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Examination of Glass

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THE EXAMINATION OF GLASS*

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The need for the examination of glass may occur in several types of offense. In cases of breaking it may be necessary to establish from which face a pane of glass was broken, and by what type of blow or instrument; in cases of the fracture of glass by projectiles it may be required to determine from which direction the bullet was fired, and whether it was one of high or low velocity. Such problems involve the examination of large, as opposed to small, pieces of glass, and their solution is based on a knowledge of the conditions determining fracture.

Other problems occur in which the essential work is the matching of fragments of glass with some comparison glass from which they may be derived. This may happen in cases of breakings in which entry has been obtained by breaking a window and fragments of glass have been found in the clothes or on the person of a suspect. Many examples of this type of problem occur in cases of motor accidents. Here, fragments of glass found at the scene of the accident or on the body of a victim may have to be compared with glass remaining in the windows, windscreen or lamps of a car suspected of having been involved in the accident. Such comparisons sometime involve examinations of the fracture, and piecing together of the fragments; but more often in such cases it is a matter of determining by means of physical and chemical examination whether the fragments in question could have come from a suspected source.

For these reasons it is convenient to discuss the examination of glass under the two headings of *fracture* and *comparison of properties.*

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* [EDITOR'S NOTE: Due to the excellence of this article, which appeared originally in a recent number of *The Police Journal* (of England) (Vol. 12, No. 3, 1939), we requested and obtained permission to reproduce it for the benefit of criminal investigators in this country. To the author, and to Mr. P. B. M. Allan, Editor of *The Police Journal,* we express our gratitude.

The drawings appearing in the article were modeled after those in the original publication. The photograph is one of our own which has been inserted in place of several of similar nature used by Dr. Tryborn.]

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Problems of Fracture

Simple Breaking

Matwejeff[1] has pointed out that the examination of the edges of a piece of broken glass shows that they usually bear certain markings by means of which it may be possible to deduce which face received the impact causing fracture.

A sheet of glass may be regarded as a slightly elastic medium of uniform composition. As a result of this slight elasticity the application of a force at a point on a sheet of glass will produce a slight bulging of the sheet, so that it becomes concave on the side on which the force acts, and convex on the other (Fig. 1-A). The curvature, and therefore the strain, of the glass will be greatest at the point *x*, opposite the point of impact of the force. When the limit of the elasticity of the glass is reached and the strain on the surface becomes greater than the tensile forces in the surface of the glass, fracture will occur. The release of the strain usually occurs in several directions at the same moment and causes a series of cracks radiating from the point of impact (Fig. 1-B). These cracks start from the point of impact and travel away from it, producing a star-shaped group of cracks; these are termed "radial" cracks. They open on the face away from the side of impact, *i.e.*, on the face where the strain was greatest. A sharp blow from a pointed instrument may produce fractures of this type alone, the length of the cracks depending on the force of the blow, the brittleness of the glass, the manner in which the edges of the sheet are held, and similar factors. Figure 1-C shows how these cracks open at the moment of formation.

If the instrument is blunt-ended, or tapers abruptly to a point, or if the blow is of the "follow through" type, the forward passage of the instrument will tend to bend the apices of the triangular areas *p*, *q*, *r*, etc., in the direction of the motion. This will cause new strains in the surface of the glass on the side of impact; when the limit of elasticity is exceeded a new series of cracks, shown by dotted lines in Figure 1-B will occur. These, as will be realized by reference to Figure 1-D, will open on the face of the glass which received the impact. Such cracks are called "concentric" ones. They are not always present in a fracture, but occasionally more than one set of them may be encountered. Radial cracks, however, are *invariably* present.

[1] Matwejeff, S. N., Archiv für Kriminologie *86*:100 (1930). Reprinted in Am. J. Police Sci. 2(2):148 (1931).

