

*PROCEEDINGS*

THE THIRTY-NINTH  
SYMPOSIUM

ON THE

**ART OF SCIENTIFIC  
GLASSBLOWING**

**1994**



THE  
AMERICAN SCIENTIFIC GLASSBLOWERS SOCIETY

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# The Fabrication of Precision Solid Glass Spheres from Cubes of Ohara E-6 Glass

by  
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## Introduction:

The challenge of making precision glass spheres arose from a casual conversation with a staff member of the University of Arizona Mirror Laboratory. Originally, the precision spheres were to be fabricated from Corning 7740 rod. During a Mirror Laboratory staff meeting, the need to have the spheres fabricated from Ohara E-6 borosilicate was determined. This was the most acceptable material since the mirror was cast from E-6 glass.

The spheres became necessary when bubbles were formed during spin casting of the 22,000 pound, 6.5 meter, honeycombed, concave, telescope mirror. The grinding procedure removes 1/2-inch from the 1 1/2-inch top surface of the mirror blank, exposing bubbles. The E-6 precision spheres of 21, 28, and 33 millimeters are required to fill the exposed holes. Thus, the opportunity arose to transform 6-inch (5kg) cubes of E-6 glass into precision solid glass spheres.

The first step was to divide the 6-inch cube into workable size blocks of E-6 glass (Fig. 1). The surface of the cube was scored on four sides with a diamond pencil. Using a National hand torch, with a piloted No. 5 tip at maximum flame intensity, the scoring on one surface was heated for 15 seconds. A paper towel saturated with water was applied to the heated surface and, after a few seconds, the cube split along the score marks. The newly formed cubes were repeatedly split until we arrived at a 2 1/2-inch cube.

The 2 1/2-inch cubes were drawn into rod form to fabricate the spheres. To stretch the cube, a 19mm pyrex rod that had been chucked in the lathe was fused to the E-6 glass. The pyrex rod/E-6 cube was then brought to the annealing temperature using a gas-air flame. Another 19mm pyrex rod was then fused to the opposing end of the cube. Lathe burners were used to soften the glass for stretching. At this point a minor setback occurred. The normal gas-oxygen flame caused the E-6 glass to become cloudy. Realizing this reaction was similar to Uranium Glass (Corning #3320), an oxygen rich hissing flame was used for stretching the cube to form, with only minor discoloration (Fig. 2).

With the lathe at a moderate speed, the E-6 rod was heated, paddled, and shaped into a half-sphere (Fig. 3). A molten pyrex rod was then stuck to the still hot E-6 half-sphere, not allowing it to deform (Fig. 4). At this point the E-6 rod is burnt off, leaving enough glass to form the second half-sphere. The final shaping of the sphere is left approximately 1mm larger than desired specifications, to allow for precision grinding (Fig. 5).

Once in sphere form, a more intense flame may be used to remove any remaining discoloration. The spheres are annealed before cutting the sphere from the rod.

In the fabrication of the prototype 28mm spheres, the decision was made to use 28/15 socket joints for grinding. The requirement of various specific dimensions demanded the machining of precision grinding tools. The tools were developed out of brass stock by the University of Arizona Chemistry Department Machine Shop (Fig. 6).

Using a cut-off saw, the sphere was removed from the pyrex rod, leaving enough glass to ensure the E-6 glass was not disturbed. A wet belt sander with a 100 grit belt was used to remove the remaining pyrex. Initially, in the grinding procedure, the glassblowing lathe was used for turning the grinding tool (Fig 7). When the number of spheres required increased, the need for a faster approach to grinding became apparent. Realizing the need for increased RPM's, the existing tools were modified to be used with a drill press. The brass socket grinding tool is rotated by the drill press while the other is hand-held. A generous amount of 60 grit carborundum slurry is applied to the top of the sphere as needed. During grinding, built-up slurry is removed as necessary to increase efficiency.

## **Conclusions:**

While the process of working the Ohara E-6 glass cubes was complicated, the fabrication of the precision spheres was a simple task. A glass shop with limited resources can fabricate precision spheres on a consistent basis with tolerances to 0.020 of an inch. Closer tolerances are attainable with time and effort.

## **Acknowledgments:**

We would like to acknowledge the following colleagues for making this project possible: Wally Stoss from The University of Arizona Mirror Lab for supplying us with the opportunity & E-6 glass; Susan Summers and University of Arizona Video Communications for editing our presentation video; Bob Smith and Ron Clayton from The University of Arizona Chemistry Department Machine Shop for manufacturing precision glass grinding tools; Elaine Hoeflinger for the slides and photographs used in our presentation and in our paper; and the University of Arizona Chemistry Department for support and the opportunity to present this work at the 39th Annual symposium of Scientific Glass in Pittsburgh.

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7. Grinding with lathe.

FIGURE 1.



FIGURE 2.



FIGURE 3.



FIGURE 4.



FIGURE 5.



FIGURE 6.



FIGURE 7.



# An Elliptical Glass Coil

Allan B. Brown  
University of Connecticut

An elliptical glass coil is a challenge to construct. The reason for this is that an elliptical coil has a very precise shape and dimensions and yet a standard mandrel cannot be used. A new mandrel must thus be created in order to realize the proper size and shape. While an elliptical glass coil may be an unusual request for a glassblower to receive, its construction is an example of the need for glassblowers to be creative: through ingenuity and the use of available resources, a new mandrel can easily be constructed. This paper will detail the process which I used to produce an elliptical glass coil.

A Marine Biologist had asked me to make a glass cooling coil to help maintain a constant temperature for growing sea lettuce. The container he provided turned out to be elliptical (Picture 1). The finished dimensions of the coil were to be 4 1/2 inches wide by 7 1/4 inches long. I decided to use 8mm medium wall tubing for the coil as this would allow the tubing to stay hot longer thus ensuring smoother bends. Next I needed to produce a most important item: a mandrel on which to wrap the tubing.

To determine the amount of material needed to make the special mandrel, I used a piece of corrugated cardboard and placed it inside the elliptical container. I then reduced the diameter of the cardboard coil by rolling it on itself, leaving approximately a 1/4 inch space between the cardboard and the inside of the container. Masking tape was used to hold it together. After removing the cardboard from the container, I drew a pencil line of the seam, then, using a pair of scissors, I cut along the pencil line. I now had a piece of cardboard that was the exact length, from which I could make a mandrel of the correct diameter.

For the actual mandrel itself, I decided to use an 18 gauge galvanized piece of sheet metal (Picture 2) because this material was readily available. Moreover, 18 gauge galvanized sheet metal does not expand a large amount due to its thickness and can easily be formed into whatever shape may be required. I laid the piece of corrugated cardboard onto the piece of galvanized sheet metal and added one inch to the length to allow for spot welding. After cutting the sheet metal to size with a shear (Picture 3), I used a set of rollers (Picture 4) to form the galvanized sheet into a circle (Picture 5). Next, I placed the galvanized circle inside the elliptical container and compressed it to the proper diameter. This allowed me to check the diameter and to make sure that there was at least 1/4 inch clearance all around.

The mandrel was now ready to be spot welded (Pictures 6,7 & 8). After spot welding it, I placed the mandrel in a large vise (Picture 9) and squeezed it to obtain the proper elliptical shape. Since there is not much elasticity in the galvanized metal, the squeezed mandrel held its shape and was easily checked with a ruler (Pictures 10 & 11). Once again, I placed the mandrel in the container to verify that the proper dimensions had been obtained.

The mandrel was now ready to have a coil wrapped on it. I chucked it up in the lathe. I then took a four foot piece of 8mm medium wall tubing and bent it at a 90 degree angle approximately 8 inches in from one end (Picture 12). After the tubing was cool enough to handle, I taped the 8 inch end to the chuck arm using masking tape (Picture 13).

For the actual heating, I chose a National hand torch with a number 3 tip. Since I have equipped my shop with regulators in order to have more control of my fire configurations, I used 18 lbs oxygen pressure and 10 lbs propane pressure for the heating. This combination allowed me to create a nice bushy fire that was hot enough to bend the 8mm medium wall tubing without collapsing it (Picture 14). As a result, I did not need to use a blow hose. I started heating the tubing at the top of the mandrel using even strokes of the bushy fire up and down until the tubing softened and laid down onto the mandrel. I continued this motion with the torch and bushy fire (Picture 15) and, at the same time, rotated the lathe chuck by hand so as to prevent any kinking in the tubing (Pictures 16, 17 & 18). After using four feet of tubing, I added an additional four feet (Picture 19) until all the tubing had been used and wrapped around the mandrel. An advantage of using 18 gauge galvanized sheet metal for the mandrel is that when heated, the latter expanded approximately 1mm; but when cool again, it shrunk back to its original size and allowed the coil to slide off easily (Picture 20). As soon as the coil was cool enough to handle, I added a piece of 8mm medium wall tubing to the end of the tubing and bent it up parallel to the original stem (Picture 21).

The individual coils now needed to be spaced evenly not only for proper cooling but also for appearance. I placed pieces of 7mm tubing between each layer of the coil to ensure uniform spacing (Picture 22). With the coil ready for its first annealing, I laid a piece of 1/4 inch window glass in the oven as a support for the coil and its spacers (Picture 23). Both sides of the coil were braced with pieces of heavy wall glass pipe to prevent it from sagging to one side (Picture 24). For the annealing process, I raised the temperature an additional five degrees: this elevated annealing allowed the coil to relax and take its proper shape.

This initial annealing removed all the stress from the coil. After I had added a piece of solid cane as a support for the two uprights, the coil was ready for the final annealing (Picture 25). This was done at the regular annealing temperature, with the same 7mm supports as before.

An elliptical coil is unique, but it is no more difficult to make than a regular coil once you have a proper mandrel. The procedure detailed here to construct a mandrel of a different shape can be used to make any coil of unusual form. The manufacture of an elliptical coil such as this is proof that scientific glassblowers must always be willing to use ingenuity and readily available resources to achieve their goals.

FIGURE 1.



FIGURE 2.



FIGURE 3.



FIGURE 4.



FIGURE 5.

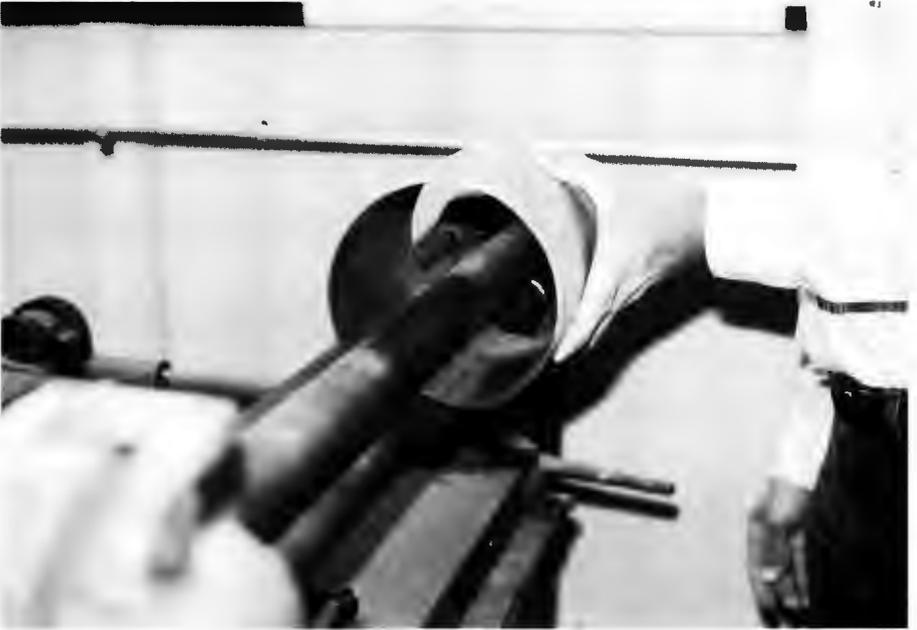


FIGURE 6.



**FIGURE 7.**



**FIGURE 8.**



**FIGURE 9.**



**FIGURE 10.**



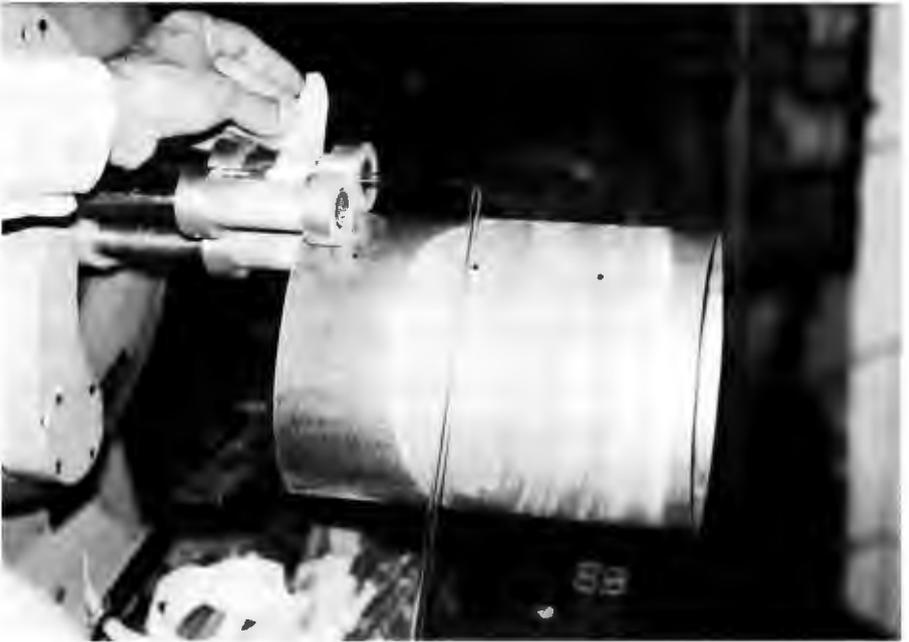
FIGURE 11.



