PROCEEDINGS

THE THIRD SYMPOSIUM
ON THE
ART OF GLASSBLOWING

1958

THE AMERICAN SCIENTIFIC
GLASSBLOWERS SOCIETY

THE THIRD SYMPOSIUM ON THE ART OF GLASSBLOWING

SOME PRACTICAL ASPECTS OF WORKING WITH GLASS

Sponsored by

THE AMERICAN SCIENTIFIC GLASSBLOWERS SOCIETY

In Cooperation With

KIMBLE GLASS COMPANY

and

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F O R E W O R D

After holding our first two annual symposiums in Corning, N. Y., we traveled to Toledo, Ohio — "The Glass Center of the World" — for our third.

Our gracious hosts on this occasion were the Kimble Glass Company and the University of Toledo. On behalf of our Society, I express sincere appreciation to our co-sponsors for a stimulating and highly informative program.

I also wish to acknowledge a debt of gratitude to our own Vice President and Program Chairman, Leigh B. Howell, and to Kimble's James F. Ryley, David S. McLean and James J. Moran. Much of the work in setting up this symposium fell on their shoulders. The success of the meeting attests to how well they did the job.

I would like to share with you the feelings I had as the time approached for this symposium. My thoughts wandered back to that first meeting three years ago. I recalled the anxiety that prevailed. While we shared much in common by virtue of our profession; nevertheless, we were virtually a society of strangers. Hence, there was much concern about the reaction to that first meeting and whether or not it would serve a useful purpose.

Over the years that apprehension has disappeared, for we know these symposiums do serve a definite purpose for our membership and are worth the time and effort devoted to them. Furthermore, they serve as an occasion to renew acquaintances each year and to build new friendships, which weld us closer together as a Society.

In these last three years, I've also formed an impression of the man in our profession whom I shall label "Mr. Average Glassblower."

He is serious-minded, intensely interested in his profession and derives much personal satisfaction from the complex, intricate glass apparatus he creates with his knowledge, skill, coordination and dexterity.

Mr. Average Glassblower has a deep desire to learn more about this business of glassblowing and to keep abreast of the latest developments. With the knowledge that these symposiums help satisfy that desire, I hope you share with me the pride I have in our accomplishments of the last three years.

Because many of our members, as well as others interested in our field, could not attend this symposium and share first-hand with us this wonderful experience, we once again commit to print much of what transpired so that the information may be disseminated for the benefit of the greatest number.

J. Allen Alexander, *President*
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Frontiers of Glass Technology

O. G. Burch

Owens-Illinois Glass Company

Mr. Burch received his B.S. Degree in Chemical Engineering and M.S. in Chemistry from Washington University in St. Louis. He started with Owens-Illinois in 1921 and has been a vice president of the company since 1950. He is a specialist in glass technology, the development of glass-forming machinery and plastic fabrications. He is a Fellow in the British Society of Glass Technology and The American Ceramic Society of which he also is the president-elect.

As the first representative of the glass industry of Toledo to speak to you, I wish to welcome you to what we call "The Glass Center of the World." I hope that your visit will be a pleasant one and that you may have the opportunity of seeing the many things in glass which are happening in Toledo. I know that you have a very great appreciation for glass and for the working of it, since I understand that each of you is actively engaged in the preparation of specialized glass apparatus used for scientific purposes. You work daily with the world's oldest thermoplastic material. Glass, as you know, is a material which can be softened by heat and worked and re-worked into various forms. It also possesses many other excellent properties necessary for its broad economic usage.

Today, I wish to speak broadly for the glass industry in general concerning some of the frontiers which have faced us, many which now face us, and others which will face us in the future.

The simplest definition of glass known to me states that it is a very viscous liquid which solidifies without crystallization to form a vitreous, rigid mass at room temperature. This is in contrast to most liquids, such as water, in which crystals of ice form at the freezing point, or molten metals, which change rapidly to crystalline structures at their respective freezing points. One of the most important properties of glass is its great increase of viscosity as it cools down. In fact, the rate of change of viscosity with temperature is so important that it controls most of the various processes used in the fabrication of glass. A few degrees lowering of temperature will cause a doubling of the viscosity, and this change in resistance to flow permits the forming of the material into multitudinous and varied shapes. While most people who are concerned with the use of glass at room temperature do not know this great temperature sensitivity in the fabrication process, it is, I am sure, old stuff to each of you. Because of this, I shall not dwell further upon this very important property, which really defines glass: that of cooling through a viscous range, without formation of crystals, to a rigid body which carries all the characteristics of a solid.

I should like now to briefly discuss the early history of glass. Figure 1 covers, in a very broad fashion, the early development of glass as a utilitarian material. We enter at the bottom where it is noted that the use of natural volcanic glass as weapons and as tools was common in ancient times. Subsequently, there developed the early ceramic industry, which we classify here as the working of clay to produce various objects, followed by the glazing of such ceramic bodies to produce a nonporous, vitreous surface. The glaze is a true glass and it is possible that the first transparent glass object was made by digging out the soft clay background of a vessel and leaving the glaze intact in the shape of the original clay article. At least, it is known that somewhere between 3000 and 2000 B.C., there occurred a probable accidental discovery of manufactured hollowed glass articles. The first such articles were not made by blowing, but rather by forming or shaping the glass around a solid core of sand or other earthy material which could subsequently be dug away, leaving the hollow article. At this stage, glass became, in the period before Christ, a luxury item available only to the royalty or to the rich.

Somewhere in approximately the 3rd Century B.C., the use of the blow pipe was discovered in Greece. The Egyptians and

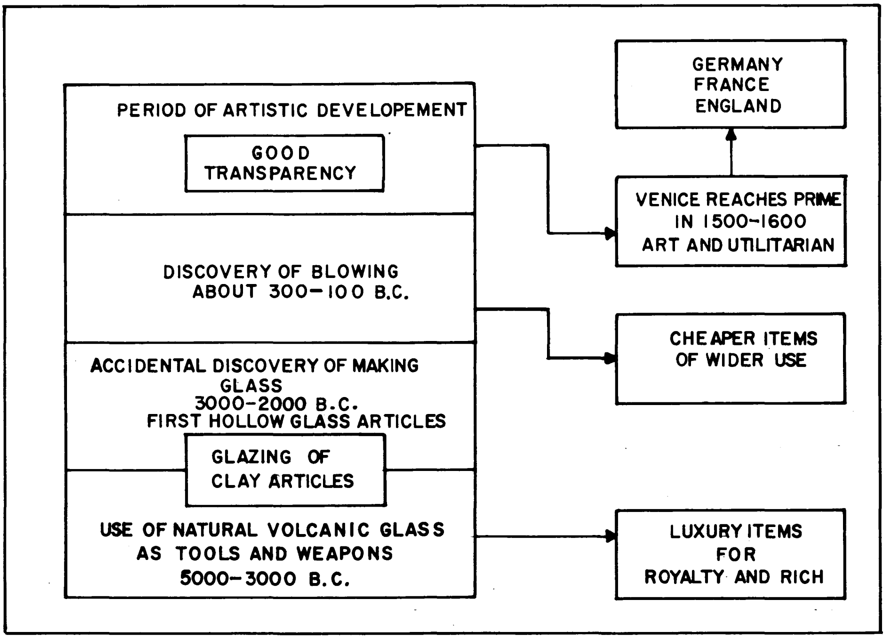

Figure 1

Romans made the first significant use of this instrument, and this led to a rapid expansion in the use of glass in the form of blown vessels. Mirrors began to appear in Greece, Egypt and Rome during the 1st Century B.C., and glass was apparently first blown into molds about the same time. The first transparent glass which has been found was made by the Romans about the beginning of the Christian era. Shortly after this, the manufacture of glass vessels spread rapidly, spreading as far west as Germany in the 2nd Century A.D. and as far east as Constantinople in the 4th Century A.D.

Stained glass windows were made in Constantinople in the 6th Century A.D. and in France in the 7th Century. The period of artistic development perhaps reached its peak in the Venetian glass industry in the 16th Century A.D. Obviously, glass has become more utilitarian with the passage of time.

It required approximately 2,000 years between the discovery of the method of manufacturing glass and the discovery of producing good hollow articles from the material. Almost another 2,000 years passed before two other great things happened in the history of glass. We have attempted to illustrate these events and their significance in the developments of glass in two additional fields in Figure 2. As may be noted therein, one of these was the first real scientific study of the properties of glass, as affected by its composition, which took place in Germany in the latter part of the 19th Century. During this period, much basic information was developed concerning the effect of glass composition on the optical properties, the chemical resistance, and such physical properties as the co-efficient expansion of glass. These studies were greatly responsible for the evolution and development of both the optical glass industry and the scientific ware glass industry.

The second thing, which occurred about the same time, might be called the mechanical revolution in the glass industry, beginning about 1880 and extending to the early part of the 20th Century. During this period, the following occurred:

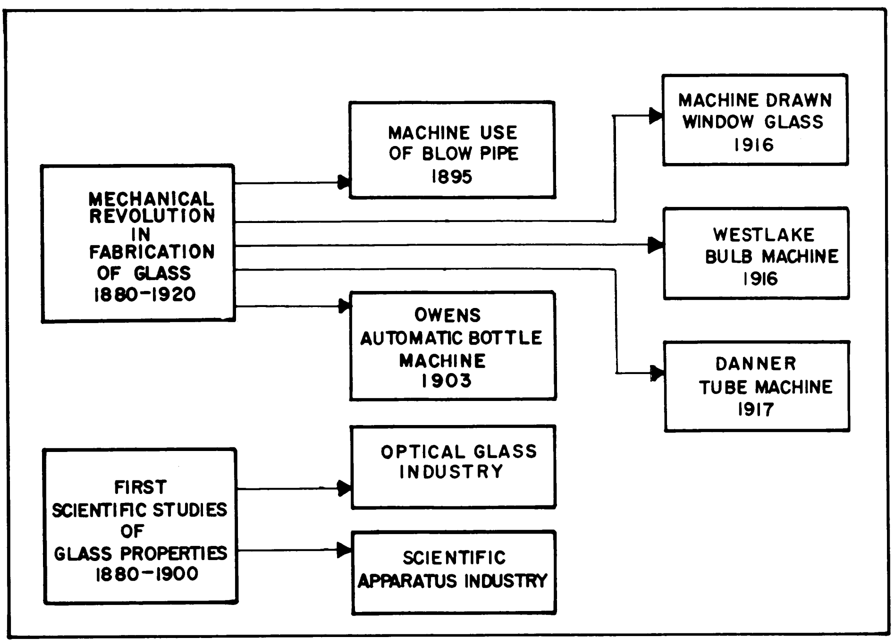

Figure 2

A. Plate glass was first produced in the early 1880s by the pot casting method.

B. The cylinder method for making window glass was mechanized from its previously hand-blown method.

C. In about 1895, a glass blower named Mike Owens, backed financially by Edward Libbey, produced the first mechanical blowing of glass containers by introducing blow pipes into a machine for blowing after the glass had been gathered by hand. Following this, in the early 1900s, approximately 1903, Mr. Owens conceived and developed the Owens' automatic glass bottle blowing machine. A few years later, Owens developed the same vacuum principle for glass gathering to build a machine for the manufacture of lamp chimneys. This occurred in 1911, and in 1916, the machine was further developed for the manufacture of light bulbs and eventually for making of paste mold tumblers.

D. In the meantime, Mr. Owens and Mr. Libbey had heard of some experimentation being conducted in a method of drawing window glass. This venture had driven the inventors into bankruptcy several times. Owens and Libbey purchased the rights to the process and within a few years made it successful and thus formed the background for the Libbey-Owens Sheet Glass Company in 1916.

E. Further, in about 1917, the Libbey Glass Works developed the Danner tube process, which is still used for the production of a considerable amount of tubing, a form of glass with which you all have had considerable experience.

Hence, the Libbey Glass Company, which had moved from New England to Toledo in 1888, made a gradual transition from hand operation to machine operation of various types of glass articles in slightly over 20 years.

Since then, there have been many additional mechanical developments in the glass industry. Among these may be mentioned the Fourcault process, numerous types of glass container forming machines, the ribbon machine used for making lamp bulbs, etc. Nevertheless, in the early part of this century, the combination of Owens, a mechanical genius, with Libbey, a financial genius, set the stage for much of the present Toledo glass industry, which last year had total sales of almost one billion dollars.

With this background, I believe you will realize why we Toledoans consider our city as "The Glass Center of the World." We, in Owens-Illinois, feel that we have one of the best engineering, development, and research staffs on glass in the world. I am sure that those who made the trip through the Owens-Illinois Technical Center were impressed by our facilities, which allow us to carry on research and development work from the small 1-gram melt scale through to the fully automatic machine development necessary for low-cost production.

As mentioned earlier, I am going to talk to you now about the present situation which exists in the glass industry from a technical point of view. We have a very great faith in the future of glass and know many of its outstanding advantages. We are also cognizant of some of its deficiencies. Glass is really more of a generic term than a specific term, because there are many thousands of possible compositions having many and varied properties. Figure 3 illustrates our present feeling about the many properties of glass. It represents an effort to put down on paper our present qualitative evaluation of scientific knowledge in certain realms of glass technology. This considers many of the major properties of glass, with which most of you are familiar, and presents them as an entity. At the same time, it shows many spokes of the wheel where we feel our knowledge is deficient even in our present-day situation. The rim of the wheel is not an effort to define a limit of development but rather an effort to define a practically satisfactory state of most of the various properties, some of which are already attained and others of which deserve considerable research attention. Obviously, I do not wish you to believe that when I show that we have reached the rim of the wheel by a spoke representing a certain property, we do not expect to improve that property. We intend to do everything possible to improve any and all properties of glass. Those properties of glass which I feel warrant very specific and concentrated attention, are represented by short spokes in the wheel. The closer the spoke approaches the rim of the wheel, the lesser attention we are giving to development in the respective area. Thus, we are not defining the outer circles of development nor the ultimate development, but rather attempting to give a relative situation on which we can base an over-all qualitative discussion. I know that it would be impossible for me to discuss all the

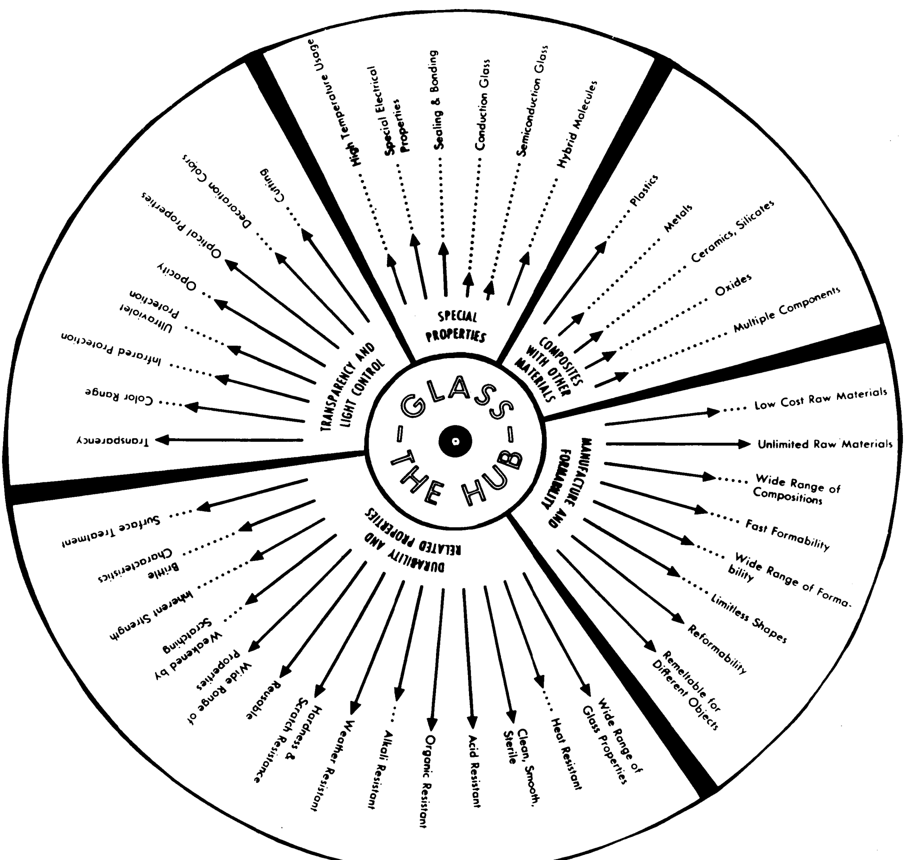

Figure 3

spokes of the wheel. I will, therefore, proceed to discuss certain specific areas of it. An enlargement of the center hub of Figure 3 is shown in Figure 4. Here we note main realms of properties as follows:

1. Durability and Related Properties;

2. Manufacture and Formability;

3. Transparency and Light Control;

4. Special Properties;

5. Composites of Glasses with Other Materials.

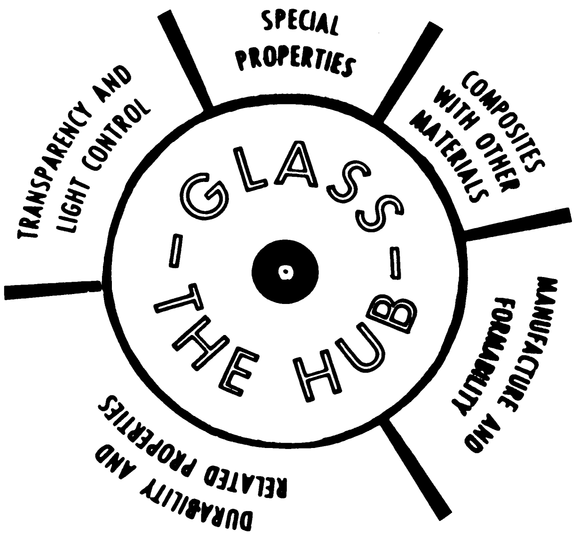

Figure 4

These factors, we consider, cover the realm of the glass era in which we now live. I shall talk briefly about each of these areas.

Figure 5 shows the area of Durability and Related Properties. You are well aware of the properties of glass which are outstanding and which give it acceptance. These things, such as

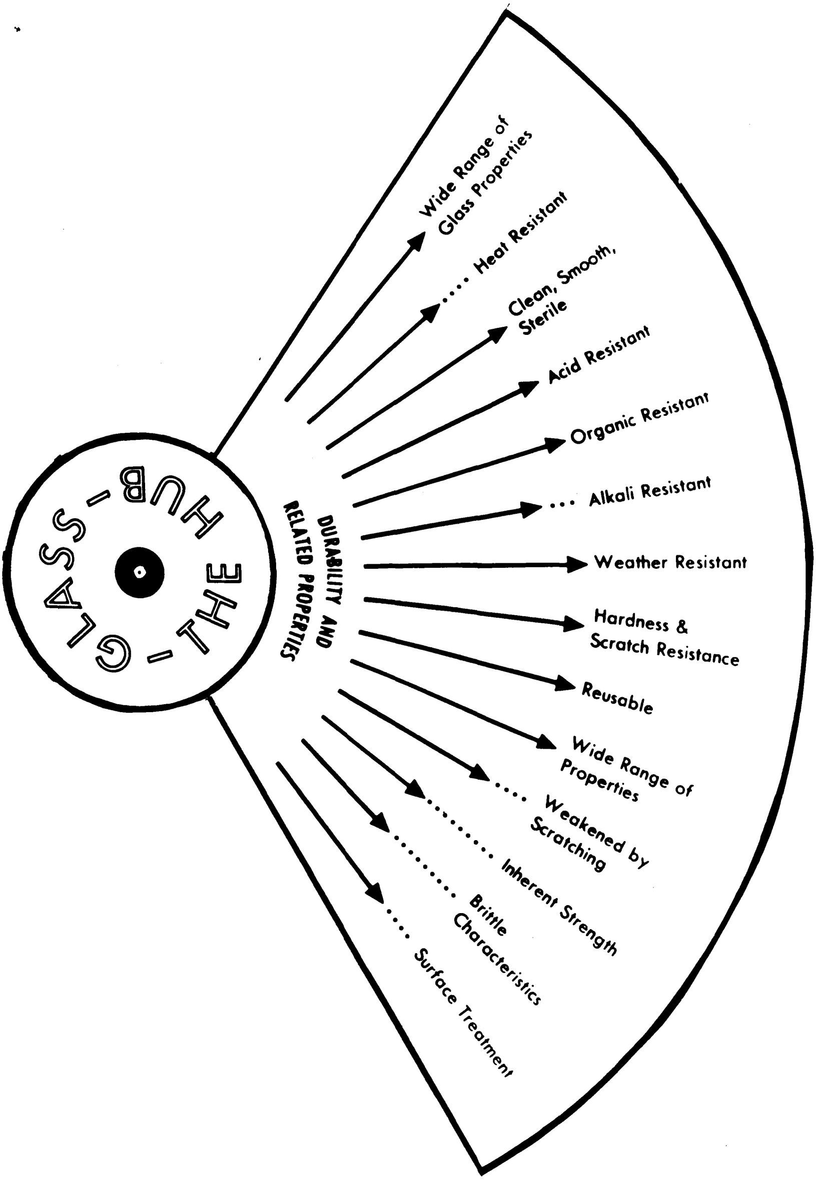
GLASS-THE-HUB
DURABILITY AND RELATED PROPERTIES
Wide Range of Glass Properties
Heat Resistant
Clean, Smooth, Sterile
Acid Resistant
Organic Resistant
Alkali Resistant
Weather Resistant
Hardness & Scratch Resistance
Reusable
Wide Range of Properties
Weakened by Scratching
Inherent Strength
Brittle Characteristics
Surface Treatment

Figure 5

weather resistance, hardness, cleanness, and smoothness, are all quite important. Glass is highly resistant to atmospheric conditions. However, it sometimes develops a cloudy surface, which is very noticeable due to its transparency. Therefore, improvement in the resistance of glass to alkalis is desirable.