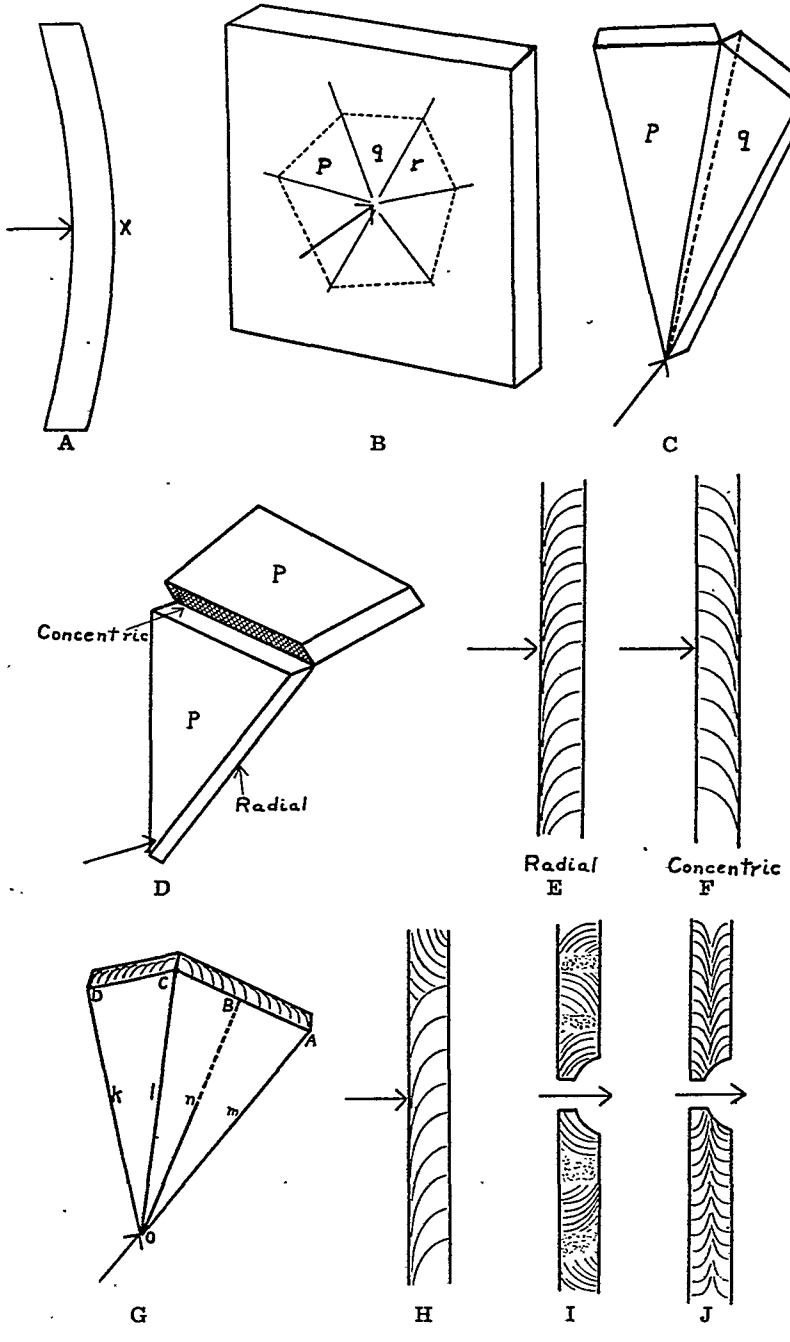
X
A
P
q
r
B
P
q
C
P
Concentric
P
Radial
D
Radial
E
Concentric
F
D
C
B
A
k
l
n
m
O
G
H
I
J

FIGURE 1

FIGURE 2
Photograph of Edge of Glass Showing Radial Fracture.

