

PROCEEDINGS
THE SECOND SYMPOSIUM
ON THE
ART OF GLASSBLOWING

1957

THE AMERICAN SCIENTIFIC
GLASSBLOWERS SOCIETY

**THE SECOND SYMPOSIUM
ON THE
ART OF GLASSBLOWING**

**TECHNOLOGY AND
MANIPULATION OF GLASS**

Sponsored By
**THE AMERICAN SCIENTIFIC
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F O R E W O R D

The Second Symposium on the Art of Glassblowing—like the first—exceeded our fondest expectations and the credit belongs to many.

Once again, the members of The American Scientific Glassblowers Society were the guests of Corning Glass Works, and we are deeply indebted to this firm for its interest, generous hospitality and fine cooperation which added immeasurably to our program. The fact that our membership has increased by some 60 per cent during the past year can be attributed largely to these technical meetings.

The Symposium Committee, under the capable leadership of Leigh B. Howell of Olin Mathieson Chemical Corporation, also is to be congratulated for the splendid job it did and on behalf of the Society I extend sincere thanks for a job well done.

The success of this Symposium—and the keen interest it generated among our members—is sufficient proof, I believe, that at last we as glassblowers are achieving a united front for the advancement of our profession. Gradually the curtain of secrecy and suspicion, which long has shielded the arts of our trade, is being rolled back, and there is evolving a new spirit of cooperation, which can only be beneficial to all of us. In the language of the day, as an organization “we have arrived.”

The vehicle to foster this spirit and to further its growth is, of course, A.S.G.S.—and it will continue to progress only so long as we are willing to exchange information and ideas to help each other and the profession.

Publication of the proceedings of the Second Symposium is one of the services performed by A.S.G.S. to disseminate the valuable information that was imparted to those attending the three-day meeting. This provides a permanent record and enables us to share our experience with those unable to attend, but who, nevertheless, are vitally interested in our endeavors.

J. Allen Alexander, *President*
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Welcome Address To The American Scientific Glassblowers Society

Olaf M. Loytty

It is again my sincere pleasure to extend to each of you, on behalf of your committee and Corning Glass Works, a most cordial welcome to the second symposium on the Art of Glassblowing.

The past few years have been eventful ones for the glass industry. They have marked a new high in the amount of public recognition to the importance of glass and of the men who make it. No doubt you have seen in the various trade journals, business papers, and leading newspapers, accounts of the technological advances which have taken place over the past few decades.

In Jamestown, Virginia, we are commemorating the founding, in 1607, of the first permanent settlement to be made in the area which is now the United States. Visitors to this town on the banks of the James River will see there a replica of the first chemical industry—an authentic reproduction of the old glass house. There they can watch glassblowers, dressed in Elizabethan costume, fashioning glass objects in the same manner as it was done in the original plant, 350 years ago.

To make a rapid transition to the present—Corning Glass Works, only last week, was the source of much national interest when it announced the development of a family of revolutionary new materials—“PYROCERAM”. At the same time our new research and administration buildings, which together with the Glass Center comprise Houghton Park, were dedicated to the employees of Corning.

To digress just a moment, we feel that it is noteworthy that Corning Glass Works was the first glass company in the United States to start its own research laboratory and was one of the very first industrial companies to allocate a part of its sales dollar for research. Right now we spend twice as much as the average company percentage-wise to further research and development. From these research laboratories have come the famous "PYREX" and "VYCOR" brand glasses, silicones and now "PYROCERAM".

We feel that "PYROCERAM" will be one answer in the future to more severe demands being made on basic materials by designers in all parts of industry. At this point we don't know where it will fit in the laboratory business, but you may be sure it will have a place somewhere along the line. It has been conceded that the new Houghton Park development gives Corning the most modern and complete glass research facilities to be found anywhere.

Of course, arrangements have been made to provide to the technical and trade journals complete coverage of the meeting you are now attending.

Corning takes deep pleasure in paying tribute to a group of men who have in so many ways contributed to the wonderful standard of living enjoyed by most Americans. We mean, of course, yourselves—Scientific Glassblowers. It is true that the public is hardly aware of the importance of your work to their health and comfort. Probably there are many uninformed individuals who believe that the lampworker's work is manufacturing the novelty creatures sold at county fairs. It is also very possible that scientists do not consciously realize the full measure of the lampworker's importance.

Since this is the case, let us look objectively at this basic question: "How many of the necessities of life, how many luxuries that we have today, would be ours today were it not for the skill of the scientific lampworker?"

These products—products of chemistry—were developed in a

laboratory in glass apparatus created by one of you, or by one of your associates.

1. Pesticides to protect growing food—chemicals to keep it after it has been processed.
2. Synthetic fibers which alone, or blended with other fibers, provide a great percentage of the clothing worn today.
3. The automobile, tires, paint, glass and upholstery.
4. Fuels for gasoline, diesel and rocket engines.
5. Pharmaceuticals, developed in glass apparatus, processed in glass systems.

Perhaps the most dramatic example of the lampworker's skill is the artificial heart. A necessarily complicated mechanism and made entirely of glass, this instrument is used in some severe cardiac operations. Its purpose is to take over the pumping functions while the surgeons correct the damaged human organ.

We could go on citing examples of direct and indirect products of the lampworker's skill, but I believe the short list we have just covered is ample proof of the value of you gentlemen to our civilization.

You—the men who create glass apparatus—will have even greater responsibilities in the future with the growth of atomic research. The need for glass apparatus in this field is a certainty.

The directions in which you will be working are so very difficult to predict because of the universal applications of the atom.

Its use as an energy source is a certainty—a cube of uranium the size of two lumps of sugar has an energy potential, after atomic reaction, equal to 1,500 tons of coal. It is presently used in industry to gauge weight and thickness of materials produced in continuous processes.

Radiation treatments used in medicine are more and more replacing dangerous surgery.

Someday our homes may be heated by steam generated in central nuclear plants; our automobiles may be made of completely new materials; our tables set with cheaper, better foods.

To gain these and other goals, the cooperation of the scientific lampworker becomes increasingly important. The importance of the lampworker and the apparatus industry can be measured too, in another way, if we trace the growth of the industry over the past 25 years.

For example, in 1934 the total annual sales of the entire apparatus industry was \$15,200,000. Within 10 years this figure had more than tripled, and through the post World War II years to the end of 1956, the total annual industry sales had skyrocketed to a figure of nearly 12 times that of 1934—a percentage of better than 1,000 per cent.

We also have had much the same growth pattern in the laboratory glassware line and it comprises an important part of the total Corning Glass Works business. To make the future even better, we are building a new \$5.5 million apparatus plant to further improve quality, price and delivery of our products which all of you have so faithfully used for the past 42 years. We know that you'll continue to support Corning products in the years to come as you have in the past. Your presence at this meeting clearly shows your willingness to be prepared to meet this industrial growth. These annual meetings seem to be the most practical method of keeping abreast of the latest developments in the field.

We hope that in listening to the glass technologists and engineers, by discussing problems with them and with other delegates to the symposium, you will return to your shops better equipped to do the tremendous job that will be expected of you.

I'd like to express again my pleasure in seeing you all here. We sincerely hope that you'll accept our invitation to make this an annual affair in Corning.

Our best wishes to you for a good meeting and good luck to all of you.

Glass And Atomic Energy

Vaughn Culler

Corning Glass Works

Dr. Culler received his A.B. and M.S. from West Virginia University and his Ph. D. from Harvard. He was affiliated with Argonne National Laboratory in 1950, was a staff member at Massachusetts Institute of Technology in 1954 and has been with Corning Glass Works since 1955. He served in the U. S. Army in 1945-46.

The subject—glass and atomic energy—divides itself very neatly into two parts or topics. The first we shall refer to as the present uses of glass, the latter as future uses and implications.

Some of the present uses are well known in the pharmaceutical industry; for example, it is now a standard procedure to put drugs inside glass ampoules, seal the ampoules, then sterilize the drugs and ship them to the customer. The radiation does not affect the glass but does sterilize the drugs. Starting out with a sealed but unsterilized unit, irradiation produces a sterile unit which can be delivered to a customer and which stays sterile.

I understand that experimental work has been performed on the use of glass as a container for *live* polio viruses. The sealed containers are then irradiated, killing the virus, and producing a safe polio vaccine. How successful this is I do not know. This is a project which we can watch to see how it works out.

Another use of glass is in the radiation dosimeter (Figure 1). These small devices have inside them a tiny rectangular piece of a silver-activated phosphate glass. This is rather a unique glass.

It turns slightly dark when irradiated but the important thing is that under ultra-violet light the glass glows if it has been in the presence of radiation. The amount of this glow or luminescence, as it is called, is proportional to the amount of radiation the dosimeter has received. So the thing to do is to bottle a piece of this glass in a convenient little package and give one to each soldier

Figure 1



and sailor—to civilians too. Then in the event of an atomic attack, the people who have been subject to radiation can find out not only how much of a dose they have received but also their doctor can tell what sort of treatment, if any, is required.

In Figure 2 we can see a little something about the use of these dosimeters and how they work. Going across the figure, from

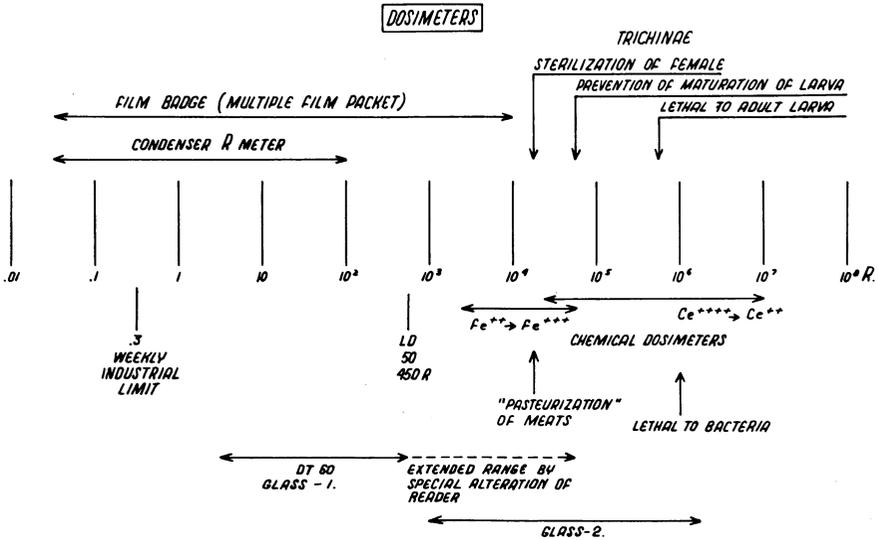


Figure 2

left to right, are doses expressed in Roentgens, the units of radiation dosage; 10^2 means 100 Roentgens, 10^3 is 1,000, and 10^8 is 100,000,000 Roentgens. The weekly industrial dose limit of 0.3 Roentgen (or 0.3 R as it is often abbreviated) is indicated on the figure. The point marked LD shows the dosage at which death to a person would be inevitable. Of course, some people would die at lower dosages and so under the LD is indicated the range of dosages below which no one would die and above which everyone would die, i.e. 50 to 450 R. We see that three radiation dosage detector devices cover the range of dosages of interest to us physiologically. They are the film badge, the condenser R meter and the DT-60 type glass dosimeter. Of these, the DT-60 glass dosimeter is the most satisfactory for long unattended possession by the wearer.

The region from about 10^4 R to about 10^6 R is a very important region in which glass dosimetry may be applied. The doses required for food sterilization are in this region. A dosimeter made of a special glass which colors proportionally to radiation exposure is a very simple and extremely useful tool for the food sterilization and processing industry.