Glass is also inherently a very strong material. You know, however, that it is also scratch-sensitive because when you wish to break a rod, you first scratch it. Further, we would be negligent if we did not mention that in the common concept glass is brittle. Just what goes into the term "brittleness," however, is not definitely known. We know something about the structure or the fundamental building blocks of glass, but this is a continual field of investigation, since we are interested in improving the properties of glass and a picture of its structure will undoubtedly help in this problem. You are acquainted with low design strengths of most massive glass articles. The apparatus which you fabricate, window glass, glass containers—all fail at their surfaces and in tension at levels of 5 to 10,000 pounds per square inch. Very fine glass fibers, having their surface carefully protected, have attained tensile strengths of almost one million pounds per square inch. We have subjected massive pieces of glass to stresses in the order of 2 to 4 million pounds per square inch without causing fracture. However, these stresses were made within the body of the glass and did not reach its surface. Glass is thus recognized as surface-sensitive or scratch-sensitive, and the idea of improving its surface is one method of approach for improving its strength. It is in this realm of our wheel we feel that there is considerable room for research and development. The spokes are just too short!

A second major area which makes glass what it is and contributes to the wheel on which we are riding is its Manufacture and Formability (Figure 6). Glass, as stated earlier, can be made in a very wide range of compositions. In fact, there are almost limitless combinations of materials which can be made into glasses. Due to this, there is a rather wide range of properties available because the basic properties depend to a great extent upon the composition. Some compositions are very expensive, due either to high costs of materials or to high costs of processing. However, the major share of glasses is made from relatively cheap raw materials—certainly cheap in comparison to other

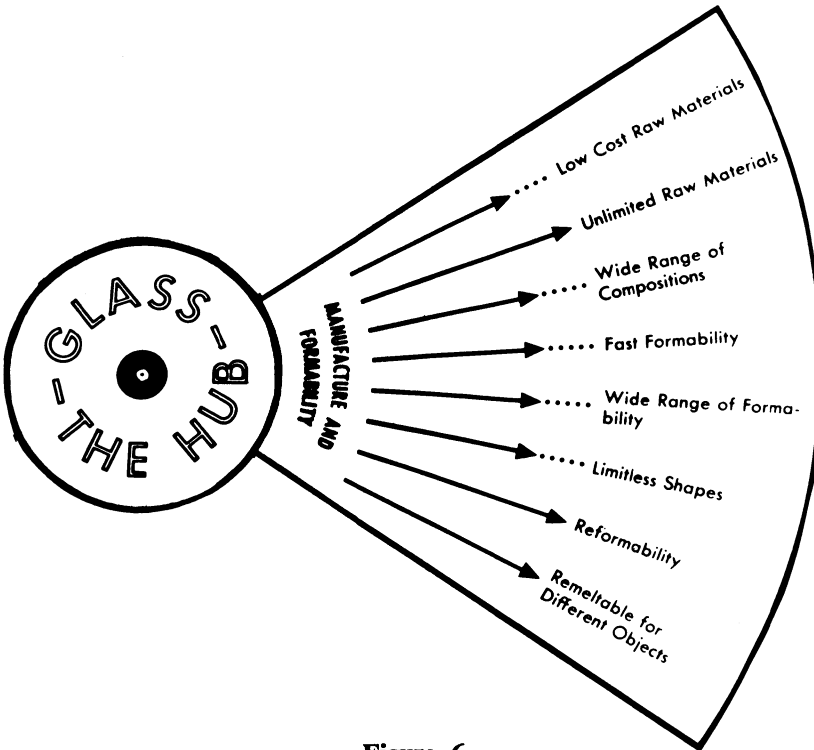

Figure 6

materials, such as metals, plastics, etc. I do not wish, however, to oversell this point because we make many efforts from the standpoint of the raw material to improve the composition of the glass or to lower the cost of the material itself. Furthermore, when we want to develop a new composition having certain specific desirable properties, we do not limit ourselves to low-cost materials, and, in many cases, we must use materials which are very costly to produce the desired effects.

Another item in fabrication is that glass can be made into almost limitless shapes. There are certain things which do bother us in the relation of shaping. For example, to produce a hole in a piece of glass to really close tolerances, whether it be done by blowing, drawing—in the case of tubing—or pressing, is quite a costly process. We must improve the dimensional tolerances now attainable on glass objects by improved fabricating techniques. I need not enlarge on the reformability of glass as you are all experts in that field. Neither do I believe it necessary to discuss

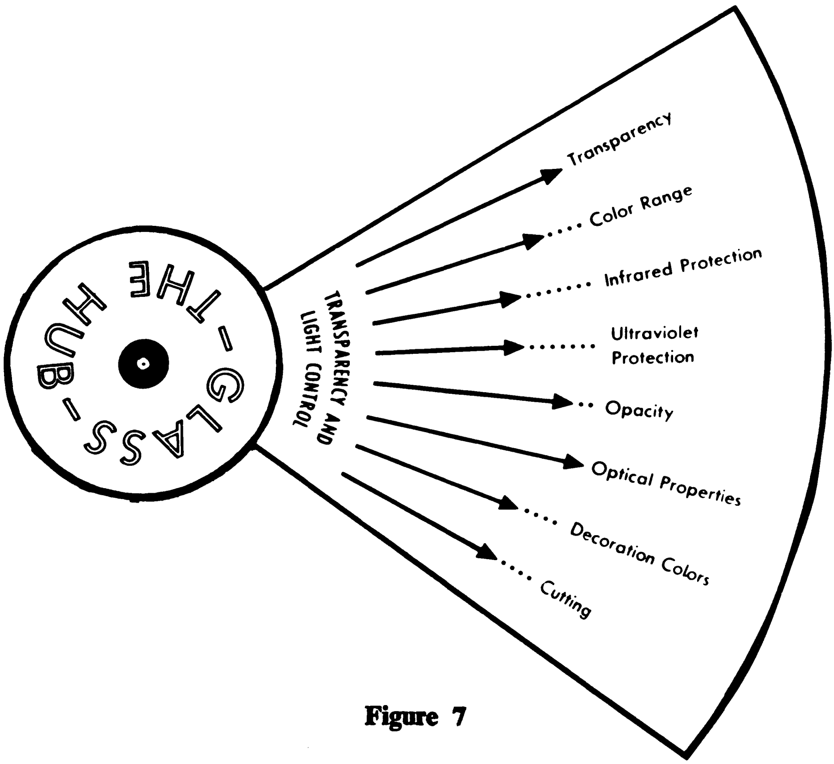

Figure 7

some of the speeds of fabrication which are being attained by the many phases of the industry. These speeds, of course, are dependent upon the process and product, but to a very great extent are very high compared to many of the speeds by which other materials are fabricated. The speeds attained and the low cost of the raw material are responsible in part for the sale of low-cost glass articles.

Perhaps the next largest group of properties of glass are concerned with Transparency and Light Control (Figure 7). You can see through glass because its molecular structure carries no holes, surfaces, or other inhomogeneities which are in the realm of dimension of light waves or which interfere with light waves. Under certain conditions, glass can become conductive like a metal, but this condition is not due to the free electrons present as in metals. The conduction in glass involves a much larger mass transfer than electrons. There are many phases of transparency and light control. The appearance of clear glass is quite pleasing. It is likely, however, that there are major developments to be made in the matter of protection from infrared or from the ultraviolet rays. Glasses can generally be made in a rather wide range of colors, although we do not like to say in an unlimited range of color. Obviously what can be done in a one pound melt cannot always be done economically at a production rate of 150 tons per day. Glass can also be made opaque or light-diffusing, and thus is widely used for control of light. Optical surfaces can be made to bend the light in such uses as glass block and lenses. Glass can be decorated with glass materials which can be made in a wide range of colors. Glass can be cut. We, therefore, find that some of the spokes of the wheel concerning transparency and light control are pretty well developed, but there are deficiencies in certain realms of transmission which are receiving continuous attention.

Another realm concerns the usage of special glasses in electrical and electronic applications (Figure 8). There are many special types of glass for electrical usage but there must be many improvements made. One composition variation, which normally

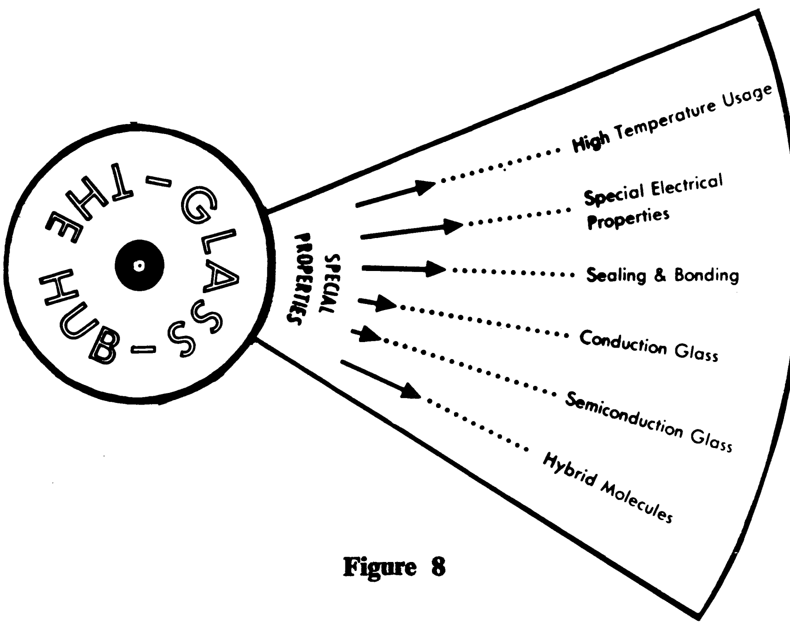

Figure 8

assists in giving improved electrical properties, is reducing the alkali content of the glass. This usually results in higher temperatures of softening, glass harder to work, and glass with lower conductivity, both surface and body. However, it is known that the temperature limitations of usage of glass, which in the ordinary glass depends on softening, can be raised to a point where the glass maintains its solid dielectric characteristics more fully at 500 or 600°C. I am, of course, talking of glasses which are formable, excluding the high silica types. On the other end of this situation is the possibility of developing very low-temperature sealing glasses for sealing various materials together, particularly materials of an insulating type.

While the fundamental structure of glass, as now envisioned, does not lend itself to electrical conduction within glasses, there are steps which can be taken to produce either conductive glasses or conductive glass surfaces. There are several who are thinking in the realm of actual semi-conduction in glasses to replace some of the solid state devices now used for electronic amplification.

Thus, our wheel, while it is rather weak from the standpoint of electrical properties, is getting stronger because of the increased temperature of usage of materials in electronic applications. The Armed Services are demanding low-cost materials which can be used at temperatures above 500° C. The field of special glasses which will withstand such temperature is open for considerable development. This type of development may make your jobs harder because it may require glasses more difficult to fabricate or make it necessary that you use higher temperatures in fabrication.

Finally, from the standpoint of structure, the question may be raised as to whether we will ever have hybrids formed between plastics and glass. The structure of glass, as now envisioned, is not generally compatible with the structure of plastics. Good adhesion between these materials is possible. When we think of producing hybrids between glass and plastics, we hope to produce new molecular materials, which have the useful characteristics of both of the individual materials.

Lastly, our wheel has a series of spokes representing Composite Materials (Figure 9). In these, glasses may be used in combination with such materials as crystalline oxides, ceramics, metals, and plastics. The low-temperature sealing glasses can be used for sealing certain ceramic materials together or for bonding various granules or crystals. Obviously, when this occurs, one loses the reformable characteristics of glass, because when

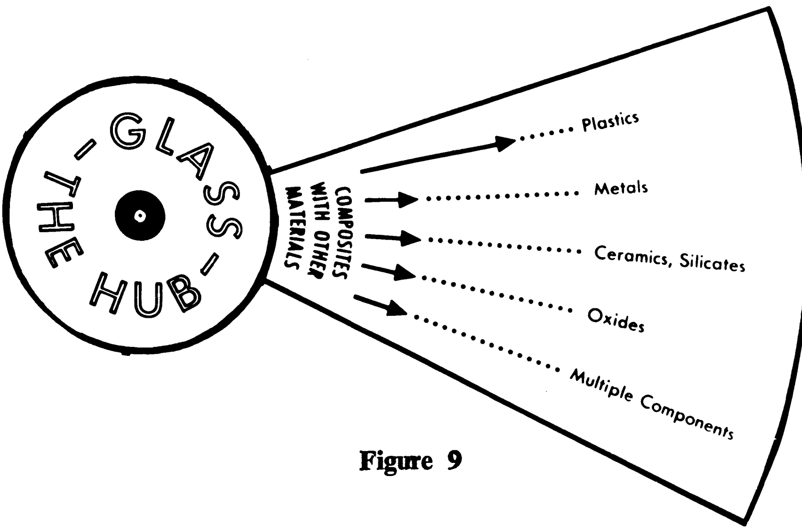

Figure 9

one puts crystals into glass, the property of forming becomes greatly influenced by the solid crystal body present. Glass-to-metal seals are quite commonplace but still intricate and very difficult to produce. Simplification of such composites is desirable. The fiberglass-plastic type of structure is one where the glass fiber gives strength to the article and the plasticity or softness of the plastic gives considerable impact resistance to the material. This results in an article quite insensitive to scratches. This is the largest used composite now available.

In conclusion, I want to present a picture of growth of glass usage (Figure 10). This summarizes my thoughts on the future of the glass industry. The glass tree contains a trunk and limbs representing:

1. A considerable growth in present product lines;
2. The expanded use of glass for electronic apparatus;
3. The expanded use of glass in national defense;

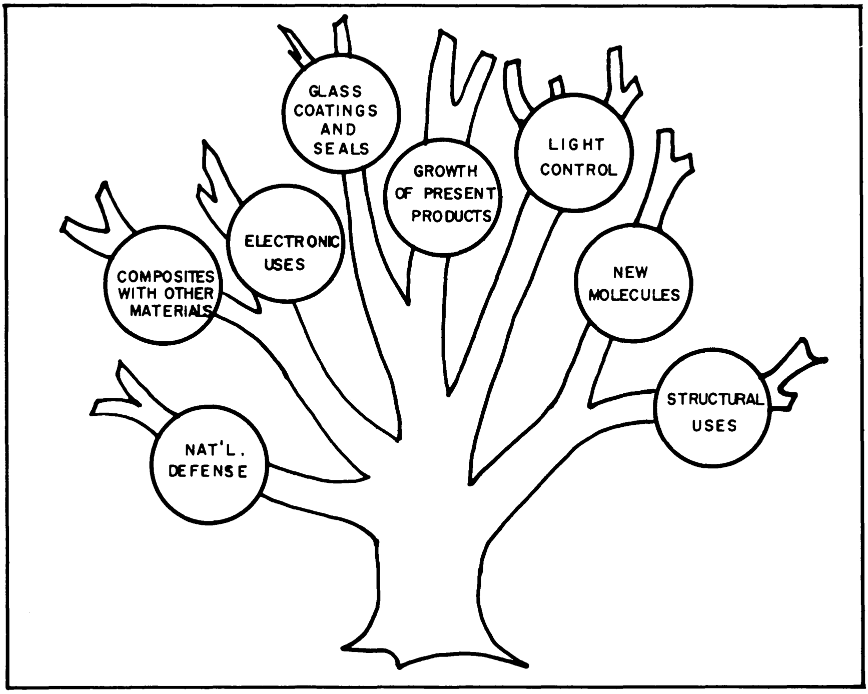

Figure 10

4. The expanded use of glass as a light-controlled medium;

5. The use of glasses having a wide range of properties as sealants, bonds, or coatings;

6. A growth in the use of bulk glass as a structural material;

7. The development of composites of glass with other materials, both organic and inorganic;

8. Finally, the development of structure and surface work to include new molecules with unusual properties.

Again, I wish to say that I have been thinking broadly from the viewpoint of the glass industry as a whole. I hope you continue to be intrigued by the material with which you work. I am!

Composition and Properties Of KG-33 Glass

Dr. Dudley C. Smith

Kimble Glass Company

Dr. Smith received his education at College of Charleston, Union College and University of Virginia. He was associated with Bell Telephone Laboratories and Penniman and Browne before joining Kimble Glass Company 21 years ago. He currently is director of Kimble's Vineland Plant Laboratory. He is affiliated with the American Chemical Society, American Ceramic Society and British Society of Glass Technology.

As the program states, I am to discuss the properties of KG-33 glass. Those who read the February (1958) issue of your excellent publication, Fusion, will realize that the topic is not new. However, I believe this subject is one that bears repeating. The properties of a glass provide the yardstick by which we can predict how well or how poorly the glass will perform in any practical situation. The potentialities of the glass can be more fully utilized when the properties of the glass are thoroughly understood by those who will use it. In discussing the properties of KG-33 glass, we will, in effect, be telling you what glassblowers can expect of this glass and what the glass will do for those who make use of it.

I hope you will not object if I begin by relating a personal experience. At one time, I attended a graduate school of chemistry which did not have the services of a professional glassblower. Anyone who required special glass apparatus had to construct it for himself. In this way, we were forced to learn a little about glassblowing, the hard way. At the cost of much time, effort and perseverance, we managed to put together the things we had to have. Occasionally, when a seal proved too difficult, we fell back on more practical expedients such as deKhotinsky cement. One day, a professor strolling down the corridor noticed the unmistakable aroma of hot resin and pitch. Lifting his long nose, he sniffed the air, turned to me and said, "One of our boys must be doing some glassblowing". Usually, our handiwork did not look very pretty and I am glad there were no industrial engineers with stopwatches to tell us how long the job had taken or how much it would have cost at so much an hour plus overhead. Probably our time would have been better spent, had we been able to concentrate on chemical research and leave glassblowing to the glassblowers. But I am sure this experience did one thing for all of us. It left us with a deep respect for the art of glassblowing. Only by going through such an experience can the chemist fully appreciate the know-how and the skills of the professional glassblower.

Science owes a great deal to the members of your profession. Through your knowledge of glass and your skill and ingenuity in working it, you have contributed very greatly to the development of glass apparatus. By helping to create these tools of research, glassblowers have made an indispensable contribution to the progress of research. By constantly working with glass, you have necessarily come to know a lot about glasses, especially their lampworking and sealing characteristics. It is therefore a privilege to be able to talk to you about KG-33 glass, the glass which is being used to make our new KIMAX line of apparatus.

What sort of glass is KG-33? How does it compare with other commercial glasses? What are the important properties of KG-33 glass? What assurance do you have that its properties will always be under control? These are questions which I will try to answer.

KG-33 glass is a "hard" borosilicate glass. The term "borosilicate" means a glass which contains a relatively high percentage of silica and boric oxide. The expression "hard" glass means a glass which is durable and can withstand high temperature and sudden changes in temperature.

The characteristics of this type of glass, and its advantages, can be better understood by comparing it with other types of commercial glasses. For practical purposes, the common commercial glasses can be classified into three types:

soda lime glasses,
lead glasses, and
borosilicate glasses.

All of these glasses have one thing in common. The principal ingredient of each of them is silica or purified sand. Commercial glasses contain from 50 to 80 per cent of silica. It is possible to make a glass from sand alone. Such glass is called fused silica or fused quartz. However, excessively high temperatures are required to melt sand and the resulting glass is not only expensive, but has a softening point in excess of 3000° F. It is therefore very difficult to work.