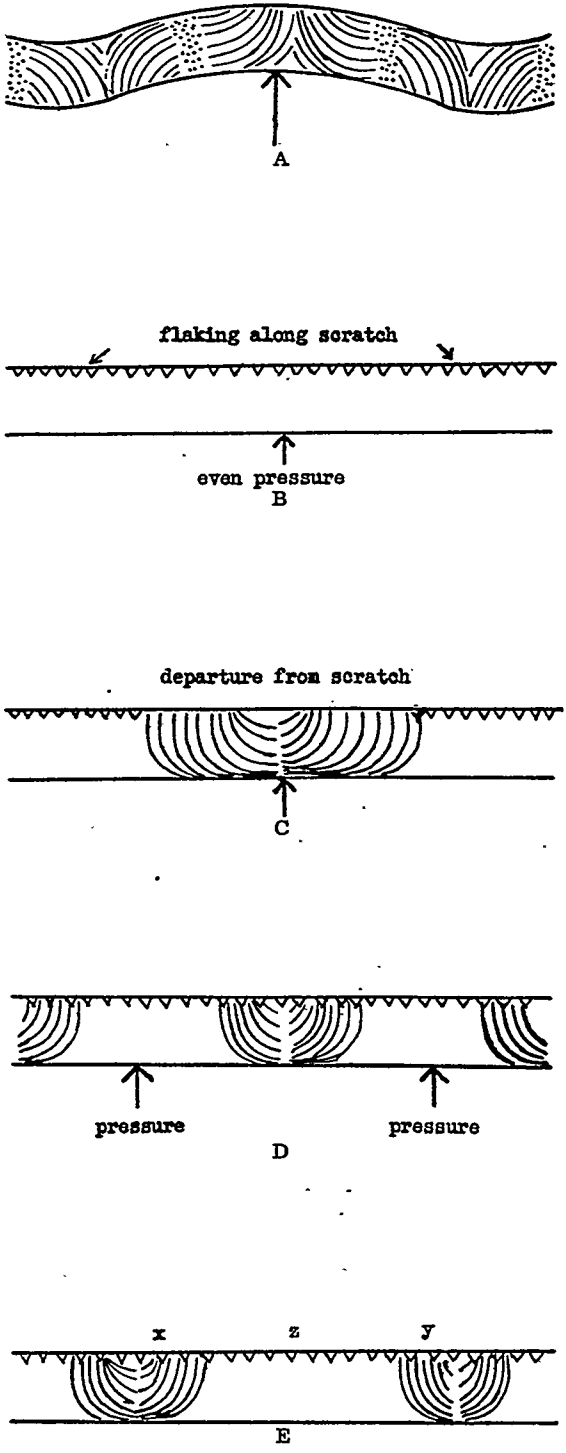

FIGURE 3

Experiment has shown that the release of strains in glass during fracture usually produces a series of markings on the fractured edges. The form and direction of these lines are determined by the manner in which the strains are released. The lines start approximately at right angles to the surface at which the fracture opened, and run tangentially to the other surface of the glass, and toward the point at which the crack began. Thus, in the case of a radial fracture, they run from the face opposite to the impact towards the point and surface of impact. In concentric fractures the lines run from the face of impact and end tangentially to the face away from impact (Figs. 1-E; 1-F).

There is less regularity shown in the direction of the lines on the edges of concentric cracks than in radial ones. The appearance of the edges of the concentric cracks depends on the relative moments at which the radial and concentric fractures occur. Figure 1-G shows the appearance of the edges of a pair of concentric cracks if these occur at the instants when the radial cracks *k, l, m* have reached, or passed, the points *D, C, A;* the radial crack *n,* though started, has not reached the point *B.* This crack *n* may reach the concentric crack *CBA* later, and cause the two pieces of glass *COB* and *BOA* to fall apart, without, of course, altering the appearance of the edges *CB* and *BA.*

These markings on the edges of cracks occur in both thick and thin glass; on thick glass they are readily visible, but on thin glass it is usually necessary to examine the glass at various angles to the incident light in order to make them apparent.

It sometimes happens that an anomalous effect is observed at the end of radial fractures (Fig. 1-H). The greater part of the fractured edge shows normal markings, but there may occur a reversal of the markings on the last ½ or ¾ inch of the crack. This anomaly occurs most frequently at the extreme edge of a sheet of glass where it is rigidly held in a frame or holder.

