the hardened balsam layer and of the softer surface material cords. Special note should be taken of the characteristic right-angled

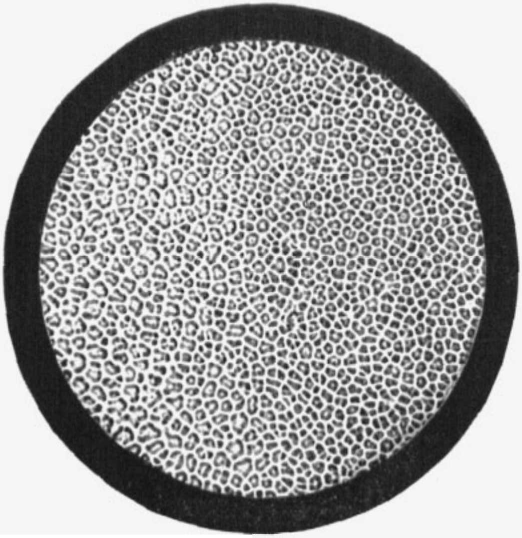


Fig. 7.—Magnification 27 diameters.

Fig. 8.—Magnification 27 diameters.

fracture of the hard layer which is sometimes seen in gelatine films. (*See illustration, page* 158.)

Fig. 12 (magnification 27 diameters) is a specimen showing how the surface layer on the hard layer has been drawn up into cords, which appear as white streaks. (*See illustration, page* 158.)

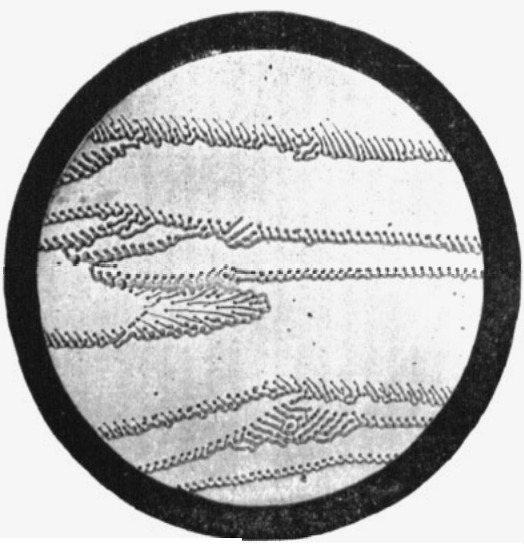


Fig. 9.—Magnification 45 diameters.

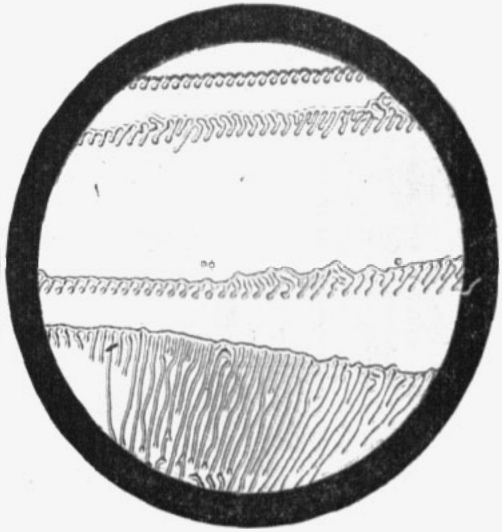


Fig. 10.—Magnification 45 diameters.

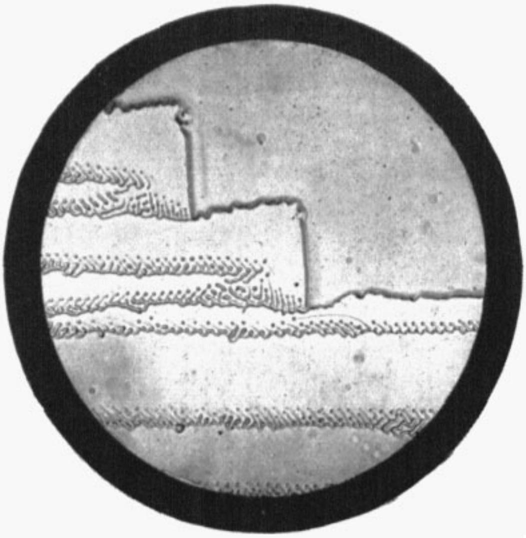


Fig. 11.—Magnification 27 diameters.