To make a useful and economical glass from sand, we must combine the silica with other glass forming ingredients which will aid in the melting of the silica. One very effective agent for this purpose is soda. A mixture of soda and silica melts very readily and the combination does produce a glass. However, soda-silica glass is lacking in what we call chemical durability, which is the ability to resist attack by water and water solutions. Sodium silicate glass dissolves in water and therefore cannot be used to make glassware.

To obtain a durable glass, we must add to the silica-soda combination certain other ingredients such as lime and alumina. If we use those two materials, we produce a typical soda lime glass, consisting essentially of silica, soda, lime and alumina.

If instead of lime, we were to use lead oxide or litharge, the result would be a lead glass, containing silica, alkali, lead and alumina.

As a third possibility, we can melt silica by combining it with borax and boric acid along with a little alumina. This produces a borosilicate glass consisting of silicate, soda, boric oxide and alumina.

Now what are the characteristics of these various glasses and why do we feel that a borosilicate glass like KG-33 provides the best material for making scientific glassware?

To help answer this question, we have prepared a table (Figure 1) which shows the chemical composition and certain properties of a few familiar glasses. Included are a lead glass, a soda lime glass and a borosilicate. The lead glass is G-12, which has been used to make electronic bulbs and components such as the necks of television tubes. The soda lime glass is Kimble's R-6, which has been widely employed to make "soft" glass apparatus. The third glass is a hard borosilicate of the type used to make such things as flasks and beakers as well as tubing and apparatus.

What are the distinguishing features of these glasses? The lead glass consists mainly of silica and lead oxide with about 12½ per cent of alkalies. The soda lime glass is mostly silica, soda and lime. The borosilicate is composed mainly of silica and boric

TYPES OF SILICATE GLASSES

TYPE OF GLASS	LEAD	SODA LIME	BOROSILICATE
PRINCIPAL USE	ELECTRONIC	"SOFT" APPARATUS	"HARD" APPARATUS
SILICA	56.5%	67.6%	80.4%
ALKALIES....SODIUM OXIDE	4.0	15.7	4.1
POTASSIUM OXIDE	8.5	0.7	-
LIME.......CALCIUM OXIDE	-	5.6	-
MAGNESIUM OXIDE	-	4.0	-
ALUMINA	1.5	2.8	2.4
BORIC OXIDE	-	1.5	12.9
BARIUM OXIDE	-	2.1	-
LEAD OXIDE	29.3	-	-
SOFTENING POINT, °F	1171	1292	1508
EXPANSION COEFFICIENT (0 - 300°C, /°C, x10⁷)	89	93	32.5
DENSITY (g/cc at 25°C)	3.05	2.53	2.23
REFRACTIVE INDEX (Sodium D Line)	1.56	1.52	1.47
ELECTRICAL RESISTIVITY (log at 350°C)	7.8	5.2	6.6
CHEMICAL DURABILITY (ASTM P/W Test)	5.4	7.9	1

Figure 1

oxide. Now let us see how the composition differences are reflected in the physical characteristics of the glasses. The lead glass is distinguished by relatively high electrical resistance and this fact makes it useful in many electrical applications. Lead also imparts to glass a high refractive index which is useful in optical glassware such as lenses and prisms. The lead glass is relatively soft with a softening point of 1171°F. The soda lime glass is somewhat harder with a softening point of 1292°F. The borosilicate glass is harder still with a softening point more than 200 degrees higher than for the soda lime glass. This means that the borosilicate glass is much more heat resistant and can be used at much higher temperatures than can lead glasses or soda lime glasses.

A very important property of any apparatus glass is heat shock resistance, or thermal endurance as it is sometimes called. This is the ability of a glass to withstand sudden changes in temperature without breaking. Thermal endurance is largely a function of expansion coefficient. The less expansion or contraction a glass undergoes with change of temperature, the better it can withstand sudden temperature changes without cracking. In the table (Figure 1), we see that the expansion coefficients range from about 90 for the lead and soda lime glasses down to 32.5 for the borosilicate. The hard apparatus borosilicate glass, with its low expansion, possesses outstanding heat shock resistance. This is a valuable asset for any glass which will be used to make beakers and flasks and all sorts of apparatus which may be exposed to sudden changes in temperature.

In lampworking operations, such as sealing, tooling, bottoming or necking, soft glasses are prone to develop fire cracks and cold checks and precautions must be taken to prevent these defects, especially in automatic or semi-automatic operations. The prevention of fire cracks and cold checks is very much easier when a low expansion glass is used. In fact, it is possible to eliminate such defects completely by using the glass which we have designated as "hard apparatus glass".

Glasses of low expansion can be cooled faster after lampworking without developing excessive cooling strains. A glass of 32.5 expansion can be lampworked and allowed to cool rapidly to room temperature with very little risk of the article cracking before it reaches the annealing lehr. This is not true of articles made from soda lime glass which must be cooled down carefully or annealed promptly after lampworking.

But there is another glass property which is perhaps of even greater importance where laboratory service is concerned. This is chemical durability. As we mentioned earlier, chemical durability is the ability of a glass to resist attack or corrosion by water, water solution, acids and alkalies. We sometimes think of glasses as being completely impervious to water but, in reality, all glasses are affected to some extent by repeated or prolonged contact with moisture, especially at elevated temperatures. When a glass of poor durability is exposed to the action of water and chemicals, some alkali is extracted from the glass surface, along with some of the other soluble ingredients of the glass. As a result, solutions contained in glassware may become contaminated and the glass surface may become roughened and cloudy. This detracts from the appearance of the article and limits its usefulness. Some glasses acquire crystalline surface deposits on being stored for extended periods, especially when exposed to high humidity. This phenomenon is called weathering. Oftentimes, the useful life of a glass article is determined by the chemical durability of the glass and whether or not its durability is adequate, for the type of service.

As one index of chemical durability, we use a standard test sponsored by the American Society for Testing Materials and also by the U. S. Pharmacopoeia. In this test, we prepare a sample of glass in pulverized form and expose this sample to the action of superheated water at 250°F for 30 minutes. We then determine the amount of alkali extracted from the glass grains by the superheated water. In this test, the lower the figure, the higher is the chemical durability of the glass. In the examples cited in our table (Figure 1), the durability figures for the lead and soda lime glasses are 5.4 and 7.9. For the borosilicate glass, the figure is less than 1. It may be questioned why we use the expression, "less than", rather than to assign a numerical value. The answer is that the chemical durability of this glass is not exactly a constant quantity, but is affected to some extent by heat treatment. It should be borne in mind that the durability values in Figure 1 represent the amount of alkali extracted from the glass surface by the water. The smaller the figure, the better is the durability of the glass. Using these figures as a yardstick, we can say that the borosilicate glass is several times more durable than either the lead or soda lime glass.

From this comparison, it can be seen that the borosilicate glass is superior as regards chemical durability, heat shock resistance and resistance to high temperatures. There are other properties that are important to an apparatus glass but none is more important than these three. The glass which appears last in our table is best suited for making laboratory glassware because it excels in the properties which are most important for such glassware. This is KG-33 glass.

For many years, Kimble Glass Company produced a line of graduated glassware and chemical apparatus which was made very largely of soft soda lime glass. Although recognized for its accuracy and precision, the Kimble glassware was unsatisfactory in certain applications because of limitations inherent in the glass. Thus, there arose a demand for a line of apparatus which would have all the good features of the Kimble line but made of a hard glass with all the best practical combination of properties. When the KIMAX program was first planned several years ago, the management of Kimble Glass Company asked the question— "What glass is best suited for this purpose?" This question was referred to glass technologists in our Technical Center in Toledo, Ohio. To answer the question, an extensive research program was carried out. Experimental glass compositions were formulated and melted and their properties carefully evaluated. It was concluded that the physical properties of the glass must be such that it would seal to and be interchangeable with the hard glass already on the market. KG-33 has these properties and is completely interchangeable with the existing hard glasses.

There are several properties of KG-33 glass which can be made the basis for a practical test to distinguish this glass (or its duplicate) from other common commercial glasses, namely, density, refractive index and thermal expansion. A suitable density liquid can be prepared by mixing tetrabromoethane and triethylene glycol in the following proportions:

tetrabromoethane	— 321 volumes
triethylene glycol	— 179 volumes

At room temperature, KG-33 floats in this liquid while glasses of greater density will sink.

A liquid of the proper refractive index can be prepared as follows:

carbon tetrachloride	— 274 volumes
benzene	— 110 volumes

When a piece of KG-33 glass is immersed in this liquid, it virtually disappears from view, while each of the other glasses remains visible. This test has the advantage that it is not destructive. In the case of the density test, it is necessary to cut off a piece of the glass so that it can be dropped into the liquid. In the refractive index test, it is only necessary to immerse the tip or a projecting portion of an article.

A third test, based on thermal expansion, tells us whether or not two pieces of glass are identical in sealing characteristics. This test, called the pull test, can be used to check the identity of a piece of glass, if we have on hand a known sample of the glass. Or it can be used to determine whether or not two different glasses can be successfully sealed together. The procedure is illustrated in Figure 2. In making the pull test, the first step is to prepare the two samples in rod form, if they are not already in that form. Next, the ends of the two rods are fused together as shown in the illustration. With a pair of tongs or pincers, a fiber is drawn. This fiber should be a few tenths of a millimeter in diameter and 2 or 3 feet in length. The fiber will consist partly of one glass and partly of the other and if the two glasses are perfectly matched, the fiber will be straight. But, if there is a difference in expansion, the fiber will take on a pronounced bow, the glass with the greater expansion being on the inside of the curve.

Figure 3 shows the actual fibers produced when certain glasses were sealed together. The first fiber was made by sealing a soft glass, R-6 to KG-33. These two glasses are widely different, the expansion coefficients being 93 and 32.5, respectively, and the resulting fiber is curled. Fiber No. 2 resulted from sealing KG-33 to Kimble's N-51A glass, which is a borosilicate with an expansion of 49.5. Fiber No. 3 was produced by sealing KG-33 to K-772, which is a lead borosilicate with an expansion of 36. Although this glass is fairly close to KG-33 in expansivity, the fiber is nevertheless quite bowed, indicating that the test is fairly sensitive. The last fiber was made by sealing KG-33 glass to a sample of Corning's 7740 Pyrex glass. This fiber is straight, indicating a very close match between the two samples.

Figure 4 shows the expansion curves for these glasses. By a comparison of such curves it is possible to roughly approximate the amount of stress to be expected when two glasses are sealed together. The stress is determined not so much by the expansion coefficients as by the difference in contraction undergone by the two glasses in cooling down from the annealing range of the softer glass. This can be understood by considering what happens after two different glasses are sealed together. As the seal begins to cool, the harder of the two glasses first reaches a temperature at which it becomes rigid. At this point, the softer of the two glasses is still relatively non-rigid and can conform to the dimensions of the harder glass. As cooling continues, the softer glass reaches its effective setting temperature which corresponds roughly to its annealing temperature. From this point on, the two glasses are rigidly welded together and any difference in contraction will cause stress.

The amount of stress can be estimated from the following relation:

$$\text{Stress} = \tfrac{1}{2}\ \Delta l/L \times E$$

where $\Delta l/L$ is the difference in contraction, per unit length, as read from expansion or contraction curves.

E is Young's modulus, which for most glasses is approximately 10 million p.s.i.

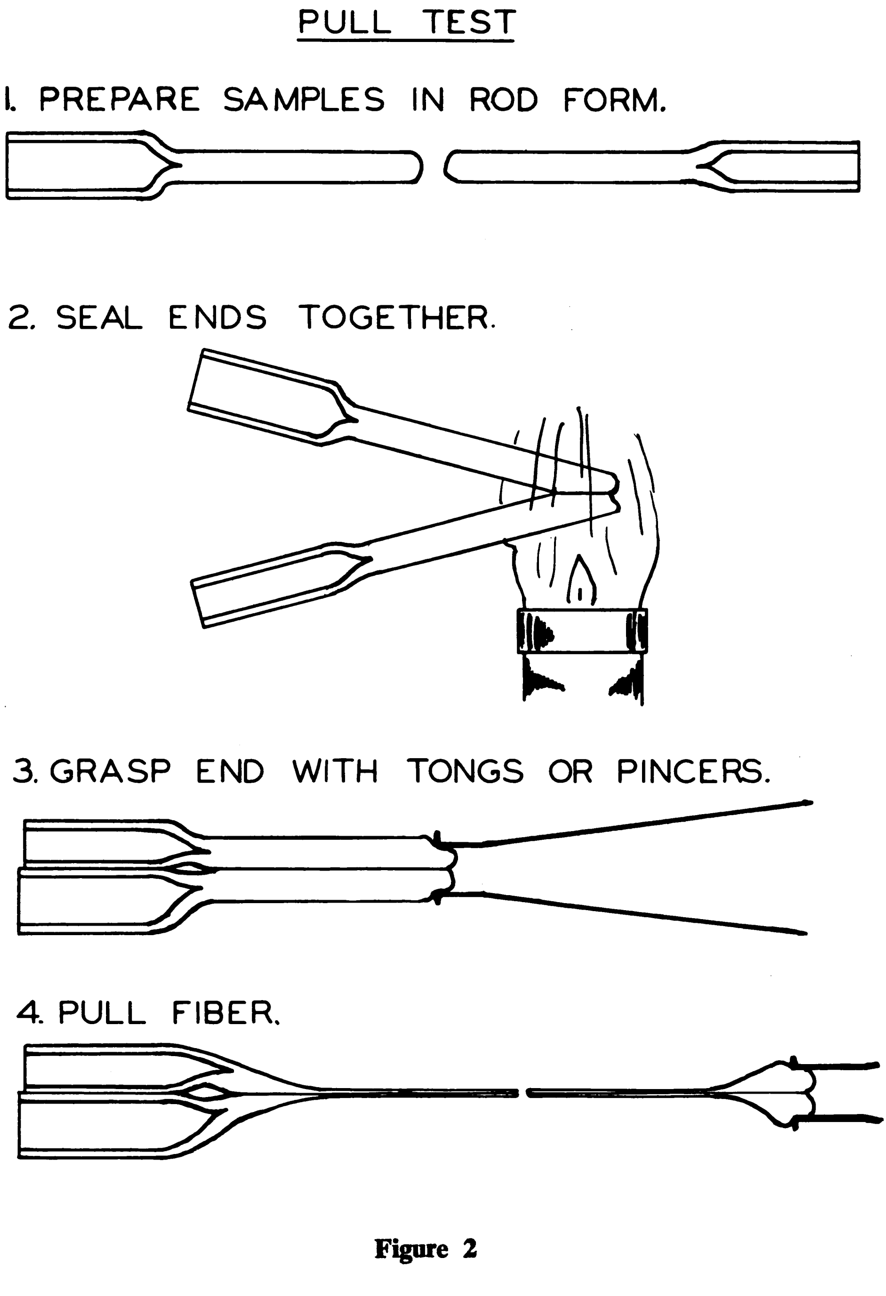
PULL TEST
1. PREPARE SAMPLES IN ROD FORM.
2. SEAL ENDS TOGETHER.
3. GRASP END WITH TONGS OR PINCERS.
4. PULL FIBER.

Figure 2

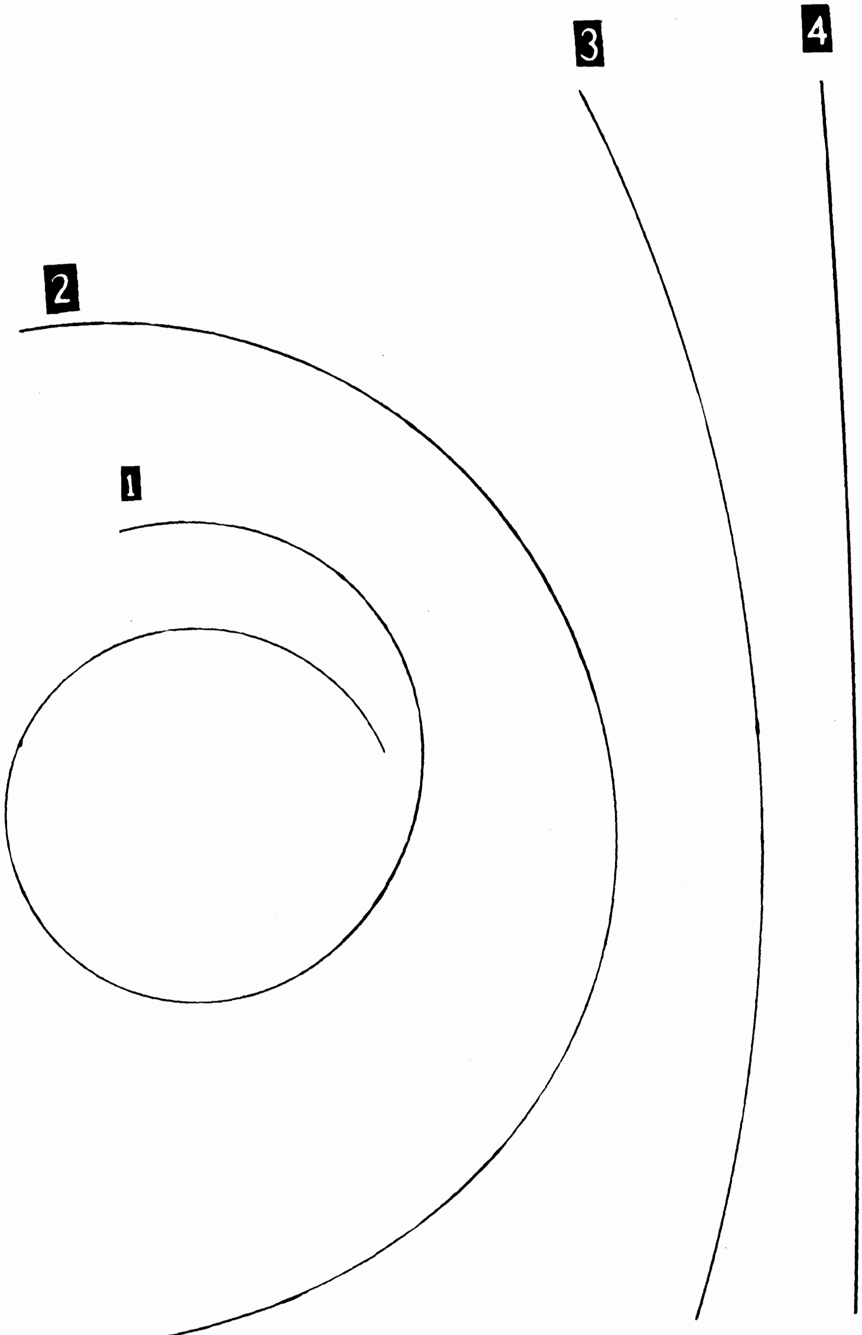

Figure 3

In the case of K-772 sealed to KG-33, the difference in contraction, represented by the distance AB in Figure 4 is approximately 6 microns per centimeter, or .0006. Substituting this in the foregoing equation, we obtain a figure of 3000 p.s.i. as the amount of stress to be expected when these two glasses are sealed together. The amount of stress which can be tolerated depends on the type of seal and how it is to be used, but for the most purposes 1500 p.s.i. is as much as can be allowed. Usually, a lower limit is advisable.

In Figure 4 curve No. 5 shows the expansion of a typical ceramic enamel. It is evident that such a material provides a good match for a high expansion glass like R-6, but does not match a low expansion glass like KG-33. This fact should be kept in mind when applying ceramic colors to borosilicate glasses. Usually considerable stress develops at the glass-color interface. To avoid objectionable effects, it is desirable to control the thickness of the applied color.

As we stated before, KG-33 glass has been so designed as to be completely interchangeable with the hard borosilicate glass which glassblowers have been using. This interchangeability applies to all of the properties of the glass, including chemical, physical and electrical properties. The applications for KG-33 glass will be those which have been found for a similar glass in the past. KG-33 will be useful whenever there is a need for a glass of excellent durability and outstanding heat shock resistance. In addition to scientific apparatus, the glass will be utilized to make such things as glass pipe and a wide range of pressed and blown articles of industrial and electronic glassware.