Now radiation is, of course, lethal to man in appreciable doses. Since we are rather irrevocably committed, and I think properly so, to further work using atomic energy, such as power reactors and the radioactive isotopes in medicine etc., we must do further research work. For that matter, when we really get down to it, when we have power reactors that are delivering electrical power in the home it is going to be more economical and most necessary that fuel elements from the reactors, which are only partially "burned up", be reprocessed and made new. In this case, we are again dealing primarily with gamma-radiation which is essentially the same as X-radiation but of higher energy. Their effect on human beings is the same and human beings must be shielded from too high a dose. Gamma-radiation penetrates any material in the following fashion; a single gamma-ray enters a piece of matter and either interacts with it or doesn't. If it does interact it is for most practical purposes gone, it is no longer there, but the next one may come on through. The number interacting is proportional to the number present. This means that regardless of how thick you make a shield there is always the possibility that one gamma-ray will pass through. But since the number that interacts is always proportional to the number that is present, if you make shields large enough and thick enough you can obtain protection from the radiations by simply decreasing the number of gamma-rays which do get through the shielding to a number you can tolerate. This principle is used in radiation laboratories to construct "hot cells". The reason they are called "hot" is because they contain radioactive or "hot" materials. They have thick walls that average 3 feet to 4 feet in depth. The same type of cell is used in the medical field where X-ray and radio-therapy are employed. In this case, a room very much the same as a hot cell, only a little larger, is used. You would not want to call it a cell and, in general, the intensity of the radiation is enough lower that the walls are thinner so it looks more like a room than a cell.

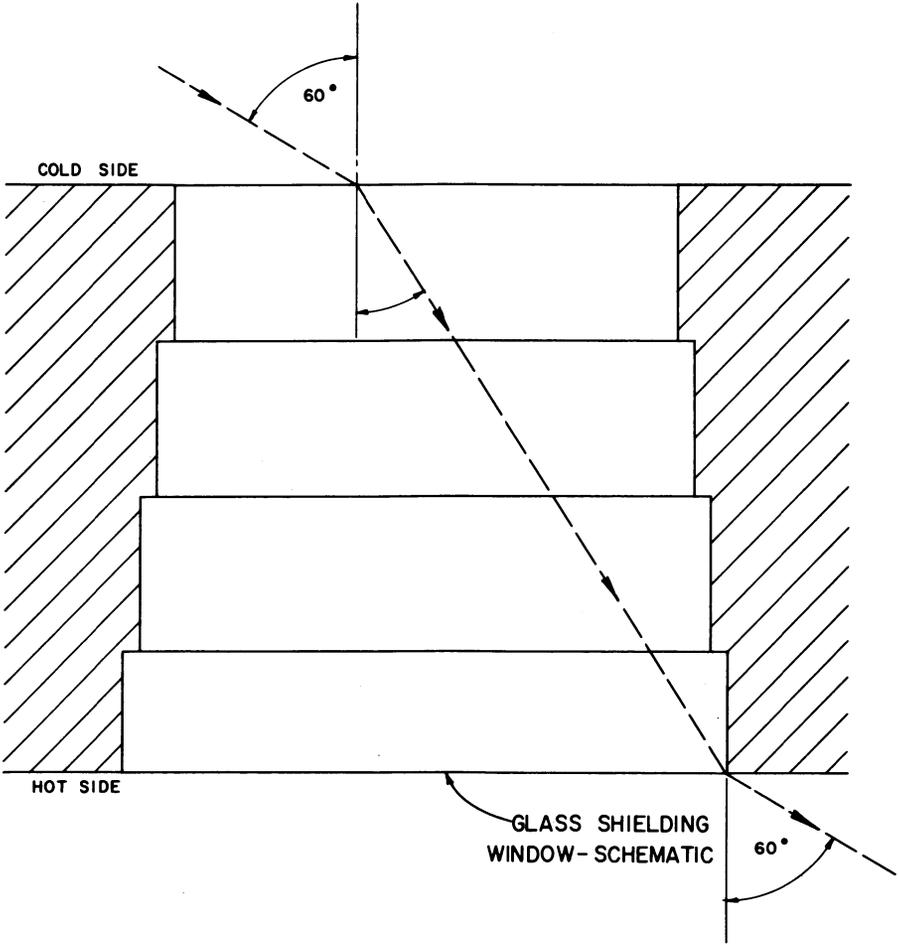


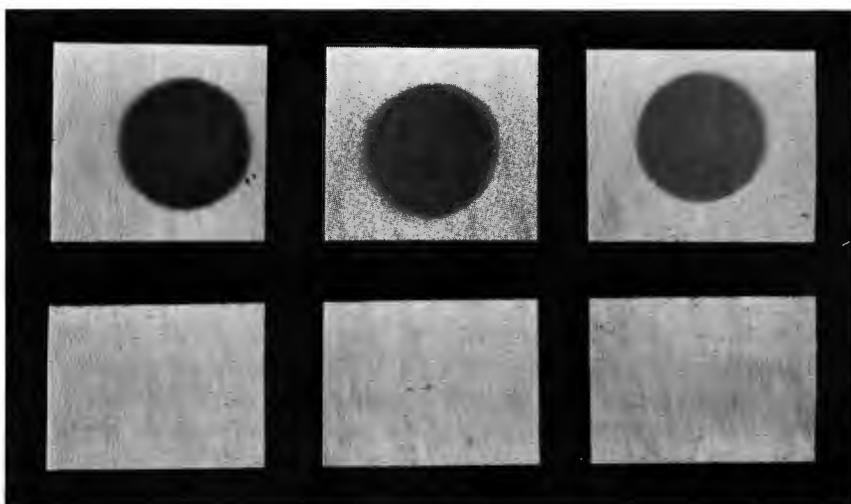
Figure 3

The problem now arises as to how a person can see what is happening inside the hot cell or the therapy room. If he stays in the cell or looks in through an opening he will soon get an overdose of radiation. The ideal solution is a glass window that is transparent but still supplies protection from radiation. So far, so good, but the glass must be as thick as the cell wall and this is a large, heavy block to move around. With the help of Figure 3 we can get an understandable schematic of a window.

To begin with, it must be sealed tightly against radiation leaks on all sides. It should be smaller on the cold or observer's side than on the hot side in order to permit a wider observer's angle. It could be a full 36 inches thick but for practical purposes it is better to use four pieces of glass 9 inches thick. I am talking about pieces of glass 9 inches thick and as much as 6 feet to 8 feet wide and 4 feet to 6 feet tall. These are pretty sizeable blocks of glass. This is a large window no matter how you consider it; it is really a picture window. It is heavy, it may weigh as much as a ton.

We have mentioned that glasses darken under gamma-radiation. In Figure 4 we can see the darkening produced by 2,000,000 R (2×10^6 R) of gamma-radiation. From left to right, the top three glasses are a soda-lime, a borosilicate, and a lead glass. We see that they have been darkened appreciably by the radiation. The bottom three glasses have not been darkened by the radiation. These are three glasses manufactured at the Harrodsburg, Kentucky plant of the Corning Glass Works expressly for radiation shielding windows. The first reading, from left to right, is very similar to an ordinary soda-lime glass except that it has been protected by the addition of a stabilizing compound, ceria. Its density is 2.7 g/cm^3 ; it is designated as Code No. 8365 glass. The second glass is also protected by ceria. Designated by Code No.

Figure 4



8362, its density of 3.3 g/cm^3 matches almost exactly that of the high density concrete frequently used for the walls of the hot cells. Third glass has an amazing inherent resistance to darkening and, in addition, loses the darkening coloration at a very fast rate. Its very high density of 6.2 g/cm^3 makes this Code No. 8363 glass very useful when very high density concrete is used for the wall of the hot cell since this glass can be used to make the overall density of the shielding window equal to that of the wall and still permits the window to be the same thickness as the wall.

Looking into the future of glass in this atomic age we might consider the high neutron absorption ability of boron for use in borosilicate glasses as shields around the reactors. This problem is now being considered and we shall learn more about it in the next few months. Another possibility is in atomic fuel reprocessing. New techniques will probably call for a casting method in which case glass will enter the picture. This novel use for "Vycor" Brand glasses, which Dr. Munier will show you, is to impregnate the porous form with radioactive waste and then sinter it into a solid non-porous glass. This forms a waste-disposal package which can be buried in the ground with no fear of its ever getting spread by ground water leaching into human water supplies. Another possible use of the porous glass is to encapsulate in this manner single radioactive isotopes. Such "packaged" isotopes could be used in many ways since it would be next to impossible for the radioactive isotopes to be spread over large areas as is possible if the isotopes are in gaseous, liquid, or powder forms.

Research in glass is proceeding along the line of nuclear studies. You have all heard, I am sure, of nuclear magnetic resonance. The procedure is to study irradiated glasses using these techniques in an effort to learn more of the basic properties of the material. For example, why do some glasses discolor while others remain clear? Or why do some show an optical band structure while others do not?

Nuclear radiation, neutrons in particular, can be used to determine the chemical composition of glass. This holds especially true of trace elements which do not easily respond to analysis. These are but a few of the many uses in which nuclear techniques

may be employed for research in glass. Thus, as we learn more about the uses of glass in atomic installations and in atomic energy applications we also learn more about the day to day applications of glass in the home, office, laboratory, industry or wherever glass is used.

Glass As A Heating Element

Everett Kelm

Corning Glass Works

Mr. Kelm received his M.S. in Chemistry from Iowa State College in 1935. He joined the Corning Glass Works in 1936 and is the holder of many patents in the pharmaceutical and laboratory field.

Glass has many interesting properties which make it useful in the manufacture of heating elements. It is strong and possesses a high dielectric strength. It can be used as an insulator as well as for supports. It can be worked easily into various forms and shapes pointing to other applications.

The original use of glass for electrical heat was in the monotype lamp bulb. Here a filament was enclosed in an envelope to furnish light. Shortly thereafter someone decided to improve the design to furnish heat. Of course, we all have seen instances where heat is furnished by lamp bulbs but this is not a very efficient method.

Improvements in glass making have evolved harder, stronger, more heat resistant glasses which are now used in various heat lamps for physical therapy, industrial heating, drying and baking. These lamps are rated between 250 and 350 watts. A few years ago, Corning developed a lamp that puts out 1,500 watts which proved very applicable to cooking. It was attached to the range and proved to be a rapid cooker as well as efficient. Unfortunately, the cost of manufacturing them—tungsten filament and graded seals—did not prove economical.

A recent development in this field is the line of E-C glass. This is a coined name meaning electrical conducting. In this process,

a conducting oxide film is laid down on the glass in such a manner that it becomes an integral component. The resistance of this layer can be varied between 6 ohms and 100 ohms per square. It is very stable inasmuch as it is not subject to oxidation. Our life tests are not complete but we say 5,000 hours. However, we see no reason why it should not be 10,000 hours and, if you think it should be 15,000 hours, we will go along with that! These units are in commercial use and holding up very well under varied conditions of operation.

You have been shown a 1,500 watt heater. The heat is evenly distributed over the surface and is free of hot-spots. An interesting feature is its insensitivity to color which causes it to blend harmoniously with the surroundings. It is a safe and efficient heater for the home. Commercially, they are used in ovens for paint drying etc.

On display is a panel of E-C glass with screws holding the bus bar. These films are thin and are deposited on the reverse side. This not only makes them safe electrically but provides excellent visibility. The film also acts as a heat reflector, thus adding to their efficiency. Our contacting system, contrary to other methods, is not a simple one.

We are unable to use soldered connections because we use a very low expansion glass. Therefore, we fire on a silvered bus bar type of thing on the indium film and it makes contact with the carbon button system which has proven satisfactory and there is no oxidation. On our tubular forms it would be very convenient if we could solder the connections but inasmuch as they operate at around 350°C this is impossible.

Recently on the market we have seen a high temperature tungsten lamp sealed in a fused silica or quartz envelope. This is a very high wattage lamp using about 500 volts. It is a very brilliant lamp and puts out considerable light. Thought has been given to its use as a tubular heater on a lower voltage. Our 7900 glass has been placed in a wire element which is compatible with the glass and used as a heater. Although in the experimental stage, we feel it has a place somewhere between the high temperature

lamp and the low temperature E-C glass. These units are not sealed into an envelope and they operate in a horizontal position. We envision their use in the laboratory as well as in the home.

While on the subject of heating units, we have a cute little oddity. It is a heater built for special applications. It contains about 60 thicknesses of resistance wire which was put in straight and then on one operation all bends were made in the glass and the wire locked in place! This required a bit of planning ahead of time and we were well pleased with the final product. Now we are engaged in research to find a suitable sheath for these units. We would like to seal them hermetically but it poses several problems. So far we feel that tin is the answer. Some day this may be of interest in your field of endeavor because there has not been much done in the field of "hem" sealing types.