FIGURE 12.



**FIGURE 13.**



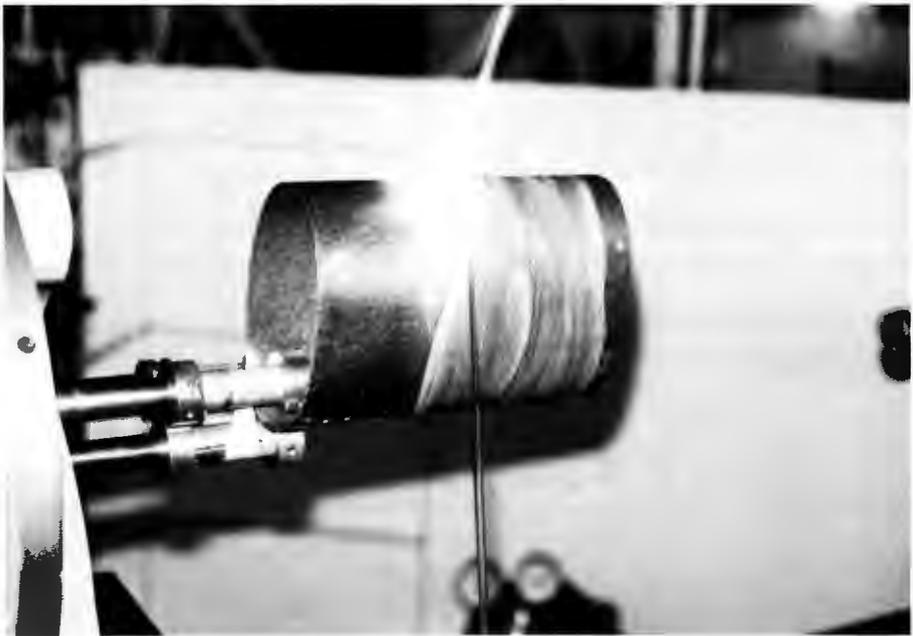
**FIGURE 14.**



**FIGURE 15.**



**FIGURE 16.**



**FIGURE 17.**



**FIGURE 18.**

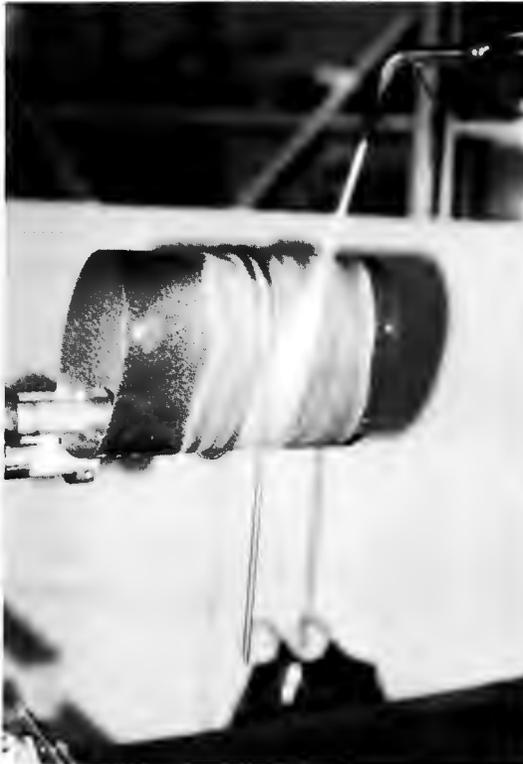


FIGURE 19.



FIGURE 20.



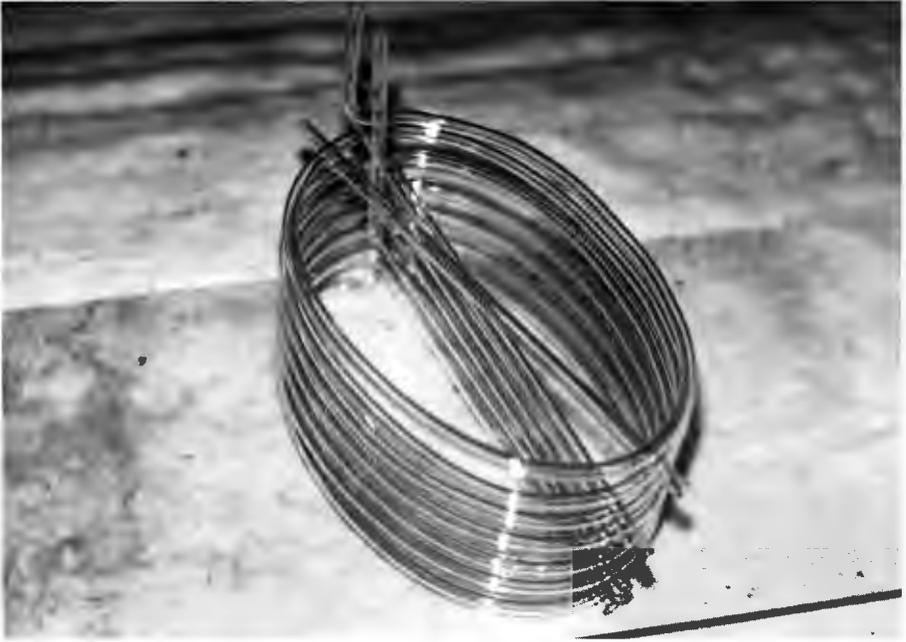
**FIGURE 21.**



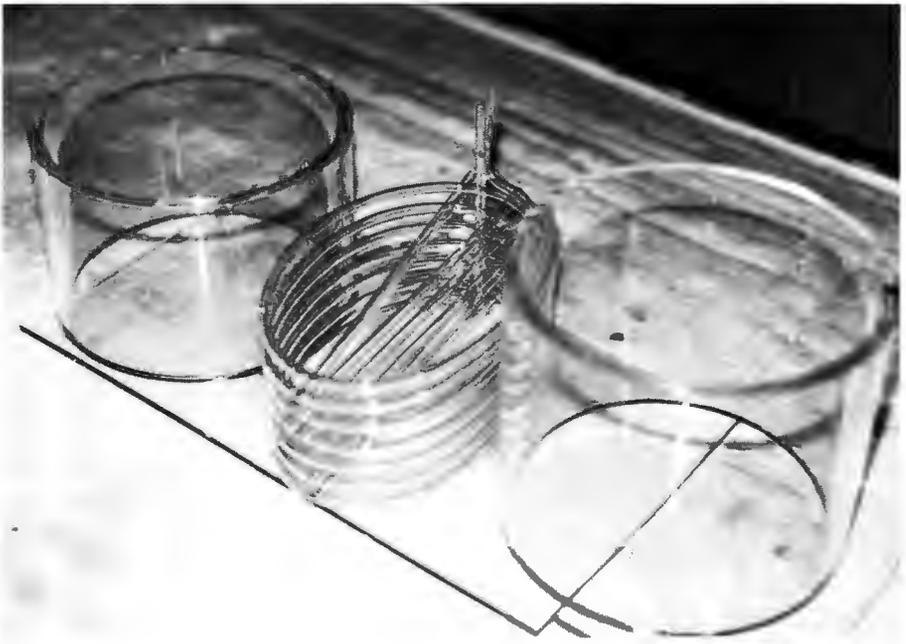
**FIGURE 22.**



**FIGURE 23.**



**FIGURE 24.**



**FIGURE 25.**



# Forming and Implementing a Customer Focus Team

by Royce Carter

The services groups in corporate research division of Texas Instruments have been striving to become self-directed work teams for the last few years.

These groups include the model shop, graphic services, computer resources, electronic support, stock room, publications, and the glass shop.

One common problem of all the groups was getting honest feedback from our customers when we sent out customer survey questionnaires.

The purpose of customer surveys was to improve services and customer satisfaction through better interaction and involvement in our customer's projects. We hoped to improve turnaround times, understand needs and capabilities, and especially, encourage candid conversation without fear of retribution.

Our captive customers were hesitant to complain about mistakes or misunderstandings on our part fearing that their job may never be completed, leading to less than honest, trustful relations.

Interestingly, written surveys resulted in many 'attaboys' with signatures and a number of scathing complaints with no signatures.

It became obvious that to improve customer service, we had to improve customer communication especially when the customer was not on the top of our list of good friends and vice versa.

Here is how we are accomplishing that.

1. A person who is not a member of the service group is selected as the facilitator of a series of meetings with the group's customers. No one from the service group attends these first meetings. The meetings are held to a small number of attendees to encourage participation.
2. The facilitator must, and does, convince the customers that real honest feedback is requested by the service group, especially criticisms. They are assured that their names will not be used from this initial meeting. The customers are asked individually to explain their expectations, experiences, and capability preferences of the service group being discussed. The facilitator must be adept at encouraging one or two of the customers to speak their mind, then the whole group usually will join in the discussion.
3. The information gathered at these initial meetings is categorized as to number of suggestions or complaints and then presented to the service group. The service group discusses and determines how they will resolve these items and the order in which they will be approached. Some items are simple and can be

resolved quickly, others take more time, and some even longer or perhaps cannot be resolved. This information is decided by the service group. Their facilitator or supervisor does not suggest what they should do.

4. Once this information is finalized, other meetings are held with the customers, but this time a customer service team made up of the service group members is in charge of the meeting. They explain to the customers how they intend to resolve the items listed, and the time frame required. They ask for more input from the customer. The customers are encouraged by the team members to bring their needs, problems, and/or criticisms directly to the person working on their project without fear of ill.

The results of these meetings are being monitored through conversations, telephone calls, and written inquiries to the customer and service groups by the facilitator.

They are very encouraging with better interaction and service. The person working with the customer is now involved from conception to completion of customer's projects.

There have been many positive benefits from these meetings, one of which is that conflict or disagreements are not always bad if we consider the other person's viewpoint and are willing to work toward a common objective together. The majority of the time we realize that we are not far apart and the next project together is much easier.

The service groups involved range from three members to fifteen members. The results are basically the same, better interaction and trust between customer and service supplier.

# **A Glassblower at Large: Travels and Tribulations in the Third World**

**John French  
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Before beginning to describe my travels through the "Third World" I want to dwell for a moment. What is this third state of existence? By definition a Third World Country may be underdeveloped or developing. In my experience it can and indeed usually is a complex mixture of the two. The sovereign states within this category are supposedly none aligned to either Communist or Democratic philosophies, what ever the case may be there is a definite tendency to lean one way or the other resulting in their general attitudes, particularly to outsiders.

Widely diversified living standards exist in all countries but this diversification reaches horrific proportions in several parts of this planet. Ports of entry be they airports, docks or highway locations, are much the same world over. The hotel, that vital component in a visit is usually acceptable. If you wish to preserve your opinion of the place, stick to the beach and organized tours. Walking around the back of the hotel opens up a vista most people prefer to avoid. Culture shock can be devastating. Some timid souls head out by the next plane, others drawing from their edogenous resources manage to stumble through the back streets and into the great beyond. I am one of those stumblers.

Major decisions effecting lifestyle are usually brought about by an individuals dissatisfaction with the status quo. Many people are influenced by a desire to seek new horizons. This phenomenon is fundamental to human behaviour. Our most distant ancestors just started to walk into the distance and kept on going. In more recent times when stability is a dominant desire inspiration alone is insufficient. What's needed is a trigger, circumstances maybe or luck, a combination of which usually does the trick.

What caused me to depart from a secure, but relatively, uneventful existence in England? An encounter with a student from far away South America and the Marshal Plan. During the middle fifties, I was working at Imperial College in London running the glass lab, a frequent visitor seeking this service was a young man from Chile. We talked about his homeland - its beauty, culture, etc., and something started to linger around the back of my neck. Amongst other things we discussed the facilities which existed at his parent University in Santiago. By the then modern standards these people were in the Ark. My obvious interest must have sparked something because a few weeks later this same student sought me out.

"Had I heard about the Marshal Plan to aid in the development of teaching facilities in less fortunate countries" He asked.

"One of the stipulations for receiving a grant is that a person trained in the use of modern

equipment must be on hand to use it. Would you come to Chile,"He asked. "Yes", I replied with a nod of my head.

It takes one word and the right stimulus. Thus began my "Third World" adventures.