It will be realized from the description given that an examination of the edges of a piece of fractured glass will readily indicate from which surface the crack opened. If the piece of glass under examination is still in a window-frame the direction of the impact which broke it can easily be determined; but if the glass has been forced from the window it is necessary to know its original orientation in the frame before the problem of direction of impact can be solved. In general it is fairly easy to recognize on an isolated piece of broken glass which edges represent radial, and which con-

centric, cracks. If the piece has the shape of a long isosceles triangle (Fig. 1-C, *p* or *q*) the long edges represent radial, and the short concentric, fractures.

In removing broken glass from a window frame for examination a mark should first be made on one face of the glass with grease pencil for reference purposes. The piece of glass may then be removed and the edges of its radial fractures examined. If it is necessary to break off a piece of partially fractured glass in this process and so extend a radial crack, it should be remembered that the characteristic markings on the edges will be observed only to the point at which the original crack ended. This point should therefore be marked with grease pencil before the glass is broken apart. If too little glass is left in the frame for a satisfactory examination to be possible, the broken pieces of glass must be pieced together, as in a jig-saw puzzle, until a sufficient area has been pieced together to make it possible to determine how it originally was related to such glass as is left in the frame. A short cut is sometimes possible when dealing with pieces of *old* window glass. The outside surface of a window is gradually attacked by corrosive agents in the air and by the abrasive action of sand and dust; the former cause minute cracks visible under a reasonably powered microscope, and the latter tiny pittings. These are rendered more easily visible if the glass is treated with a solution of a dye-stuff, such as methyl violet or malachite green, the surplus dye being washed off after a few minutes. In this process the dye is absorbed into the surface cracks and makes them more easily visible. This method is helpful in determining which face of an isolated piece of glass was the weather side, but is applicable only to glass that has been in use for several years.

Fracture by Projectiles

The perforation or fracture of glass by bullets presents a problem of a different type. In these cases the velocity of the projectile is so rapid that it may have penetrated the glass before there has been time for radial or concentric fractures to occur; it then happens that a more or less clean hole is drilled through the glass, with the invariable characteristic that the diameter of the hole on the entrance side is smaller than on the exit side. Usually considerable flaking of the glass occurs on the surface of the exit side. For these effects to occur it is necessary that the velocity of the projectile should be high and the glass relatively thin. If the

projectile has been fired from a distance, or if the glass is 3/16 of an inch or more in thickness, the glass is uually shattered. If a piece of glass so shattered is examined it is found that the edges exhibit a confused system of markings; at one point the markings may be of the radial type, at another of the concentric type, and at a third they may consist of lines running at right angles to both faces. In all cases there is at least one region surrounding the primary perforation in which the glass appears to have been "ground" or devitrified. Sometimes the "ground" effect is quite coarse, at others it is merely a slight dulling of the surface. In thick glass, such as a motor-car windscreen of the non-safety type, two or even three such dulled regions are seen (Fig. 1-I). In nearly every case the markings on the edge of the glass undergo reversal from the "concentric" to the "radial" type, or *vice versa*, when one of these dulled zones is crossed.

In some specimens prepared by shattering thick glass from a distance of about five feet with a .22 projectile from a miniature rifle the characteristic markings on the edges of the fractures, near the point of impact, were noticed to start from a line which ran midway through the glass, and to branch more or less symmetrically in opposite directions from this line (Fig. 1-J).

The essential difference between the appearance of glass shattered by a bullet and of glass broken by a brick or hammer lies in the fact that in the former case the force applied is of exceedingly short duration, and in the latter the force acts comparatively gradually. In the former case the impact sets the glass vibrating before fracture occurs. Strain waves from the point of impact are reflected back from the edges producing interference effects between the two sets of vibrations; the result is that at certain points in the glass zones occur in which the glass is under compression simultaneously from two directions. It is in these zones that the dulled fractures seem to occur. On either side of such a zone the glass is under tension from one face or the other according to the direction of the curvature produced by the vibration; the glass thus fractures from opposite sides as a dulled zone is passed, thus causing a reversal of the type of markings produced on the fractured edge (Fig. 3-A).

Fracture After Scratching of the Surface

When a piece of glass is scratched with a diamond or a hard steel cutter, a trough of 1/500 in. to 1/250 in. depth is produced.