When discussing E-C glass we mentioned the operating surface temperature as about 350°C. In our endeavor to push this limit higher we have changed the composition of the glass and now have this material which can safely operate at around 450°C. We consider this operation at a dull red heat quite an achievement and hope to make it available commercially in the near future. It is also quite possible that we will be using the Pyrocerams previously mentioned for electric heat.

New Concepts In Glass

J. H. Munier

Corning Glass Works

Dr. Munier studied at U.C.L.A. and was awarded his doctorate from the John Hopkins University. He joined the Corning Glass Works in 1939 and worked on such projects as metalized glassware, Multiform and photo sensitive glass.

The 20th Century in which we live is an amazing period. Whether one considers glass, electronics, travel, or communications, the growth is far greater in the past 50 years than in all of previous history put together.

We who are working with glass are well acquainted with its many properties and diversified uses. However, the average man on the street thinks of it as possessing primarily two major properties: most of it is clear and it all breaks easily! Glass has, of course, many more properties. Let us consider some of the highlights in the development of this material and note some of the valuable applications which appeared in the course of its growth.

Glass is unique in that it is the oldest man-made material. It is true that nature's glass, obsidian, has been in use for thousands of years but we find the first man-made glass as far back as 4000 BC. At this time, quartz beads with green glaze were in use. The manufacture of pure glass molded into amulets has been traced back to about 2200 BC. It is interesting to contemplate the practical knowledge which these ancient people had in those early primitive times. Even in those days tin oxide was used to produce a white opal and copper was known to produce glasses with turquoise, red or green coloring. About 1500 BC the first hollow

vessels were formed by winding rods of hot glass on cores made of sand. After the glass was cooled, the sand was removed from the center thus producing a hollow vessel. About 1450 BC small pieces of glass were pressed in very crude molds.

Perhaps one of the greatest discoveries of man was the blowpipe, which appeared around the 1st century BC. The blowpipes used then were similar to those in use today. They were four to five feet long with a mouth piece at one end and a knob at the other for gathering glass.

Clear glass appeared around the beginning of the Christian era. We have evidence that clear glass was used in windows at an early date for in 298 AD Lactantius wrote "our soul sees and distinguishes objects by the eyes of the body as through windows filled with glass."

In 1900 AD, glass-making techniques were not much different than in 1500 AD. Since the turn of the century changes have taken place very rapidly. Today we have literally thousands of articles made of glass; in addition we have thousands of compositions and many types of high speed, automatic machinery in modern factories.

We might separate the present glass industry into four broad areas. The first being that of flat glass, the second that of glass containers, the third fiber glass and the fourth a very large group of miscellaneous applications. Here at Corning we are especially interested in the fourth group which includes many technical and scientific items as well as consumer products. Each year we melt in commercial production about 400 different compositions. We actually have over 65,000 formulae for glass and we produce about 35,000 different items annually.

Up to 1910 all glasses were the so-called soft type i.e., soda, lime and lead compositions. With the advent of carbon arc street lamps and railroad signals, thermal breakage became a serious problem since all glasses at that time had a high thermal expansion coefficient. These lamps would be burning brightly and a sudden rain storm would cause them to shatter.

In 1908, Corning employed a lone scientist and one assistant and housed them in an upper room in the main plant. One of the first results of this step was the creation of the family of low expansion borosilicate compositions, with their many excellent features such as chemical durability, resistance to thermal shock, improved dielectric properties and increased mechanical strength. These are excellent glasses. No other group of composition can compare with the borosilicate family when it comes to the breadth and variety of uses to which it can be put. Other examples are home baking ware, chemical piping, sealed beam headlamps, and a multitude of applications too numerous to mention. Today, glass plays just as important a part in our lives as does steel.

In compounding glasses we use about 60 per cent of the periodic table. It is interesting to note how the properties of glass change by varying the ingredients. A demonstration with a lamp used in a motion picture projector helps to make this clear. About 92 per cent of the energy is not visible; only 8 per cent is in the visible range, the remainder is in heat. This heat can be absorbed or transmitted by glass. The focal point of the lamp can be determined by blowing smoke into the beam. Then a glass is placed directly over the lamp, and a piece of paper is placed at the focal point. It immediately begins to turn brown and smolders, then bursts into flame. Upon touching the plate, it is found to be cool. It has absorbed practically no energy from the lamp either in heat or light. Another piece of glass, which can be seen through very clearly, is placed on the lamp and when the paper is held at the focal point it does not even char. The glass, however, is quite hot which indicates that it has absorbed the heat but allowed the visible light to pass through. A piece of glass so dark that not even the visible light of the lamp will shine through can be used in another demonstration. A piece of paper held at the focal point now bursts into flame and the glass is only slightly warm to the touch. This piece is the direct reverse to the second example since it absorbs the visible but transmits the heat. This is a good example of the way in which properties can be altered by changes in compositions.

In the early 1900s, a new technique was discovered by which it was possible to improve the mechanical strength of glass. This process is known as tempering. It is a heat-treating process which

results in a compressive layer over the whole glass surface. In order to break such a piece of glass it is first necessary to stress it to the point where the compression in this layer is overcome and the surface is put into tension. A coffee cup of such a strengthened piece of glass can be used to drive a nail into a block of wood.

The new borosilicate glasses required higher melting temperatures during melting. This immediately produced a new problem since the higher temperatures of the new compositions worked together to shorten the life of a glass tank. The study of this problem resulted in our becoming involved in refractory work and this eventuated in the formation of Corhart Refractory Company in 1927. This whole problem gave birth to the refractory business which now not only serves the glass industry but the steel industry also.

A recent outgrowth of this refractory development is a new technique of casting materials. This process, known as Glascast, makes it possible to mass produce metal parts to very close tolerances. To make such a casting mold, a wax model is made of the item having the necessary tolerances. This wax is coated by dipping in a glass slurry and is then fired. In this operation, the wax melts out and the glass shell is sintered just enough to hold it together. The molten metal is poured into this mold and, after it hardens, the glass is broken away leaving the metal casting whose tolerances can be controlled to \pm or -0.005 inch.

For many years glass was used in the building trades for windows and lamp shades. In recent years, glass has been used in the form of blocks as a whole front for buildings or in the form of polished plate of varying colors. In the early '30s Corning began work in this area and the result has been the development of glass building blocks of various designs, some of which contain prisms which reflect the incoming sunlight to the ceiling of a room, eliminating glare and improving lighting conditions. The Pittsburgh Corning Corporation was formed in 1937 and is engaged in the manufacture of these building blocks which are sold the world over.

Another development of this same period is foam glass. This

material is filled with small bubbles but is not permeable and therefore it will float on water. This light weight material has very good heat-insulating properties and can be used as pipe coverings and similar applications. Because of its buoyancy it has also been used for life rafts.

Another branch of the field of glass with which we are all familiar is that of glass fibers. The uses of glass fibers are so numerous that to properly describe them would occupy a complete lecture in itself. We might be reminded, however, that the present day uses extend to the textile industry for clothing, curtains and drapes; the electrical industry for high temperature insulation; the automobile industry for heat insulation and sound proofing; and the builder who uses it for home insulation and fire proofing. We all have it in our possession in one form or another in our refrigerators, ovens, thermos jugs and many other items. One fact of interest is this: the small marble, $\frac{3}{4}$ inch in diameter, will produce a single strand of AA fiber which will stretch $\frac{4}{5}$ of the way around the earth at the equator. The original development of the fiber glass project was begun in Corning in the early '30s and in 1938 the Owens-Corning Fiberglass Corporation was formed.

The 96 per cent silica process developed by Corning in the 1930s is said to be the only radically new way of making glass since the days of the Egyptians. This process begins with the formation of a soft glass which can be handled easily by normal forming technique. The blown or pressed object is placed in an acid bath which leaches out most of the flux leaving an open silica network. When placed in a furnace and fired at an elevated temperature, the silica network closes up producing, as a final product, a glassy material which is 96 per cent silica. This glass will withstand high temperatures and is not subject to breakage from thermal shock because its thermal expansion is comparable to that of fused silica. We believe the full potential of this material has by no means been reached; it is in exactly the same stage today as were borosilicate glasses at about 1918.

Another entire industry has developed as an outgrowth of research in glass. I refer to the field of silicones. Some years ago a young organic chemist with considerable experience in carbon re-

search joined our organization. He concentrated his effort in an attempt to overlap the two fields of organic and inorganic materials. Combination of carbon and silica resulted in the development of the silicone family of materials. The Dow Corning Corporation, formed in 1943, is now the largest producer of products made from silicones. These products range from rubbers, water repellent materials, high temperature oils, greases, anti-foam agents to cosmetics.

During this same period, a new technique was developed to extend the range of forming of glass. This new process is known as "Multiform". It is a high precision, high speed process. In this process the glass is powdered and mixed with a binder after which it is pressed or slip-cast into a mold. It is then placed in a lehr and fired. In the firing operation, the binder is burned out and the glass particles are sintered together. Many products can be made by this process which can not be done by conventional methods. There are times also when items which can be made by conventional methods can be produced more quickly and more cheaply by the multiforming process.

The year 1944 produced a revolution in the optical glass field. Up to this period the process had remained virtually unchanged for many years. This old fashioned method consisted of melting a pot full, each pot containing about one ton of glass. It was permitted to soak until it was fairly well fined after which it was withdrawn and allowed to cool slowly. Due to its size and the high expansion, it would crack as it cooled into shells very much like an onion. These pieces would be inspected; only those free of striae and imperfections could be used and this amounted to only 15 per cent of the total melt. The selected pieces would then be reheated and pressed into rough shape and then ground and polished. The entire process was indeed wasteful and inefficient. Today a plant one-third the size of our Parkersburg plant can produce as much optical glass as was made in the year of 1945. Up to 1952, nearly all glass used in this country for aerial cameras was produced in Europe. Today, not only is this glass made in this country but both England and France have adopted our method of making optical glass.

The experience and technology gained in the development of the manufacture of high quality optical glass has made possible the production of new products. A glass with a slightly yellow tint is used as a window in atomic energy installations since it absorbs neutron radiations to protect personnel and is sufficiently clear and free of imperfections that a thickness of several feet will not interfere with visibility.

The television industry has also profited from the optical techniques. It is now possible to produce high quality panels for large mass-produced television bulbs. However, some of you who toured the Pressware Plant have seen the centrifugal casting method in action as well as the pressing of panels. You also had an opportunity to observe the electrical method of sealing the panel to the funnel. With the advent of color television a new problem presented itself. Inasmuch as the customer has considerable work to do in placing arrays of phosphor dots on the inside of the panel and finally inserting the aperture mask in place, we could not attach the panel to the funnel before shipment. This final sealing problem was then in the hands of the tube manufacturer. Because of the extreme heat generated in the electrical sealing operation, which would be injurious to the mask and phosphors, new methods of sealing the panel to the funnel had to be devised or invented. This problem was solved through the use of what we call solder glasses. There are many types of these and the one used for the colored bulb fuses and seals and then devitrifies in place and will not remelt at the temperatures required in vacuum baking of the tube.

The rapidly expanding and exacting field of electronics has stimulated our efforts in the development of electronics and components. Demands for higher operating temperatures and close tolerances have been met quite well through glass components. To help replace and supplement mica during World War II, we developed a process whereby glass ribbon could be drawn continuously and wound on spools. This ribbon ranges from 0.0005 inch to 0.003 inch in thickness. Capacitors are constructed by alternately stacking a layer of glass and a layer of aluminum foil. These stacks are then pressed in a furnace under pressure, which easily seals the capacitor within a glass envelope.

They are very stable over a wide temperature range and are impervious to the conditions of surrounding atmosphere.

Much effort has been spent in developing another type of glass for electrical use. The glass itself is not conductive but contains on its surface a thin oxide film which carries the electric current. It is known as an EC film, which means electrically conducting. A similar type of film is being used to produce a whole family of close-tolerance, high quality resistors for electronic uses.