We have talked about some of the more important properties of KG-33 glass. In manufacturing the glass, it is important that its properties be closely controlled so that every stick of tubing will seal perfectly to every other stick of tubing and every lot of the glass will closely match every other lot of the glass, whether made today, tomorrow, next year or 10 years from now. That is what glass control means to us. Control is not something that just happens. It is achieved only by means of a control program, a comprehensive, day-by-day program. Our glass control program is administered by the laboratory, but its success depends

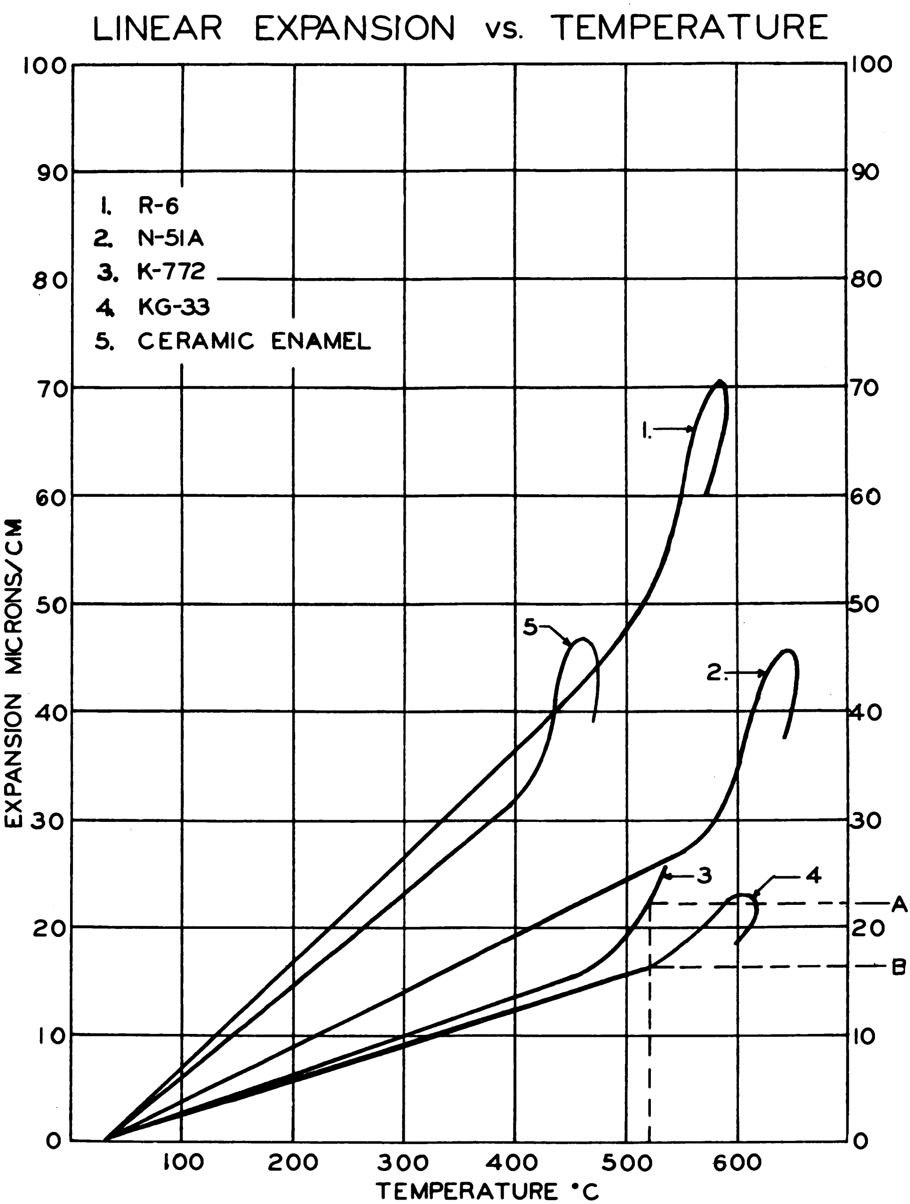
LINEAR EXPANSION vs. TEMPERATURE
1. R-6
2. N-51A
3. K-772
4. KG-33
5. CERAMIC ENAMEL
EXPANSION MICRONS/CM
TEMPERATURE °C
100
90
80
70
60
50
40
30
20
10
0
100
200
300
400
500
600
1.
2.
3
4
5
A
B

Figure 4

upon very close cooperation with the purchasing department, the companies who supply our raw materials, the batch house where raw materials are weighed out and mixed and the factory departments where glass is melted and formed. The necessity for this can be seen from Figure 5 which shows the glass-making process in the form of a flow sheet.

Paralleling the production line is the corresponding sequence of control operations. Glass control starts with the preparation of specifications for the various glass-making materials. The purchasing department transmits these specifications to the suppliers of raw materials and reports back to them any deviations or undesirable trends which the laboratory may detect. Incoming shipments are sampled and tested. The laboratory also issues to the batch house instructions for the correct proportioning of raw materials so as to produce the desired glass. These instructions are called batch sheets.

The raw batch is melted in furnaces and the resulting glass is formed into tubing and various other kinds of ware. The glasses are sampled every day and tested by the laboratory. Test results are reviewed to determine whether any glass is in need of change or adjustment. This situation is followed very closely so that undesirable trends can be corrected before the glass gets outside of specifications. In this connection, it is very important that we receive information from the furnace departments concerning any changes in operating conditions that may have even a slight effect on the composition or properties of the glass being melted in the furnace. This includes such data as temperatures, furnace load and equipment problems. When necessary, the laboratory issues revised batch sheets. Technical information and advice are also furnished to the furnace departments as required.

The tests which are used in controlling glasses are of two kinds: chemical analysis and physical tests. Chemical analysis has certain advantages—it tells you not only whether a glass is off but, also, it shows exactly what is wrong and by how much. The correct remedial step is therefore indicated. Conversely, when the chemical composition of a glass is right, all of its properties will be right. We therefore make frequent use of chemical analysis. However, analysis is time-consuming. A complete analysis of a glass normally requires a day and a half of elapsed time

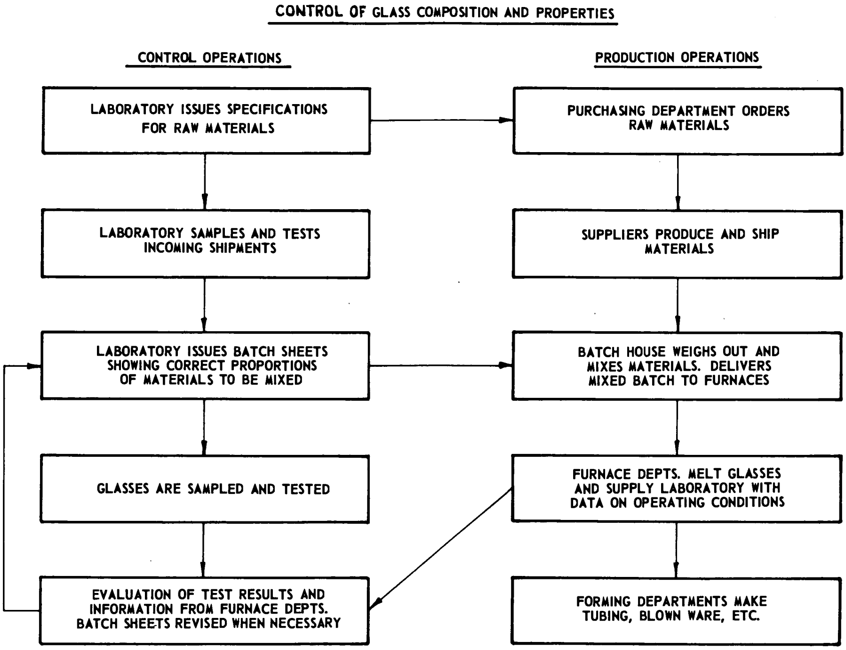

Figure 5

and about three man days of labor. Chemical analysis is therefore too slow and too costly for routine day-to-day control, and so for this purpose, we rely on physical tests. The tests most frequently used are: density, seal test, glass color, softening point, annealing point, strain point, thermal expansion, chemical durability and electrical resistance.

We do not perform every test every day on every glass. Instead, we apply a pattern of tests which experience has shown to be adequate. The schedule of tests varies from glass to glass and furnace to furnace, being tailored to meet the individual requirements of each situation. This program has evolved over the years and is the result of practical experience.

Test results tell us whether or not our glasses are within specifications, but they also do much more than this. Tests on consecutive daily samples reveal trends, which, if not corrected, might lead to serious trouble later on. Thus, we are usually able to foresee and prevent the production of any off-composition glass.

This is, of course, the first objective of our glass control program. However, if at any time, any off-composition glass is produced, then we must make certain that none of this glass gets through to our customers or into our own fabricating departments. That is the second and more important objective of the program.

We feel our management acted wisely in selecting KG-33 glass to make the new KIMAX line of ware because its properties are well suited for the purpose. We take very seriously our responsibility to see to it that the glass will at all times be closely controlled as to composition and properties. Only in this way can we be sure the glass will always serve its purpose and never cause trouble in the hands of a customer. The program which has been outlined is one means to this end.

Close control of glass properties has always been a tradition, in fact, almost a religion with us. This spirit is typical of our people who contribute to the making of glass, including the production worker, the quality control inspector and the technologist, as well as management. The attitude might be called enlightened self-interest, since what is best for our customers, is also best for us. But it is also your best assurance that KG-33 glass will serve you well.

Practical Aspects Of Glass Strength

R. R. Kegg

Kimble Glass Company

Mr. Kegg, who is director of Kimble's Chemical Engineering Laboratory, holds a B.S. Degree in Chemical Engineering from University of Toledo where he also has done post-graduate work in glass technology. His affiliations include the American Chemical Society, American Society for Quality Control and American Society for Testing Materials.

In this brief report, we are going to attack the problem of glass strength from the practical standpoint only. We will try to show what makes glass strong, what makes it weak, and some practical advances in enhancing glass strength. Also, we will give some practical precautions to preserve the strength of glass. From the practical standpoint, it must be stated:

1. That glass breaks only in tension and,

2. That it will break at the point which is usually associated with a defect in the glass surface.

To demonstrate this, we shall use a rubber eraser which simulates the structure of glass from the practical standpoint. The rubber eraser can be bent back and forth, without breaking, as long as it has no defects in the outside surface. In the bending of the rubber eraser, we will place the one surface in the compression and the opposite surface in the tension. Now, let us place a defect in the rubber eraser and bend the eraser so that the defect surface is in compression. It can readily be seen that this defect does not open up while in compression. Let us reverse the situation and bend the eraser so that the defect is now under tension. It can be seen that the defect readily opens up and this is due to the defect being placed in a tension area. There is an actual stress concentration of tension at the bottom of the defect.

You have encountered this situation, I am certain, time after time, when you want to fracture glass tubing. It takes a considerable amount of pressure to break glass tubing which has no defects in it, but if we simply score the tubing and place this point in tension, it is relatively easy to fracture the glass tubing at the score point.

Stress Associated With Defects

At this point we would like to demonstrate the value of proper stresses in glass. It has been shown that glass does not break in compression, therefore, it behooves us to place as much of the glass surface in compression as possible. At this point, it is desirable to demonstrate how stresses are obtained in glass, and also, the way stresses are developed in glass due to bending and thermal shocking of glass.

From the demonstration the following can be observed:

	Stress on Surface	*Breaking Strength*
Dead Annealing	0	4000 pounds
Tension on Surface	2000 tension	2000 pounds
Compression on Surface	2000 compression	6000 pounds

We should state that glass without defects and with a compression layer on the surface, is many times stronger than glass which is dead annealed and contains defects. It can be seen that compression on the outside of the glass and at the point of defect, makes a considerable strong glass article. An additional way of increasing strength of glass is to place a coating on the surface so that it can not be abraded easily. Such coatings as silicone will make the glass resistant to abrasion, therefore, eliminating defects, and in turn, increasing the strength of the glass considerably.

(Editor's Note: The remainder of Mr. Kegg's talk was given extemporaneously and no summary is available.)

Glass Surface Treatment

Dr. John H. Glaser

UNI-SCIENCE, Inc.

Dr. Glaser, a native of Austria, was graduated magna cum laude from Technical University in Vienna, where he received his doctorate in chemical engineering. After many years with companies in Europe, Canada and the United States, he joined UNI-SCIENCE, Inc. in 1954 as director of research. He holds a number of patents and is the author of numerous publications.

In glass, the surface is deceiving.

It appears to be ideal, smooth, homogeneous, transparent, impervious to liquids and gases, hard, stable, resistant to water, acids and alkaline solutions. Unfortunately, this is only partly true. To be inert or unaffected is a question of degrees and many times, for all practical purposes, glass is usable and suitable for a specific job.

The surface of a freshly processed sheetglass is never absolutely plane. It is wavy with slight undulations, which can be seen when held at an oblique angle in front of a line pattern. It reflects limitations imposed by the manufacturing process and is caused by its surface tension. Uneven cooling will do the same to glass-piping, tubing or rods if proper care is not taken.

Glass is homogeneous, i.e. uniform in composition and properties, only—broadly speaking—when used for technical requirements. Scientifically speaking, it has a pattern of irregularities caused by composition and thermal history. As these are rarely uniform in a larger melt, optical and molecular properties will vary. When treated with acid fumes, we get a distinct pattern of crystalline etchings, resembling a honeycomb structure with cells of different size and shape held together at their corners.

Transparency in glass is limited, ranging from about 2,000 °/A, which is part of the U.V. range for special glasses and vitreous quartz, through the visible range to about 35,000 °/A, which is the infrared or heat portion of the electromagnetic wave spectrum. Many crystals appearing in nature, or created by synthesis, have much wider range either in the U.V. or infrared. So you see there is still room for improvement in finding new glasses which will be stable and allow us to extend our range of transmission from about 1,000 °/A to 150,000 °/A.

Impervious to gases. Most glasses will allow helium, one of the noble gases, to diffuse at high vacuum, i.e. 6×10^{-10}, a range which is used quite frequently today in mass spectographic work. Metal ions like gold, platinum, silver, copper and others will diffuse quite readily through a glass wall of a vessel at a slightly elevated temperature, if an electrical potential is brought into contact between the opposing glass surfaces.

Hardness. Glasses are graded on the Mohs scale between 5 and 8 according to composition and their thermal history. We are aware that many crystals, like diamonds, corundum, sapphires, carbides, cermets and hard metals, will readily scratch and cut glasses.

Aging, resistance to water, acids and alkaline solutions. You have seen blind windows of iridescent appearance. Here the glass surface has been eroded by time, moisture and weather changes. Water leaching alkalies from the surfaces, from rain and condensation and these concentrate alkaline solutions, dissolving the glass surface and drying up into many fine layers of crystalline skeletons which are responsible for the interference colors of the rainbow effect.

High pressure steam glasses have to be protected on the steam-glass inter-surface by a thin sheet of mica to prevent the rapid breakdown of the glass. From the acid group, hydrofluoric and phosphoric acid will cause a rapid attack and solution of the glass surface. From these we learn that our wonderful glasses have severe limitations and we have to be selective to obtain the best results.

Now if we desire to change the glass surface to meet spec requirements, we have to make allowances for these inherent limitations and proceed accordingly.

To grind a glass surface with any of the various grinding media, as sand, carborundum, Aloxite, emery or diamonds, ample cooling and wetting of the glass surface is essential. The hard grain of the abrasive, pressed against the glass surface, causes minute fissures which will break open into conchial (shell-like) fractures. The abrasive can be used loose on a cast iron disk or mill, or bound into a grinding wheel by ceramic, rubber, metal or plastic bond. The peripheral speed, i.e. the speed in feet per minute of the grinding wheel rim, and the pressure upon the glass controls the removal of glass and is limited by the strengths of the bond in the wheel and its resistance to heat and pressure.

Fundamental rules are:

(1) Good cooling and washing away of ground material,

(2) Prevention of shocks and blows to wheel and glass, and

(3) Careful grinding at the edges to prevent chipping and tearing; preferably grinding in from the edge to prevent breaking out of the glass.

Drilling and engraving comes under the same heading, if it is with a three cornered file at slow speed, a special hard steel or a hollow diamond drill at high speed. If possible, always have pressure exerted against the opposing surface to prevent a breakthrough and tearing of the glass. In tubing, fill with hard wax or resin prior to drilling and see that the solid glass around the hole exceeds the cross section of the hole in size. A ground and drilled surface is a rough and unoriented structure which can be smoothed out by grinding it with finer and ultrafine grinding media, and finally polishing with the oxides of iron (rouge), cerium, zircon and many other propriety brands on a wood, felt, rubber or pitch support.

Polishing a glass surface is many times obtained with acids, as in the lead crystal glass industry. Tumblers, wine glasses, bowls and vases are cut either by hand or machines until a pattern of the right depth and angle appears. They are then dipped repeatedly into a mixture of hot hydrofluoric and sulfuric acid until a firm white coat covers the complete article. Finally they are rinsed in hot water and dried. A very brilliant, polished surface appears, characteristic of lead crystal glassware.

Electric lamp bulbs are frosted inside with a paste containing barium sulfate as a thickener and hydrofluoric acid, amonium-bifluorid, fluorspar and potassium-fluorid. Each constituent creates its own crystal pattern and coats the surface with an intricate etched crystal structure of different shape, size and configuration. These crystals grow three dimensionally on the glass surface and are finally washed out, leaving structure like "footprints" in the surface of the glass which will diffuse the light and act like a small prism. A second acid wash of hydrofluoric acid and water is necessary to round off these sharply defined crystal prints, which would otherwise cause and be the starting point of many fractures and make the glass very fragile. However, the final acid and hot water rinsed glass surface will be much stronger on impact than the original unetched glass, in spite of having been reduced in thickness by the etching process. Most of the stress centers have been removed and the surface area has been increased. A similar example would be a thin sheet of metal. It will bend and deform easily, but having been embossed or corrugated will take considerable load without deforming.

To obtain a mat effect for pictures, scales, markings, patterns, etc., different compositions of etches are used. But nearly all contain hydrofluoric acid and fluor compounds. Similar effects can be achieved by using different grades of fine sand or carborundum powder and blowing it with air or steam against the glass surface. The pattern of the sandblast, however, has no oriented structure and consists of innumerable fine fissures in the surface.

An interesting picture or effect of ice flowers can be obtained by coating a thoroughly cleaned and sandblasted surface with hot animal glue, letting it cool and dry hard. In the coated area, it will tear the surface into a distinct pattern, resembling frozen over windows with lovely ice flowers.

To enamel glass, either wholly, as in colored bulbs or lighting fixtures seen on the seaside and amusement parks, or partly, as used with transfers and many decorative glasses for lighting, table and scientific and architectural glassware, a firing-in process is used.

Glass enamels are usually low melting glasses or frits which have been melted under special conditions, chilled by running from the melt into water or cooled metal drums or belts and finally ground and mixed with additives to assure a good bond and stability to the subsurface. Metallic oxides are used for color and sometimes opacifiers are added to obtain the desired light reflection or diffusion. The enamel is mixed with a mixture of water, alcohol and turpentine in a ball mill and screened through a 400 mesh/inch filter prior to spraying, dipping or painting and printing. In screen printing, as for tumblers and containerware, hot resins have been used as transfer medium with good success. The coat of enamel is dried and fired-in, preferably in an electric furnace or lehr, where atmosphere, temperature, ventilation and timing can be closely controlled. Temperatures vary from 400° to 1000° C and have to be matched closely to the softening point of the glass. At this temperature, the enamel, which appears mat in the application, will melt and obtain the desired surface, glossy or otherwise, and will bond firmly to the glass. Then the glass is slowly cooled to room temperature to prevent the forming of stresses and strain. It is essential that the thermal expansion of enamel and glass should match in the temperature range the glass will be used, and that the enamel is resistant to all mechanical, chemical and physical requirements the article might be used for.

Metallic lustres and noble metals will diffuse into the glass when fired-in at the correct temperature and will form a film of gold, platinum, copper and many other alloys, and iridescent film from tin, cadmium, indium, iron chloride and many others. Enamels and metallic coatings printed on transfers are used widely when a multicolored effect with close registration and relatively small quantities are required. The transfers are soaked in clean water, the cover film withdrawn and the enameled surface of the transfer rolled onto the glass surface. Excess water and air are removed carefully, then the article is air dried and fired-in in the same process as directly enameled glassware.

Metallic soft coatings, as in mirrors, are obtained by reducing chemically a metal salt solution and precipitating metal molecules on a previously activated glass surface. Silver, lead, copper, gold, platinum and many others are used, but are not too permanent and have to be protected from mechanical, chemical and physical attacks.

A newer method of sputtering, or vacuum coating, has found industrial acceptance. Here metals are evaporated under reduced pressure in an evacuated vessel and condensed onto the glass surface, giving a continuous film of uniform thickness, good hardness with specific properties, i.e. infrared and ultraviolet reflection, dichroic mirrors, transparent electro-conductive films and many others. These can be coated with a transparent film of silicon oxide, which will protect the softer metals without interfering with their specific properties.