Lesson number one - patience and still more patience. Several months passed by during which tentative plans were made to start the ball rolling. Eventually I was contacted by the British Council who advised me that a senior professor from Chile was visiting the UK (obviously seeking funds) and wished to meet with me in my lab. We met together with a gentleman from the British Council who made several suggestions for my welfare, principal amongst which was that I ought to insist on being paid in U.S. Dollars - that, as it turned out was a very sound piece of advice. At the end of the meeting, interview hardly being an appropriate word, we parted company. Around two months later I received a detailed contract in Spanish setting out the terms and conditions of a contractual agreement which would make me a Professore of the University. Fortunately, as all indications were positive, I has started learning Spanish and it was with the assistance of my tutor that the vital document was rendered comprehensible. There followed a little running around, organizing visa, etc., and a visit to the steamship company to select my cabin. Things were definitely looking up, and continued to improve when shortly before departure I received a letter from the Rector welcoming me to Chile and enclosing a \$100 cheque for my enjoyment at the ships bar. In 1958, one could purchase a lot of joy at the duty free rates in the bar.

It was a cold and miserable day that my family and I set sail from Liverpool and headed down the Irish Sea towards France. Two days later, we stepped ashore amidst flowers. After a long and pleasant voyage and many ports of call we arrived at Valpariso. At this stage I was beginning to feel some slight anxiety because other travelers who had had experience of Chilean customs warned that they were a difficult bunch. I was rumbling this information around in my head while seated at breakfast prior to disembarking when my steward approached me with a lady. This lady introduced herself to me as the Rector's personal secretary and advised that other members of the university were awaiting my convenience of the Quayside. We made haste and shortly thereafter disembarked on to Chilean soil. Once again introductions, the Director of the Institute of Physics and mathematics who would be my chief, a Dutch gentlemen under contract as Science Director at the institute and finally the Public Relations officer of the University. This was heady stuff - but I adapted quickly.

Accompanied by our PA man we breezed through immigration and moved onto customs. We had with us our immediate needs leaving several crates to be cleared later. I put my several cases on the table and waited, a few moments later I became aware that Mr. PA (who was actually a Dr. of Biology) had engaged a customs officer in a heated conversation. I didn't get all of it but the gist of the altercation was clear. The desire of the customs to inconvenience the professore by having to termerity to search his baggage was inexcusable amounting to an insult no less. Now one of the Golden Rules of travel is always be polite to customs officials. This, I thought had the seeds of imminent disaster already in germination. Finally Dr. PA turned to me and apologized that this fellow, meaning the customs officer insisted on complying with the regulations, more apologies, etc. I complied with a polite request to unlock my bags. The officer

approached and while studying some fly's on the wall swiftly opened and reclosed each case. He had been satisfied. We departed quietly to a pre-arranged hotel in Santiago. We were left in peace for two days then I received a message from Dr. PA to meet him outside at 6:00am. We were off to Valpo to clear the rest of my things. We went straight to a very tall building and proceeded to the top of it. There I was ushered into the largest office I have seen, to be introduced to a Vice-Admiral-Chief of the port. They sat me down at a table with some English magazines and maintained a steady supply of coffee. Dr. PA and great man talked and referred to books for quite some time - then we were joined by a Chief superintendent of customs, he took Dr. PA and myself to the custom shed which was very large but almost empty. My crates were set out in the middle of the floor. Some men with crow bars started towards the crates but were swiftly dismissed. With a quiet smile, the super shook my hand, welcomed me to Chile and departed. The crates were transported to the University for storage until I found permanent accommodation. Thus I made my triumphant entry into the Third World in a euphoric daze.

Aside from small details like finding a house and buying furniture ( I had been on full pay since the day of sailing) it was time to get some work done. Leaving my wife with enough problems to keep her occupied, I went to work.

First came an office (I'd never had one before) and a secretary who spoke excellent English. The director advised me that for three months everybody would address me in English, after that Spanish would be desirable, I took more lessons and got down to preparing a Summer School for my colleagues. Vacuum technique, etc., etc., this by mutual consent was delivered in English and a good thing too. Curiously enough the desire to have me deliver my stuff in English arose a few months later when I embarked upon a training scheme for the undergraduates, this was a basic course in general laboratory techniques. With much effort by me, by dictionary and my secretary the whole course of instruction was set out in good Spanish. Away we went, before me sat a large group of bright young people anxious to learn. I started reading my introductory lecture taking care to pronounce my words properly and trying not to lose my place, eyes fixed firmly on the paper. The whole lot of them could have crept away with my knowing it. After a few minutes of this I realized that there was a subdued discussion going on. I looked from my labours and immediately one of the group rose and politely asked me if I would consider continuing the course in English. The young people needed to practice their English particularly the technical stuff and this would be a good opportunity to do so. It took me about 2/5's of a second to agree and after that we had a merry time. I prefer the Socratic approach to teaching were everybody mingles together and questions and queries are dealt with on the spot. We had to mess about with some of the definitions but that just added to the fun.

While teaching assignments were moving on the paper work was bearing fruit and things started arriving at the port. The lathe, oven, saw, etc. were positioned without much trouble. Such was my occupation with many different things that time had way of slipping by. Almost two years had passed by but I'd learned a lot of tricks, one of which involved persuading government officials to agree to bend the rules a bit to smooth things along. Visits to the various offices produced stagnation. Some friends of mine in the British Council office in Santiago, several of whom were frequent guests at my house,

advised me that most Chileans will say yes to a reasonable request when its put to them as guests in my house especially after a couple of stiff brandies, it works.

Around the middle of my contract three things took place which were to complicate my working days. At that time South America could boast of only three first class boys boarding schools, one of them, the Grange was located in Santiago. I had met the Headmaster socially several times so it came as no surprise when he and his wife visited us by chance on Sunday afternoon. I was living at this time in the Andean Mountains so several people took the opportunity to drop in from time to time. After some idle chatter the Head got down to the reason for his visit. He had problem, what's new glassblowers are always on the receiving end of the problems, not of their making. Several of the boys at The Grange were the sons of diplomats, and would soon be sent to Europe to take their university entrance examinations. There existed no facility to teach European style General Science, if a lab could be set up would I consider teaching these youngsters on a Saturday morning. In return I was to have the convenience of a large apartment within the school with services and a modest salary on top as well. It would involve House Master duties two evenings a week in the dormitories and an occasional week-end as well. The offer was too good to pass up, Enter House Master French, what next.

The Rector requests my presence so off I go. "We should consider taking steps to bring a fundamental appreciation of science to children in the remote corners of Chile I want you to undertake a feasibility study and advise me in the near future was the gist of his remarks.

"Yes", you don't say no to Rector's!

He had a large lump of sugar in his hand. I was to go to the UK and seek the supplies I would need. Of course General Marshall was going to receive another tap on the shoulder.

The timing could not have been better, the birth of our second child was not far off and it meant that the birth would take place in England. In fact my son arrived in the same hospital as our first born, pretty long odds.

On the professional side, I journeyed far and wide procuring several bits and pieces from manufacturers of scientific wares. Every process is beset by rejects. One needs to take a close look at some of these rejects; one example will suffice. One of my "victims" manufactured balances of the highest quality and sensitivity. The resolution of a balance is determined largely by the quality of the knife edges used in its construction and those which were less than perfect were cast out into a box. I was offered several boxes of these rejects, enough to produce several thousand simple student quality balances. Sufficient to introduce basic physics and chemistry to hundreds of thousands of children. Doing it is a lot more fun and is far better remembered than just reading about it.

Towards the end of my third year I shifted gears by joining with an Italian Colleague to study Solar Energy Conversions. Somebody in the government had decided that all that sunshine which poured daily over the Atacama Desert in Northern Chile should be put

to some use. My colleague already reached the point where further progress required technologies which were outside his field. The university decided they were inside mine. Farewell office and secretary. We occupied a large laboratory and spread ourselves out. We had to build the tools before starting the research; spot welder, vacuum system, zone melting apparatus, a wire abrasive saw to cut our monocrystals. It all came together, we tended to retire to club a short walk away at days end to talk over our progress. Some interesting results were beginning to emerge. I would be the first to admit that modern procedures would have rendered our efforts obsolete in a few years, but without those first steps there is no progress.

My contract was all but finished and as a final feather in my cap, I was offered a renewal with a fifty percent hike in salary. They must have liked me. About that time some dark political clouds were starting to gather on the horizon. The Hammer and Sickle was beginning to flutter. My position in a country under the communist banner would have been untenable and even hazardous. The presence of my wife and two small sons left me with only one choice. We returned to England for a rest and lo behold the communist didn't get elected, this frustrated me, but next time around the tables were turned, with catastrophic results. In the end I had made the wisest decision of my life.

After tossing up between several potential jobs (In those far off halcyon days there were lots of opportunities). I settled for the University of Kentucky. No glassblowing facility existed, so it was back to square one, with a difference, money was readily available for equipment so that setting things up was relatively painless. The early sixties were troubled ones for many people. It was a time of pending change. Rather than be affected I moved up to Canada handing over the reigns to the glass-shop to Wilber Mateyka. Wilber was to spend many years at University of Kentucky before seeking his own path.

Several years spent in Canada during which time I sought self employment brought me into contact with Trent University in Ontario. One of the staff a fellow "Brit" had in his earlier days been a lecturer in Nigeria at the then University College of Ibadan. (Now, since independence the University of Ibadan), one of the students under his tutelage was an exceptionally bright young man name Donald Ekong. Ekong went on to become a Professor of Ibadan. During the mid-seventies there was a drive to expand the university system throughout Nigeria. There was lots of oil money around. In order to cover the area around the Niger Delta the government set aside 27 square miles of Rain Forest in which to build the University of Port Harcourt. The town of Port Harcourt lay some 25 miles to the South. Ekong was appointed Vice-Chancellor to watch over and develop a seat learning starting with a considerable number of trees, but nothing else. Development of the University was planned as a two stage project; temporary facilities on a cleared site provided teaching and administrative facilities; wells were dug and generators installed to supply power. Electricity reached up from Port Harcourt and provided a chancy service. The power authority was named NEPA, Nigerian Electric Power Authority; it became known as Never Any Power Available. On a good day the chance of a failure was 10%, and it could take a week to be restored, in the mean time the generators took over the load, then they were functioning. Moving along with the story it became evident in the late 70's that some technical facility was necessary in order to cope with the increasing emphasis on lab work. This inadequacy became a subject for correspondence between Trent and Port Harcourt. Guess who they came to.

My happy recollections of Chile promoted me to seek adventure in far away places, the lure and romance of Africa exerted quite a pull. After all things could only be better. The usual correspondence started with attendant delays but this time the delays sometimes needed a firmly worded follow up in order to jog Port Harcourt awake, but that's just power for the course.

Finally on a snowy day in December of '78, I went to Trent for a meeting with the VC who was on a fund raising mission to the U.S. and Canada. We had a convivial discussion in the presence of the VC's former tutor. Once again more a meeting than an interview. It became clear that I had the job when I went outside into the snow-soon to become a memory. Months went by and nothing happened so I wrote to the Register to find out the score. Still nothing happened, it was now seven months since the meeting so I sent a rather stiff letter off with the feeling that if offense was taken it would be just too bad. There had to be a decision. It takes about three weeks for a letter from Canada to penetrate into an African Rain Forest. Nevertheless, a month or so later, a cable gram was phoned into my home formally offering me a post as the Chief Technologist of Port Harcourt. I sent a cable and a letter accepting. I found out later that they never received the cable, no telephone.

There was the usual messing about with papers and visa, medicals and several shots. Finally on a cold November day in '78, I boarded a flight to Kennedy to connect up with Nigerian Airlines. There was nobody at their stand and my flight was supposed to depart in a couple of hours. Still no show so I sought enlightenment at British Airways. Oh, they've changed the schedule, your departure is in seven hours time. It's started! I had made arrangements to be met in Lagos, so didn't worry. I was sure that they would know about the changed arrival, wrong. Arriving finally at Lagos I disembarked into a Sauna Bath. Immigration went off all right now for the bags. I arrived at the baggage area soaked with sweat to discover that an oversized crate had broken the conveyer belt trapping my bags in a tunnel. Eventually and at significant expense employing a porter to extricate my things from the tunnel I reached the domestic airport. The next flight to Port Harcourt was in four hours. There were no display indications which concourse, no concern. Lots of planes parked out in a large field. Destinations were announced in Pigeon English. I couldn't understand a word. By this time my anxiety gauge was well into the red.

More by luck than good judgment, I boarded the right flight to Port Harcourt - nobody there to meet me either, a taxi was organized by somebody and I reached the Campus. It was so late the gate keeper didn't want to open up. A display of fury and indignation on my part changed his mind. The Guest House was closed, try the Faculty Club, that was closed as well. I got lucky, I met two people having a conversation outside the club. They both expressed concern for my exhausted state. One an English Lady who turned out to be a professor of English offered me the use of her guest room, we returned to her bungalow where I was sat down to a plate of bacon and eggs, and a large cold beer. I keep a special place in my heart for that lady.

During the course of the several days following my arrival I managed to get organized with a furnished chalet bank account etc., etc. and finally about two months after my arrival I managed to get started. This kind of non-progress was apparently par for the

course. There was only one course of action open to me I know I couldn't beat em so I jointed em!