The deposition of metallic silver on the surface of glass is familiar to all of us and has been used for many years as a decorative technique. In 1940, we began a development to turn this art into a technical engineering process. It is now being used to make trimmer capacitors and induction coils of very high reliability and accuracy. This technique is also used to form hermetically sealed envelopes for military grade capacitors and resistors. The resistor is placed inside the glass tube and metal caps are soldered to the metallized ends of the tube. The test requirements on this assembly are exceedingly high. They are cycled a number of times from an operating temperature of 275°C, held for one hour, and then immersed in ice water. The only type of enclosure which repeatedly survives this test is made from tempered borosilicate glass tubing, metallized and hermetically sealed.

Within very recent years, Corning Glass Research has developed a new process by which silica of high purity and homogeneity can be produced. Impurities are down to one part in a hundred million. The high degree of homogeneity and anisotropy make it ideal for acoustical delay lines. The process is not conducive to low cost but the properties of the material make it essential to certain types of applications. The low attenuation of sound makes it ideal for delay line application in electronic radar circuitry.

The next subject, photosensitive glass, is interesting in that it makes use of a phenomenon which has, in general, been carefully avoided in glass manufacture for many centuries, viz., devitrification. Composition research, conducted by Dr. S. Donald Stookey of our laboratories, resulted in unique glasses in which devitrification can be controlled. FOTOFORM glass is one of these. It is a glass containing an unstable phase which would crystallize

or precipitate throughout the body of the glass except that, in manufacture, the increase in viscosity outruns the rate of crystallization during cooling of the glass, preventing the formation of crystals.

After formation of the sheet glass, it can be processed in a manner entirely analogous to positive picture printing in photography. A contact print is made using ultraviolet light as the light source. Wherever this radiation penetrates the clear parts of the negative, it passes into the Fotoform glass beneath, sensitizing the glass. The latent image thus produced is not visible, but upon placing the "exposed" piece of glass in a furnace and heating it in a specified way, crystallization takes place in those parts which have been exposed to ultraviolet radiation through the negative. A positive pattern, duplicating the negative pattern, is therefore obtained with crystalline areas corresponding to clear areas of the film negative.

The final outstanding characteristic of this Fotoform composition is contained in the fact that the crystalline image is soluble in hydrofluoric acid. If a sheet of this glass, containing a crystalline pattern, is soaked in a 10 per cent solution of this acid, the sheet will, in time, contain holes in place of the crystalline image.

To anyone who has familiarity with the process of drilling holes in glass, the significance of this Fotoform process is immediately recognized. It is now possible to produce complex shapes in sheet glass by a straightforward photo-etch process with a considerable degree of precision. For example, consider the aperture mask for a color television picture tube. This sheet of glass is approximately 16 inches x 18 inches and contains about 360,000 holes, 10 mils in diameter and having a tolerance of + or - ½ mil.

Even more amazing is the fine mesh screen, about 2 inches square and 5 mils thick having 90,000 holes per square inch, designed for use in cathode ray tubes. Screens are being made today having 560,000 holes per square inch.

This glass has other advantages also. After a sheet has been

processed and contains the desired array of holes, this perforated piece can be wholly flooded with ultraviolet light and heat treated again. Depending upon the amount of radiation and the thermal treatment, this piece can end up in one of three ways.

1. It can be a dark chocolate brown which is opaque to visible light. This is referred to as Fotoform E.
2. It can be yellow and opaque, the acid soluble phase, referred to as Fotoform C.
3. Or it can be subjected to an extreme thermal treatment, producing a crystalline transition resulting in a very strong, hard material referred to as Fotoceram.

All three types have a volume resistivity 1,000 times higher than the original clear Fotoform glass. The Fotoform C is about twice as strong as the clear glass; Fotoceram is about four times as strong. Fotoceram is a heat resistant material, it will withstand temperatures of 500°C without deformation or change in physical properties. This material is finding use in the field of printed circuitry for military applications where dimensional and electrical stability is needed at high ambient temperatures.

We believe that only the surface has been scratched in the potential uses of this unique material.

The general trend of technology today is toward higher speed, higher temperature, higher strength, higher efficiency. This poses new problems for which new materials must be sought. Materials for fabricating supersonic aircraft and missiles, as well as electronic components, call for stronger, lighter, more heat resistant and, in general, more superior products. The demands of high temperature chemistry are constantly increasing.

Just last week, Corning announced a new family of fine-grained crystalline materials made from glass, distinguished by the Corning trademark "PYROCERAM". These new materials are melted into various products and, by a single heat treating

cycle, they are later converted into fine grained crystalline bodies having vastly different properties than the original glass.

Some of the unique aspects of this process are as follows:

Because of the use of modern glass melting technology, composition and hence, properties can be very accurately controlled.

Present high speed glass forming techniques can be used to produce required shapes. This is an aid to cost reduction.

Since the materials begin as glasses, they are free of voids and remain so after transformation into the ceramic state. Inspection is also made possible while in the glassy state.

Because of small dimensional change in going from glass to ceramic, finishing, down to almost final tolerance, can be done in the glassy state which is much easier to grind than in the final ceramic state.

Some compositions have the very low coefficients of thermal expansion, even negative values, while others are very high on the positive side. Present compositions in the laboratory range from -7 to $+200 \times 10^{-7}/^{\circ}\text{C}$.

The mechanical strength of these materials ranges from three to four times that of window glass.

With the combination of high strength and low coefficient of expansion, it is virtually impossible to fracture some of these materials by thermal shock.

Other compositions possess a high degree stability of electrical properties over wide ranges of frequency and temperature; they rank among the very best of dielectric materials.

Pyoceram can be used for tubing, saucepans, sheet, coffee makers, solid cane and a cast shear blade.

Strength at high temperature can be illustrated by heating a Pyoceram cone to 1300°F in a furnace and using it as a hammer to drive a 30 penny nail into a block of wood.

Resistance to thermal shock can be shown by removing a Pyroceram dish from a furnace at 1300°F, placing it on a wood block and pouring ice water into the dish. Steam and wood smoke are the only result.

The missile radome is a product centrifugally cast, inspected, machined to approximate dimensions, cerammed and touched up to final specifications. This is the first product to be made from one of these new materials, and we expect Pyroceram materials to contribute in some measure to national defense. We believe these new materials will assist in pushing back the frontiers of this age of atoms, missiles and supersonic speeds. This new process opens up an almost infinite variety of possible compositions, the potential of which cannot yet be estimated. What you see here today is but a modest beginning.

Highlights In The History Of Glass Fabrication

Vincent C. DeMaria

Sylvania Electric Products

Mr. DeMaria received his education at Stuyvesant High School in Brooklyn, N. Y., and took additional work in glassblowing, inorganic chemistry and mathematics. He is a member of the editorial staff of Fusion, the journal of the American Scientific Glassblowers Society, and writes the Patent Abstracts section. He was active at CBS in the development of the color television tube. Before joining the Sylvania Company, he conducted his own business, the DeMarr Glass Products Company.

The progress and development of scientific glassblowing over the centuries has been closely related to, and has derived much of its impetus from, the physical and natural sciences. At the same time, glassblowers have contributed valuable tools and techniques to the sciences. This paper will cover highlights of the history of scientific glassblowing and will indicate its connection with the sciences as well as the effects on it of related industries, and of improvements in glass working technology in general.

The evolution of glass as a material, and of glass working tools and methods, will serve to illustrate the progress that has been made since earliest times, and to indicate the direction of further advances (Figure 1).

Some of the earliest known glass vessels were used as containers. They were fashioned by coating sand forms with softened glass. Other early references survive to record that Democritus, in 460 BC, and Plautus, in 245 BC, used crude lenses and magni-

fying glasses. The appearance, probably in Syria, about 100 BC of the long metal blowpipe for gathering and blowing molten glass was a major advance in the art of forming hollow glass objects. Improvements in forming techniques then came from many corners of the world. Molds were known in ancient Rome and the decorative touch seems to have been popular with the advent of the engraving wheel in Byzantium. The novelty of mirrors is recorded in Rome in 31 BC when the backing of glass with lead was in use.

The advance to the use of blown glass bottles as standards of liquid measure as early as 8 AD probably represents the origin of our present day volumetric glassware and these, together with the alembic, eventually became the basic glass apparatus of the alchemist. History records very little in the way of significant developments along these lines until about 1000 AD. At this point we find renewed interest; in 1100 AD for instance, the medical school at Salerno became concerned over leaching from distillation glassware. Efforts to overcome this problem are among the first attempts to improve the quality of scientific glassware.

In 1317 we see the invention of spectacles, and in Venice at this time, the tin amalgam backed mirror, the finest of its time, had come into existence, while in the same city diamonds came into use for engraving purposes. In France also, at this time, diamonds were used in the cutting of flat glass.

By the middle of the 16th Century barometers and thermometers had been invented, and this was the basis for increased interest in glassblowing for scientific purposes. The microscope came on the scene in 1570 and the telescope in 1609. Both developments were the common stimulus to the glass workers for the creation of improved optical materials. Shortly afterward, in 1610, the first known observation of chemical etching was recorded when mixtures of nitric acid and fluorescent emerald (probably calcium fluoride) were used. During this period, the use of ground joints on chemical apparatus was introduced. These first versions were not interchangeable, but were acceptable glass closures.

As the need for more elaborate glass apparatus grew, the difficulty of blowing laboratory ware from "gobs" of glass gave rise

HISTORICAL EVOLUTION OF *Scientific Glassblowing*

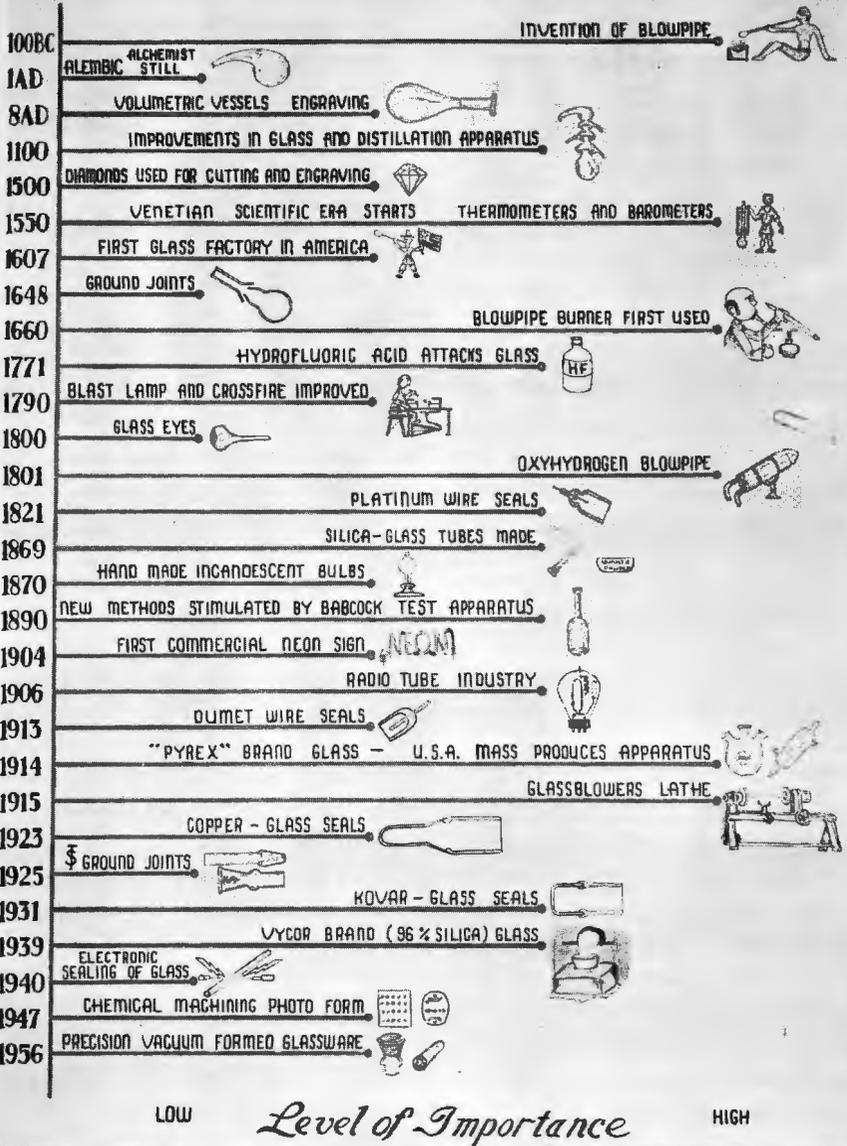


Figure 1

to a search for a more practical heat source than the furnace and its "glory hole". So, in 1660, the chemist's tinned iron blowpipe, originally used for charcoal block analysis, was pressed into service as a bench glass working burner by Florentine glassblowers. The use of this tool spread rapidly, and we find in the book, "The Art of Glass Blowing", published by the chemist Kunkel in 1679, the suggestion of supplying air to the blowpipe by means of a bellows.