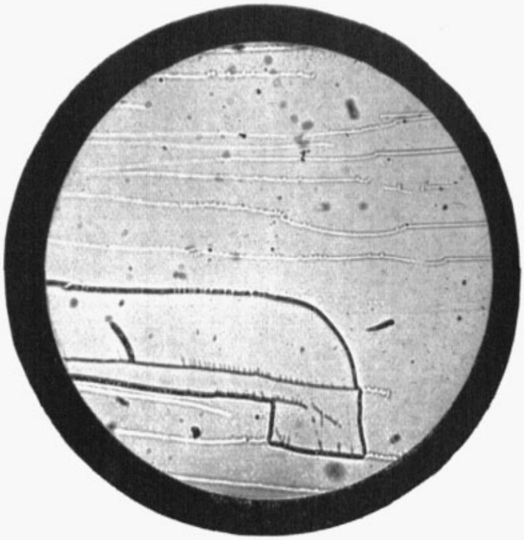


Fig. 12.—Magnification 27 diameters.

Fig. 13 (magnification 27 diameters) is a specimen baked for 120 hours. There are still evidences of the soft surface layer.

Certain specimens exhibited a granulated appearance which at first was difficult to explain. One of these specimens is illustrated by Fig. 14 (magnification 27 diameters). The balsam was baked for 11 hours.

Fig. 13.—Magnification 27 diameters.

Fig. 14.—Magnification 27 diameters.

From a subsequent specimen, Fig. 15 (magnified 45 diameters) of harder balsam baked for 40 hours, a clue to the phenomenon was obtained. It was found that the markings were limited to the portion of the layer represented in the photo-micrograph. There were no markings on the adjoining removed portion. Therefore the appearance was due to some accidental external cause. It was soon found that moisture such as the breath, or even moist vapour from the hand was sufficient to produce the effect illustrated. Under the microscope, the action of a minute drop of water on a separated balsam layer is very curious. The globule appeared to burrow right into the thickness of the layer and to become enclosed within a tough skin which later assumed a crinkled appearance.

Fig. 15.—Magnification 45 diameters.

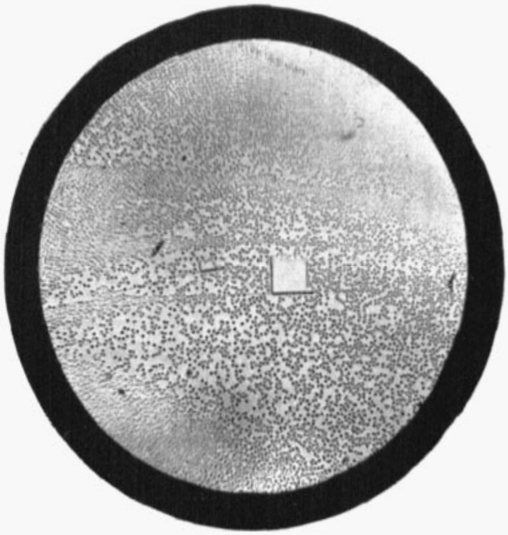


Fig. 16.—Magnification 27 diameters.

As the balsam hardened and the water evaporated, a permanent pit remained. Certain specimens showed the whole transition from the isolated globules to the granulated appearance.

To some extent this transition is indicated in Fig. 16 (magnification 27 diameters), which is of special interest on account of the square portion that has been removed. This right angle fracture is curious and difficult to explain, except perhaps as the result of crystallisation. But on no occasion have I been able to find any evidence of crystallisation in Canada balsam. It is true that certain resins crystallise and that adulterated balsam may be so affected. Personally I do not think there is any practical evidence of either granulation or crystallisation in good Canada balsam.

I must reserve for some future occasion the results of tests of Canada balsam and other materials under various conditions, which I had intended to deal with.

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## DISCUSSION.