The scratch consists of a series of small cavities caused by the flaking of the glass. If the glass is then broken by *even* pressure along the scratch from the opposite face an almost structureless fracture may be produced (Fig. 3-B). If the fracture departs at all from the scratch mark it will at the points of departure show markings typical of a crack opening from the face scratched (Fig. 3-C). If the glass is broken by *uneven* pressure at points along the underside of the scratch, the fracture will appear structureless in the regions where the pressure was applied, and in the others will show markings running perpendicularly from the face of the scratch and tangentially to the other face (Fig. 3-D). In all cases the flaking along the scratch line will be visible—usually to the naked eye, but sometimes only with low-power magnification—when fractures that have closely followed the scratch are examined.

The results are not so simple when the scratch has been converted into a crack by tapping the glass along the scratch. It is immaterial on which side of the glass the tapping occurs. The cracks in all cases begin on the scratched side, but not every tap may produce a crack. However, where cracks appear they will show markings running perpendicularly from the scratched face and tangentially to the other. When the glass is afterwards broken, structureless fracture occurs at places where there were discontinuities in the cracks made by tapping. In Figure 3-E the points x and y represent cracks made by tapping, and z the structureless fracture between those cracks.

Comparison of Properties

When small fragments of glass are recovered in the investigation of breakings or of motor accidents the problem presented is usually that of determining whether the fragments came from a given source, *e.g.*, a particular window, windscreen or lamp-glass. In most of such examples *conclusive* proof of the origin of the fragments is difficult to obtain. As is so often the case with circumstantial evidence the result of the examination usually indicates the *probable* rather than the *actual* source of the glass. The value of such evidence is determined by the number and the nature of the tests applied, and, the more numerous the correspondences between the fragments and the comparison material, the more weighty is the evidence. Many of the tests applicable are simple and may be regarded as preliminary checks to be made before a detailed examination is undertaken. Provided it has been ascertained that

the fragments are free from stains (*e.g.*, blood), and from adherent matter, many of the tests may be applied without risk of making it impossible to carry out a more exhaustive examination later.

It is useful to consider the tests under four headings, those in the first two groups being applicable without risk of damage to the specimens.

Examination of "Form"

It is clear that the only conclusive proof of the origin of a fragment of glass is the finding among the "comparison" glass of a piece or pieces with which the "exhibit" fragment shows a perfect fit. This is a task which becomes the more difficult, if not impossible, the smaller the fragment and the greater the number of companion pieces. If the fragments are from a plane sheet of glass the problem is complicated by the lack of knowledge as to which is the "back" and "front" of the specimen, unless, as is seldom the case, this can be decided by the methods suggested above. This complication does not arise if the original glass possessed curvature or pattern, as usually is the case with lamp-glasses. In all cases of discovering a "fit" between pieces of glass the problem, if soluble, is a matter more of patience than anything else.

Even if it is not possible to relate a fragment to its origin by piecing together, it is often possible to indicate its probable origin if it possesses marked form or pattern. This frequently happens when examining fragments of lamp-glasses in motor accidents. Such glasses usually possess a moulded rim (often with lettering or figures on it), curvature, and usually a fluted or ribbed surface. Nearly 90 per cent of British cars are fitted with Lucas headlamps and glasses. Reference to the manufacturer's list (*e.g.*, Lucas list No. 400A) enables a rapid determination to be made of the type of glass fitted to a given make or date of car, or, what is often more useful, what cars and of what dates were fitted with a glass of a given size, pattern and type. Of the cars not described in this list most will be found in the Delco-Remy list.

When two plane surfaces are evident on a fragment the thickness should be measured. This is best done by means of a micrometer gauge. The mean of not less than a dozen measurements should be taken on both the "exhibit" and "comparison" specimens, because there is frequently an appreciable variation in the thickness of both drawn and cast glass. Measurements of thickness are not of much use in the case of fragments of curved lamp-glasses,

which taper in thickness from the periphery to the center, unless the measurements can be made of portions of the rim.

If the glass fragment forms part of a lens-shaped whole, the radius of curvature may be measured by a sphereometer. It should, however, be remembered that the curvature of a moulded glass is not usually as constant or as accurate as it would be in an optical or spectacle lens.