Bench glassblowing is less than 300 years old. But stories of its origin have circulated in a "can you top this?" manner. I felt it would be amusing to try topping these stories. The results are shown in Figure 2.

As we emerge from the middle ages where progress was slow, and enter the era of the workers who formed the basis of our modern science, we see much more rapid and significant advances made, and by the middle of the 18th Century we find that most chemists had actually become their own glassblowers. In 1771, Scheel discovered hydrofluoric acid, and waxed engravings came into use for calibrating glassware. During this same period improvements in optical glass were made by Guinard's method of stirring molten glass while in the pot, thus making optical quality lenses available in 1790.

Progress in heat sources for working glass continued so that in 1790 blast lamps and cross fires had come into use in the form of rectangular cans with wicks dipped in tree oil or lard oil as fuel, and with primitive air supplies. These sharp air-oil fires were adequate for working the low-softening temperature glasses, but it remained for the invention of the oxy-hydrogen blowpipe by Hare in 1801 to provide the first high temperature flame.

Progress along other lines was also evident in this period as Davy, in 1821, made the first metal to glass seal by fusing glass around a platinum wire and thus opening up the important area of electrical experiments in sealed glass vessels.

Among the many contributions to scientific glassware at this time we should not overlook Liebig's invention of the water



-FIRST SCIENTIFIC GLASSBLOWER?

Figure 2

jacketed condenser in 1824, an item still made in large numbers today.

Around this time, a material previously not used for these purposes received increased attention, as in 1839, the Frenchman Goudin fused quartz and made it into shot and fibers. Within 30 years, Gautier, a German, had made silica glass tubing and by the turn of the century, England was producing silica glass tubing that could be worked into useful apparatus. We can close, in review of this intermediate period, with a reference to the discovery by Petit Jean in 1855, that an ammoniacal silver nitrate solution could be used to deposit silver on glass chemically, an observation that enhanced the important invention of the double walled evacuated flask by Dewar in 1884. Shortly afterwards, Victor Durand of Vineland began manufacture of this now common item.

Those parts of our present-day glass technology that do not still rest on old techniques had their real beginning at about this time, that is, the late 1800s and early 1900s, as the innovations and inventions came more rapidly. For one thing, machine glass making now came into its own in certain lines. It was in 1880 that Wright and MacKie introduced the glass lathe in England. And, as you know, in 1882 Edison's carbon filament incandescent lamp went into production and tubulating bulbs, stem making and sealing in the mounted filament were all the glassblower's responsibility. Small bulbs made from tubing were produced at the rate of 400 per 9-hour day at that time.

In other areas of industry, Babcock's butterfat test set a standard for the milk industry in 1890 and this gave rise to a demand for large volumes of milk-testing glassware. This in turn caused the development of new and more rapid fabricating and calibrating techniques.

Meanwhile, in the realm of glass formulations, the new Jena borosilicate glass for laboratory use became available in 1894 making heat resistant chemical apparatus available that could be heated in open flames.

As the trend to automatic machinery continued, American in-

genuity took the initiative, and in 1905, Ewan Kimble left Chicago to set up the first ampoule machine in Vineland, New Jersey.

At this time a new product that was to achieve tremendous importance for glassworkers, got its start as DeForest introduced his improved electron tube in 1906. All the glasswork on these early tubes was done by hand. Shortly thereafter, in 1910, Claude's introduction of the illuminated advertising signs using glass tubing began the growth to popularity of a business that was to become the training ground for hundreds of glassblowers.

In 1913, the use of platinum wire for metal-through-glass seals gave way before the invention of the more economical Dumet wire by Eldred, and in 1914, the major development of Pyrex was achieved by Sullivan and Taylor of Corning after eight years of borosilicate glass research. A series of Pyrex glasses have since been developed with properties suited for numerous chemical, electrical and other applications.

The glass lathe first appeared in America at McCandel's Lamp Works in Brooklyn in 1914, and by 1915, it was in use by other people. The lathe greatly simplified large diameter work and has made accurate glassblowing a routine.

In the glass-to-metal seal work, the tubular and the disc seal became feasible with the invention in 1923, by Housekeeper, of a feather-edge copper seal. This greatly simplified the construction of high power transmitting tubes because problems in heat dissipation could more easily be solved. The use of ground joints, known for years, also shared in the general advancements in the scientific glass industry, as the efforts at standardizing and making these joints interchangeable was accomplished under National Bureau of Standards' sponsorship in 1925.

A new development in glassworking technology came about in 1929 with the development by Ellis and then by Litton of silent surface combustion burners that would not back flash. An improved multi-tube version of these torches has since been incorporated in lathe burners and hand torches, which make possible the handling of extremely large diameter silica glass work.

The significant development by Scott, in 1931, of Kovar as a sealing metal greatly simplified the construction of glass-to-metal seals with improved reliability.

As progress in developing new techniques and new machines continued, a significant advance in high silica glass was made in 1939, when Vycor was developed by Hood and Nordberg, making available a variety of 96 per cent silica glassware by a practical forming process.

A further item in this chronological series of important developments is the use, from about 1940 on, of electronic sealing of glass. As you all know, this is a technique in which glass, already being heated by flames, receives through the flames an electric current. This current, flowing through the somewhat resistant glass, heats it still further and hastens the softening process. This technique has the advantages of localizing the heat and preventing surface boiling.

A number of new forms of glass have been described by other speakers. They should not escape mention here as we bring our survey up to date with some of the most recent developments in the glass industry.

The multiform process, first used commercially in 1942 by Corning, consists in sintering glass powder pressed to shape in a die. Other applications of the powdered glass technique will, in all probability, be extended to the manufacture of new industrial items.

Photosensitive glass, announced in 1947, made possible the development of the scientifically significant chemical glass machining process by which accurate openings in glass, previously considered impossible, can now be produced.

Tempering will extend the life of glassware. Weak points, such as tube openings of expensive apparatus, can be toughened as is now done on glass pipe. The process is limited to simple shapes, but the benefits make this a challenging project worth investigating further.

Conductive glass, made by coating glass with films of tin oxide, find use for column heaters, static charge removal, electroluminescent lamps and other devices.

Foam glass, which is easily worked with cork borers and a hacksaw blade, form convenient apparatus jackets or containers for innumerable heat insulating uses.

Ultra-fine silica glass fibers require no binder, are useful for wicks and filters and for cushioning the inside of chemical and vacuum systems requiring high purity and high temperature operation.

Glass can be combined with new substances, such as silicones, for the protection of glass surfaces and teflon and polyethylene for non-corrosive moving parts. In this way new applications and improved apparatus can be expected to develop.

In connection with these up-to-date materials, I should like to indicate some new techniques that may be of interest to you. We have referred earlier to the introduction of the glass lathe. Figure 3 illustrates a method of increasing the usefulness of the lathe by securing a standard metal working lathe milling attachment to the burner carriage, thus making feasible the rigid support of carbon paddles and templates. These tools, controlled by the feed screw, can be adjusted to form the glass appropriately in increments of a thousandth of an inch. Accurate angles can be set and reproduced in glass and pipe flanges, and ST ground joints may be duplicated without the need of special tools. Any configuration that can be rotated in a mold can be formed with inexpensive carbon templates in this way. This phase of modern glassworking is making the glassworking lathes as important as bench glassworking.

Another useful technique is vacuum forming (Figure 4). The accuracy of the precision mandrel can be transferred to the softened glass by uniform atmospheric pressure. The glass tubing, containing the mandrel, is secured in the lathe chucks. Rubber hose connects the tube's open end with a vacuum swivel to form a closed vacuum circuit to the mechanical pump. The opposite

end of the glass tube is closed. The gas air ribbon burner preheats the entire mandrel while the evacuated glass tube rotates in the lathe. A hand burner flame is applied to the glass enclosed mandrel end farthest from the vacuum source. The glass tube commences to shrink about the mandrel with an obvious visual change. Travel of the hand operated shrinking burner toward the vacuum end is adjusted to the rate at which the glass collapses.

Figure 3



Construction of silica glass apparatus is simplified by use of vacuum forming (Figure 5). This thin wall oven, used as a sample holder in the mass spectrometer, was formed on a two piece carbon mandrel which allowed the center ground joint to be made during the vacuum forming process. Parallel holes in the plug, seven thousandths of an inch in diameter, were vacuum formed also. The absence of air prevented oxidation of the tungsten wires which were temporarily used to form the holes. After shrinking,

Figure 4



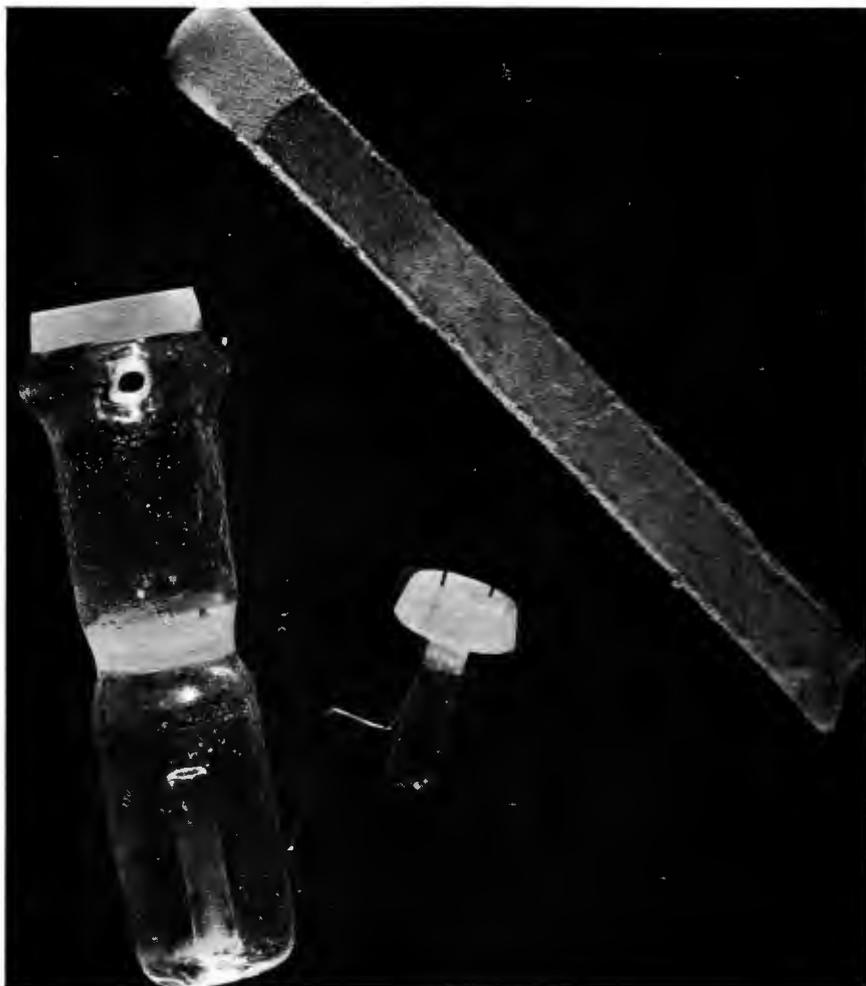


Figure 5

these wires were removed by an electrolytic etching (reverse plating) in a sodium nitrite solution. Difficulties in working small diameter thin wall silica glass were overcome and duplicates were identical in size.