Dr. CLAY suggested that a method of drying balsamed lenses analagous to that employed in the wood-work industries for seasoning timber might be found of use. In recent years timber has been artificially dried by stacking it with suitable fillets in a room which was heated by a mixture of steam and hot air. The proportion of steam was gradually reduced until finally the atmosphere was entirely dry. In this way the formation of an outer dried surface layer before the moisture of the underlying parts had had time to escape was prevented. In a similar way, if balsamed lenses were placed in a vessel filled with a mixture of turpentine and air at a high temperature, and the proportion of turpentine vapour were gradually reduced, the escape of the turpentine from the central part of the lenses might be effected before the outer layers became hard. He referred to experiments illustrating the very forces which were brought into play by the adhesive power of liquids, which fully accounted for the difficulty in cementing large surfaces of glass, which had different coefficients of expansion. Strains would always be caused by these expansions if the cementing layer was a solid. If, however, it were a very viscous fluid any strain set up would slowly relieve itself. The ideal cementing medium would thus appear to be a viscous liquid, of which pitch was an example. Unfortunately pitch was not transparent. It would appear from Mr. French's experiments that dry Canada balsam was a solid. As regards the preparation of balsam, he suggested that dust and other solid impurities might better be removed by a centrifugal than a gravity method. It might be bleached by exposure to sunlight in quartz tubes.

Mr. J. RHEINBERG said he had hoped to hear something as to the relative merits of cementing with hard and soft balsam, since opinions differed widely as to which was preferable. No doubt it depended largely on the nature of the work.

Mr. W. GAMBLE described the method used in cementing discs of plate glass up to 40 inches diameter used for screens in process work. The discs were laid upon a steam-heated table, and when the two had been put together weights were superposed. The balsam, of a specially white grade, was used as hard as possible and was poured on from the pot in which it was heated. Gelatine had been proposed for cementing together colour filters but had proved unsuitable because of the difficulty of separating the plates again. Meta-gelatine would be better than gelatine. Samples of copal specially selected for their light colour had been used by the late Mr. C. D. Ahrens. This was advantageous for Nicol prisms owing to the difference in refractive index, that for balsam being 1·535 and that of copal 1·528.*

Mr. H. A. HUGHES stated that balsam cementing failed rapidly when subjected to a warm damp atmosphere—such atmospheres for example as those to which nautical instruments were often exposed in the Tropics.

Mr. T. SMITH referred to the frequency with which unnecessary glass air surfaces were found in instruments. A quotation in Mr. French's paper stating that thin flint lenses were to be preferred to rather thicker ones had surprised him—he understood that thicker plates were preferable on account of the greater ease in obtaining a true figure. Experience at the National Physical Laboratory suggested that much improvement in the permanence of cementing was to be desired.

Mr. P. F. EVERITT said that the presence of unnecessary glass air surfaces indicated bad designing. The preference for the thin flint lenses no longer applied, but formerly difficulties were experienced in obtaining satisfactory homogeneity with any but very thin pieces of this glass. He stated that Capaiva balsam, which remained soft at normal temperatures, was to be preferred to Canada balsam in cementing lenses over 2 or 2½ inches in diameter.

Mr. H. S. RYLAND stated that he had found it best to use hard balsam with the addition of 4 per cent. castor oil; after cementing, the edge of the lens should be varnished with shellac, thus avoiding the penetration of damp. He considered it desirable to insert a felt pad in the cell on which the lens should rest and thus avoid strain on the glass due to screwing up the metal ring too tightly. Faults in cementing were frequently due to improper cleaning of the glass—the material used for this purpose was of importance. Xylol was, he thought, to be preferred to turpentine. For removing impurities from balsam a centrifuge was used in America. Resins were sometimes mixed with balsam.

* [cf. the values, due to Sir David Brewster, quoted by the author on p. 150. Very little information regarding the refractive indices of Canada balsam, etc., is obtainable from reference tables. The following values are taken from the Smithsonian Tables, 1914, and Prof. Everett's "Units and Physical Constants," 1879.

| | | |
|---|---|---|
| Canada balsam | $\mu$ (red) 1·528 [Wollaston] | $\mu$ (yellow) 1·532 [Young] |
| Colophony | $\mu$ (red) 1·548 [Jamin] | $\mu$ (extreme red) 1·543 [Wollaston] |
| Copal | $\mu$ (red) 1·528 [Jamin] | |

The authority is given in square brackets. The refractive index for Canada balsam is given in Kohlrausch's "Praktische Physik," 1905, as 1·54. In no case is either the concentration or the source of supply indicated.—ED.]

His experiences of many mixtures was that all added substances with the exception of castor oil darkened the balsam. A common practice is to depend upon the balsam alone carrying the weight of prisms. This should be avoided.