Eventually some classes were organized, propane and oxygen was made available and the technical services building plans were approved. About a year had passed and the materials and equipment started to arrive. Some of the reasons for the delays were due to international bureaucracy. The bureaucracy coupled with that which dominated Nigeria could, and often did create a state of negative progress. Early on in my negotiations I had indicated the importance of my being responsible for the selection of equipment; This was agreed upon; of course it didn't work out. Some time prior to my arrival one of the staff acting on the Dean's orders had selected things from a catalog which he felt would be appropriate for a glass shop. This person had never seen a glass shop, yet along work in one. The 6" Heathway was acceptable, I had planned on a Universal model. The oven when it turned up was not a canopy model, the monster could be adapted to cook pizzas; it came in a large crate and we gathered around to have a look at it. The glass shop had been constructed so that the oven would occupy a separate room, a necessity if one is to survive in a Sauna Bath. The plans had been made without too much concern being given to the size of the oven. Upon being exposed to the light of day one minor detail was apparent. There was no way of getting it into its location. Everybody, including the Dean looked at me - why me! What to do? We knock a hole in the outside wall, build a ramp and put the oven into position with a fork lift and that's just what we did. There are but two courses of action to bewildered expatriates confronted with African thinking, give and go home, many did! Or laugh, I laughed and survived.

In the midst of all this seemingly endless chaos I received a visitor. One fine morning a young post graduate of pleasant personality came to me with a message. He sought a Ph.D. and whether I liked or not I was to be the motivating force for the research which was to be conducted towards that coveted Ph.D. His supervisor, an essential ingredient in any Ph.D. had instructed the young man to study very small marine animals. Now in the natural state micro-organisms are moved involuntarily by the flow of the tide. As animal species increase in size and complexity some show an ability to move voluntarily while bigger ones, fishes, shrimp, etc. fight the current at will. The marine species to be investigated were those with intermediate voluntary mobility and inhabiting the tidal waters of the Bight of Benin. These creatures are much too small to observe through the glass bottom of a boat. For a start, wild surf along the coast would render launching a small craft almost impossible. One would need a vessel the size of a fishing trawler and these don't come equipped with glass bottoms. How was I supposed to help this project, easy he wanted me to build a Tidal Simulator. There are a few of them around, probably Woods Hole has or Naples has one, there's two or three on the Pacific West Coast. They run several million dollars a piece. What funds are likely to be available? Maybe I could anticipate 2,000 dollars. Rather than shoot the student down I suggested he return in a month.

First steps to finding solutions to problems should be to examine the fundamental issue. A tidal flow is nothing more than a quantity of water moved by gravitational forces back and forth in a predicable manner. If an open ended cylinder of handleable diameter is placed beneath the surface of the water such that its longitudinal axis lies along the

directional flow of the current that cylinder of water becomes the site of study. It now becomes necessary to relocate the cylinder in a suitable location on land maintaining its axis relative to the natural site just in case unforeseen magnetic influences etc., might hinder things. Fill it up with water taken from the specific locality and of course containing the little animals to be studied. The extremities of the cylinder are connected through a system of valves driven by a clockwork mechanism to allow water to flow down from header tanks in phase with the natural tidal rhythm. Tidal times change daily by an amount which varies in different parts of the world but it's roughly an hour later every 24 hours.

A robust clockwork alarm which was adjusted to run slow was put into service to operate a series of valves. Tides have two periods of slack water one at each end of the cycle and flow builds slowly to a maximum and then reduces to slack it then changes direction. This rhythm is repeated endlessly. The valve assemblies were made of locally available materials. The alarm clock was donated and I seem to recall tanks were obtained at a low cost. The water pump did cost some money. The complexities of the set were published back in 1983 via UNESCO and the Royal Danish School of Educational Studies. It is beyond the scope of this paper to present a detailed observation of the system. It is sufficient to state that this Heath Robinson device worked in principal. I know not the outcome of the study as I departed from Nigeria shortly after assembling it. It was an interesting and challenging project. There were others including another balance even more basic in design but following the same principals. Several pieces of apparatus were put together with the proverbial bailing wire and string. Every year the special projects which were mandatory for fourth year honour students brought many headaches and moments of great amusement. One such antic needed a tall metal cylinder several inches in diameter which could be closed top and bottom with detachable caps. A visit to a paint factory produced several one gallon cans with no bottoms only top ones. It was a simbiotic relationship, there was a problem knowing how to test for leaks in the welds of the cans so I suggested pressure testing in water with a dependable safety valve to protect the operator, the ideas went down well. I will always remember the puzzled smile on the man's face when he rolled lips on both ends of a paint can. He had no idea why I needed them, but owibos (whitemen) were strange anyway! Adaptation of everyday items into workable equipment was the order of the day, there were a few dull moments. We ever produced wrapping quality paper from the fibrous trunk of the Papaya tree, so on and so forth. I feel that the foregoing is sufficient in content to give the reader an idea of what to expect if anybody might yield the travel bug.

Looking back over the years, I have experienced many emotions from elation all the way through to terror. Yet not withstanding all of the vicissitudes of survival I have had the rare privilege to touch common humanity, and in so doing I have reached up and touched the stars.

# Micro-Fine Wire to Glass Seals

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In order to conduct plasma research, Dr. John Benage and his research assistant, Gene Linzey, approached the Materials Science and Technology Group (MST-7) Glass Shop with an unusual project. Originally, Dr. Benage wanted a .004" diameter aluminum wire sealed inside a quartz sheath. It was also desired that a technique be developed which could be reproduced in other labs by non-glassblowing personnel.

The challenge was sealing quartz, which doesn't soften until well over 2,000° F, to a wire that burns in half when exposed to a match flame. Traditional lampworking techniques failed even when lower temperature glasses and wire cooling techniques were used. Accomplishing the seal seemed unlikely.

When we finally abandoned any ideas about flame working the glass, we began to experience some limited success. While any soft glass with a low melting temperature would work, we used Corning #7570 frit. Using the Corning specifications<sup>1</sup>, we tried several graphite molds that held the wire and frit in place during oven firing. The result was successful in that the glass was fused and the wire sealed, but the resulting glass was opaque. Since research depended on photographing a transformation of the wire, glass clarity was essential.

To solve the problem, the frit was fired in a crucible to 1850°F and allowed to "fine out." Once the glass reached the desired transparency, it was poured onto a graphite flat to produce plate and oven annealed. For the final firing a high temperature mold was made using Fredrick Carder's glass casting formula as given in Glass Forming, by Keith Cummings<sup>1</sup>. Small rectangles were cut from the plate glass and placed in the mold with the aluminum wire sandwiched in-between. Narrow grooves were cut in the mold on either side of the cavity to hold the wire in place. Plain plaster of paris has been found to be an acceptable substitute for the high temperature mold formula. If precision isn't necessary, the glass rectangles can simply be placed on top of any high temperature surface coated with a separator and fired.

The mold, with glass and wire in place, was then fired to the lowest possible fusing temperature, in this case 900°F. Better results are achieved by firing at a low temperature and holding that temperature for a period of time as opposed to raising the temperature to fire more quickly. The oven is allowed to cool slowly with the lid closed. The residual plaster can easily be cleaned off and the seal is strong enough to withstand grinding and polishing.

Since the techniques used did not require glassblowing skills, they were easily performed in the other laboratories. The process has been improved by designing a stainless

steel mold into which the molten glass is poured. When cool, the glass forms are easily removed from the mold without use of a separator. Also, a lucite form has been utilized for imprinting the plaster mold which is used in the final firing. The lucite mold was coated with a separator, Ram 225, pushed into the liquid plaster and allowed to set.

Subsequent research has verified that a variety of micro-fine wires and glasses can be substituted with satisfactory results. Since most metals and alloys melt above the melting temperature of aluminum, higher temperature glasses can also be used. We obtained satisfactory results with chromel, alumel, iron and copper in combination with Kimble R-6 flint glass and Duran-Schott RD-50 lead glass.

We also experimented with drawing capillary tubing in the torch previous to making the glass to metal seal in the oven. Once the capillary was pulled to match the drawing dimensions, the wire was fed through the capillary and fired in the oven the same way the rectangles were fired. The finished seal was much closer to the dimensions on the original drawing, but this technique would be difficult to pass along to Laboratory personnel unskilled in glassblowing.

In this case, trying to seal quartz to aluminum wire with a hand torch was costly and unproductive. Using a lead glass in the oven allowed us to fuse the glass at a low temperature and avoid melting the wire. The oven firing also avoided unexpected reactions between gases, glasses and metals at high temperature. Finally, since the set-up was done cold, the glass and wire could be placed precisely.

This technique is successful with a wide variety of wires and glasses. Since the wire is so fine, expansion coefficients are immaterial. The difference between the melting temperature of the metal and the fusing temperature of the glass is the only real consideration in making the seal. Once a glass and metal have been chosen, an endless variety of configurations can be produced simply by changing the design of the mold.

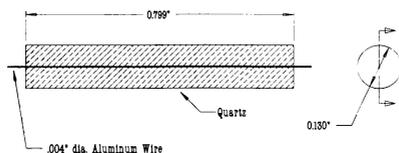
Acknowledgments:

We thank our customer, Dr. John Benage of Los Alamos National Laboratory (LANL) and Joseph R. Laia and Jake Bartos (MST-7, LANL) for their support.

Footnotes:

- <sup>1</sup> Applications Information Sheet for 7570 Glass (New York: Corning Inc., 1977).
- <sup>2</sup> Keith Cummings, The Technique of Glass Forming (Essex: B T Batsford Ltd., 1980), p. 143.

#### Micro fine aluminum wire to quartz seals



# 53 Years of Fascination with Glass

by Joe Luisi

The reason I volunteered to give this paper is because I'm thrilled to learn that so many of my former students and graduates of Salem Community College have been so very successful in distinguishing themselves in the field of Scientific Glassblowing. The president of our Society, Robert Ponton is a former graduate of Salem Community College and many of the officers are former students of mine and, of course, I'm proud that I could play a part in their education.

I would also like to share some of my life experiences prior to fifty three years of glassblowing. To me my life was **very exciting**. I hope you at least find it **interesting**, for you see, I became a glassblower purely by accident. If I may, I'd like to take you back to the year of 1930. I always say this was the year my life really began. I was nine years old and in the hospital having my tonsils removed and my parents bought me a ukulele. Remember these were the depression years and I really did appreciate them giving me this gift. Prior to receiving this ukulele I was always singing, dancing, acting and all I had to accompany myself was a cigar box in which my dad attached a wooden neck and ran rubber bands across the body to pluck on. After I was discharged from the hospital, a musician friend of my father began giving me lessons and in a short time I was doing so well that my parents bought me a four string guitar and before the year had passed my fingers were finally large enough to play a six string guitar. At ten years old I was taking lessons from a professional guitarist and began entertaining at schools, civic clubs and at movie theaters throughout South Jersey. Back in those days, after the movie was shown, five acts were presented. The first prize awarded was 5 dollars, second prize of 3 dollars and third prize was 2 dollars. I was making the circuit and won fourteen straight first prizes playing and singing and for my fifteenth appearance I was scheduled to appear at my hometown of Vineland, NJ and in my mind I figured how could I lose in my hometown? Well! This was my first rude awakening that life was not all a bed of roses, for I didn't win first prize or second either. I did, however win third prize. I was crushed, but I survived. At one of my performances a man approached my parents and asked if he could take me to Philadelphia to appear on the Children's Hour of WCAU Radio. They agreed and I was a regular on the show for five years.

At thirteen years old I was asked to join a big band, it was one of the best bands in South Jersey and I enthusiastically accepted. However, the only thing they insisted upon was that I wear long pants. Up until this time I only wore knickers. I had a tailor make me a pair of long pants and began playing steadily. To sum it all up, I was playing with a big band, appearing on the radio, and in school I was doing a lot of entertaining, directing plays, acting in musical, singing and dancing and really enjoying my school days.

Finally, it came time for me to enter Vineland High School and I'll never forget my first day at the new school. My homeroom teacher was calling the roll for attendance and when she called my name I answered "here" and her response was "Oh, so you're the great Joe Luisi I hear so much about. Well! Let me tell you, you're not going to run this school like you did the last two." I was flabbergasted and being a very sensitive person I said to myself O.K. I'll show her and I probably made a very poor decision, I did not join the

drama club. I did not join the orchestra and I engaged in no extra curricular activities. Because of this incident I became very nervous and self-conscious. However, I did continue to entertain outside of school and upon graduation I was offered an opportunity to play with a big band in New York. I also was offered a chance to entertain on a boat going back and forth to Bermuda. In both instances I reluctantly refused. I was very young, all my friends were here and I suppose I was just afraid to leave home to go out on my own. I felt very bad about my decision because my parents had sacrificed so much to pay for my music and voice lessons and here I was not taking advantage of my opportunities. I remember my Dad saying "Don't worry son, whatever you decide is fine with Mother and I. At least you have developed your talent."

Upon hearing this I felt better and decided to take a job just for the summer, and I planned to later enroll in a conservatory of music. Well! I took a job and guess where? Ace Glass Inc. My first job was washing glass in an area adjacent to the grinding department and this old German foreman almost fired me because he didn't approve of me singing while I worked. But he mellowed and in fact he gave me a better job fulfilling a vacancy in the grinding department. I'll never forget, my first check was thirteen dollars and twenty cents a week and my take home pay was twelve dollars and ninety four cents a week. There were two levels at Ace Glass and one day I went upstairs to investigate. That's when my life got turned around for when I entered the lamp department and saw glass blowing for the first time, I was fascinated by this unique craft and I expressed, to the company, my desire to serve as an apprentice. I figured I'll delay going to the Conservatory of Music because the World War had begun and I probably would be drafted to enter the service. It wasn't long before I got my chance to serve an apprenticeship in the lamp room which was the start of my career in Scientific Glassblowing. I had to serve 7000 hours or 3 1/2 years to be classed at a third class journeyman.