The oldest form, and still one of the finest, in the treatment of glass surfaces is the fire polish. The cooler glass surface is reheated to its softening range so the surface tension of the glass will form a smoothing-out operation, healing-up forming and cooling fissures, rounding off sharp edges, threadlike moldmarks, etc. This makes the glass stronger, shinier and more serviceable. A rapid and controlled cooling of the surface will introduce uniform contraction of the outer glass surfaces, creating compression upon the inner mass, which is still relatively hotter due to the poor heat conductivity of the glass. This pre-stressing or compression of the outer glass is commonly termed "tempering" and will make the glass more resistant to impact, load and thermal shock. It has found application in a wide field, ranging from rear windows in motorcars to cups, saucers, plates, pipes, heaters and tubes, insulators, instrument glasses and oven and boiler sight glasses.

As craftsmen working with glass, we can generally say that glass is as strong as its surface, as beautiful as its function and as useful as we can make it.

Practical Aspects Of Marking Glass

W. W. Collicott

Kimble Glass Company

Mr. Collicott received his B.S. and M.A. degrees from New York University. He served in the U. S. Army four years during World War II and was commanding officer of the 3rd Battalion of the 108th Infantry Regiment, 40th Division in Korea. He has been with Kimble Glass Company since 1946 and has been superintendent of the Scientific Division Manufacturing Operation since 1950.

It will not be the purpose of this talk to deal with details of the techniques of marking glass. It has been assumed in preparing the talk that you have a basic knowledge of the various methods used. Since most of you have had years of experience in working with glass, and the various means of marking glass have been used so widely, you must certainly have come in contact with them.

Instead, as the subject states, I will try to deal with practical aspects of the use of various existing methods—to discuss practical problems likely to be encountered in their use, the advantages and disadvantages of the common methods, and wherever possible, to give practical suggestions on the use of various marking methods.

Let's start by asking the question: Why do we mark glass? Each of you during your experience in working with glass has had many occasions, I'm sure, to need to place markings on glass

— and probably the reasons have been among some of the following:

1. To indicate fabricator identity, trademarks, etc.

2. To indicate volumetric capacities.

3. To code for future use, as in research.

4. To identify as parts of an assembly.

5. To mark points at which seals or cuts are to be made.

6. To decorate.

Dependent upon the circumstances surrounding the marking, and the intended use and purpose of the markings, they can be temporary or permanent in nature. They can also be placed by either freehand or mechanical methods. I imagine that many of you in your glassblowing work make daily use of the temporary and freehand methods. They are numerous and can be of much practical assistance. Perhaps a brief discussion at this point of some of the most common and most practical of these will be worthwhile.

Freehand and Temporary Marking Methods

1. Use of Glass-Marking Crayons and Inks

The various crayons and inks are convenient to use and it is this element of convenience which is their chief advantage. The limitations of this type of marking medium are those of impermanency and appearance. Within this group, however, there is some variation in degrees of durability. For instance, markings made by some of the wax crayons can be removed easily by rubbing with a cloth or paper, or dissolved easily when washed routinely in hot water. These are useful in work where it is desirable to remove all traces of markings frequently. Other wax pencils are heat resistant to a greater degree, being capable of withstanding hot air or steam pressure sterilization and the heat of flasks in which liquids are boiling without spreading or blurring.

Some crayons leave markings which are legible after exposure to flame but are not burned in and, therefore, can be removed when so desired.

Marking ***inks,*** placed freehand on glass with brush, felt tip pen, ballpoint pen, or regular type pen, provide a somewhat more durable type of marking. Ceramic and non-ceramic inks are available. Many glass-marking inks are water solutions of colored materials containing sodium silicate. Inks are used commonly for numbering beakers, labeling parts, reagent bottles, etc. Many of these inks are not affected by usual laboratory solvents and are resistant to some degree to both acids and alkalies.

Inks and crayons in a variety of colors are listed in many laboratory supply catalogs, with descriptions of the amount of durability to be expected from each. If you are interested in these, consult these catalogs.

2. Use of Diamond Pencils

Another freehand method, of course, is the use of a diamond pencil. Diamond pencils also are obtainable from laboratory supply houses. Similarly to crayons and inks, they are very convenient to use. A practical advantage of diamond marking is permanency, but this advantage is offset by several rather serious disadvantages. The first, and perhaps most serious, is the fact that diamond scoring substantially weakens the glass at the point where the surface is broken. Diamond marking also has relatively poor legibility because of its faintness. In order to achieve neatness and a tailored appearance in the marking, skill in use of the pencil is needed.

3. Glass to Glass Abrasion

Of the same general nature as diamond marking is abrasion marking with another piece of glass. This is undoubtedly done by many of you to mark length, using a backstop to insure uniformity of length from piece to piece.

4. Use of Pressure Sensitive Tapes

For convenient freehand labeling of glass parts, there are several pressure sensitive adhesive tapes on the market. These are useful in places where it is undesirable or inconvenient to keep inks or crayons about. These tapes also are listed in most laboratory supply catalogs.

5. *Rubber Stamping or Writing With Etching Compound*

Rubber stamping with etching compounds is another relatively simple means of marking glass. The markings made by this method are light and often not too striking or attractive in appearance, but they are permanent, and the method has the advantage of being inexpensive and easy to set up. In this method, a common etching compound is one combining ammonium bifluoride, hydrochloric acid (60 per cent), barium sulfate and sugar. A cloth or felt pad is saturated with the fluid and a rubber stamp or other means is used to transfer the fluid to the glass surface, where the fluid is allowed to remain about one minute, then is rinsed off with water, leaving a frosted marking. From the practical standpoint, this method should be used with adequate safety precautions in the form of good ventilation to prevent excessive breathing of the HF fumes by the marker. Provision also should be made for protection of hands from contact with the solution.

6. *Use of Decalcomanias*

The use of decalcomanias or "decals" will be discussed separately later, but mention of them also is timely while we are thinking in terms of marking methods which are convenient for use by the glassblower or laboratory technician. They can be very useful and convenient for placement of lines, scales, arrows, symbols, titles, etc. Your own organization has had decal sheets prepared which have a variety of the most frequently needed types of printed information on them. These can be obtained easily, at a very reasonable cost, through your headquarters.

The methods of marking discussed thus far have been chiefly non-production methods. They are satisfactory for occasional use, but they are not the methods used in most of the work in glass-marking done on a manufacturing basis. We will discuss next some of these latter methods.

Production Type Marking Methods

1. *Blasting*

One of the most common production type methods of marking glass is by blasting with abrasive powders or grits. This is a very practical method because it is fast and the equipment needed is relatively inexpensive. It is effective for forming marking spaces on glassware, making permanent labels, trademarks, or printed identifying data and the like. The design desired is obtained by using a stencil cut usually from soft rubber. Rubber is used because this material is more effective in resisting the abrasive action of the various blasting compounds than harder materials such as steel, plastics, etc.

A practical aspect to be considered in setting up blasting methods is that of dust control. Blasting equipment must be adequately equipped with dust collecting and exhausting facilities or the working area will quickly become undesirable as to working conditions both for worker and for the product. In providing such dust collecting facilities, it is well to think in terms of materials for ductwork which will keep maintenance at a minimum. Once again, as in the case of stencils, rubber is the most favorable material.

2. *Printing*

Marking glass by printing directly on its surface is one of the most widely used methods today because of the universal practice among bottle making concerns of using applied color labels and decorations on their ware; and also because of the printing process used to identify electric bulbs, radio tubes, etc.

The marking materials used in printing on glassware are of a variety of types. Before discussing the materials I'd like to discuss briefly the methods of application.

a. *Offset Printing*

This method uses an intermediate pick-up principle. That is, the type does not contact the glass directly. It places an imprint on a gelatin or rubber mat and this is transferred to the glass by rolling the glass over the pad to pick up the image.

This type of printing is used mostly for placement of trademarks and other identification purposes. The deposit of color obtained by this method is so thin the imprinted marking is usually too light for decorative purposes or for calibration lines. The mark is somewhat akin to a watermark trademark in paper.

The method has a definite advantage in the fact that it also is inexpensive to set up and production can be rapid. Ordinary readily available metal type can be used. Ceramic inks or non-ceramic inks can be used in offset printing. If ceramic inks are used, a reasonable degree of permanency is achieved. The durability of the imprint is generally in proportion to the thickness of the application. The offset printing method is not capable of giving as thick a deposit of color as the screen method of printing, which will be discussed later.

A manufacturing advantage of the offset method is that, because of the thinness of the deposit placed on the glass, it is possible to place ware directly on mesh belts for firing without incurring the expense of providing special supporting racks. These are sometimes an expensive necessity to prevent smearing during firing in other methods of printing.

b. Rubber Stamp Printing

Rubber stamp printing with an etching compound has been discussed earlier in this talk as an off-hand method. However, the use of rubber stamps should be mentioned among the production methods also, because rubber stamping directly on glass is the method used to identify electric bulbs, fluorescent fixtures, radio and other electronic tubes, etc. In terms of the number of units processed annually, perhaps it would be safe to say that this is the ***most*** used method of any. With electric bulbs and the like, the most popular printing material is a silver type ink, usually silver nitrate. The printing is flame fired using a light non-oxidizing fire. Ceramic inks and enamels can be used in the rubber stamp process, as in the offset printing method. A little more color is deposited by the rubber stamp method than by the offset method. The key to successful transfer of imprint by the rubber stamp method is the use of a "rolling action" rather than direct pressure. This is also true in the offset method.

From the standpoint of practical considerations, the rubber stamp method also has the advantage of being easy and inexpensive to set up. The availability of rubber stamps is good, and the other equipment necessary is comparatively simple. Special racks for support during firing are usually not needed for rubber stamp printed items for the same reasons as those given for offset printed items.

c. Screen Printing

Screen printing is another of the most widely used methods of marking glass. It is used in both decorative marking and in marking for calibration purposes. Its use in the latter field is growing rapidly.

Screen printing in bottle plants for applied color labels is done mostly by automatic machines. In many printing installations, however, hand-operated machines are still in use.

Screen printing uses the screen and squeegee method. The principle is so well known it need not be discussed here. However, perhaps it would be well to mention some of the practical improvements in screens themselves in recent years. Silk or fine mesh wire screens were most common at one time. Now, however, monofilament materials are supplanting these materials in many applications. Nylon and Perlon (an imported product) are examples of the monofilament group. They are so named because each thread is a single strand, not a twist of many smaller strands. Silk and dacron are examples of the latter type. A few of the practical advantages of monofilament screens are:

(1) They come in finer mesh.

(2) They have good resistance to acids and alkalis.

(3) Their moisture absorption rate is very low.

Screen printing has several practical advantages over other methods of marking glass. It also has definite limitations. Among its advantages are:

(1) Attractive appearance.

  (a) Multi-color effects are possible.

  (b) Intricate and attractive designs are possible.

  (c) Imprints have a tailored and finished appearance.

(2) Relatively good durability (dependent upon type of color used).

(3) Rapid application is possible, even by hand.

(4) Hand equipment is comparatively simple and inexpensive.

In the use of screen printing for calibration marks there is a rather severe disadvantage in that the scales cannot be made to vary in length piece to piece as easily as in the etching method. Therefore, either precision bore tubing must be used or a close preliminary sorting of tubing into bore diameter groups must be made. The latter, with all the handling and identification problems involved if applied to mass production, can to some degree negate the economies which the screen method versus the etching method offers.

Another disadvantage of screen printing of scales exists only if enamels are used. This is the fact that the marking is placed only on the surface of the glass as compared with being imbedded in an etched line. Tests have shown that even fused enamel markings are less durable in printed scales than in etched scales. In addition, even if the coloring eventually is removed from the etched scale, the etched line is still present to mark the capacity.

However, while the above can be stated as a disadvantage, it can also be stated that the increasing use of stains for both printed lines and printed legends or inscriptions is rapidly removing this as a disadvantage. In the field of legends, particularly, screen printing offers a distinct advantage over etching, in that it makes possible thick line block lettering which is much more legible and, with regard to capacity markings especially, helps preclude the possibility of using an instrument of incorrect size.

3. Use of Decalcomanias

The use of decalcomanias in marking glassware is increasing. They are being used for trademarks, inscriptions, decorative purposes and for capacity scales.

Decals can be obtained in ceramic colors, non-ceramic and in stains. In some ways the use of decals is one of the quickest and best methods for general identification use. Their application is a single process and needs only simple equipment in the form of jigs, etc., to insure accurate placement on ware. The expense of unit cost per decal is sometimes a practical disadvantage as compared with some of the other methods of marking.

With regard to their use for calibration purposes, they involve the same problems mentioned in discussing screen printing. Their use pre-supposes the use of precision bore tubing or close bore sorting of tubing prior to placement of decals.

Decals, in general, offer advantages in that they are available printed in several colors, precisely registered, and with a range of shading not possible in other glass marking methods. All in all, increased development work among decal companies indicates that they are hopeful of stimulating much broader use than has been the case in the past. Reduction of unit costs and more efficient labor saving means of transfer are under study.

4. Etching

In connection with ***calibrated*** glassware, the most widely used method of marking glassware is the etching process, using hydrofluoric acid. In this process, the ware must first be coated with wax. The desired markings are then engraved in the wax coating and, after this step, the ware is dipped in hydrofluoric acid. The final step is the removal of the wax coating. Incidentally, the removal of the last minute traces of wax, which is necessary on calibrated ware, is not exactly an easy problem. Various methods are in common use, including the use of steam, strong hot water sprays, hot water with strong detergents, vapor degreasing equipment, etc.

The engraving portion of the etching method makes use of various types of machines, among them being jewelers' engraving machines for numbering, segmental hand lining machines and, of course, numerous kinds of single and multiple lining and numbering machines for mass production. Many of the latter are machines developed in particular factories for their own types of uses and, therefore, are highly specialized in design. There are a few commercial machines available, however, through companies such as Fish-Schurman.

The waxes used now in the etching method are mostly the micro-crystalline type of petroleum origin. These are sold by various oil companies. Beeswax and a combination of beeswax and paraffin used to be the most widely used waxes. No matter what type wax is used, the temperature of the melted wax is important. It must be adjusted in relation to the thickness of wax coating desired. In the waxing process, humidity is a factor to be considered. It can have a detrimental effect on the protection afforded by the wax coating. Ware should be thoroughly dry before being dipped for its coating.

Other ***practical*** considerations in the etching process are:

a. Control of temperature of hydrofluoric acid.

b. Ventilation of etching area to safeguard health of employees.

c. Protection of personnel from danger of acid burns.

d. Protection of wax coating on ware to prevent removal of the coating from portions not desired.

e. Maintenance of equipment. Deterioration is rapid because of the HF fumes.

f. Neutralization of drain-off water to prevent acid contamination of sewerage and resultant destruction of sewer pipes and contamination of streams.

g. Protection of ware after dewaxing so it will not be frosted by HF fumes.

Some of the above considerations can be looked upon as disadvantages of the etching method as compared with other marking methods. Its greatest disadvantage, however, lies in the fact that it is a costly multi-step process. Instead of a single direct application of a color and then firing, the ware must go through the ***five-stage*** process of waxing, engraving, acid dipping, dewaxing and filling-in of etched lines before the firing process. Each step involves labor costs and the hazard of loss of ware through damage.

The acid etching method also presents problems in obtaining the proper type of etched line to receive and hold the filler. This problem varies with the different types of glasses. The type of etched line produced in the lime glasses is rougher and, therefore, fills more easily than etched lines in borosilicate glasses.

Etching has a very practical and real advantage for calibrated ware. As mentioned briefly previously, even though color may eventually come out of an etched line, the piece of ware will still be usable because the line will still be there to see and use. Another advantage of etched lines lies in the fact that they can be finer than printed or abrasively produced lines. They can also be placed completely around the circumference of the ware, when this feature is desirable.

The etching process sounds complex and perhaps not suitable for use by the individual glassblower who wishes to calibrate a few pieces of ware. However, I know that many of you here realize from experience that simplification to a point practical for such a person to use is entirely possible. The glassblower can use a small wax pot to wax the portion he needs protected. He can engrave a line by hand, and then pour HF over the engraved portion. After this step, the dewaxing process for a small number of pieces can be much simpler than in a mass production operation.

Types of Colors Used in Marking Ware

In the screen printing, offset printing, decalcomania and etching methods of marking glassware, the range of types of marking materials available for use and possible to use are similar. These fall into three general categories:

1. Non-ceramic colors.
2. Ceramic colors.
3. Stains.

The particular type of color employed will depend upon the expected end use of the item in question. In general, ***non-ceramic*** colors include such media as inks, paints, epoxy resin based colors and silicone based colors. These, of course, may be of any desired hue. They are used in applications where resistance to heat, water, solvents or other chemicals is not an important factor. These non-ceramic colors are sometimes referred to as cold-colors because they can be applied to glass when it is not possible to re-fire the item. They will dry in air or when baked at temperatures up to 300°F to 500°F. While they lack the permanency of ceramic colors, they offer the advantage of rapid and relatively inexpensive application. With the recent development of the epoxy resins and the silicone based colors, a degree of permanence never possible before has been achieved.

Ceramic colors are, in general, pulverized glasses of low softening point and rather high expansivity which, when applied to glass and fired above the softening point of the color, fuse to the base glass. The range of hues is somewhat more limited than non-ceramic colors but still covers a wide variety. Usually they are produced by melting a colorless flux and grinding with it the desired amounts of coloring oxides.

Ceramic colors are classified into two main categories as to firing characteristics: — (1) low-firing colors and (2) high-firing colors. Assuming that an annealing type of firing schedule is used (15-minute soak period), the low-firing group of colors will fire at temperatures under 1000°F and the high-firing colors will fire at 1050°F to 1100°F. It must be remembered that firing temperatures and the time element are closely inter-related. Higher temperatures can be used if the firing process is of the flash type. Other factors also enter into the question of firing temperatures, such as wall thickness and type of glass.

When ceramic colors are properly fired, they show a good gloss and a considerably greater degree of durability than non-ceramic colors. They have one outstanding disadvantage. They must be matched with regard to thermal expansion to the glass on which they are applied. If this is not done, strains are set up in the base glass when the color cools. These strains, in the case of small diameter items like pipets or thermometers, may lead to breakage at the point where the color is applied. In other cases, the color may chip off the surface of the glass, leaving unsightly, broken areas. In printed inscriptions, particularly, this is a hazard. In practice, most colors approximate the soft lime glasses in expansivity and, therefore, there is little or none of this weakening effect in cases where colors are applied to such glasses. However, in cases where the colors are applied to borosilicate glasses, there is a marked difference in expansivity and weakening will occur. This may amount to as much as 40 per cent to 50 per cent loss in strength due to color. It is for this reason that stains have been developed for our borosilicate glasses.

The third class of colorants are the ionic ***stains.*** These are generally fine powders containing salts of silver, copper and iron. At present, they are limited to shades of yellow, brown and red. They are also relatively much more expensive. Variations in tint can occur due to variations in firing temperatures and also due to the types of glass on which they are applied. They have two outstanding advantages which, in some cases, make up for these drawbacks. These advantages are:

1. Outstanding durability in that they are not affected by any chemical that does not dissolve the glass itself.

2. They produce no weakening effect on any type of glass.

Thus far in this talk, discussion has touched upon some of the methods used in marking glass and the types of colors used. To complete the discussion, a brief summary of practical tests to determine durability of markings is in order.

Testing Methods

1. Non-Ceramic Colors

The use to which printed articles will be put, determines, to a large extent, the requirements and tests for durability. For example, in the case of ***non-ceramic*** colors, which will not stand excessive heat or chemical attack, the following tests have been used:

> Immersion in 5 per cent phenol at room temperature. This test is part of the government specifications for the filler on blood pipets. The requirement is that the color shall not be removed after one hour's immersion. Other reagents which have been used for testing non-ceramic colors are:
>
> 1. Alcohol
> 2. Lubricating oil
> 3. Boiling water
> 4. Carbon tetrachloride
> 5. Toluene

The more recent developments in this field, such as the silicone based paints, show considerably better resistance to these materials than paints which were used a few years ago.

2. *Ceramic colors*

As regards the durability of ceramic colors, here again the expected use of the item determines the durability requirements and tests. For colors which may be in contact with foods or beverages, immersion in a citric acid solution is widely used. The lead dissolved after a prescribed length of time can then be determined and the relative durability of the colors estimated. Kimble items are not generally so used and, therefore, we do not regularly use this test. Our items may be exposed to:

a. Disinfectants, such as the phenol solution mentioned above.

b. Detergents, such as are used to wash glassware.

c. Chemical agents, such as acids and alkalies, to which our scientific glassware may be exposed.