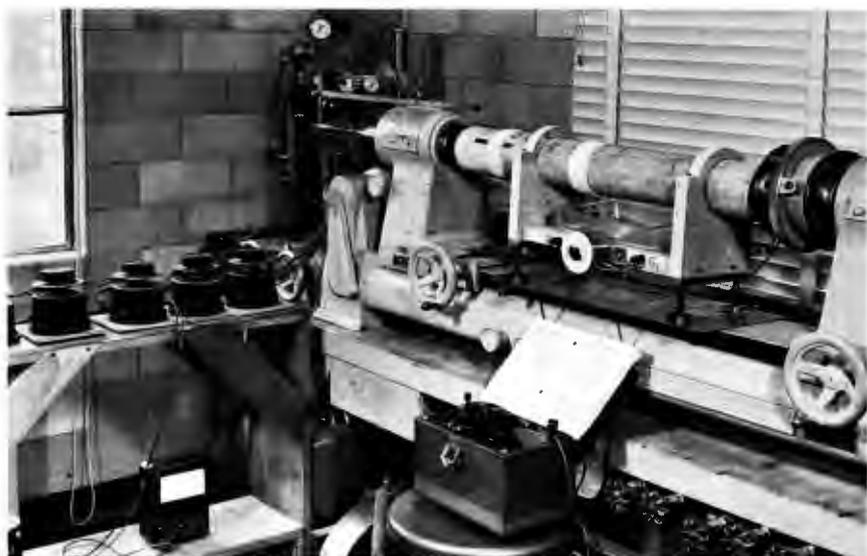
Although open flames are still the best known medium for heating glass for most scientific glassblowing jobs, the solution to difficult problems will often be found when new fabricating approaches are used (Figure 6). This precision temperature controlled oven mounted on a standard glass lathe, was used to

vacuum form glass over a metal helix so that only 1 per cent of the area of each turn of wire was contacted by glass. The oven is wound with resistance wire in sections; the temperature in each section is regulated with a Variac and indicated by a thermocouple. Thermal variations of less than 5°C over the oven length were maintained.

A number of aids have been made available to glassblowers. One example is the polariscope (Figure 7). For strain detection, its importance is analogous to the physician's X-ray machine. The polariscope has been reduced from an expensive optical instrument to a tool as convenient as a micrometer. Strains appear in color because of a full wave plate in the viewer.

The glassblower's burner of the future may use solar energy. Large mirrors focus the parallel rays of the sun on a small area producing temperatures in excess of 2500°C. Glass has been melted and studied using this pure heating method. Improvements in glass have made it a more versatile material for research. With further advances in glass technology, malleable or unbreakable glass may someday become a reality. By means of meetings and

Figure 6



publications of the American Scientific Glassblowers Society, glass apparatus construction will become a unified scientifically sound modern art.



Figure 7

The Varieties of Glass

Oscar H. Grauer

Fischer & Porter Co.

Mr. Grauer studied at City College of New York, George Washington University and the Graduate School of the Bureau of Standards. For the past two years, he has been a glass technologist for Fischer and Porter Glass Division. Previously, he was employed at the National Bureau of Standards.

Before discussing the varieties of glass, it might be helpful to describe something about the what and the how, if not the why, of glass and its behaviour. A useful, though not complete, definition of glass is the following: an inorganic product of fusion which has been permitted to cool to the rigid condition without crystallization taking place. When glass is chipped it exhibits a conchoidal fracture.

Even though this definition does not specify the composition range of glasses or the units of its structure, it does present the basic mechanism of glass formation, namely, the undercooling of a liquid (fusion) to a point where its viscosity has become so great that it is practically solid (rigid), the viscosity of the cooling glass having overcome the tendency towards crystallization.

Evidence that tends to support the definition of glass as an undercooled liquid rather than a solid (crystal) is the fact that glass does not have a sharp melting point like solids, but rather an extended temperature range in which it gradually becomes less viscous and more fluid as it is heated. Also X-ray diffraction patterns of glass generally show diffuse bands which are characteristic of the disorder in liquids rather than the sharp peaks

which result from the regularly repeating geometric structure of a solid (crystal).

In view of the random distribution in the structure of glass, it is not surprising that glass is isotropic, or possesses no preferred direction with respect to its physical properties. As a matter of fact, conchoidal fracture in glass demonstrates the directional equality of the elastic waves.

CRYSTALLIZATION AND OTHER CHARACTERISTICS

Crystallization (Figure 1) of glass educes more than just theoretical interest. The making of any new glass is greatly dependent upon the crystallizing power of the composition. Even after glass has been manufactured, there is always present the possibility of it reverting back to the crystalline form or devitrifying as a result of any excessive heating operation.

A very practical and useful way to express crystallization effects is through an E-C or expansion-crystallization diagram (Figure 2). In such a diagram, the linear thermal expansion and the linear rate of crystal growth are plotted as ordinates using a common temperature scale as abscissa. Such a diagram has been used for solving problems in connection with the slumping of large discs of optical glass for use as thick "Schlieren" windows.

Insofar as the great thickness (over 10 inches) of the window necessitated a very slow rate of cooling, heavy surface devitrification would result. Upon further cooling, fracture would occur due to the differential expansion between the devitrified surface and the bulk glass. Thus a dilemma was created in which rapid cooling caused breakage because of thermal stress and slow cooling caused devitrification and subsequent breakage too.

By means of an E-C diagram, the solution to the problem was made evident. It was noted that three main zones existed. In zone A on the diagram, breakage could occur due to expansion but no danger of crystallization existed. In zone B, the only problem was devitrification since thermal strains would be instantly relieved. While in zone C, above the liquids temperature, neither breakage nor devitrification could occur.

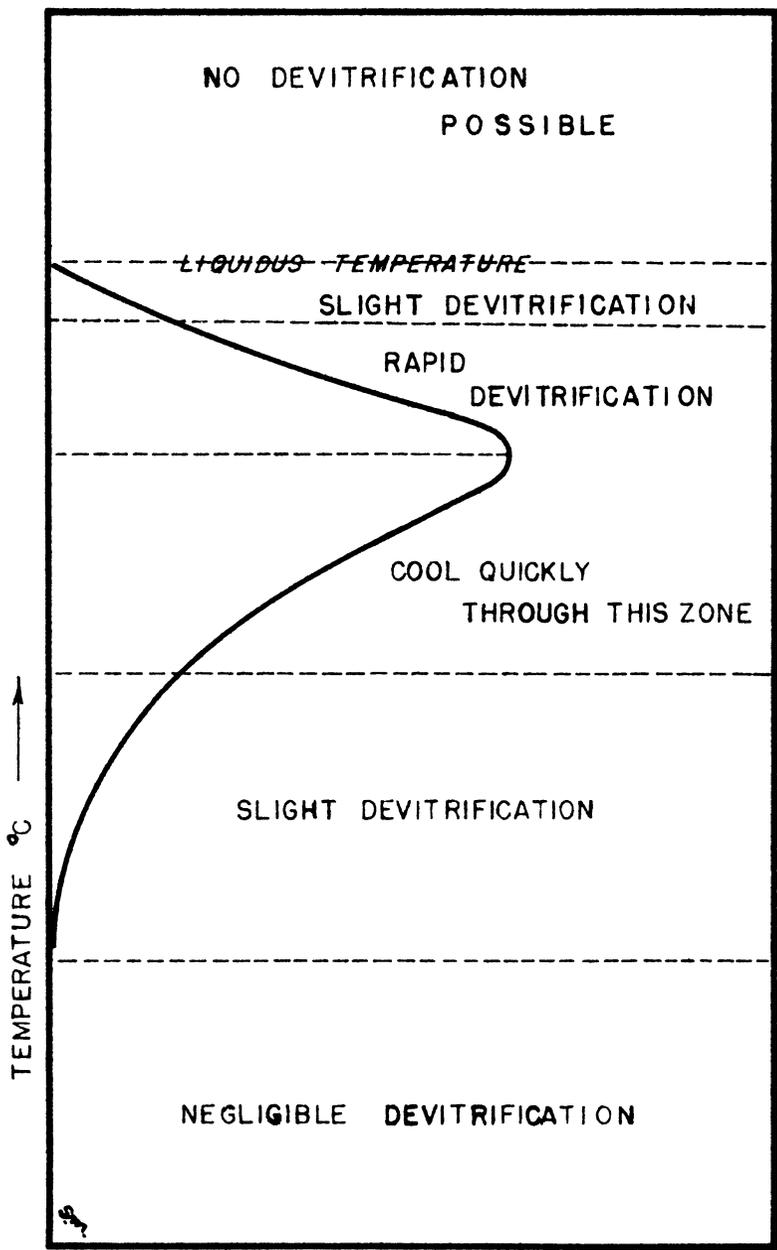


Figure 1

tions. It is indicative of the fact that the stress concentration of tiny fissures in the glass surface rather than the composition of its bulk is the limiting factor with respect to strength.

Other influences will be found to have important bearings upon the strength of glass. Thus a harder glass which would be less susceptible to scratching and abrading will show increased strength for this reason. Similarly, a glass with a low thermal expansion will show superior resistance to thermal shock and temperature gradient simply because less stress upon the glass will be generated. The thermal expansions of different glasses vary considerably, but the general shape of the curves is the same.

Optical uses of glass derive from its high transparency, and the fact that its index of refraction, dispersion, and absorption can be controlled over a wide range. Electrical properties, like resistivity and dielectric constant, also put glass in a favored position for insulators, condensers, and even transparent conductors.

In addition to the above properties of glass, the persistent occurrence of certain defects in glass practically assures their inclusion as characteristics, if not properties. Such defects include bubbles, air lines, striae, cords and stones. Bubbles are due to the incomplete fining of the glass. In drawing glass tubing, the bubbles are elongated into narrow cylindrical pockets of gas called air lines. Striae arise from lack of complete homogenizing of the glass during melting and from solution of the refractory tank parts. Where the striae is localized to narrow, stringy, off-composition streaks, it is called cord. Stones are small lumps of crystalline material, usually white in color, arising from incomplete fusion or droppings of refractory materials from the tank crown or sides.

Although glass has been defined as an undercooled liquid, the raw materials of glass are crystalline or solid (silica, soda, alumina, etc.). Before glass can be made these materials have to be put into the liquid state by melting. The melting point of SiO_2 , the chief oxide (about 20 per cent by weight of a typical glass), is 3135°F . This temperature is well above the practical range of most furnaces. It is due to the fortunate circumstance

that the melting point of a mixture of two substances can be lower than the melting point of either, that glass was able to be made since earliest times. When SiO_2 (with its melting point of 3135°F) is mixed with different amounts of Na_2OSiO_2 (with a melting point of 1990°F) a certain ratio of the mixture will result in the melting point being lowered to only 1439°F which is a readily attained temperature even for a primitive furnace. The ratio of SiO_2 and Na_2O in the resultant minimum temperature of eutectic glass will be found to be 73 per cent silica—23 per cent Na_2O . When a few per cent of lime (CaO) is added to this to make the glass more resistant to weathering, we have what amounts to the basic soda-lime-silica glass which is used for bottles, windows, plate glass containers, etc. and which represents to the glass industry about what iron is to the metallurgical industry.

GLASS COMPOSITION

The basis of most modern glass is silica (SiO_2). However, glasses are not confined to this type exclusively. Extensive families of glasses have been made with boric oxide (B_2O_3) and phosphoric pentoxide (P_2O_5) as the basic constituent. Indeed, glasses are not confined even to oxides. Glasses have also been made of fluoride and chlorides. Even gases such as oxygen, carbon dioxide, water vapor, etc., have been found to be absorbed in glass in amounts varying from a fraction of 1 per cent to several per cent. In addition to silica, most modern glasses contain some of the following— Na_2O , CaO , K_2O , Al_2O_3 , B_2O_3 . Some special glasses may contain BbO , BaO , Li_2O , etc. As a matter of fact, almost every element in the periodic table has been incorporated into glasses of one kind or another. Insofar as glasses are solutions of their respective constituents, they can be combined in any proportions provided the resultant can be cooled to standard conditions without crystallizing. As a consequence of this, an endless variety of physical and chemical properties can be imparted to glass by seeking out the proper constituents and the correct percentages. Some typical glasses with compositions are:

Fused silica in many respects is the ideal glass. Its high softening point, extremely low thermal expansion, inertness and high transparency in the ultra-violet have led to its widespread use

for such scientific and high temperature applications as length standards, optical flats, windows, prisms, photo cells and reaction vessels.