In looking back, my instruction in glassblowing was a whole lot different than the instruction one gets at SCC. I wasn't taught the basics of Scientific Glassblowing, I was given a job which was soft glass stopcocks. The foreman would sit down and make a couple and would leave me alone to duplicate his actions by whatever method I observed.

In fact I remember many times when I tried to observe the other workers, they would stop working and walk away. Glassblowing was a very guarded craft back then. In spite of this I progressed very fast. I was working over sixty hours a week learning from some of the country's best and loving it. One company policy which worked out well for me was they would allow you to fabricate any available glassblowing job that you felt confident of trying. I had been blowing glass for two years and I constructed a giant condenser at the bench. I blew five 75 mm bulbs on 32 mm tubing and sealed it into a 100mm jacket with male and female joints sealed to each end and the sides were hose connections. Of course I was nervous and I struggled somewhat but I did complete it satisfactorily.

Five times I was notified to appear to be inducted in the service. Each time I was told that I was in the army but when I returned home I was given a deferment and I never knew why until the war ended and I was told that we at Ace Glass were working with the government on the Manhattan Project, which was the code name for the atomic bomb.

In 1945 the war ended and I made my first artistic sculpture.

I was inspired by my high school's championship basketball team and made a glass trophy as a tribute to their success. Because of working at Ace Glass and entertaining musically I had little time to devote to artistic glassblowing. Therefore, I only made something every three or four years. In the early fifties I was commissioned to sculpture a figure of Joe DiMaggio. I was told that the finished product was fantastic. They said I not only captured his physical features but also his character and I was urged to give up music which would enable me to concentrate on artistic glassblowing to develop this unique talent. I just couldn't give up music. Remember. It was my first love.

In 1959, while serving as instructor for Ace Glass, I was asked if I would be willing to set up a glass blowing program and teach Scientific Glassblowing at Salem Vocational Technical Institute. They said I would be the first Scientific Glassblowing instructor in the United States to teach at a Vocational Technical Institute. So while on loan at Ace Glass I decided to accept the position. The only requirement was I had to take college courses working towards a degree. I had nine students and I'm happy to say eight of the nine students have been very successful. A few owned their own business, one was president of a company and all held position as top men in companies they worked for. After one year I was given the option to stay and teach or to return to industry. Because they wouldn't allow me to major in music I decided to return to industry where I worked, played music and occasionally fashioned an artistic sculpture. In the sixties I made a handblown sculpture of Elvis Presley and his guitar. It was quite large (2 feet tall) and again many of my peers tried to persuade me to give up music so that I could concentrate on Artistic Glassblowing. They felt as though my talent was so exceptional that it was a shame not to continue to develop it.

Finally in 1978 I was approached and asked if I would be willing to go back to teach Scientific Glassblowing at SCC which was formally the Vocational Technical Institute in the program where I was the first instructor. I was told that the glass program has deteriorated somewhat. They only had five students enrolled and they were on the verge of discontinuing the glass program. I had completed forty years at Ace Glass and decided that this probably would be a good time for a change. I remember enjoying the one year that I was instructor and decided to accept the position. I also decided finally to give up music so that I could concentrate on Artistic Glassblowing. I was hired and given the title of Special Chair, Professor of Scientific Glass Technology. It is the only college of its kind in the country that offers a degree in Scientific Glassblowing. Our philosophy is to teach the basics of glassblowing together with the related subjects of English, Math, Physics, Glass Chemistry etc. in the hope that after two years they should be able to fit into most positions with a minimum of instruction. Our students come to learn from all over the country and various parts of the world and after graduation are willing to relocate to wherever a position is offered.

In my opinion, Scientific Glassblowing is the most difficult craft there is to master. It is also one of the most fascinating. I also have learned that no matter how talented one is, to be able to teach is a whole different challenge. It has taken me years to analyze and develop a technique so as to transfer my knowledge and each year I feel as though I'm better than the previous year.

What I teach the first day of school, in my opinion, is the most important instruction in free hand glassblowing and I believe its the ultimate formula for success.

In a visual demonstration I hope to point out the importance of the necessary procedures for success in free hand glassblowing. In order of importance I would list hands positioning first, balance of left and right hands next followed by control and coordination in turning glass tubing so as not to twist the glass. Marking the glass on each side of the heated area will help the student to recognize if the hand coordination is out of sync. I also stress short strokes and intermittent hand turning for better control of glass tubing when melted. Next I explain what I refer to as parallel evenness which is to be careful not to allow the melted portion of glass tubing to be pulled apart and also not to push the melted area together so a to buckle the glass.

Next the importance of blowing pressure can't be stressed enough. If one blows too soon, too hard, too late, not hard enough each of these actions will effect the result. Of course, one has to be aware of the temperature of the fire. The temperature of the fire has to coincide with the skill that the student possesses at that time. With more experience **adjusting** to the situation will come easier, and finally the one thing that can't be taught. That is **timing**. Only gaining a natural feel thru repetitious practicing can help in achieving success. As an example, I always refer to the baseball player batting a ball. They can be shown how to properly hold the bat, stand at plate etc., but can't be shown the exact timing of when to hit the ball. In closing, I'm happy to say that after giving up music for 12 years to concentrate on artistic glassblowing I was invited to a conference in Carmel, California as one of the world's best flame working artists and recognized as the world's leading flame working artist of hand blown sculptures of the human form.

I attribute much of my success in artistic glassblowing to the fact that I had an excellent background in Scientific Glassblowing and this is the technique that I employ in my sculptures.

Remember real old glassblowers don't fade away, they just keep hanging on, so don't be surprised if you hear from me again.



# Three Fluid Mixing Variations

By

Frank Meints

Upjohn Laboratories, The Upjohn Company

The stirring and mixing of chemicals is one of the most common operations in chemical processing. Yet I believe that most of us have given little thought to this process. As glassblowers, we think of making straight stirring rods or removing teflon paddles stuck inside flasks when the joints are frozen and the stir shaft breaks. In this paper I will give some general information about stirring and mixing, and then relate my experience in three unique problems involving this process.

Indeed, the process of fluid mixing or stirring can be very complex. There is no limit to the variables involved in mixing: container size and shape, volume and viscosity of material, size, shape, angle and speed of propeller mechanism, and the desired end results. I found several books on the subject and realized a person could make a life long study of this and still not cover it all. The books and other reports on mixing have some formidable equations, and are more appropriate to large scale operations compared to what is encountered in the laboratory. The example vessel is normally a flat bottom cylinder with baffles at the side or bottom. The impeller is usually made of metal and is one of three common types: marine type, pitched blade, and flat blade. I won't go into the mathematics involved, except to say there are formulas involved that are meant for someone studying fluid mechanics. However, a few basic rules apply in fluid-fluid mixing of which some are obvious. The larger the propeller blade and/or the faster it turns, the more liquid it is capable of moving. Mounting the propeller at an angle or off center of the vessel will usually eliminate a v-shaped whirlpool called a vortex. A vortex is undesirable in mixing because the fluid gets trapped in the whirlpool and therefore does not mix with the rest of the material. Baffles are normally used in mixing to help break up radial or circular flow, thereby increasing the turbulence and intermingling of the molecules. Baffles also aid in axial, (up and down) flow. The viscosity of the material being mixed will affect propeller design and speed. Going from a high viscosity to a low viscosity is like mixing milk in coffee compared to mixing milk in pancake batter.

Being a glassblower, the way I approached this was to narrow it down to something manageable. The first thing is to determine as many fixed parameters as possible and then concentrate on the variables.

## Design No. 1

The goal of this stirring rod design was to improve the mixing of a chemical entity in a conical vessel (fig. 1). The fixed items were: the liquid being mixed, the vessel shape, the amount of clearance for the stirring mechanism, the angle for the stir rod and the position of the temperature probe which acted somewhat like a baffle. The variables were the number and shape of the mixing vanes and the speed of rotation of the stirring rod. The conical shape allowed the vessel to be used to mix small volumes of fluid. The difficulties associated with this design were the centered shaft which tends to produce a vortex, the conical vessel shape, and the small area allowed for the blades. One of the

manufacturers supplied stirrers had five set of blades going up the shaft so as volume increased, more blades would be active in solution. The blades were square and flat, mounted at a 45 degree angle. At full volume the blades produces mostly localized radial flow and insufficient axial flow for the process. In other words, the liquid tended to swirl in circles instead of mixing top to bottom. Using the supplied stirrers, it was necessary to run at a high speed for an extended length of time to complete the reaction. This required frequent monitoring to prevent overheating of the bearings and possible stir shaft breakage.

The researcher working on this problem provided a very visual and helpful method to see what is really happening. The action of various stirring rods in this vessel was videotaped. Using a 26% solution of sodium bromide to match the buoyancy of red and yellow plastic beads, various designs of stirrers at various speeds and volumes were tried. By watching the movement of the red and yellow beads, the pattern of fluid motion could be visually observed. The shaft with five sets of flat blades produced mostly radial mixing. Removing three sets of blades from the middle of the shaft had no effect on the mixing pattern. Several modifications to the stirring shafts were tried. The one that improved overall mixing by improving axial flow was a foil shaped blade. The results of this example showed that the foil designed blade delivered more uniform overall mixing than the flat blade. There is still room for improvement, and we are still experimenting at this time to find improved mixing at a slower speed.

## **Making the Blades**

I first tried making a tool to form the blade shape I wanted. This worked, but not very well because many blades had to be made to get them enough alike to be balanced. I found a simpler method which was cutting sections from borosilicate tubing that has the radius and thickness desired to make the needed blade stock. The blades were then sealed to the stir rod (fig. 2). I used alligator clips to hold the blades at the desired angle and marked 180 to 120 degree lines on the work bench to get the proper spacing. At this point, if you desire, you can reheat and soften the blades slightly and put a slight twist similar to an airplane propeller. The last step is to make sure that the shaft will run true.

## **Design No. 2**

I received a request for a glass coated magnetic stir bar to perform inside a 10mm o.d. square cuvette (Fig. 3). Using what I had available, I took a 3/8 x 3/16 teflon coated magnet, stripped off the teflon and ground it down to a 5mm length. A slot was sawed into the end of a 6 mm rod. The magnet was put into the slot and sealed over with glass. After cooling, a 4mm section containing the magnet was sawed off. This was put in the cuvette which was filled with water one inch deep. The cuvette was set on a adjustable speed magnetic stirring plate. The magnet turned very nicely at all speeds. To experiment, I added a little scouring powder to see what would happen. The powder sunk to the bottom and swirled, but stayed in the bottom third of liquid. This was not adequate because the customer wanted the entire mixture to be stirred. I made another stir bar like the first and this time sawed off a 6mm section. I then sawed an "x" across the previously sawed end. It was difficult to hold on to while doing this and consequently the resulting

surface was irregular. I tried this one and found that the irregular surface caused the stir bar to turn in an erratic fashion but fortunately, this type of action provided the mixing needed. The scouring powder swirled through the entire solution. I constructed several more of the (sawed X) model and all provided better mixing than the smooth model. Each stir bar behaved differently in regard to its optimum rotational speed and mixing effect, so several may have to be made to get the desired effect for a particular situation.

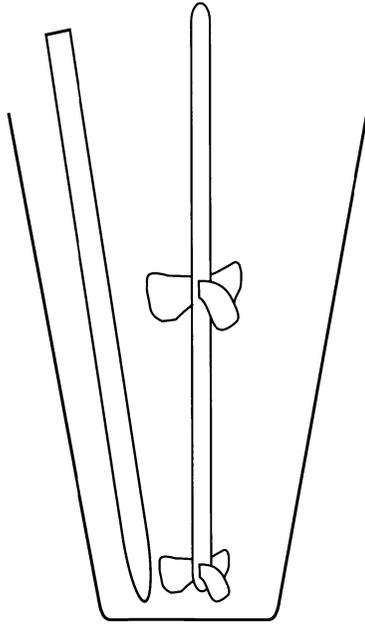
### **Design 3**

A researcher was encountering a problem of entrapment of crystals in a suspension in the process of measuring the dissolution rate of tablets (fig. 4). A sample tablet was being put into solution in a 150 or 450 ml beaker which fit into a chamber of the analyzing instrument. The beaker was being stirred by a "mouse ear" shaped two blade stirrer at a 30 degree angle. A sample tube is also present in the mixture to extract samples at various set times in order to measure the rate of dissolution. It appeared by observation that mixing was not uniform and granules were settling to the bottom corners of the beakers, therefore; the sample taken was not as accurate as it should be. Here the fixed parameters were the sample probe, the area allowed for the mixing blades, the size of the container, and the speed range and angle of the propeller. The variables were the shape of the containers and the design of the propeller. We found that two vessel sizes would accommodate the largest and smallest volumes encountered and still fit in the area of the instrument. These were 60mm o.d. by 90mm tall and 85mm o.d. by 115mm tall. By changing the design of the lower configuration of the vessels, we were able to improve the mixing action.