Ceramic colors vary widely in their resistance to any or all of these classes of materials. For example, in the case of phenol, one red color tested showed discoloration at the end of one week. Others remained unaffected for months. Any colors used for printing drug labels must withstand at least six weeks immersion in this solution.

As regards detergents, those containing phosphates are more severe in their attack on printed ceramic colors than other types. In tests made in our laboratory, among those showing severe attack were Surf, Fab, Alconox and Tide. Moderate attacks were produced by Dural H, Ivory soap, Haemo-Sol and Fels Naptha soap. Some detergents that gave little or no attack on colors were Vel, Oakite, Dreft, Calgonite, Diversey D'Luxe, Safe-T-Clean and Super Soilax.

At present, we are using a boiling test in a solution of Alconox as a screening test to determine whether or not a new ceramic color has adequate resistance to detergents. If the color is relatively unaffected by this test, we consider it satisfactory. Results may range from no effect up to complete removal in one-half hour.

With respect to chemicals, such as acids and alkalies, we use two separate tests. The first is a boiling test in a diluted hydrochloric acid solution; the second, a boiling test in a solution of sodium hydroxide. Roughly 2/3 of the ceramic colors we have tested in these reagents fail in one or the other. Our test is more severe than a test often required in a federal specification, which calls for no color removal when samples are immersed for one hour in either concentrated hydrochloride acid, sulfuric or 4 per cent sodium hydroxide solution. The more resistant colors will pass the test in sodium hydroxide but may fail in acids. When a color passes both of these requirements, we include it in our list with the proper notations. All of the colors used in filling-in our graduated glassware will pass all of the above tests. It should be pointed out in this connection, that the test is more severe when the color is printed on the surface of the glass than when it is filled into a graduated line. It is not always possible to obtain this extreme durability when the colors are printed on the surface of an item. This is particularly true of reds and yellows. Blues, blacks, greens and whites will usually show better resistance to chemical attack.

3. Stains

A brief comment on testing stains for durability will conclude this discussion.

In general, the same tests are used on the ionic stains as on ceramic colors, but since these stains become an actual part of the base glass, no attack is found generally in the tests in acids (except hydrofluoric), alkalies, detergents and antiseptics. It might be said, in general, that the stains are as resistant to attack as the glass surface itself.

Mechanization Of Lampworking Techniques

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Most of his time has been devoted to glass laboratory apparatus, including the manufacturing, advertising and selling operations. He presently is Technical Director for the Scientific Sales Division and in this capacity is concerned with processes used to make laboratory apparatus and the correctness of the finished product.

When the term mechanization is used in industry, it is usually applied to the complete or partial substitution of machines for human skill in the manufacture of products sold in large quantities.

There are a number of examples in the glass industry of complete substitution of machines to produce products that were made at one time by hand from tubing by glassblowers. Test tubes, culture tubes, ampuls and vials are in this category.

Ampuls and vials are primarily containers and, as such, are used only once. They must be low in cost. Test and culture tubes are re-used but the quantities needed are large and users insist that these items also be inexpensive.

Even if it were possible to find or train sufficient people to produce all of these items by hand, the cost would be excessive. Hence, machines had to be developed.

In most instances, these automatic machines use the same basic techniques for forming the glass that are employed at the bench. But, mechanical and electrical devices have been substituted for the judgment of the glassblower and the skill of his hands.

There are many other pieces of glass equipment that might be made completely by mechanical means, but the volume of sales, while large, still does not warrant the expenditures that would be needed to develop the required machinery. In addition, there are items whose shapes do not lend themselves to automatic fabrication, even though sales are reasonably large.

Nevertheless, even in such cases, partial mechanization is sometimes possible and advantage has been taken of the possibilities. This is particularly true of the simple, common parts frequently needed. The production by pressing of feet for cylinders, of stopcock plugs and stopcock barrels may be mentioned. Also, the forming by machine of inlet and outlet tubes for condensers, filter flasks and other instruments is done; as well as the fashioning of screw threads for necks of Erlenmeyer flasks. Originally, all of these operations were carried out in lamprooms.

Another example of partial mechanization is the use of lathes for many production operations. Until recently, the assembly of all apparatus was done by skilled glassblowers working at the bench. Now, unless the pieces to be made are too complex, this work is being done on lathes by unskilled operators. After a short period of training, these operators turn out work of excellent quality.

These are some of the jobs successfully performed on lathes by these unskilled operators:

1. Sealing of stopcock barrels to tips and graduated tubes to make burets.

2. Sealing of feet to open-end tubes to form footed cylinders.

3. Sealing of suction and delivery tubes to bodies to make volumetric pipets.

4. Sealing of stopcock barrels to delivery stems and factory-blown bodies to form separatory funnels.

5. Sealing of stems to pressed bowls to make filtering funnels.

6. Sealing of sidearms to factory-blown bulbs with long necks to form distilling flasks.

Production, also, is greater with lathes. In fact, it would be difficult to obtain enough glassblowers of sufficient skill to do the amount of work required.

There still remain many glass items that have comparatively small sales or are quite complicated. This is the field where the skilled glassblower still reigns supreme. Usually the work is done at a bench, although lathes may be used here, too, at times. In this case, the lathe is a mechanical adjunct and not a substitute for skill.

Even in this work, however, the availability of machine-made parts and of the simpler complete pieces of apparatus provided by the lathe operators are highly desirable as raw material for his work.

There is little challenge for the highly skilled glassblower in the production of such pieces. By having these pieces at hand, he is enabled to use his skill to the best advantage and greatest personal satisfaction. Ground joints, stopcocks, round bottomed tubes and various starting shapes, such as footed cylinders, flat and round bottomed flasks, are important examples of this kind of raw material.

While this talk could include a description of machines producing automatically products, such as test tubes, vials and ampuls, I believe such a discussion would be of interest to only a minority of the members of the American Scientific Glassblowers Society.

Consequently, I am going to devote most of the time allotted to devices developed to simplify the production by hand of various shapes from tubing, or to aid in the assembly of finished apparatus.

Many mechanical devices have been developed to assist the glassblower at the bench. The usual hand tools possessed by every glassblower can be so classified. Among them are the usual tapered and straight reamers of various cross-sections, triangular shapers, etc. At first these were made of wood; now carbon is used. For making small holes, carballoy reamers have also been satisfactory. Metal reamers have been tried, but they leave a metallic deposit in the glass. Holders for tubing and flasks have also been made to various designs, as needed by individual workers. Today, ground glass joints are frequently used to hold pieces being worked.

Benches have also been rigged so that the glass to be worked can be preheated mechanically to cut down on the time that the glassblower will need to handle the glass.

Figure 1 shows a typical set-up when the end of a glass tube is to be shaped by inserting the heated end in a forming tool.

First, the end of the tube is preheated by the wing-tipped burner and cross-fires at the right rear. The tube rests on the rollers and is kept turning.

The actual forming is accomplished at the cross-fires located at the front of the bench. Here, the glass is further heated until soft, while being rotated on the rollers by hand. The glass is then inserted in the forming tool and shaped, usually while still being rotated.

Finally, the finished piece is placed up on the rollers at the left rear. At this station, a wing-tipped burner bathes the hot end in a soft fire to give it a partial annealing. This prevents cracking until such time as the piece can be annealed.

Rotation of the rollers used in the preheating and after-heating operations is accomplished by strong cords attached to the shaft of a small motor.

Figure 1

Many special devices have been provided the bench worker to assist him in shaping glass articles. One of the most commonly performed operations is reduction of the end of a piece of tubing to form a neck. Figure 2 shows a typical tool for this purpose.

Originally, tools of this type were used in the production of vials when vials were made at the bench. The great problem was to get necks of precise inside diameter so that one size of cork or rubber stopper could be used for all vials of a size. A tool such as the one shown will do this job.

The forming portion consists of two flat plates, called the jaws, and a plug. The plates are mounted on opposite sides of a frame. The plug is attached to the end of a rod extending from the left end of the frame. In this case, the plates have a groove since the neck is to have a beaded finish at the open end. The ends of the plates that touch the glass are rounded to give a radius to the shoulder of the glass instead of a sharp corner.

The frame is constructed so that the jaws will be some distance from the plug when tool is not in use. In order to form a neck, the tool is brought into contact with the heated end of a piece of tubing and the tool squeezed by one hand while the tube is rotated by the other hand or by rollers. The jaws reduce the diameter of the tubing until the tubing is in contact with the plug.

Hand-made vials, of course, are seldom produced today, but this style of tool is used for many other purposes. For example, the necks of many factory blown shapes, such as separatory funnels and volumetric flasks, must have closely controlled inside diameters so that these necks can be ground to take interchangeable stoppers. As produced, such necks vary considerably, for the outside diameter only is controlled. Tools such as the one illustrated are used to obtain the necessary uniformity.

These tools — perhaps with some slight modification — are also used to form from tubing the blanks for ground joints and weighing bottles. It is even possible to have the neck smaller at the opening than it is further back. One way to do this is to have the plug in two halves and to incorporate in the tool a means to cause the end of each half to move outward while the plug is inserted in the tubing.

The tool is lubricated before being applied to the glass. With soft glass, reasonably good results have been obtained with steel plates and plugs, using tallow for lubricant. Borosilicate glasses, however, are much hotter when being shaped and tallow evaporates. A liquid graphite lubricant is necessary, which forms a coating on the tool.

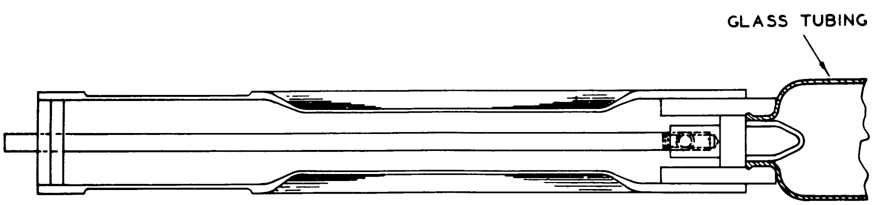


Figure 2

Cast iron is much more satisfactory than steel for the jaws and plug and is in general use today. The surface of steel is too smooth to hold the graphite in an even coating and has a tendency to stick to the glass.

Figure 3 illustrates the method of producing a stopcock barrel by a tool that is quite similar to the necking device just described. The shapes of the plates and plug are shown in 3 and the cross-sectional view. The plates for the jaw are flat and the plug has two flat sides.

The operation is illustrated in 1 to 7. Starting with a cut length (1), the tube is flared as shown in 2. Then, the tool is used to form the taper and the bead at the large end, as shown in 3 and 4. The tool is used again to finish the bead at the small end, and at the same time a bulge is blown just beyond this bead, as seen in 5. The space between bead and bulge serves as a guide to the glass-blower for placing his scoring knife when scratching the glass to detach the finished barrel. Following this the holes are punched (6) and the barrel is severed from the tube, as indicated in 7. The operator then proceeds to tool a second barrel at the severed end of the original length of tubing. It will be seen that the enlargement on the end of the original tubing also provides extra glass to help in forming the bead of the next barrel.

To punch the holes, the barrel is heated strongly at the approximate location where the holes are to appear. Then the barrel is placed over a vertical hollow mandrel having the dimensions of the inside of the barrel. The mandrel has openings in the side corresponding to the location of the holes to be made in the barrel. Then two rods are caused to move into the glass, punching the holes.

This mechanical operation has been of great help in forming holes at exactly the proper places in barrels where stems are to be sealed on.

Several types of tools have been developed for blowing shapes at the bench. The most common is shown in Figure 4.

This tool is used to produce the bodies of small flasks, although any article of circular cross-section can be made in a similar tool.

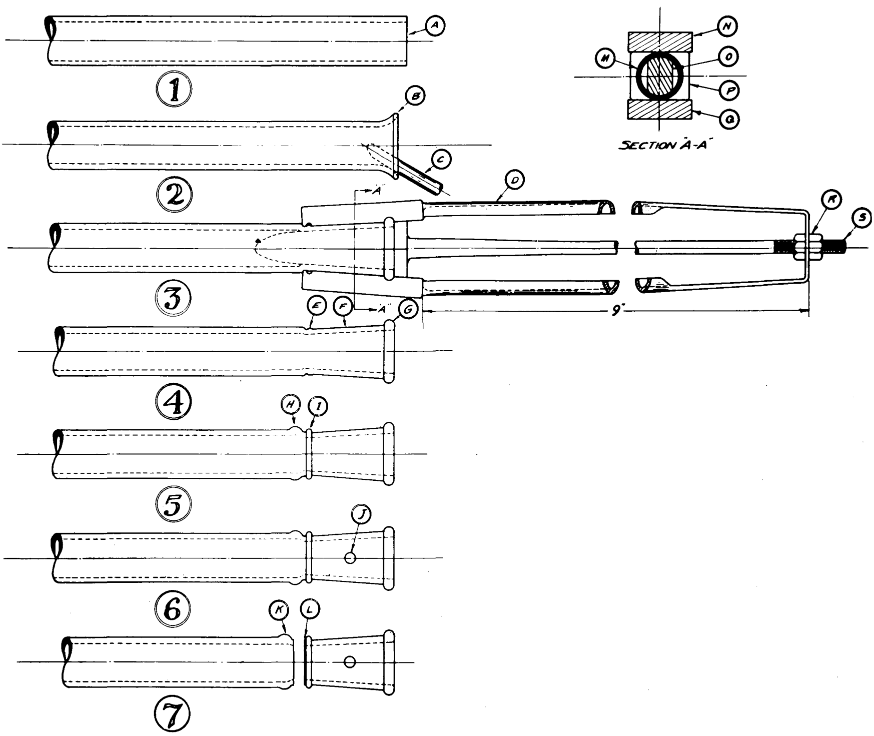


Figure 3

Here we have a jaw consisting of two shaped plates. No plug is needed. The plates have the same thickness throughout the length of the body to secure an even heating of the tool. This prevents sticking of the glass. Notice also the small space between the plates. This is to take care of variations in the diameter of the glass tubing used.

In a production factory, the jaws and plug used to form a particular item are usually kept attached to the same frame, so that the complete tool will be available for instant use. For the small job-work shop, it may be advantageous to have a few frames and attach different jaws and plugs, as needed.

Another type of tool used for blowing shapes is shown in

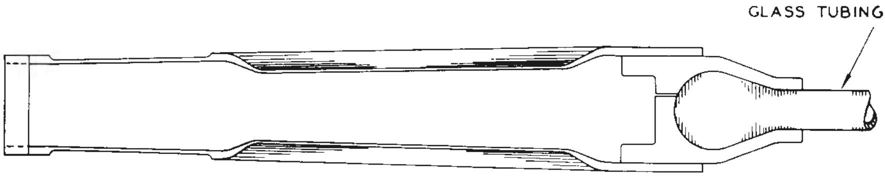
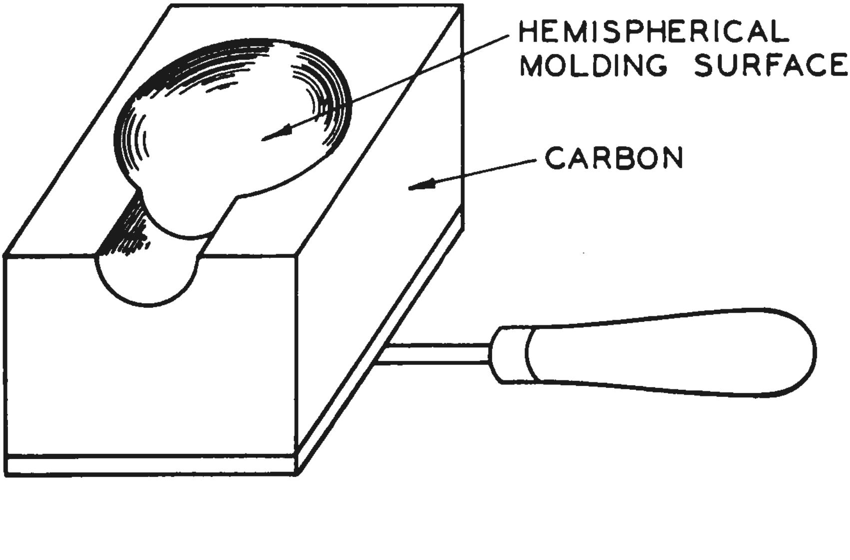


Figure 4

Figure 5. It will produce a bulb on the end of a piece of glass tubing. This mold is made of carbon. The glass is turned, of course, while being blown.

Figure 6 shows a slightly different type of carbon form for blowing a bulb in the middle of a tube. The openings in the ends are placed on the tube beyond the heated zone so that the bulb will be centered when blown while the tubing is being turned.

Bulbs blown in tools such as those shown will be more uniform in size than if made off-hand with the aid of calipers. This is particularly important if the bulbs are to hold an exact capacity.



LATHE TOOL FOR FLASK BULBS

Figure 5

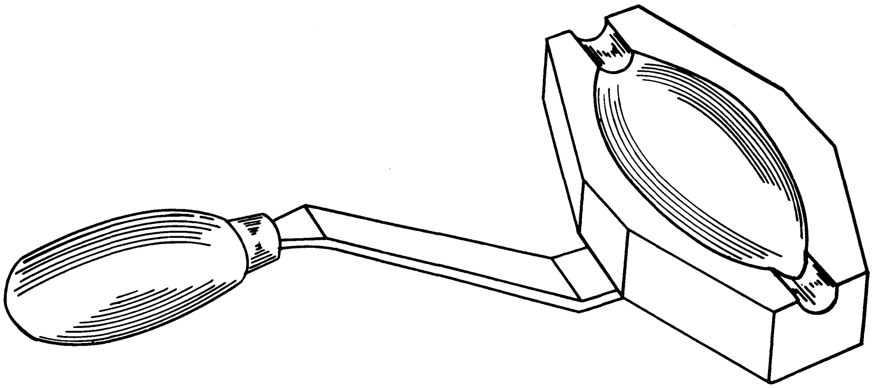


Figure 6

Carbon tools are easily adjustable for size. For example, the bulb produced in the tool shown in Figure 6 is expected to hold exactly 47.5 ml. The carbon is first made slightly smaller than the dimensions secured from an off-hand bulb of correct capacity. Bulbs blown in the tool are then calibrated. If small, the off-hand sample is mounted in a lathe. With the lathe turning, the carbon is held against it, using an abrasive slurry to grind the carbon. This treatment also is used to produce a fine surface on the carbon.

The tools described so far are used to form objects of circular cross-section. Tools can be made, however, to enable the glassblower to make other shapes, starting with round tubing.

The instruments shown in Figure 7 are examples of such a technique. They are called Earle's T-flasks. A method of making them has been described in a publication of the National Cancer Institute by Dr. Earle and Frederick Highhouse, of the Institute's glassblowing shop.

At first, the flasks were blown in a bench mold from tubing, but the result was unsatisfactory. The molded flasks were thin at the corners and the wide sides did not have the uniform wall thickness throughout which is needed for the work to be done.

The tools used in the method of manufacture finally adopted are shown in Figure 8. These are the tools for the largest flask.