Vycor, a 96 per cent silica glass, is made by leaching out the acid soluble component of an alkali boro-silicate melt and compacting the almost all silica remainder by a heat treatment. Its usefulness is enhanced by the fact that it can be molded at normal glass temperatures and, after leaching and compacting, assumes properties comparable to fused quartz. It finds uses as ultra-violet lamp envelopes, crucibles, high temperature electrical insulators, and generally where a high temperature, thermal shock resistant glass is required.

Soda-lime-silica glass constitutes about 90 per cent of all the glass that is manufactured today. It is inexpensive, easy to fabricate, and consists of readily obtainable raw materials.

Almost all bottle ware, tumblers, windows, plate glass, mirrors are made of soda-lime-silica glass. Slight additions of MgO , Al_2O_3 , K_2O , BaO , ZrO_2 , and others may be used but the basic composition does not change much.

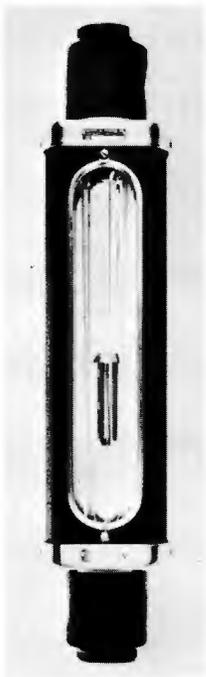


Figure 3

Borosilicate, low expansion glasses are made with a relatively small amount of *alkali* oxide. The amount of SiO_2 is increased over the regular soda-lime glasses and the other important constituents are B_2O_3 , which acts as a flux, plus a lesser amount of Al_2O_3 . The relatively low thermal expansion of these glasses, about $\frac{1}{2}$ to $\frac{1}{3}$ that of soda-lime glass, coupled with superior hardness and chemical resistance, make them the almost universally selected material for laboratory ware, glass blowing, oven ware and industrial process equipment such as glass pipe and fittings, and rotameter tubes (Figure 3).

Lead glasses have the CaO of the soda-lime glasses replaced in part or in whole by PbO . These glasses are denser, have more brilliance, greater refractivity, and higher electrical resis-

tivity. Their thermal expansion is similar to the soda-lime glasses. A relatively low softening temperature and long working range make these glasses easy to fabricate.

Electric light bulb stems, cut glass, art glass, thermometer stems use lead glasses. By further increasing the percentage of lead, X-ray shielding windows may be obtained. Adding other high atomic number constituents and using large thicknesses results in windows suitable for providing protection from high energy radiation.

Alumino-silicate glasses are characterized by a high alumina content. They are harder, have higher mechanical strength, higher softening points, and lower expansion than soda-lime and lead glasses. They find use in bakeware, boiler gauge tubes, and high temperature thermometers.

Opal glass is made that way by the inclusion of crystallizing materials like CaF_2 in the batch. A translucent to opaque appearance is produced due to the multiple reflections at the millions of glass to crystal interfaces. Opal glass may be made in a number of different base glass compositions. It is used extensively for illumination ware, diffusers and refrigerators and mixing bowls.

Sealing glasses are made to have specific thermal expansivities and softening points so that they can be welded to other glasses or metals without cracking due to difference in expansion. Where a large difference in expansion exists between two glasses, or a metal and a glass, a graded seal can be used without the introduction of excessive strain. The graded seal consists of a number of intermediate glasses with increasing expansivity from the low to the high expansion member. By dividing the total expansivity of the end members through the intermediate ones, the stresses are in effect divided to a point well below the breaking strength of the glass. Through the use of lead-borate and silicate eutectic compositions, low melting sealing glasses or "solder" glasses may be obtained.

Ophthalmic glass is a high quality crown glass used for spectacles. Bubbles and any visible striae can not be tolerated in ophthalmic glass. High transparency, freedom from color, and good weathering are other necessary requisites. The index of refraction of ophthalmic glass is generally 1.523. For bifocal spectacles the lower fused insert used for reading may be ground with the same curve as the entire lens provided a higher index glass like a lead flint is used which may have an index of 1.62 or 1.64.

Optical glass represents the highest quality as well as the greatest variety of glass. Extreme variations in composition are used to secure a wide range of optical properties. Values of index of refraction ranging all the way from 1.35 to 2.20 have been obtained. Abbe values (ND-1/NC-NF) are a reciprocal measure of the difference in index or light bending power between the red and blue portions of the spectrum referred to the yellow sodium light index, less one. These values range from over 100 for light fluor-crown glasses to about 15 for the densest lead and titanium glasses. Very delicate tests are used to detect flaws in optical glass and as a result a typical melt results in a yield of only 10 per cent to 15 per cent of acceptable glass.

An important contribution to improved optical systems has been the recently discovered high index, low dispersion glasses made with rare earth oxides. Due to the high index of refraction more optical power can be secured with shallower curves resulting in less distortion. Also due to the low dispersion less color aberration is introduced.

VARIETY THROUGH FORM AND TREATMENT

Variation in glass properties need not be solely produced by variation in composition. Changes in form and treatment can also bring about profound changes in properties. Thus, a completely new industry has been created by fiberglass, an old friend in thinned and elongated form. Foam glass, or glass which has been cellulated by the incorporation of gassing agents that pro-

duce multitudes of small bubbles which remain after the glass cools, finds increasing use as an insulating material.

Precision reformed glass is low expansion borosilicate glass which is shaped to microscopic accuracy by slumping and shrinking (Figure 4) over heated mandrels. Such glass is now contributing its share to the automation of process control instrumentation and also as complete instruments by themselves.

By manipulating the thermal expansion property of glass, the same glass can have imparted to it a several fold increase in its strength property. When glass is heated to its upper annealing range and then rapidly and uniformly chilled, as with an air blast or oil spray, a strong compressive force is set up on its outer surface as the entire glass cools. Since glass can only fail under tension, this compressive stress can be three or four times the practical tensile strength of the glass without fracture occurring. Of course, equilibrium requires equal, but opposite signed (tensile) forces at the center of the glass. However, since the interior of the glass is not subject to the stress magnifying fissures found on the outer surface, this interior tension can be tolerated. It is this counterbalancing interior tension which sets a limit to the amount of allowable compressive stress. Glass, so treated, is called tempered glass. Before such glass can be broken, the surface compressive stress must first be overcome and then its tensile strength exceeded. Thus, tempered glass can be four to five times as strong as the same glass, untempered. Should the outer compressive layer be nicked or deeply scratched, the strength of the tempered glass could be severely diminished. The amount of stress that can be imparted to glass by chilling is directly proportional to the thermal expansion coefficient. The consequence of this condition is that low expansion borosilicate glasses can receive less tempering or mechanical strengthening than the higher expansion glasses like the soda-lime-silica family. Of course, the very fact of its low expansion will also mean that a low expansion borosilicate glass will be subject to less thermal

stress for a given temperature difference, so that the relative suitability will depend upon the specific application.

The field of glass compositions is enormous and every day new glasses are added to it. At most, I can only hope to have indicated a few of the elements that go into the processes connected with the producing of varieties in glass.



Figure 4

Glass To Metal Seals

Charles Cassidy

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Within the past 25 years, with ever-increasing tempo, methods have been sought and found, whereby glasses and metals of many varied properties can be permanently united so that the welded material can be made the basis of valuable scientific and technical devices and apparatus. These developments, now very numerous and important, range in size from the tiny electric lamps used in medicine and surgery for internal exploration to great radio transmitting tubes several feet long, X-ray tubes operated at a voltage greater than a million, and many types of mercury arc rectifiers as large as two feet in diameter. The sealed in components may vary in dimensions from very fine diametric wires to heavy metal flanges.

Much research has gone into this successful development of sealing techniques. In considerable measure, the effort has been expended in developing a wide range of glasses, and of metals and metal alloys, such that, according to the purpose in view, a glass and metal can be selected which can be united to form a strong and permanent seal. The criterion normally employed for selecting the glass and metal is that they shall have closely similar characteristics of thermal expansion and contraction over the range of temperature from that of the atmosphere to that at which the seal is made.

This criterion remains as a sound and guiding principle but many of the important developments in techniques in recent years have come about by seeming to deny this principle. In 1923, W. G. Housekeeper showed in his paper on "The Act of Sealing Base Metals Through Glass" that it was possible to seal one end of a copper tube of linear thermal expansion of 17×10^{-6} to Pyrex glass of coefficient 3×10^{-6} , and the other end to lead glass having a coefficient of 9×10^{-6} .

This accomplishment, which with similar ones has now become commonplace in the electronic industry, involving metal to glass seals did not prove that close similarity of thermal expansion and contraction was not necessary or desirable. It emphasized rather, that the prime factor which governs the permanence or otherwise of a seal is the character and intensity of the internal stress at the joint. The stress could, it was true, usually be kept well below the fracture value by selecting glass and metal of similar thermal expansion and contraction coefficients; but there were other ways equally based on scientific principles, so it was now shown, of preventing the stress from reaching the level which would cause fracture. Such methods include the use of soft metals like copper in which stresses resulting from the seal were in a large measure dissipated by the yielding of the component material. The accumulations of stresses could also be avoided by paying attention to the dimensions of the glass and metal contact, especially their thickness at the point of contact. The acceptance of these new points of view greatly assisted the development of glass to metal seals particularly in apparatus of large dimensions.

In order to produce a satisfactory seal, it is necessary that the fused glass wet the metal to produce a good strong bond, and, as previously mentioned, that the stresses resulting from the sealing operation do not exceed the tensile strength of the glass. For glass to wet a metal surface, it is necessary to provide a thin continuous adherent film of oxide on the metal. During the sealing operation the temperature is raised to the point where the glass partially dissolves the oxide to form a continuous gradient so that no discontinuities of compositions occur which could result in a weak bond of glass-to-metal oxide.

The degree of adherence of the metal oxide film to the metal

is a function of the thickness of the film and the duration of the heating cycle. When the oxide film is too thin or the heating time prolonged at the softening temperature of the glass, the glass will absorb practically all of the oxide which results in a weak bond between the metal and the glass. When the oxide film is too thick, poor adhesion between the metal and the metal oxide will result.

Two types of glass-to-metal seals in general use on laboratory projects are:

Type I "Matched" seals in which the metal is sealed directly to the glass, the resulting stress in which is kept within a safe limit by selecting a glass and metal of coefficients of expansion and contraction closely alike.

Type II "Unmatched" seals in which the thermal expansion of the metal differs from that of the glass and dangerously high stresses which normally arise are avoided by using —

- (1) Metal of small diameters—
- (2) Ductile metals which by their yielding give some relief to the stresses in the glass or—
- (3) Intermediate glasses and graded seals: the final seal between the metal and the last member of the intermediate glasses being the matched type.