Determination of Physical Properties

Certain physical properties of glass, such as specific gravity, hardness, refractive index, etc., are closely related to the chemical composition of the material and alter appreciably in their values with even slight changes in composition. They are, moreover, properties which are easily measured with a high degree of accuracy, and thus are extremely useful in characterizing a glass. In the descriptions given the methods suggested are rather those to be chosen in a preliminary examination than those employed in a detailed examination. The accurate determination of the values of such properties demands the use of sensitive and expensive instruments; but, as a rule, comparative measures of the properties may be made with simple equipment.

Specific Gravity

The definition of specific gravity may be taken as the weight in grams of a cube of a substance of 1 centimeter edge. Since the weight of such a cube of water at 20° C. is 1 gram, the specific gravity measured at the same temperature gives the density of a substance relative to water.

In a preliminary examination it is enough to determine whether the specific gravity of an "exhibit" fragment is the same as, or different from, that of the "comparison" material. The simplest method of ascertaining this is based on the fact that a fragment of a solid will remain suspended (*i.e.*, neither floating nor sinking) in a liquid of specific gravity equal to its own. In a lighter liquid it will sink, and in a heavier one it will float. The specific gravity of common glass lies between 2 and 3. That of most ordinary glasses is between 2.4 and 2.65. Thus, almost any specimen of glass likely to be encountered will float in bromoform (specific gravity, 2.65) or in methylene iodide (specific gravity, 3.33). By adding alcohol (*e.g.*, industrial methylated spirits) to either of these liquids, mix-

tures of lower specific gravity may be made, of which the specific gravity approaches 0.79 as the amount of alcohol is increased indefinitely.

The simplest way of comparing the densities of two fragments of glass is to allow one piece to float on the surface of bromoform or methylene iodide and then to add gradually alcohol until a mixture is obtained in which the specimen remains suspended. It is convenient to begin with about ½ inch of the heavy liquid in a test-tube and to add the alcohol drop by drop from a fountain-pen filler, with thorough mixing between each addition, until the mixture of correct density is obtained. The behavior of the "comparison" fragment in this mixture is then determined; it will, of course, remain suspended in the liquid if it has the same density as that of the exhibit. In making rough comparisons of density by this method changes of temperature must be reduced to a minimum. This is conveniently done by immersing the test-tube in a larger vessel of water at room temperature during the test. When it is required to determine the exact value of the density of a glass fragment, the density of a liquid mixture in which it just remains suspended may be measured by any of the usual laboratory methods. Similarly, in the examination of larger pieces of glass (*e.g.*, of weight over 2-3 grams) it is best to determine the density directly by weighing first in air and then in water in the common laboratory method.

Refractive Index

When light passes at an angle other than perpendicular from one medium to another it suffers, in general, a slight change of direction. This process is termed *refraction*, and the specific power of a substance in producing this effect is measured by its "refractive index." The refractive index of common glasses lies between 1.5 and 1.9, and is a property which varies sharply with the nature and composition of the glass, and, by suitable instruments is capable of rapid and highly accurate measurement. The refractive index of a substance varies also with the wave length of the light for which it is measured, and with temperature. In precise measurements, therefore, the refractive index has to be determined at a measured temperature and for light of a known wave length. But, as in the case of density measurements, it is a simple matter to make comparisons of the refractive index of glass fragments in a preliminary examination. This determination is based on the fact

that a fragment of glass in a liquid of the same color is visible only if there is a difference of refractive index between the glass and the liquid. Of the several methods available the simplest is analogous to that used in the comparison of densities. The "exhibit" fragment of glass is placed in a few drops of a liquid of refractive index higher than its own, and then a liquid of much lower refractive index is added, drop by drop, with thorough mixing after each addition, until the fragment of glass suddenly becomes invisible. The refractive index of the liquid is then identical with that of the glass fragment. The "comparison" fragment is then placed in the liquid. If this fragment remains visible it has a refractive index different from the "exhibit." In practice it is unusual to meet with glass fragments of refractive index greater than 1.65. Thus, mono-bromo-naphthalene (refractive index 1.66) diluted with alcohol (refractive index 1.37) as described, will serve for all practical purposes. Mixtures of these two liquids give a range of refractive index from 1.66 to 1.37. For glass of uncommonly high refractive index methylene iodide-alcohol mixtures may be used. These give a range of refractive index from 1.74 to 1.37.