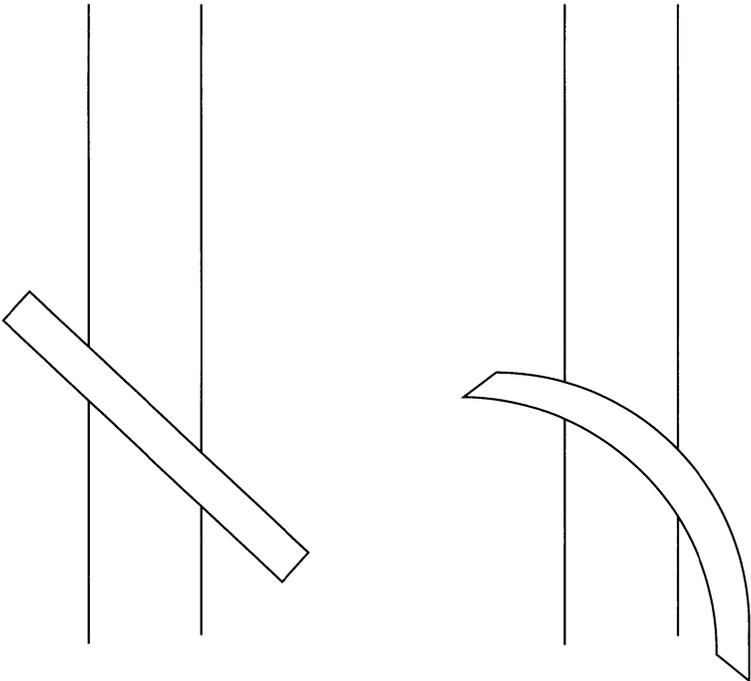
To make this vessel design, I rounded the ends of a 60mm and a 85mm tube and while still soft, the center was sucked in to form the indented bottom. The bottom was paddled flat to make it sit without wobble. This design improves circulation by eliminating the sharp angle surfaces. The crystals had no corners to settle in. The other variable that we changed was the number and shape of the stirring blades. We added a third blade and also changed to a curved shape instead of flat. The stirring blades were made by cutting 1/2 inch circles out of 18mm tubing using a 9/16 diamond core drill. This gave uniform weight and shape to the blades. An 8mm ball was made on the end of a 4mm rod and the blades were sealed to the ball at an approximate 45 degree angle. For testing, one stirrer was made of the naturally curled blades, and one was made of flattened blades. The curled ones worked the best in this situation.

In conclusion, mixing is so routine, yet can be so very complex. Each situation is unique and often changes as the process continues. Looking for the variables and understanding the principles of mixing will help find answers to mixing problems. I want to thank Don Knoechel, Ph.D. Research Scientist at The Upjohn Company, for the test of plastic beads in sodium bromide and also for design suggestions.

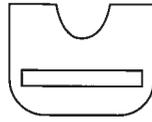
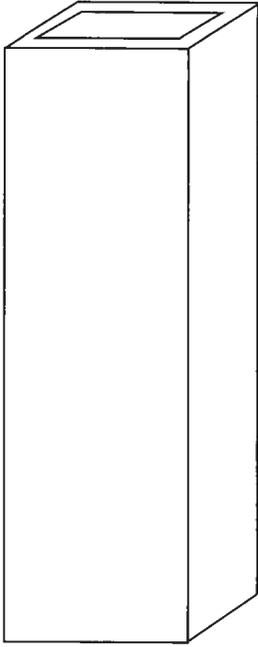
**FIGURE 1.**



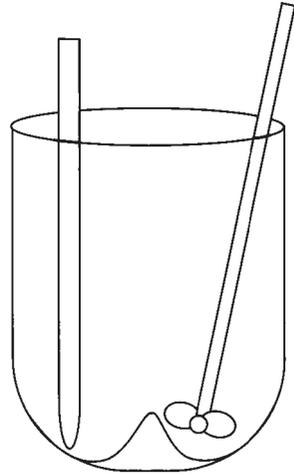
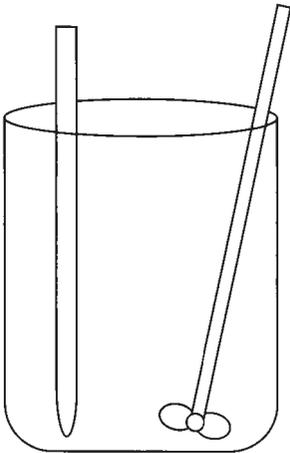
**FIGURE 2.**



**FIGURE 3.**



**FIGURE 4.**



# Opaque Fused Quartz for Heat Shielding Components

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## **Abstract**

Fused quartz is extensively used in equipment for the high temperature processing of semiconductor wafers. Opaque or translucent versions of quartz are incorporated in areas of these furnaces where heat transfer needs to be reduced. The various types of fused quartz available for heat shielding will be reviewed and the benefits of each discussed.

## **Introduction**

Due to its purity, heat resistance, and chemical compatibility with silicon, fused quartz is a preferred material in the construction of chambers for the thermal processing of semiconductor wafers. Typically, two different types of fused quartz are used together. Clear fused quartz is utilized where heat needs to be transferred into the chamber, by lamps or resistance elements for example. Opaque or translucent fused quartz is put into areas where heat flow needs to be minimized. Heat transfer depends on how much radiant energy is transmitted through the fused quartz, as will be explained later.

There are several reasons for lowering the transfer of heat out of chambers in semiconductor wafer furnaces: 1) Reduced energy loss and furnace power consumption; 2) More even heat distribution inside the processing chamber, resulting in more uniform processing of the wafers and improved wafer consistency. This also helps to reduce or eliminate furnace cold spots which tend to accumulate deposits. The deposits can shed particles onto the wafers during processing and may be difficult to remove during furnace cleaning. Minimizing deposits helps to reduce wafer contamination, as well as furnace maintenance and downtime; 3) Protection of heat-sensitive components located near the chamber (e.g. O-rings). Extending the life of these components helps to reduce the frequency of furnace maintenance and downtime. Also, since some materials will off gas contaminates when exposed to heat, wafer yields should be improved.

Typically, furnace chambers are constructed by welding clear and opaque fused quartz together into an assembly that has some sort of opening for the introduction of wafers. Fused quartz can also be used in the component that mates up against the opening of the assembly, forming a closed chamber. When a chamber for a semiconductor wafer furnace is designed, decisions are made as to where heat transfer needs to be maximized and minimized. For example, a vertical or horizontal tube furnace uses clear fused quartz in the center because this is where the resistance heaters are located. Opaque or translucent quartz is placed at both ends of the tube, which is where the greatest amount of heat is usually lost. Chamber designs vary depending on the type of furnace, e.g. oxidation, epitaxial, annealing, rapid thermal processing, etc.

When choosing a type of fused quartz for heat shielding, three factors need to be

considered: 1) Its purity; 2) The ease of fabricating an assembly with the material; 3) Its effectiveness in reducing thermal transfer. Unfortunately, the third factor is not always given as much attention as it deserves. How a fused quartz can be evaluated for its heat shielding effectiveness will be discussed later. Also, selection of a heat shielding fused quartz can involve three different groups of people: 1) The semiconductor device manufacturers who use the furnace; 2) The designers of the chamber (usually the original equipment manufacturer); and 3) The glass shop that fabricates the chamber assembly. All three groups need to fully evaluate the three critical factors in heat shield selection.

There are three types of fused quartz typically used for heat shielding in semiconductor wafer furnaces: sandblasting clear, opaque ingot, and opaque molded. (Opaque arc-fused quartz is a fourth type that is occasionally utilized.) Sandblasting the outside surfaces of clear fused quartz makes the material translucent, allowing it to be used as a type of heat shield. However, it will be seen that the opaque fused quartz grades are much more effective in reducing heat loss. Fused quartz is made opaque by generating a large number of bubbles in the material during processing. These bubbles can be filled with any type of gases, but inert gas is preferred for semiconductor applications. The size and number of bubbles can vary significantly among the different opaque grades. This can be seen both in Figure 1 and the image analysis data presented in Table 1.

### **Types of Heat Transfer**

Heat can be transferred in three different ways: convection, conduction, and radiation. Convection occurs in gases and liquids and is not relevant to this application of fused quartz. The conduction of heat through clear fused quartz is unaffected when the surfaces have been sandblasted. The thermal conductivity in opaque grades is approximately 10% lower than that of clear grades, which is not a very significant difference. For the temperature range typical in the thermal processing of semiconductor wafers (800 to 1200°C) radiant heating is the predominate mode of thermal transfer. Radiant heating results when infrared, visible, and ultraviolet light is emitted by a heat source and is absorbed by a material. The effectiveness of a fused quartz as a heat shield depends on how well it can reduce transmission of this radiation.

Figure 2 represents how the radiant energy of a black body emitter increases as the temperature increases. It is seen that the total energy generated is distributed over a range of wavelengths and that the wavelength of maximum energy decreases as the temperature increases. An important property of fused quartz to also keep in mind is that it stops transmitting light at wavelengths approximately below 0.2 and above 5.0 microns. Near and mid-infrared radiation is of primary interest when evaluating fused quartz for semiconductor furnaces due to the temperatures involved and the transmission properties of the material.

### **Heat Shielding Effectiveness of Fused Quartz**

The measurement of radiation transmission through a material is the best method to determine its effectiveness as a heat shield. However, the way the test was carried out and how the data is presented must be clearly understood, otherwise the results can be misconstrued.

Transmission analysis is carried out by beaming light through a sample and measuring the percentage of light transmitted (Figure 3). The diffuse method utilizes an integrating sphere which collects all of the light transmitted (both the scattered and direct type). Therefore the values generated by diffuse analysis are significantly greater than those from the direct method (Figure 4). Also, diffuse analysis is more representative of how light is transmitted in semiconductor furnaces. An instrument called a spectrophotometer is utilized for these measurements. Spectrophotometers usually can not cover the entire spectrum, so transmission scans are typically divided between the ultraviolet/visible/near-IR and mid-IR/far-IR regions.

Due to the way that radiation interacts with fused quartz, the amount of light transmitted depends of the wavelength. Also, the amount of light that fused quartz transmits depends on the thickness of the sample (Figure 5). Therefore, when evaluating the transmissions of different materials, it is critical to know both the thickness of the samples and the radiation wavelength at which they are being compared.

When comparing transmission data, it is obvious that sandblasted clear fused quartz is much less effective as a heat shield than the opaque grades (Figure 6). Also, due to dissimilar bubble contents, there are significant differences between the various opaque grades in their transmission percentages and, hence, their heat shielding effectiveness.

### **Purity, Availability, and Fabrication**

There are many clear tube and ingot grades available from US, Japanese, and European suppliers. The grades typically used in semiconductor furnaces contain less than 25 ppm total impurities. Depending on final assembly requirements, clear tubes are either blown up or drawn down to produce the necessary shapes. Components produced out of clear ingots require extensive machining of all surfaces with diamond-tipped tooling, followed by grinding and polishing to achieve acceptable finishes. It is relatively easy to produce translucent fused quartz by sandblasting clear material. However, there is some possibility that damage may occur to the component during this step because of handling or over-aggressive blasting.

Molded opaque fused quartz is produced by Pyromatics, Inc. It is available in four semiconductor grades all containing less than 25 ppm total impurities, with standard and specialty shapes readily obtainable. The biggest advantage in utilizing Pyromatics' molded material is that parts can be achieved which are either impossible or extremely difficult to acquire by fabricating either sandblasted clear or competitive opaque grades. A net-shape molded component helps to minimize the amount of machining required. These parts can be incorporated into an assembly together with either clear or competitive opaque fused quartz by using conventional welding techniques.

Opaque fused quartz ingot grades are available from producers in Japan, the US, and, most recently, Europe. The most widely used material in the US and European markets comes from Japan, having a typical total impurity content of 140 ppm (120 ppm of which is aluminum). Higher purity Japanese grades with less than 25 ppm impurities are expensive and rarely used outside of Japan. European grades are available with less than 100 ppm contamination, and US grades with less than 25 ppm total impurities. Many

shapes and sizes are possible when using opaque fused quartz ingot grades. However, as with the clear ingot material, all component surfaces need to be machined, ground, and polished. Due to the large bubbles typically found in the ingot grades, it is difficult to produce high quality surface finishes. This causes problems in applications that require leak-free surfaces, such as flange and o-ring seals.

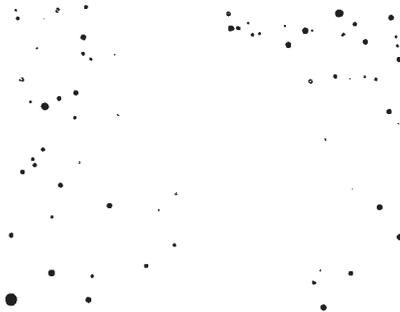
### Summary

In order to maximize the performance of a fused quartz furnace chamber in semiconductor processing, select a heat shielding grade by its impurity, effectiveness, and how easily it can be incorporated into the assembly.

Transmission analysis is a powerful tool in determining the effectiveness of a heat shielding material but must be properly used and interpreted.