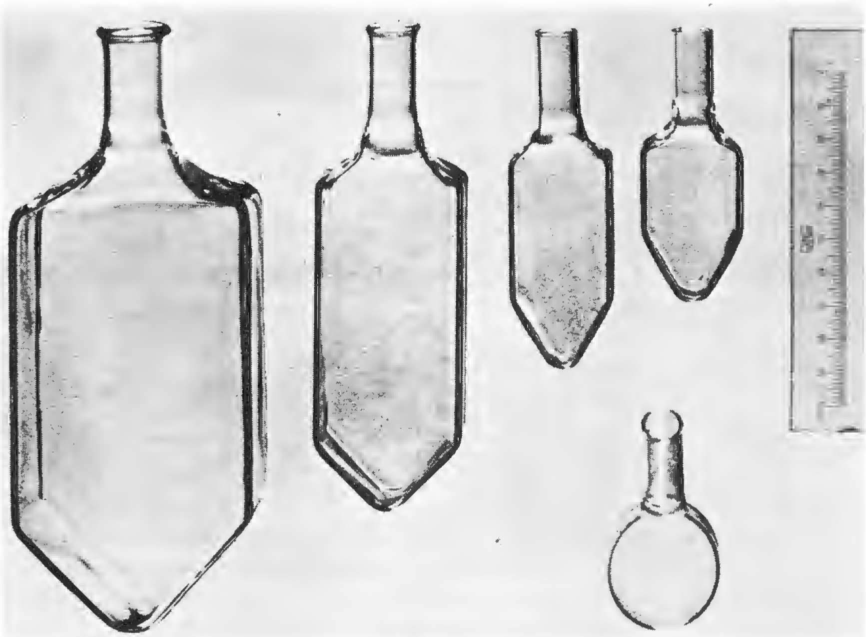


Figure 7

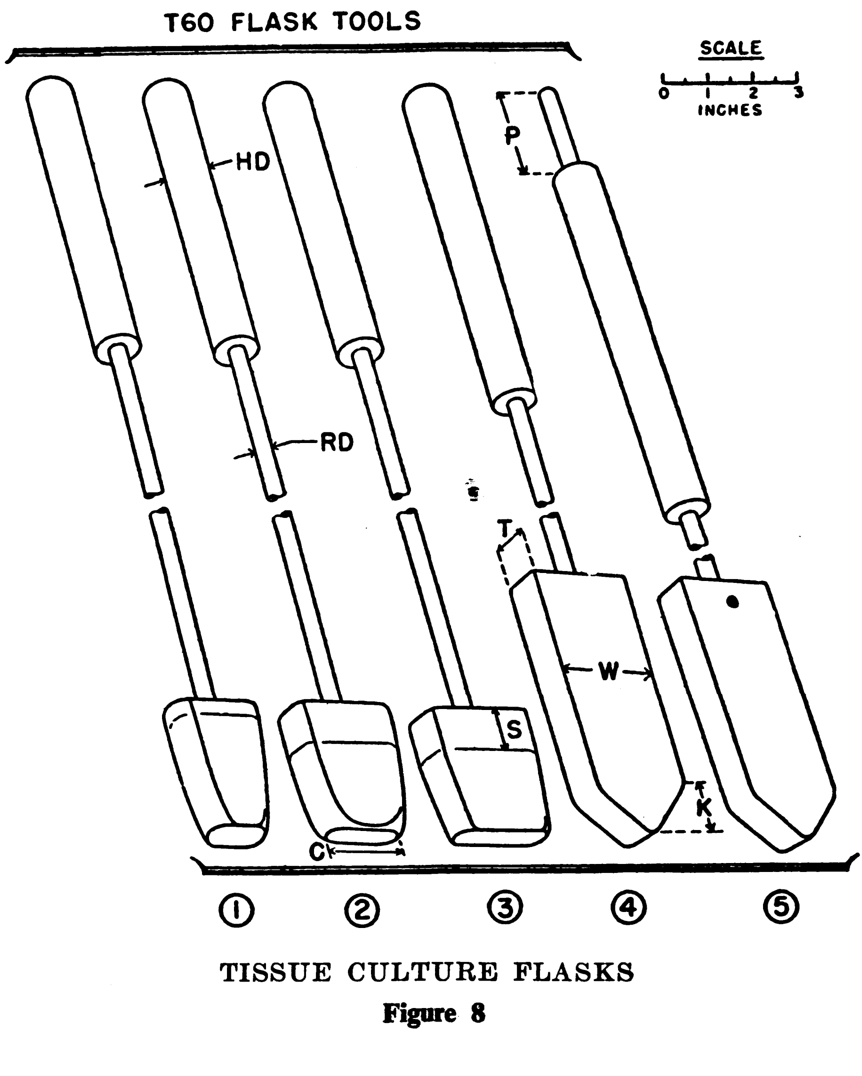
A piece of 54 mm tubing is heated until somewhat plastic in a broad and bushy flame. While in the flame, the tubing is stretched laterally and flattened by rapidly and consecutively passing down into it, and then withdrawing each of the first four mandrels shown. The closed end is formed when the last mandrel is in the tube. These mandrels are made of carbon. Finally, the last mandrel, made of polished cast iron, is inserted and vacuum applied to shrink the glass to the shape of the mandrel.

This series of operations produces a tube of rectangular cross-section with a tapered bottom. Later, the open end is pulled down, keeping a rectangular cross-section, and the neck is sealed on.

While rollers are used to good advantage in bench work to support the glass while it is being heated or formed, the glass-blower usually must keep both hands on the glass. This limits, to some extent, his ability to manipulate glass and flame. In addition, when a seal is being made, centering of the various parts is dependent on the skill of the blower. Finally, large diameters and long lengths cannot be handled well, if at all.

The introduction of glassblowing lathes into most shops has been done to eliminate these difficulties. This change from complete dependence on bench work is probably the most significant mechanical development made so far.

With lathes, it is easy to get good alignment when making seals.



TISSUE CULTURE FLASKS

Figure 8

Both of the operator's hands are free to adjust the position of chucks holding the glass, and to adjust the amount of heat delivered by the burner. The range of diameters that can be handled has been greatly increased.

The operation performed most frequently on lathes is straight sealing; for example, the joining of a bulb to a suction tube and delivery tube to form a volumetric pipet. Simple chucks for the head stock and tail stock are sufficient to hold the glass pieces for work of this nature.

Off-center sealing can be done by providing special jigs to hold the ware.

Figure 9 is reproduced from a catalog issued by Q.V.F., Limited of England. It illustrates not only off-center sealing but also the handling of a large piece on a lathe. A side-neck is being sealed

Figure 9

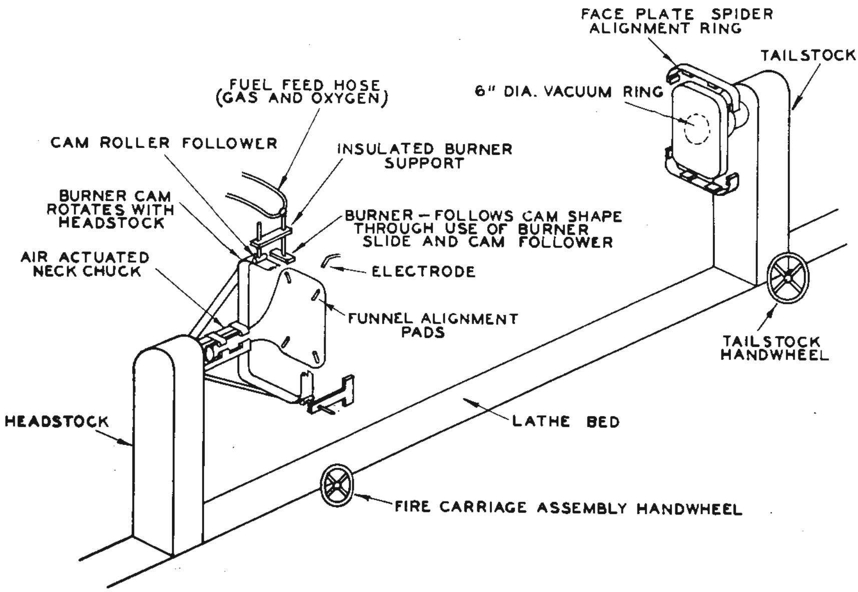


Figure 10

to a flask of about 72 liter capacity. Notice that the flask is held by a ring attached to the head stock of a lathe by rods. They can be tightened after the center of the spot where the sidearm is to be placed has been centered.

One of the most interesting developments in the application of lathes to the sealing together of large pieces is the assembly of parts for a rectangular television bulb. This operation, as presently carried out, includes not only the use of conventional gas fires to seal the neck to the funnel-shaped part, but also the sealing of this sub-assembly to a face plate with the help of a high-frequency current.

The setup for the final sealing operation is shown in Figure 10. The sub-assembly of neck and funnel are held in an air-actuated chuck. The force of the chuck fingers is sufficient to hold the funnel in alignment.

The face plate is held by a vacuum chuck. A rubber ring makes the seal against the outer face of the plate. Appropriately shaped guides hold the plate in proper alignment.

The entire working area is surrounded by a protecting housing that has windows for the operator to view the operation.

To start the operation, the face plate is moved toward the funnel until the proper gap is obtained. Then, a number of gas-oxygen burners are lit. These are suspended from above and connected to a roller. The roller rests on a cam which has the same shape as the cross-section of the ends of the face plate and funnel. This cam rotates with the glass pieces so that the burners are always at the same distance from the glass.

When the glass is heated sufficiently to carry electric current, power is introduced through two or more gas-oxygen electrodes. As soon as the edges of the glass parts are fluid, the two pieces are jammed together and the heating continued until the seal is completed.

Ordinarily, such a sealing operation would require the services of a highly skilled glassblower. However, by predetermining the characteristics for the various steps so that mechanical and electrical aids could be used, it has been possible to train ordinary workers to do the job. This has been necessary because of the large number of bulbs needed.

A recent patent illustrates a unique combination of shrinking and sealing operations to make blood diluting pipets (Figure 11).

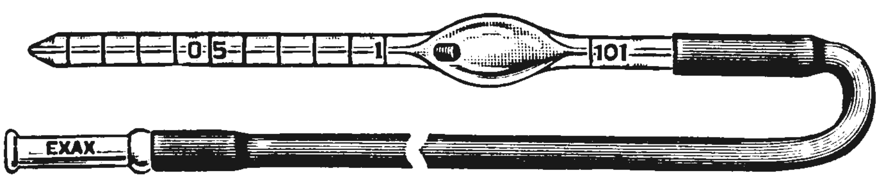


Figure 11

The pipet is constructed so that the volume of the graduated stem is one one-hundredth of the volume of the bulb. There is a small loose glass rod sealed into the bulb. Since the tubing ordinarily used for the stem varies in diameter, its volume will vary, and the bulb must vary accordingly. In the usual method of manufacture, tubing is pre-sorted and a bulb blown in the tubing, using a bench mold. Different sizes of molds are used, according to the diameter of the stem. After the bulb is blown, it is cut apart, the small rod inserted and the bulb resealed.

U. S. Patent 2,735,230 discloses a new method of manufacture which produces stems and bulbs of uniform volume.

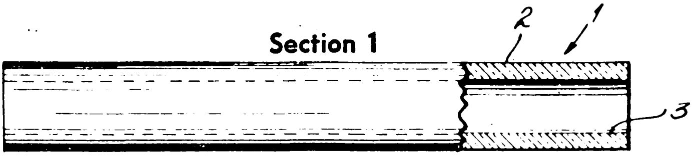
The raw material is ordinary tubing of average wall as shown in Section 1 of Figure 12. This tubing is mounted on supports 4 and 5 (Section 2) that have the exact diameter of the inside diameter wanted for a finished bulb. Extending through the tube is a smaller mandrel (5). Heat is applied to the tube and as it softens the three rollers shown in Section 3 are moved against the tube. Section 2 shows the completion of this stage of the operation, with each end of the tube shaped and the center with smaller bore and thickened wall.

Following this, the center mandrel is removed and replaced by a still smaller mandrel which has the exact diameter wanted for the finished stem of the pipet. The tubing is again heated and the bore reduced further.

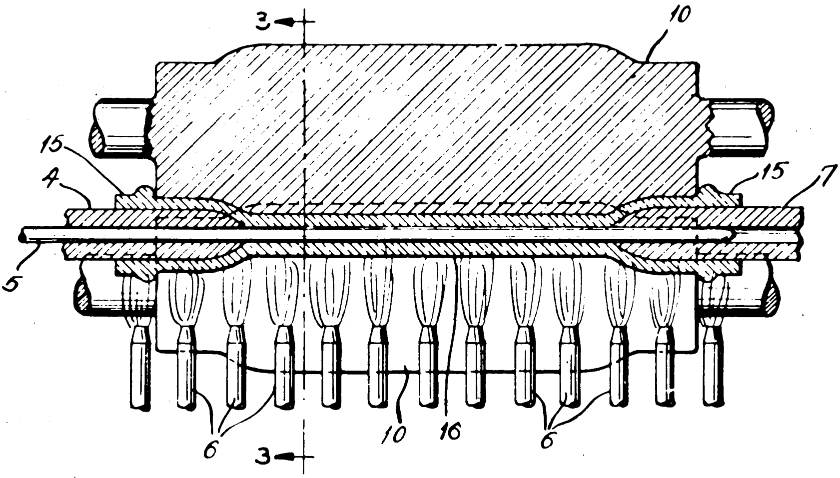
Following this, the tubing is placed in another lathe (Figure 13), the small mandrel partly withdrawn, and the center of the tube heated, while shaping rollers are applied. At the left of the flame the rollers form a tip, while at the right, a top end of enlarged bore is produced. Notice that the mandrel is placed so that the bore of the tip is controlled.

After the tube is severed at the middle (Figure 14), the enlarged ends are sliced leaving just enough length to give one-half the volume of a finished bulb. Then the two large ends are placed in chucks and butted together. At this time, a rocker arm is set so the plate at its end just touches the glass. The arm is swung out of the way, the chucks moved apart slightly and heat applied. When the edges of the glass are soft, the chucks are moved toward each other until the glass parts touch, and the rocker arm brought back until the plate is in the same place it was originally. Some air may be introduced through a chuck to be certain that the glass is in contact with the plate. Thus,

Section 1



Section 2



Section 3

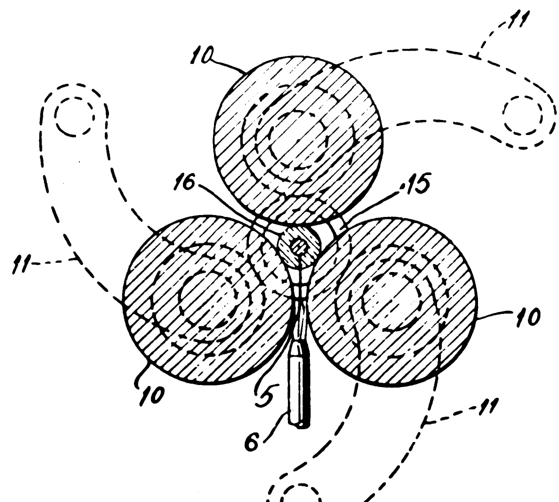


Figure 12

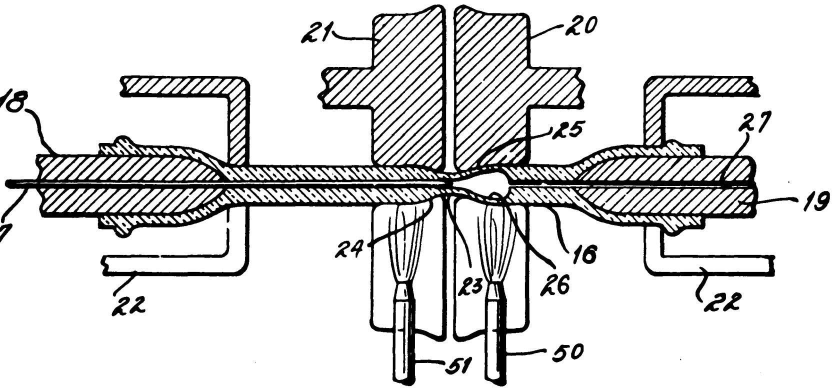


Figure 13

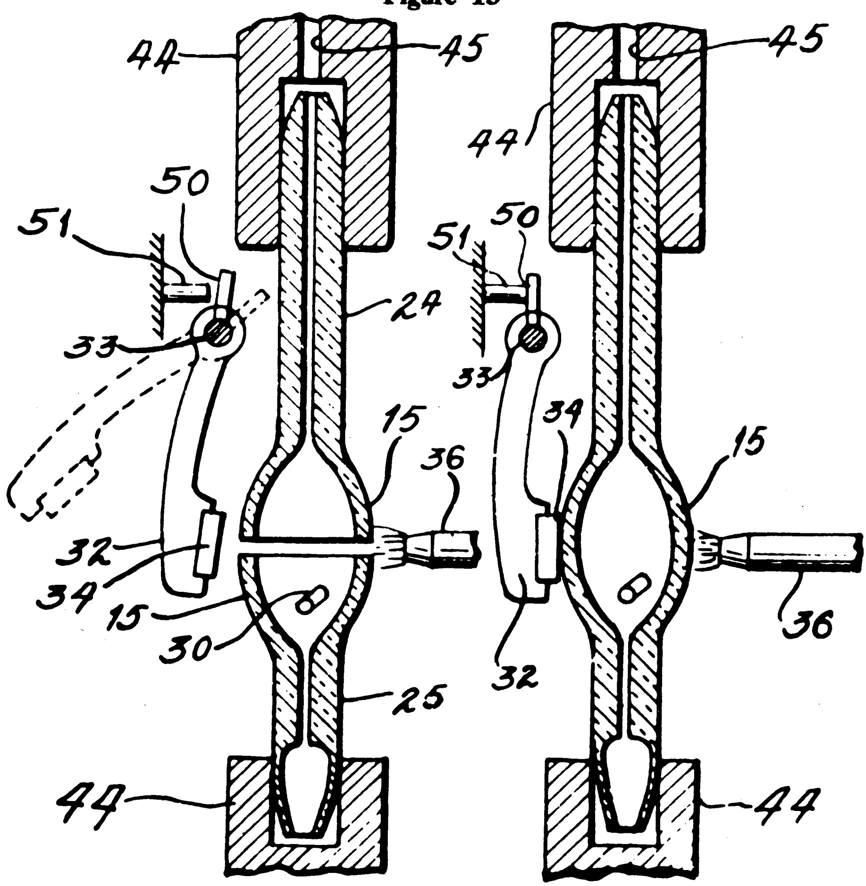


Figure 14

the outside shape is unchanged, and the volume has not been altered because the amount of glass has not changed.

The same inventor has also devised a second method for making these pipets. While details are not known yet, glass samples seen at a show sometime ago indicated that the pipets were formed in one piece. Hollow metal hemispheres are mounted on the middle of a small mandrel, and the tubing shrunk around the entire mandrel assembly. The small glass rod is placed inside the hollow mandrels. After shrinking, acid is presumably used to remove the metal from the bulb.

I have not mentioned burners, although they are an important part of any glass-working setup. For those needed for mechanical glass-working, each case requires individual study. The answers depend somewhat on the person charged with developing the process.

I feel sure, however, that no modern shop will have one of these (Figure 15). This is the great granddaddy of burners. It was popular in the Thuringen forest in Germany during the early part of the last century.

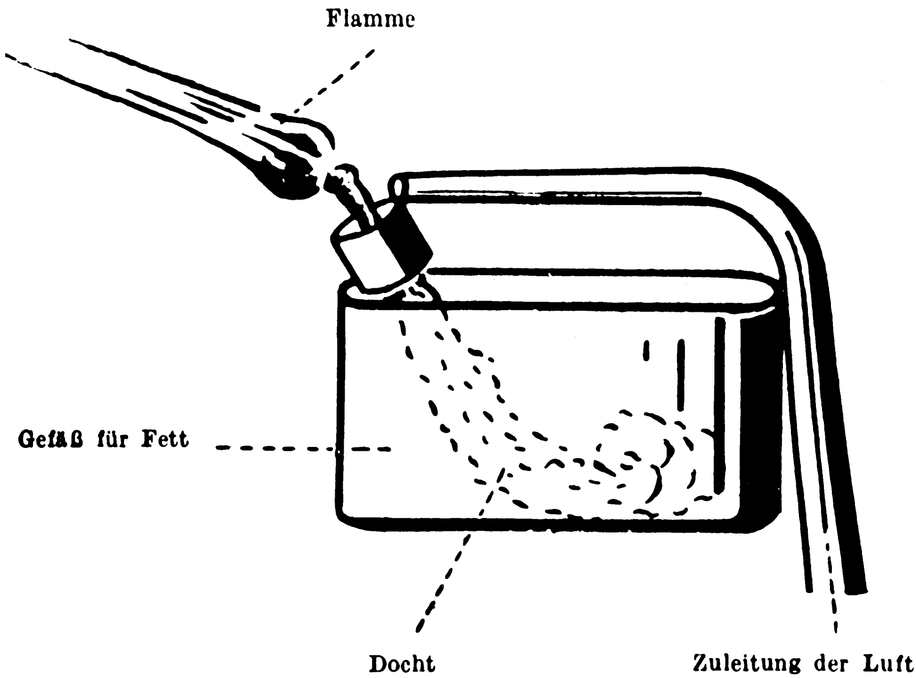
The pan contained beef tallow, or a mixture of beef tallow and butter. Indeed, an old history indicates that butter was sometimes used alone for very fine work. At the left is a wick. Air coming from a tip directed a pointed flame toward the glass.

I have been requested to include in this talk some guesses as to the future of mechanical glassblowing.

Due to constantly increasing costs, it seems obvious that much thought will be given to completely or partially mechanizing the manufacture of any item that is needed in some quantity. The new methods of making blood pipets are illustrations of what can be accomplished.

There also will be an increased use of parts made mechanically by blowing or pressing.

There will be greater use of tubing of uniform diameter,



Eine alte Glasbläserlampe.

Figure 15

whether it is drawn to close tolerances or reformed later.

Greater use will be made of high frequency sealing. It is conceivable that less expensive equipment will be made available so that the small shop can use this technique.