For reasonably large fragments of glass this method may be carried out in the smallest sized test-tube that will accommodate the specimen. Owing to its high cost, the mixtures should always be made by diluting the mono-bromo-naphthalene with alcohol and not *vice versa*. For tiny fragments of glass, such as may be recovered from the débris of a suspect's clothes, the comparison of refractive indices may be carried out on a microscope slide. The fragment is placed on the slide and covered with a drop of mono-bromo-naphthalene. Tiny drops of alcohol are then added and thoroughly mixed until the fragment becomes invisible. The behavior of a similar fragment of the "comparison" glass in the mixture is then noted.

Where the numerical value of the refractive index is needed it may be rapidly found by measuring by usual laboratory methods the index of the critical mixture in which the specimen became invisible.

Hardness

Since different glasses vary considerably in hardness it is usually possible to obtain an additional point of difference or resemblance by comparing the hardness of "exhibit" and "comparison" fragments. It is not easy to make precise measurements of hard-

ness. In comparing the hardness of minerals it is possible to set up an arbitrary scale of hardness by taking the following series of substances:

1. talc	3. calcite	5. apatite	7. quartz	9. corundum
2. rocksalt	4. fluorite	6. felspar	8. topaz	10. diamond

Each member of this series is harder than, and will therefore scratch, any members coming before it in the series. On this scale glasses have a hardness between 4½ and 6½, that is, the softer commercial glasses will scratch fluorite but not apatite, and the harder ones will scratch felspar but not quartz. It is clearly not possible to determine hardness with any precision by this scale. It is more convenient in examining glass specimens to construct one's own scale of hardness by placing in order of hardness (as determined by their mutual scratching powers) a series of fifteen to twenty fragments of different kinds of glass. Although a scale so built up is a purely arbitrary one it permits a more precise comparison of the relative hardness of glass specimens than does the usual mineral scale given above.

Color

Two fragments of glass from the same source, should, after any necessary cleaning, match in color. If there are differences in color obvious to the eye, and it is known that neither of the samples under comparison has been exposed to strong heat or to chemical action, it is justifiable to assume that they differ in origin. It is, however, not safe to assume that two specimens are of common origin because the eye cannot discern differences of tint between them. The eye is insufficiently sensitive to color to be able to distinguish minute, but real, differences in tint. Failure to distinguish visually between the tints of two glass fragments suspected of having a common origin should be regarded as strong justification for submitting the specimens to a rigorous laboratory examination, in which their colors may be compared scientifically in a tintometer or by measurements of their absorption spectra.

Ultra-Violet Fluorescence

Glasses of different compositions show different fluorescence colors when examined in ultra-violet light. The colors vary from black, through brown, violet, purple to lightish green or blue. The

test is of limited use because it distinguishes only between glasses of markedly different composition, and the majority of common glasses fluoresce with a brownish-violet color. It is, however, a test so easily and rapidly applied that it is conveniently made a matter of routine. It is well, perhaps, to emphasize that here, as in most of its applications, the value of ultra-violet light examination lies primarily in its ability to give evidence of *dissimilarity* rather than establishing *similarity.*

Evidence of similarity based on examination in ultra-violet light can only be regarded as strong if the precaution has been taken of measuring spectroscopically the wave lengths of the fluorescent light emitted by the specimen. This can be done only under laboratory conditions and by the use of rather elaborate apparatus.

Chemical Composition

The complete chemical analysis of a glass is a long and laborious process, and requires a considerable amount of material. The complete analysis of glass fragments is therefore not possible. Even if it were possible its value would be limited because of the rather narrow variations in the nature and proportions of the constituents of ordinary glasses. Micro-analytical methods have been worked out by means of which some of the constituents of a tiny fragment of a glass may be determined. But the constituents which it is feasible to recognize by such methods (*e.g.*, silica, oxides of calcium, barium, boron, magnesium, zinc, lead and aluminum) are merely those which are common to the majority of glasses. On the whole, it must be stated, little evidence of similarity or difference in the case of small fragments of glass can be obtained by chemical methods that could not be obtained much more easily and rapidly by the physical methods previously described.