The information presented in this paper may also be utilized when selecting a fused quartz heat shield for applications other than semiconductor wafer processing.

**BUBBLE STRUCTURE  
MOLDED OPAQUE (100x)  
FIGURE 1a.**



**OPAQUE INGOT (100x)  
FIGURE 1b.**

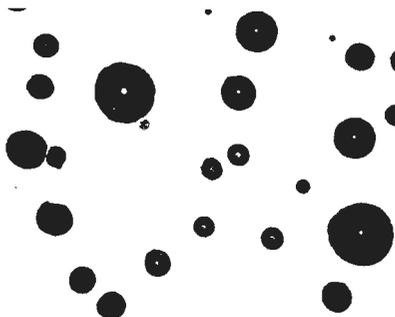


TABLE 1.

## IMAGE ANALYSIS OF TWO OPAQUE FUSED QUARTZ GRADES

	<u>Molded</u>	<u>Ingot</u>
Ave. Bubble Diameter :	18.3	77.7 $\mu\text{m}$
Bubble Concentration :	53.6	17.6 / $\text{mm}^2$
Total Bubble Content :	1.08	8.86 vol. %

Analysis carried out on polished samples at 100x, using a Bausch and Lomb Research II metallograph and a Buehler Omnimet image analyzer.

FIGURE 2.

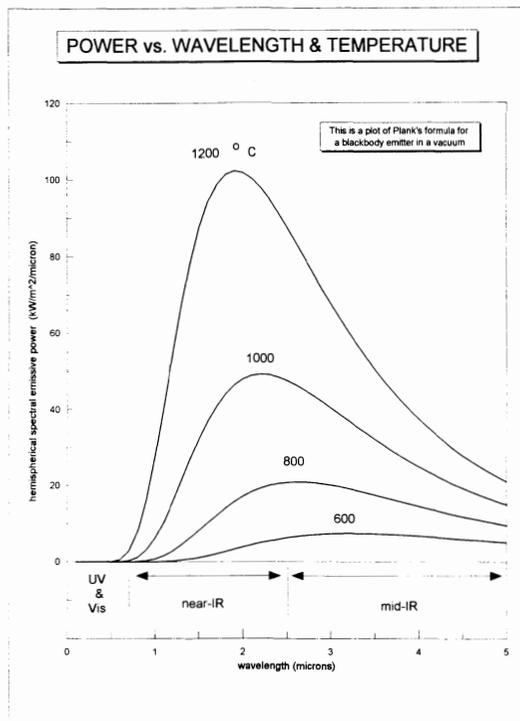


FIGURE 3a.

Measurement Of Radiation Transmission

Direct

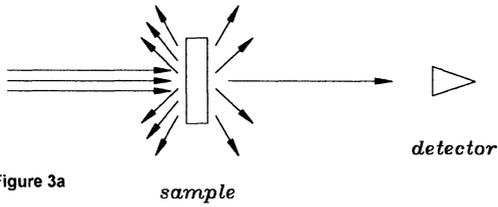


Figure 3a

FIGURE 3b.  
Diffuse

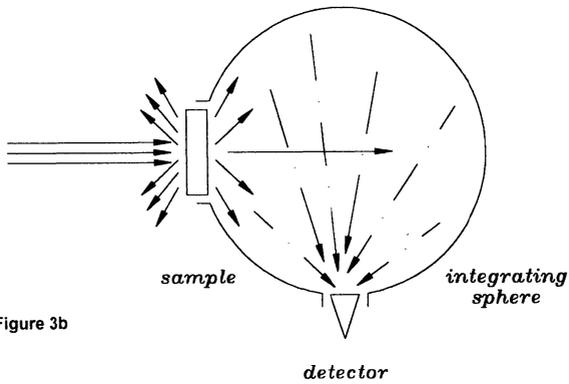
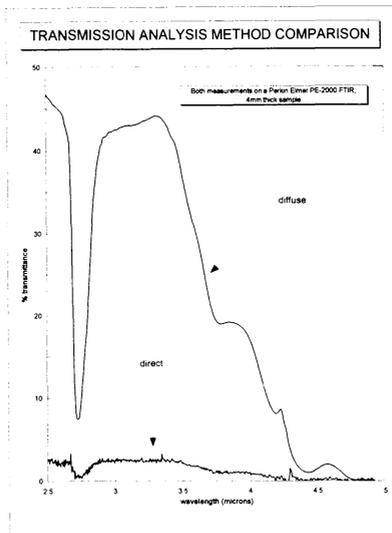
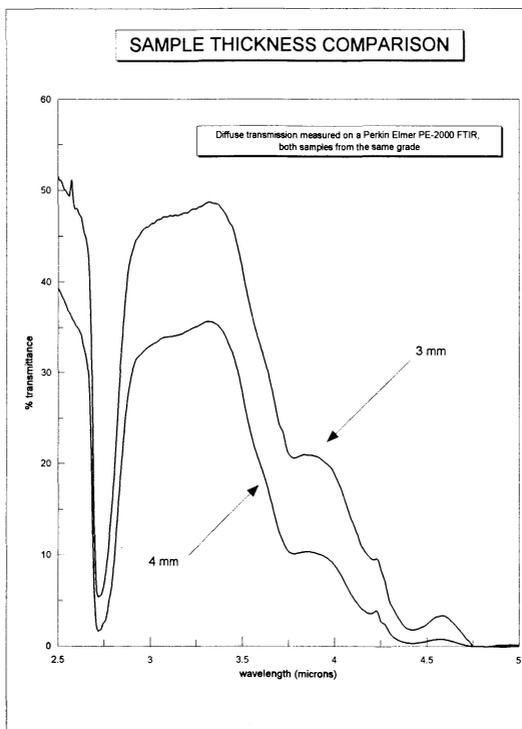


Figure 3b

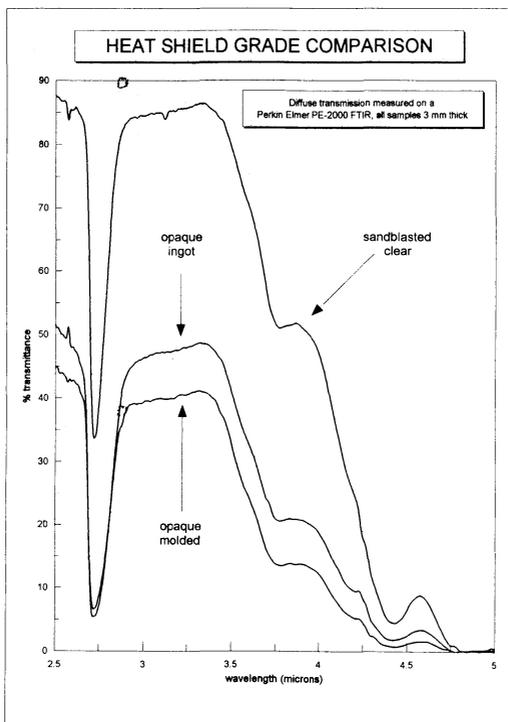
FIGURE 4.



**FIGURE 5.**



**FIGURE 6.**



# Using Common Tools for Machining Glass

by Thomas K. Reddy

## Introduction

I often imagine what it would be like to work in a perfect shop in an ideal world. No job would be too large, or too small. Turn-around time? **Always** to the customers' satisfaction. Price and profit? **Always** less than the customer expected to pay, but enough to keep us all sipping Dom Perignon and driving Ferraris. And of course, **no** job would be beyond the expertise and equipment capabilities of the shop.

Fantasize with me a moment . . . A customer walks into the shop, Dr. Dirt Cheap. He has a problem; he had a lovely laser tube which is now broken beyond repair and must be replaced by the day after tomorrow. The piece includes several complex, machined infrasil discs, seated to quartz tubing. It is a partially mirrored, vacuum-jacketed, multi-armed, glassworking extravaganza. Oh, and by the way, he is on a very tight budget. **No Problem.** In our ideal shop we have ultrasonic machining, laser welding, metal deposition and sputtering; the list is endless!

In the real world, at the University of Minnesota Glass Technology Department, we are far removed from this fantasy. With the economy in its current state, and tight budgets, it is difficult enough to maintain old equipment, let alone upgrade or purchase new technologies. Yet science marches on - currently we are seeing a greater and greater demand for precision parts machined in glass and ceramic. Although the University of Minnesota has ten or more machine shops, they have limited capabilities working with these brittle materials. Glass and ceramic machining jobs all end up on our doorstep. (The confused graduate student **always** says, "but, the machine shop said **you** guys work with this stuff!")

The equipment we have will remove the materials - drill presses, saws, we sanders, sandblasters etc. - but, not with the precision that is often required. This paper is an attempt to give you an overview of some of the simple equipment upgrades we have made, and some of the techniques we have developed for machining glass. As a small research support shop, it is our mission to offer quality glassworking services, in reasonable time, and at a reasonable cost. Eventually, we will equip ourselves with ultrasonics or a similar technology, but, in the meantime we improvise.

## Inexpensive Upgrades

The first roadblock to quality machining that we encountered was indexing. Indexing plays a central role in precision machining. What we needed was a method of getting relatively accurate indexing on all of our equipment without spending a lot of money.

One of the most useful purchases we have made in our indexing quest is a woodworker's tool - the Inkra Jig<sup>1</sup>. It is a simple device designed for straight-line indexing in preset increments, either 1mm or 1/32". The Inkra Jig is a two-piece mechanism with machined interlocking teeth. (Fig. 1)

The Jig is supplied with a standard fence and right-angle fixture. These attachments give the Inkra surprising versatility. Because of the simplicity of the jig's design, it can be attached to almost any of our shop's equipment. Innumerable custom fences and fixtures can be easily attached to the Inkra Jig, depending on a job's specific requirements.

Another versatile feature is that the preset indexing can be varied. By simply having spacers available to attach to the fence, or right angle fixture, any combination of indexing is possible. We have found that with frequently-repeated jobs it is worth having a machine shop make up a special set of interlocking teeth with job-specific spacing (Fig. 2). An example of this would be the drilling of holes in a linear pattern with equidistant spacing. Only the first hole, on the first piece, would need to be aligned. All remaining pieces would be ready to go (Fig. 3).

The use of two Inkra Jigs gives complete x-y indexing capabilities. This is particularly important on the drill press, for both drilling and milling. (Fig. 4). This is not "state of the art," but has given us excellent results for most jobs. To aid in quick set-ups and take-downs, it is advisable to have a base table for the jigs that can be used over and over again. (Fig. 4)

To date, this jig has been used on our cut-off saws, belt sanders, band saw, and drill press with great results.

Another handy device, that can be used alone, or in combination with the Inkra Jig, is a drafting tool - the dual adjustable trig-scale. This inexpensive item gives an infinite number of angles that can be easily adjusted ( $0^{\circ}$  to  $360^{\circ}$ ). I've discovered the versatility of this device when our shop was requested to cut a number of shapes from mirrored tile: triangles, pentagons, octagons, etc. At first, we used the trig-scale to mark out the shape with china marker. After about the fifth octagon, we knew there had to be a better way. By attaching a fence to the front of the trig-scale, we began using it directly on the saw as an adjustable angle fence. We have also used it in the same manner on a plate glass cutter with excellent results.

Almost any drafting tool can be used as a jury-rigged jig. Triangles -  $30/60/90^{\circ}$  and  $45/90^{\circ}$  - come in various sizes, and by simply gluing on a perpendicular fence, make versatile jigs for almost any angle grinding or cutting application.

## **Combination Techniques**

The indexing equipment we use are all "stationary table jigs." This means, that unlike in most machine shop operations, the table to which the work-piece and jig are mounted does not move. Instead, the stock is moved, manually, past the cutting tool. This method introduces some important limitations. First, there is safety; these are **all** hands-on operations. Secondly, sliding glass on any surface under abrasive conditions tends to severely mar the finished product. Thirdly, size becomes an important limiting factor; how small (or large) a piece can be manually held without losing trueness or causing breakage. Finally, what about pieces that do not conform to being rigidly held and pushed (examples: oddly-shaped blown pieces, spherical pieces, etc.)?

**Safety** is always a primary concern in working with glass. Glass, is, at best, an unpredictable material to work with. Face shields, gloves, long sleeves, long pants, and boots are always recommended. For machining applications, I also recommend making a set of push sticks - these will help keep your hands away from the action. With time and patience (and also customizing your push sticks!) you will find the glass easier to manipulate in this fashion. The best push sticks I have made have been the simplest - a rod or bar of aluminum with an angle cut at the bottom and a piece of rubber glued in place to grip the glass. (Fig. 5)

Using two of these devices at once allows the work-piece to be held true to the fence while being pushed through the cutting tool.

Our initial attempts at machining glass using these stationary jigs led to **badly** scratched finished pieces. To overcome this problem, almost all of our machining procedures require our work-piece to be glued between two pieces of scrap glass - a glass sandwich. This requires additional set-up time, but, the advantages are worth the effort. The primary benefit is that drilled and sawn pieces have little or no surface chipping. A second advantage is that jig stops can be tested for drilling, etc. without wasting any good stock. We make sandwiches as shown in figure 6.

The thin top plate reduces the amount of scrap we have to drill, mill, or cut through; while the heavier base plate gives us something substantial to hold on to for milling, etc. This thicker plate also reduces the chance of cracking the work-piece on complex operations.