Now, what will be the effect on the skilled glassblower of increased mechanization. In my opinion, the true craftsman has nothing to fear. The mediocre man does, for he has always been limited to the simpler operations, and these are the ones that will be mechanized.

With the constant growth of research, the calls for the services of the all-around craftsman to build the intricate glass instruments needed will increase. He may also find his talents are needed to help mechanize the simpler operations, because his knowledge of glass behavior certainly will be helpful in the design of the machinery.

Panel Discussions

The following preliminary remarks were made by the chairmen of the various panels prior to opening the meeting for questions and discussion from the floor. Unfortunately, no usable transcript of the open discussions and questions and answers was available.

Lampworking Properties Of KG-33 Glass

Dr. Dudley C. Smith

Kimble Glass Company

In a previous talk it was my privilege to discuss the properties of KG-33 glass. In that discussion, we tried to make clear the reasons why KG-33 glass was selected by Kimble to make its new line of scientific apparatus. We also emphasized the fact that KG-33 glass is not new. Its properties are the same as those of the hard apparatus glass with which you have long been acquainted. Therefore, the problems to be faced in lampworking KG-33 glass are the same problems which have been encountered in lampworking the existing hard apparatus glass. For this reason, it is unlikely that we can say much that is new or original in discussing the lampworking of KG-33 glass. Rather, it is thought that our discussion will be in the nature of a review; a review of topics and ideas that are of mutual interest to all concerned.

To introduce the subject, it may be helpful to elaborate on some of the properties of the glass that are directly related to the problems of lampworking. Following this, we will mention a few topics that we hope may provoke discussion.

Glass is a material with a unique combination of properties that permits it to be formed and shaped in fire. A certain scientific organization has prepared an official definition of glass, which reads in part as follows: "Glass is an inorganic product of fusion which has cooled to a rigid condition without crystallizing."

Editor's Note: Other members of the panel were J. J. Moran and W. F. Schilling, both of Kimble Glass Company.

The statement that glass is an inorganic product refers to the fact that it is composed of mineral elements. This explains why glass can be plunged into fire, and melted, without being damaged or destroyed. Non-mineral materials, such as plastics, cannot be treated in this way.

The definition also calls attention to the fact that glass is essentially a non-crystalline material, and after being melted, can be cooled down to a rigid state without crystallizing. This property sets glass apart from other materials, like metals, which crystallize when they solidify.

There is another property of glass which is very important insofar as lampworking is concerned. This is the temperature-viscosity relationship. By viscosity, we mean the stiffness of glass or its resistance to flow. At high temperatures, glass is a thick liquid which can be ladled or poured. As the temperature is lowered, the viscosity steadily increases until a point is reached at which glass will not flow readily but is still soft enough to be shaped by pressing or blowing. As the temperature is lowered further, glass becomes stiff enough to hold its shape but is still sufficiently yielding to permit the release of internal strains. This is the annealing range of temperature. On lowering the temperature still further, glass gradually assumes a very rigid state in which it is too stiff to permit the release of strains.

Although basically a non-crystalline material, glass can crystallize, or devitrify, if it is held too long at a temperature below its devitrification temperature. In order to be satisfactory for lampworking, a glass must be stiff enough to work at temperatures which are safely above its devitrification temperature.

The temperature-viscosity relationship is illustrated in Figure 1, which shows the viscosity curves of KG-33 glass and the soft apparatus glass, R-6. These curves tell us quite a lot about the glasses and therefore it may be worthwhile to discuss them in some detail. The first thing to notice is that there is a smooth curve for each glass, showing that there is a continuous relationship between temperature and viscosity without a break or sudden transition at any temperature. We emphasize this point because it is one of the earmarks that differentiate glass from crystalline solids like metals or salts, which are liquids at high temperatures but solidify abruptly when cooled below their freezing points.

Next, I would like to explain why a chart like this (Figure 1) is laid out in the form in which you see it. As stated earlier, molten glasses are thick liquids, with high viscosities, even at high temperatures. For example, KG-33 glass at 2500°F has a viscosity of

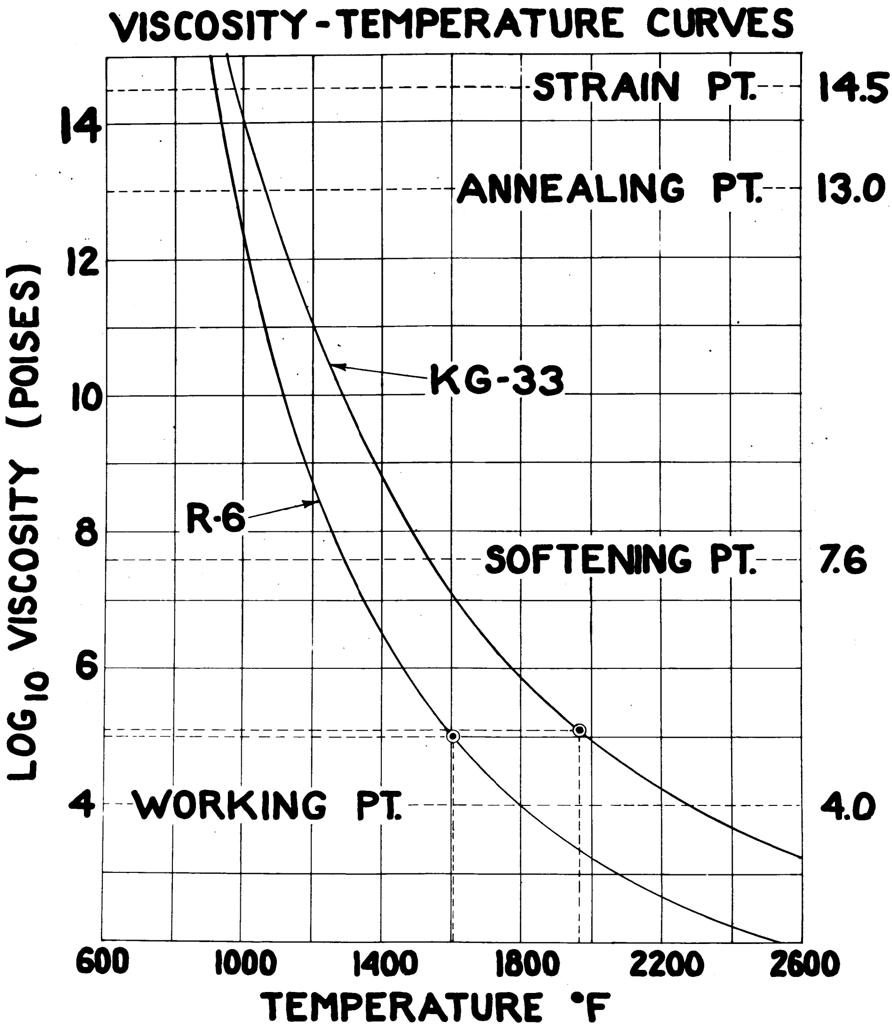


Figure 1

1000 poises. By contrast, water at room temperature has a viscosity of only 1/100th of a poise. In other words, the viscosity of the glass at 2500°F is 100,000 times as great as that of water at ordinary temperatures. At its softening point, glass has a stiffness or a viscosity of approximately 40 million poises. Since glass viscosities turn out to be such large numbers, it is necessary to use the logarithm of viscosity, rather than viscosity itself, in order to lay out a temperature viscosity chart. For the benefit of those who may not be familiar with logarithms, we might point out that the logarithm of 10 is 1, and the logarithm of 100 is 2, the logarithm of 1000 is 3, and so on. The logarithm of a number shows how many times 10 must be multiplied by itself in order to produce the number. For example, our chart shows that R-6 at its devitrification temperature has a viscosity whose logarithm is 5. This means that the viscosity at this temperature is 5 tens multiplied together or 100,000. From this you can see that by using logarithms, we can compress or scale down a very large range of numbers into a shorter range, which can then be laid out on a single chart. Only in this way can we graph the viscosity of glass over an extended range of temperatures.

This chart shows how the physical properties, such as working point and softening point, are defined. These properties are defined as viscosity levels, or degrees of stiffness of the glass, and the same is true of annealing point and strain point. Each of these properties represents the temperature at which the glass has a certain viscosity. Through the American Society for Testing Materials, the glass industry as a whole has agreed that the softening point, annealing point and strain point shall be defined as the temperatures at which a glass has log viscosities of 7.6, 13.0 and 14.5, respectively. The points in question are indicated in the chart.

The working point is designated as the temperature at which the glass has a viscosity of Log 4. Actually, the temperature at which a glass is worked will depend on the type of operation. For some manipulations, it may be desirable for the glass to be quite soft, with a viscosity as low as Log 3, while for others it may be desirable for the glass to be much stiffer, for example Log 4 or 4.5. The lower end of the working range is usually considered to be somewhere near the softening point, or Log 7.6

viscosity. However, the Log 4 temperature is usually referred to as the working point, and, if we accept this definition of the term, the working point of KG-33 glass is 2264°F. The corresponding temperature for the soft apparatus glass is 1803°, a difference of 460°F.

The devitrification temperatures of the two glasses are indicated by circles in the chart. For KG-33, the devitrification temperature is 1965°F. and for R-6, 1605°F. In each case, the devitrification temperature is considerably below the nominal working temperature. After being worked, the glass quickly cools through the devitrification range and no trouble is experienced with devitrification.

Since a hard glass like KG-33 must be worked at relatively high temperatures, this glass, on being removed from the fire, cools faster and becomes rigid more quickly than does a soft glass like R-6. This fact should be kept in mind in making seals on a lathe. If the two pieces of hard glass are not in perfect alignment, the seal may take on a whitened appearance due to chill wrinkling caused by movement of one piece relative to the other after the glass is too cold to be worked. The result may be a weak seal. For this reason, exact alignment in the lathe is more important with a borosilicate glass like KG-33 than with a soda lime or lead glass.

Another subject of practical interest is the cutting of glass. Oftentimes, before glass tubing can be lampworked, it must be cut. These days more and more sealing and forming operations are being carried out on lathes. Therefore, the old practice of pulling temporary points no longer applies. Instead, the tubing is cut, mounted on the lathe and the end paddled down by means of a carbon paddle. The cutting of large diameter tubing may present a problem. Scoring with a steel saw produces a rough type of cut, and this may result in an unsatisfactory seal containing bubbles and saw marks. When an electrically heated wire is used, the cut may be uneven. We believe that the best method of cutting, as well as the simplest, is the so-called hot-cut method. A simple arrangement for hot-cutting is shown in Figure 2.

This shows the operation as seen from above. The tubing is rotated in contact with a very sharp gas-oxygen fire from a small slit type burner. As soon as the tubing is heated sufficiently, the heated zone is chilled by touching it with a damp cloth. In this way, a clean accurate cut can be made very easily.

For use in conjunction with glass lathes, it is important to select proper auxiliary equipment, including burners, and an

SIMPLE ARRANGEMENT FOR HOT-CUTTING KG-33 TUBING

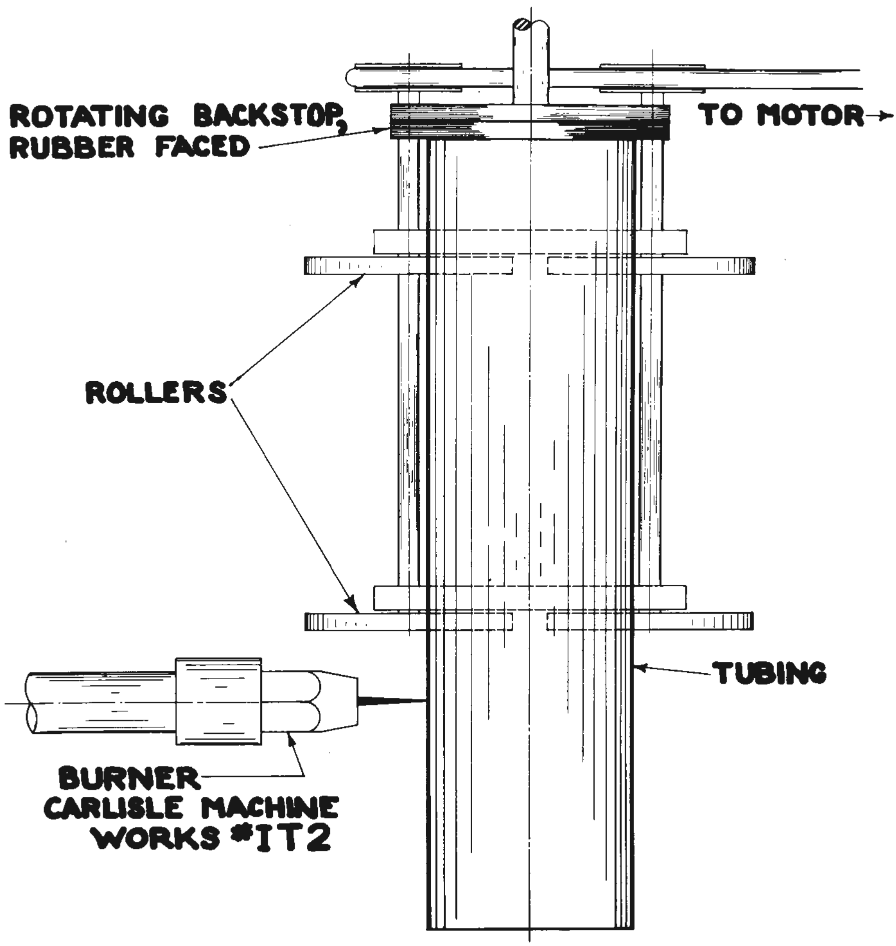


Figure 2

adequate valving system which will permit the operator to change instantly from one type of fire to another. This depends, of course, on the instantaneous adjustment of fuel mixtures. Wherever possible, paddles or other tools used in shaping glass should be made of carbon, since the material can be used without a lubricant. With steel tools, a lubricant, such as aquadag, must be used, since otherwise the metal will cause discoloration of the glass.

Another subject of possible interest is reboil, which is the occurrence of small bubbles in a seal or other lampworked area. Reboil usually has the appearance of a white line or area. It can be caused by saw cuts, scratches, or by excessive dirt on the glass surface at the time of lampworking. Borosilicate glass is somewhat more prone to reboil than soda lime glass, though less sensitive than a lead glass like G-12. To prevent reboil, the glass surface should be kept clean and should be protected against scratching or abrasion.

Working the glass at too high a temperature may be just as undesirable as to attempt to work it at too low a temperature. If an excessively hot fire is used, it is possible for the glass surface to lose a little of its boric oxide and soda. This tends to produce surface devitrification, which will appear as a white surface area. This does not seriously weaken the glass, but is an appearance defect.

To the scientific glassblower, the outstanding advantage of KG-33 glass is its low expansion. Because of this low expansion, the glass has outstanding resistance to heat shock. This means that it can be heated and cooled rapidly with little fear of fire cracks or cold checks and, after lampworking, the cooling stresses will be much less severe than is the case with soda lime or lead glasses of higher expansion. Because of its low expansion, KG-33 glass can be used to fabricate complex apparatus which would be virtually impossible to make from high expansion soda lime glass. Some types of scientific apparatus, which are considered commonplace today because made of low expansion glass, would be impossible to make from soda lime glass because the glass would crack before the glassblower could finish his work.

Practical Aspects of Annealing

E. M. Tom

Owens-Illinois Glass Company

The subject of annealing of glass is an interesting and relatively complicated one. Before opening the meeting to discussion, it seems desirable to review a few pertinent facts regarding annealing.

When glass is cooled from its softened condition, differences in temperature through the glass piece arise. These temperature differences, and the rate at which the glass contracts during cooling, result in stress being formed. That is, the temperature difference and the rate of contraction are the prime causes of stress being formed. Many factors which aggravate the differences in temperature, such as increased cooling rate or increased glass thickness, will tend to increase the stress developed in the glass.

For most practical purposes, annealing consists of heating the glass until it is soft enough so that all stresses may be relieved. Then the glass is cooled slowly enough to prevent large differences in temperature so that high stresses will not be created.

The point to remember is that temperature differences, with a particular glass and a particular item, cause stress to be formed. If these temperature differences are large, the stresses will be large. If they are small, the stresses will be small.

Editor's Note: Other members of the panel were David Berke, Corning Glass Works, and Oscar Grauer, Fischer & Porter Company.

Glass can be examined for stress by the use of the polariscope. When the item is examined, the field of the instrument appears bluish-red in color. If the glass has high stress, bright orange or green colors can be seen.

Any glass item which is suspected of having too high a stress may be checked by scratching it with a diamond point. Water may be applied to the scratch. If the glass breaks within a few minutes, this is an indication that there is a tension stress of about 2000 psi on the surface of the glass. By examining the glass in a polariscope before the scratch is made, one can quickly learn the color pattern which may be serious. Glass which has tension on the surface in the amount of 2000 psi is not suitable for most uses. By changing the annealing cycle until the colors in the polariscope are about one-half of the brightness previously seen, the glass will now have a stress of about 1000 psi tension on the surface, which is serviceable for most applications. Certain severe uses will require that the stress be reduced even further.

Practical Aspects of Marking Glass

W. W. Collicott, Chairman

Kimble Glass Company

We mark glass for purposes of establishing identity of manufacturer, to indicate volumetric capacity, for other uses of a measuring nature, to code for future reference as in the chemistry laboratory, to indicate parts of an assembly, for pure decoration, and for other reasons too numerous and varied to attempt to cite.

I suppose that the basic question in which each of us is interested, is, what is the best method, all factors considered, for marking glass for any specifically desired purpose. When we say "all factors considered," we think of some of the following:

a. Quantity of pieces to be marked.

b. Equipment and facilities available in a given situation for marking.

c. Is marking to be permanent or temporary?

d. Is economy more important than appearance?

e. How will the ware be used? What type of marking is needed for these uses, to (1) give greatest visibility, (2) give best durability, (3) give most convenience and practicality?

Editor's Note: Other members of the panel were Dr. John Glaser, UNI-SCIENCE, Inc., and L. F. Pither, Owens-Illinois.

There are undoubtedly other factors which could be enumerated.

In an earlier talk, mention was made of various methods commonly used to mark glass — by blasting, grinding, etching, printing, by diamond scoring, rubber stamping with etching compounds, by use of decals, and by numerous types of inks and crayons. It was stated that some methods have certain advantages while others have different advantages. For instance, blasting is a more direct and faster process than etching, but blasted markings are not as attractive in appearance, generally speaking, as etched markings. By the same token, screen printed markings can be more attractive than etched markings but do not have as great durability.

It was also mentioned that the colors used in marking glass can be of three main types: (1) ceramic, (2) non-ceramic, and (3) stains.

The ceramic colors, when properly fired, have advantages of durability over non-ceramic but are not as permanent as the stains. On the other hand, because they are, in general, of rather high expansivity, they must be matched to the glass on which they are applied, or strains may be set up which can lead to breakage or chippage of the color from the surface. Recent advances in non-ceramic colors, especially with the introduction of the use of epoxy resin based colors and silicone based colors, have given these colors a much greater durability than they formerly possessed. Used in applications where high resistance to solvents, chemicals, heat, etc., is not an important factor, they can be very advantageous.

Non-ceramic fillers have the advantage of having no weakening effect when used in etched lines. They do not fuse or melt to the glass to form a rigid vitreous deposit. It will be remembered, perhaps, that another advantage mentioned of non-ceramic colors is the wider variety of hues and shades in which it is possible to obtain them.

In the talks, mention of some common methods of marking glass was omitted, because it was realized it would be impractical and impossible to discuss all methods. Some of the methods omitted were copper wheel marking, grinding, pressing, etc.

In the use of any marking method commercially, an important consideration is exact knowledge on the part of the manufacturer of the durability of his marking method. This means practical testing methods must be used. Mention was made of some of these, particularly of tests for the ceramic enamels and stains. It was pointed out that tests have indicated that certain detergents, particularly those containing phosphates, are more severe in their attack on printed ceramic colors than other types. Other detergents give little or no attack. It was mentioned that for non-ceramic colors which will not stand excessive heat or chemical attack, tests involving immersion in 5 per cent phenol at room temperature, alcohol, lubricating oil, boiling water, carbon tetrachloride, and toluene all are used.

There is a saying to the effect that "No one of us is as smart as all of us." It is because of the validity of this statement that panel discussions have evolved as a means of communicating ideas and knowledge to each other.

With this brief summary the discussion is now open to all.

In Attendance

The following persons are on record as having attended the Third Symposium on the Art of Glassblowing, held at Toledo, Ohio, on Thursday, Friday and Saturday, May 22, 23 and 24, 1958. The address following the name is the mailing address as listed in the Society files.

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