Since the primary purpose of glass-metal seals in vacuum tubes, electronic devices and other laboratory applications is either to complete an electrical circuit, provide external contact or just be a supporting structure, the geometry of the seals becomes very diverse. Numerous shapes and sizes are used, depending upon many factors. Among the points which must be considered in the design are: voltage and circuit to be carried through the seal, temperature of operations of the device, rigidity of the structure, mechanical stresses applied to the seal, skill and machinery available, annealing facilities and always the cost. Nevertheless, the types of seals fall into definite patterns. A few of the basic designs are shown in Figure 1. The term "internal

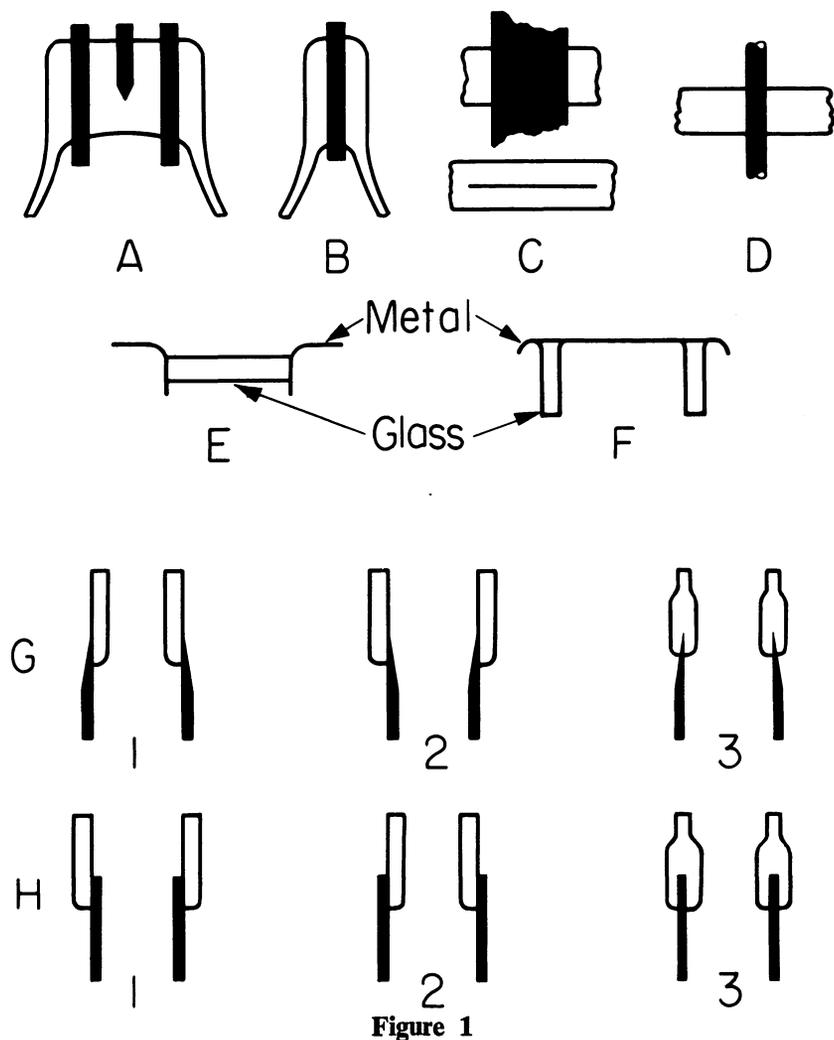


Figure 1

seal” is employed to designate seals in which the metal is enclosed in or surrounded by glass (Figure 1-A) while “external seal” designates seals in which the glass is surrounded by the metal (Figure 1-B).

Conventional internal seals with round metal wires or rods passing through or imbedded in glass are the most common type of glass-metal seal. Light bulbs, receiving tubes, power tubes and many other special purpose tubes employ internal seals, cross sections of which are shown in Figure 1-A and 1-B.

Ribbon seals shown in Figure 1-C are not widely used but the design does have certain advantages. Tubular internal seals, such as shown in Figure 1-D, are usually only incorporated into special designs.

An external seal is one in which a band of metal adheres to the glass insert (Figure 1-E). The glass insert may be a round button or disc, or it may be square, rectangular or other shape, though it may be well to bear in mind that the non-symmetrical stress distribution in all cases except the round shape makes the maintenance of a vacuum or pressure seal extremely difficult.

Tubular seals are of two types; the thin edge or Housekeeper seal (Figure 1-G, 1-2 and 3) and the "normal edge" or Kovar seal (Figure 1-H, 1-2 and 3).

The thin edge tubular seal is employed when it is necessary to choose a metal which does not match the expansion of the glass. This is especially true in the case of tubes where a great amount of heat must be dissipated by external cooling with water or air. Copper is ideal for this use due to its high thermal conductivity, machinability and adherence to glass.

The normal edge tubular seal employs a metal whose thermal expansion or elongation closely matches that of the glass. Kovar is an ideal metal which has found extensive application in this type of seal.

The simplest type of butt seal is shown by Figure 1-F where a metal disc is sealed to the end of a length of glass tubing. Such a seal does not have too much application, unless the metal is soft and thin (approximately 0.005 in.); or unless the expansion curves of glass and metal are a good match, failure of the seal is likely to occur. If a suitable glass is used on both sides of the disc, seals may be made to a much thicker metal, as in the case of Kovar.

Since, in most laboratory applications, we involve metals which are compatible with the hard glasses, it may be well to stipulate the conditions to which these metals should conform. Thus a

metal which can be attached to glass to produce a gas tight seal should meet the following requirements:

- (1) Its melting point must be higher than the working temperature of the glass.
- (2) It should be available in a clean state from a metallurgical point of view, i.e., as free as possible from nonmetallic inclusions.
- (3) It must be sufficiently ductile to enable it to be formed into various shapes without cracks or other mechanical defects.
- (4) The curves of thermal expansion of both metal and glass should, in the case of matched seals, follow one another closely over the same specified range of temperature.
- (5) No allotropic transformations, accompanied by marked changes of expansion rate, should occur in the metal over the range of temperature to which it may be subjected, either in making the seal or its subsequent use -50°C to $+2000^{\circ}\text{C}$.
- (6) Any layer of oxide formed during the process of making the glass-to-metal seal should adhere firmly to both metal and glass.
- (7) High electrical and thermal conductivity are advantageous if the metal has to carry a substantial electric current for otherwise the heating effect when current flows may result in a substantial increase in strain.
- (8) Ease of joining to other metals by welding or soldering is desirable and often essential.

Several suitable metals for joining to hard glass are tungsten, molybdenum and Kovar. Since these metals are compatible with

a number of easily obtainable glasses, and are themselves reasonably available, we have found them to be practical for most laboratory applications. Corning has published a complete and concise slide rule type of brochure which itemizes several metals and their compatible glasses.

The normal procedure for both tungsten and molybdenum seals to glass follow a rather general practice.

For tungsten, a ground or polished rod, free from longitudinal internal fissures, cracks, and scoring, is extremely important since the surface tension of the glass is not sufficiently low to fill the latter, and there is no certain way of preventing leakage through the former. Various diameters may be used, usually 0.80 inch or less, though rods as large as 0.200 inch have been successfully sealed into glass. The oxide is first removed by heating the tungsten to approximately 300°C and immersing in a bath of molten sodium or potassium nitrite which may then be removed by washing with distilled water. For laboratory applications, the potassium nitrite is available in stick forms and may be applied to the heated metal. The heat from the metal being sufficient to melt the chemical thus removes the oxide.

In the usual process for sealing tungsten through glass, a tungsten rod of the required dimensions is oxidized by heating to a yellowish-red heat. A short length of glass tubing, with inside diameter slightly greater than the diameter of the rod, is slipped around the tungsten and the glass is then fused to the metal, starting the sealing operation at one end so as to drive out the air from the space between the glass and metal. One should be careful during the operation to avoid disturbing the thin oxide layer so necessary for good adhesion. When a good seal is obtained the color at the interface of the glass and metal ranges from a golden yellow to a reddish brown.

These same procedures may be followed for cleaning and oxidizing molybdenum, except that since molybdenum rapidly becomes coated with a thick non-adherent film of oxide when heated in air, it is necessary that the access of air be restricted while coating it with glass. This operation is most easily accomplished by making the bead or sleeve of glass as close fitting

as possible and using extreme care in starting the sealing operation at one end of the sleeve and progressing to the other end without exposing this portion of the metal directly to the sealing flame. A good seal will have a brownish color at the glass metal interface. Kovar is possibly the most versatile metal for use in laboratory seals, since it can be processed in most any conceivable form. After suitable machining, cleaning, and degassing procedures have been followed, this metal can be incorporated into most any design involving glass-to-metal seals.

It is important that the machining operation provides a smooth polished surface, free of scratches or longitudinal distractions, which might not permit the glass to wet the metal completely, thus producing leaky or bubbly seals, which might also contribute to mechanical weakness

The cleaning and degassing procedures normally consist of thoroughly degreasing the metal by use of acetone or immersion in a trichloroethylene vapor degreaser. First, the part is placed in the cool chamber of a hydrogen furnace for 20 minutes in an H_2 atmosphere. Secondly, it is placed in the hot chamber for three hours at $950^\circ C$ in a wet hydrogen atmosphere, which is produced by bubbling the hydrogen through water prior to admitting the gas to the furnace. Third, the part or parts are then placed in the cool chamber and allowed to cool to room temperature in a hydrogen atmosphere before removing from the furnace. Extreme care must be taken to avoid handling the areas of the part on which the glass seal is to be made.

Kovar is oxidized by heating in air with an oxidizing flame, preferably natural gas and oxygen, to a dull red heat. The length of heating time will vary with the geometry and dimensions of the metal piece. The degree of oxidation is best determined by experience. When a large number of similar pieces are to be fabricated, pre-oxidation may be done in a furnace arrangement. But, for the average laboratory glassblower, each seal is handled independently, and the flame oxidizing technique should be developed. Usually most Kovar seals require a lathe operation and the oxidation and subsequent sealing to the glass are one continuous sequence. A good Kovar seal will have a mousy grey color at the glass metal interface, and essentially the quality of the seal is reflected in the consideration given to the components.

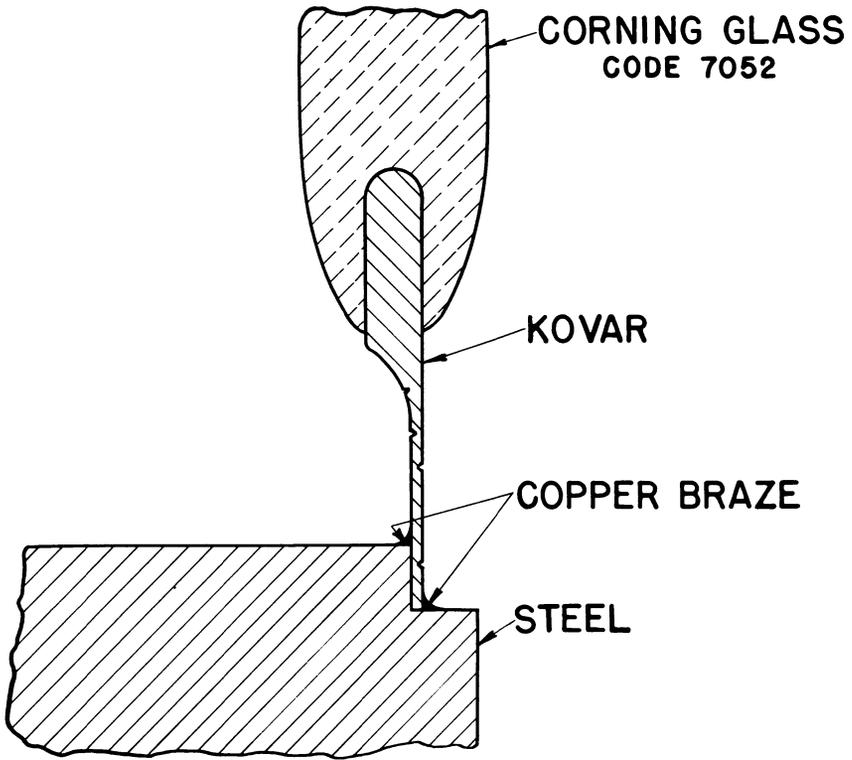


Figure 2

After the Kovar glass seal has been made, the part should be processed in the annealing oven at 490°C for about 20 minutes and then slowly returned to room temperature at a rate of about 10° per minute. For cleaning purposes, the excess oxidation on the exposed Kovar can be removed by immersing the seal into a 100 per cent solution of concentrated hydrochloride acid, heated to a temperature of 80°C, for about one-half to one minute immersion for a light scale, and one to five minutes for a heavy scale. The part should then be washed in running hot water for one minute. After the seal reaches room temperature, an immersion in an alkaline rinse for several minutes and a final wash with cold water is recommended.



Figure 3



Figure 4

Figure 2 shows a cross sectional view of a Kovar to glass seal some $7\frac{1}{2}$ inches in diameter, showing the details of the various processes involved in its construction:

- (1) The machining of the Kovar.
- (2) The brazing (1100°C for 15 minutes) and decarburizing.
- (3) The method for holding the assembly.
- (4) The forming of the glass.
- (5) Additional views of the envelope. (Figure 3)
- (6) Double ended Kovar seal. (Figure 4)

In Attendance

The following are on record as having attended the Symposium on the Art of Glassblowing held at Corning, New York on Thursday, Friday and Saturday, May 30 and 31 and June 1, 1957. The address following the name is the mailing address as listed on the Society files.

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Alexander, L.Bell Telephone Labs., Murray Hill, N. J.
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Anderson, CharlesFischer & Porter Co., Hatboro, Pa.
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Bicknell, AlfredMacalaster Bicknell Co., Cambridge, Mass.
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Brewin, Jr., Thomas A.Ryan, Velluto & Anderson, Cambridge, Mass.
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