Attempts have been made to work out spectroscopic methods for the examination of glasses. Such methods, while rapid and capable of detecting even minute traces of unusual metals in a glass, are, as a rule, not quantitative in character, and give no evidence as to how the elements found are combined in the specimen.

Special Tests

Certain special tests are being developed in the hope of characterizing glass specimens more definitely than is possible by the

methods already described. Some of these special tests have the obvious advantage that they depend on the history of the specimen rather than on its actual composition. In this way it may be possible to distinguish between specimens from the same batch of glass that differ only because they have undergone different treatments after their initial manufacture.

Because such tests are essentially more complicated than the preliminary tests described above, they will be treated in less detail.

Thermal Analysis

Pure chemical substances melt at sharp and definite temperatures. Mixtures of substances such as glass do not melt sharply, but soften over a fairly wide range of temperature and thus pass gradually from the solid to the liquid state. The melting-range of a glass is useful in characterizing it. This property is most conveniently studied by finely powdering some of the glass and then heating it in a furnace of which the temperature is steadily and gradually raised. The rising temperature of the glass is recorded mechanically on a rotating scale so that a temperature-time record is obtained. If the test is made with a standard quantity of the glass (5 grams) two specimens of similar glass will give similar temperature-time records. Any differences of softening or melting temperatures of the specimens is evident in the comparison of the temperature-time records.

This method is useful when considerable amounts of material are available, but obviously is inapplicable when the "exhibit" consists of a few tiny fragments only.

Polish Marks

Glass that has been polished or burnished has latent on its surface extremely fine irregularities left by the polishing tool. These are invisible to the eye, and, usually, undetectable by normal microscopical examination. They may, however, be made visible microscopically by the following method. The glass is cleaned by washing first in soda solution, and then in alcohol. Air is then blown by a small rubber hand-bellows through some moderately strong hydrofluoric acid and allowed to impinge on the surface of the glass. The vapor from the hydrofluoric acid etches the polish marks more deeply into the surface of the glass. After a few minutes' treatment the glass is again washed in alcohol and dried.

The "polish" marks may then be photographed in obliquely incident light through a microscope. The marks appear usually as series of parallel lines crossing each other at rather sharp angles. They are, of course, independent of the composition of the glass, and are, on the other hand, characteristic of the type of tool and abrasive used in the polishing process. This method is applicable to quite small fragments of glass, so long as some portion of a polished face is available.

"Griffith's Cracks"

When glass is annealed there are formed on the surface minute cracks, smaller than the "polish" marks, and invisible even on microscopical examination. Even hydrofluoric acid vapor fails to develop these cracks sufficiently to make them visible. It has, however, been found that if the glass is heated to about 300° C. in an atmosphere of potassium vapor at a pressure of about 1/1000 millimeter these "cracks" become sufficiently enlarged to be visible when examined in oblique light under the microscope. The Griffith's cracks are different in appearance and structure from the polish marks, but, like them are dependent on the history of the glass rather than on its composition. It is not yet possible to say how far a glass specimen can be definitely characterized by the examination of these "cracks," but experiments so far carried out suggest that this is one of the most promising methods of examination, the more so because it is applicable to quite tiny fragments of glass.

In conclusion, it may be emphasized again, that inasmuch as conclusive evidence of the identity of origin of two specimens of glass is seldom obtainable in practice, it is desirable that as many as possible of the tests described should be applied in the comparison of glass fragments. Only by so doing can any opinion expressed as to their being of common origin be raised to a high probability value of correctness. Such an opinion should be based, as a minimum, on agreement between the color, ultra-violet fluorescence, density, refractive index, hardness, form and type of fracture of the specimens. In addition, some attempt should be made to confirm the agreement of these tests by the use of one or more of the special tests described above.