Mr. H. R. FAIRBANKS considered cedar oil was preferable to castor oil for dilution. When a very fluid mixture was required benzol could be added to the balsam. An advantage of distinctly fluid mixtures was the greater ease of obtaining quickly a good contact over the whole surface free from air bubbles. Generally speaking the hardness of the balsam should be adjusted to the size of glass to be cemented; the required hardness was usually obtained by evaporation. It was important to secure uniform heating of the lenses to avoid distortion.

The PRESIDENT (Prof. Cheshire) described a visit he had paid to the late Mr. C. D. Ahrens, and the latter's indignation at the suggestion that any self-respecting optician would employ Canada balsam for cementing. No matter by whom they were made, all large Nicol prisms appeared to have gone ultimately to Ahrens before the cementing was satisfactory. Ahrens ascribed his success to the use of a solution of copal in turpentine which was applied to the prism at a distinctly high temperature. Subsequent experiments had shown, however, that the success attained should be attributed to the care with which the work was executed rather than to any special virtues of this material. After much difficulty he had induced Ahrens to describe the method of working to be adopted when he had a large prism to cement. The operation began after his family were safely in bed. He made up a large fire, placed his chair close in front of it, and there nursed the prism the whole night to keep it really warm.

A cheaper material than copal in turpentine with very similar properties was obtained by dissolving resin in the same liquid.

Canada balsam appeared to have been first used by the Chevaliers (father and son); they had been led to adopt it owing to the facility it afforded of securing very accurate centering. Several other materials are in use. Mr. Dennis Taylor prefers watch or clock oil. Reference might also be made to Mr. Martin Cole and his work in mounting microscope preparations. Such work he completed in a few minutes by warming the specimen after mounting and when the slide was cold removing all excess of cement by wiping with methylated spirits.

One of the most satisfactory processes was one employed by a German firm in cementing eye-piece lenses. The flint lens was placed on a rapidly rotating table and a drop of Canada balsam placed in the cavity; the crown lens was then placed on the top and centered while the whole was spinning. When this was satisfactorily adjusted, a plunger was pressed down on the whole lens and the superfluous balsam was expressed as a liquid sheet.

Mr. French's paper was a most interesting introduction to the subject and the experiments he had described were of great value. In thanking him for his contribution to the Society's Transactions, they would all be looking forward to the further paper he had promised.

In reply Mr. FRENCH writes:—

The statement that "Opticians know that thin plates of flint are of superior quality to thicker ones" was made by De la Lande. In those early days defects in homogeneity made it necessary to use thin pieces of flint.

As Mr. Hughes states, tropical conditions are a severe test of balsaming. Might I suggest that the rapid temperature variations at sunset and sunrise are likely to be the principal source of trouble.

In referring to the absence of crystallisation in Canada balsam, it should be understood that the statement applies to good quality balsam in very thin layers, under the conditions usual in cementing optical parts. There seems no doubt that the ingredients of balsam can be separately crystallised. In practice, however, trouble from crystallisation is unlikely to occur.

The method of cementing depends largely on the nature of the work, as Dr. Rheinberg has remarked. Unfortunately the conditions are conflicting to a great extent. The harder and thinner the layer of balsam, the less will it withstand shock, and the softer it is, the less will it resist small displacements of the parts. Thus, in optical instruments for the measurement of minute angles, the balsam should be hard baked. For most ordinary optical instruments, a softer balsam that will withstand shock is likely to prove most satisfactory.

Capaiva balsam, which remains soft at normal temperatures, or admixtures of oil, which also tend to keep the balsam soft, would be suitable for parts that have only to withstand mild shock. Nicol prisms are of this class. Comparatively speaking, the balsam may be quite soft and comparatively thick, say one thousandth of an inch. There is really no great difficulty in the actual cementing of Nicol prisms. The difficulty lies in avoiding fracture of the Iceland spar.

The late Mr. Ahrens, when he sat up all night, was no doubt guarding against sudden changes of temperature. His success, as Professor Cheshire suggests, was probably due to the personal attention he devoted to the work, rather than to the use of such a substance as copal in turpentine.

At one time I hoped to substitute white copal in turpentine for balsam. That was long before I heard of its use by Mr. Ahrens. But, as the result of further experience, I am now of the opinion that for hard cementing purposes it is not superior to resin or to Canada balsam.

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