Making sandwiches also allows us to machine small items precisely. By gluing the small work-piece to a larger base plate we eliminate many handling problems and breakage. (Fig. 7)

When the base plate is larger than the work-piece, it is advisable to be **extra** careful when indexing . . . don't forget the effect the base plate dimensions will have when setting stops on a jig, etc. This technique had made it possible for us to machine microscope coverslips (.10mm thick) and other previously impossible materials.

Gluing to a base plate also makes working with discs much easier. By adhering the disc to the same-dimension square base plate, indexing the center and drilling patterns become easy tasks.

For most machining techniques the type of adhesive is not critical; each has strengths and limitations. For example, UV curing adhesives allow rapid set-up of single-layer sandwiches and are relatively easy to remove by burning off at low temperatures in an oven. Their primary disadvantage is that UV adhesive does not work nearly as well for multi-layer sandwiches.

Wax is **very** easy to remove and works well for drilling but tends to fail under sheering forces encountered in milling, etc.

Epoxies, on the other hand, are far more difficult to clean up. Their primary advantage is that sandwiches can be made of almost any number of layers. This can be very

important in the case of making identical pieces which will be aligned with each other. The limitation to this is how deep and straight you can drill. And, secondly, how much material can be removed using the equipment and techniques available in your shop. Very rarely do we exceed 2 1/2" of laminated sheets or ten work-pieces - whichever is less.

The final machining aid we have used is sandblasting "pilots." One of the most difficult problems when machining glass is that tools can "run." Many projects have been ruined in the final stages of machining when a diamond bit or grinding tool grabs and runs on the work surface. Slight grabbing of a tool can cause holes to be non-perpendicular, troughs to be asymmetrical, surface chipping, etc.

These problems are particularly acute when machining on a rounded surface, or at a tangent to the work surface.

In most cases, we have been able to overcome this problem by creating "pilot" troughs, holes, and slots, using a sandblaster. First, we lay out the machining pattern on a sandwich with sandblast resist. A pilot of approximately 50% to 75% of the finished hole/slot size is then sandblasted. This pilot gives the grinding tool a guide to ride in, and there is far less material for the tool to remove. This speeds up the machining process and adds longevity to grinding bits.

## Conclusion

While these techniques offer excellent results for their comparative primitiveness, they do not allow us to handle every machining job. They do, however, give our customers an option for most proto-types, as well as rapid turn-around time for the majority of their machining needs.

FIGURE 1.

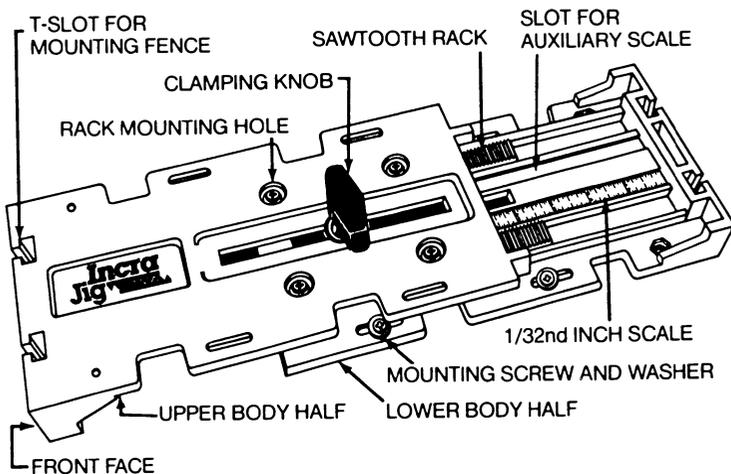


FIGURE 2.

# EQUALLY SPACED FINGER JOINT

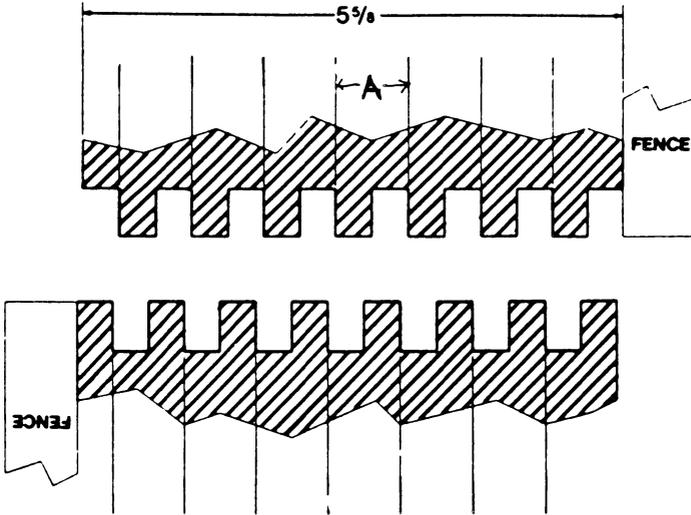


FIGURE 3.

# AUXILIARY TABLE FOR THE DRILL PRESS USING INCRA JIG AS A VARIABLE STOP BLOCK

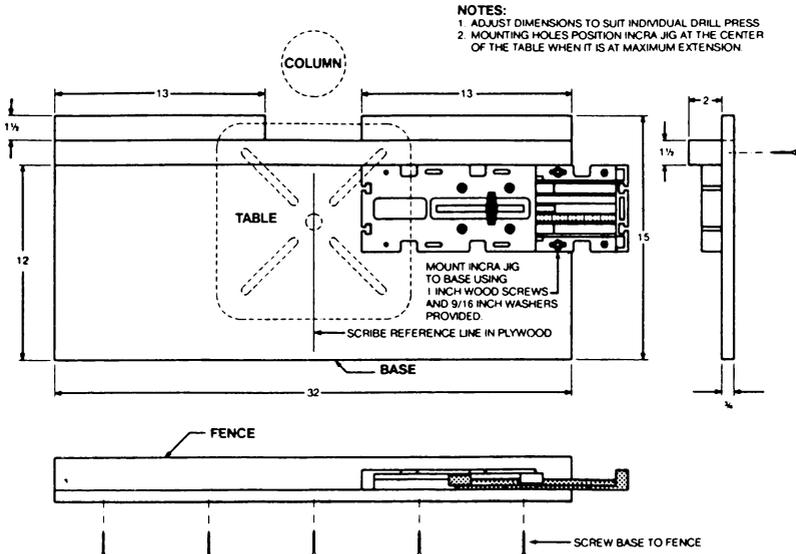




FIGURE 6.

a glass sandwich

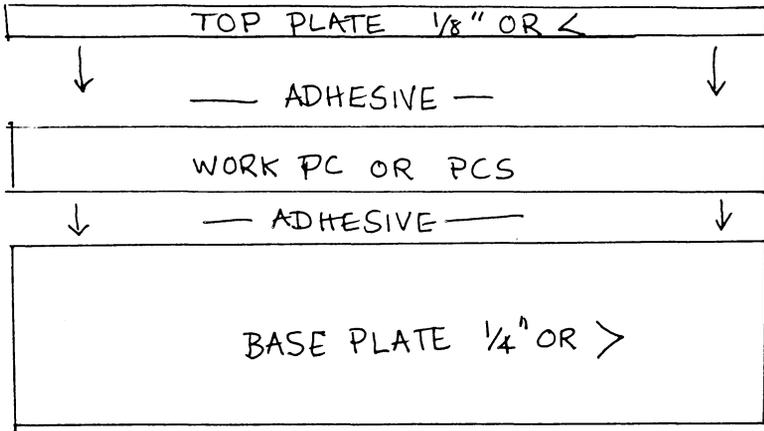
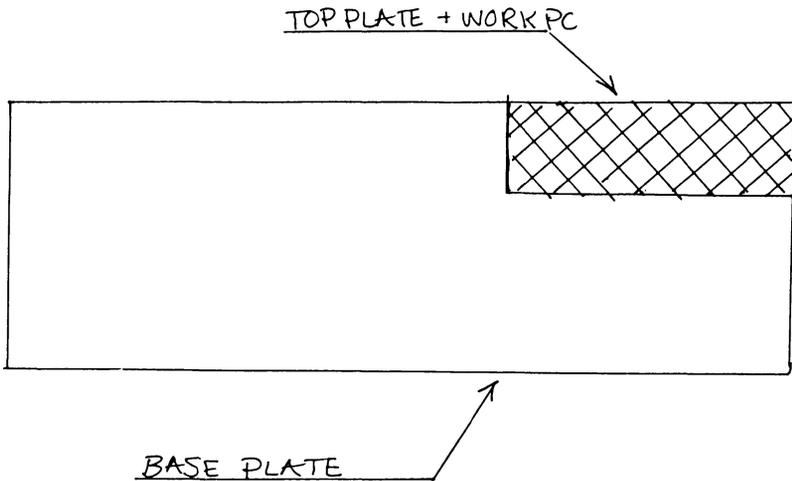


FIGURE 7.

to machine small items



# A Borosilicate Square Cell with Optical Quality Surfaces for an Ultra-High Vacuum Rubidium Atom Trap

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**Abstract:** This paper describes the construction of a rubidium atom trap made from 1.5mm Schott Tempax plate blanks measuring 23.5x64mm. The square cell is then attached to a 2" glass-to-metal seal welded to a 3-3/8" Conflat flange. Borosilicate glass was chosen over quartz for its reduced rate of helium diffusion. At room temperature this is not ordinarily a consideration. However, it becomes a concern when vacuum pressures move well into the  $10^{-12}$  Torr region. Since lasers trap and probe the cloud of atoms that magnetic fields ultimately hold in place, the glass blower must maintain optical quality surfaces throughout construction and subsequent working of the square cell.

## Introduction

After a few attempts with commercially drawn and shrunk-over-a-mandrel square tubing, it became obvious that a new technique must be developed to make optically satisfactory square tubing in order to create a cell capable of trapping and holding rubidium atoms for hundreds of seconds or more. Atoms are introduced into the chamber by slowly heating a crushed ampoule, liberating a small partial pressure of rubidium. An array of laser beams traps the rubidium atoms by virtue of the fact that the atoms absorb energy, in the form of photons, in the direction of the laser beam. However, the atoms emit the radiation back in random directions, thus giving any atom a net energy gain in the opposite direction of the photon source. If a mirror then reflects the initial beam back upon itself through the cloud of atoms, the net effect on the atoms along this axis will be essentially zero, thus trapping the atoms along this axis. There remain then two more axes requiring two more laser beams, and their reflected counterparts, in order to form a cloud of atoms which magnetic fields can then hold in place. Figure 1 shows a schematic of the cell with the laser beams and coils in place. Once the cloud forms, the lasers are ramped down while the magnetic coils are ramped up. The rubidium source is shut down and the background pumped away.

Since the strength of the magnetic field falls off with the cube of the distance, it is imperative that the cell be relatively small. The coil directions oppose each other, thus forming a net force of zero in the center of the cell. This is the trap region, and must be accessible to lasers in six directions, as well as provide a viewing opportunity for a small TV camera across a corner.

In this experiment, the chamber itself is essentially the ultra-high vacuum pump. Titanium is sublimated onto the walls of the chamber providing the same active surface present in a titanium sublimation pump; gas molecules are absorbed onto the surface.

The vacuum is calculated based on the life of the trapped atom cloud. The experimentalists have fondly dubbed this the RHV regime--Ridiculously High Vacuum. This regime is well into  $10^{-12}$  Torr. At these pressures, the number of atoms in the cloud is on the order of  $10^8$  atoms, and is sensitive to any collisions with residual gas molecules. The most abundant species is usually helium. This is due to its small atomic size, the difficulty attendant in pumping it and its well known affinity for diffusion through glass. While diffusion is most notable at elevated temperatures, it does occur at ambient temperature. While quartz would have been much easier to work with and maintain optical surfaces, it has the unhappy characteristic of suffering twice the diffusion rate as that of borosilicate glass at room temperature.

## Cell Description

Figure 2 shows the same schematic of the cell with the field coils removed. The square section measures 25mm square by 60mm long, to which a 25mm diameter window is attached. A section of 35mm tubing is attached which protrudes past the stainless-to-glass seal where it is welded to the flange. A ring seal to the 50mm glass completes the cell. The reason for the 35mm re-entrant section is to prevent the rubidium atoms from condensing on the walls of the stainless steel members before they have a chance to enter the cell. For the price of a small loss of conductance, experimentalists were able to greatly increase the number of atoms in the cloud.

## Construction

The construction of the cell employs typical glass techniques, save for the square section. Therefore, the body of this work deals mainly with the fabrication of the square tube.

First, a carbon fixture was machined as shown in figure 3. The design must account for the desired length, as well as the external dimension for the finished tube, less the thickness of the glass. This allows for the overlap necessary for the seam. Figure 4 shows an end on view of this overlap. A small rough pump, a length of rubber vacuum hose, a swivel and a metal tube to fit the threaded hole in the carbon completed the fixturing. Next, the Tempax plate was rough-cut, waxed to a square brass tool milled to the finish width of the blanks, and lapped to size. In this case, the width was 23.5mm, plus the 1.5mm thickness to end up with a 25mm square.

After many failed attempts at trying various methods in the lathe to keep everything warm at once, this approach was abandoned in favor of placing the fixture in the annealing oven set at  $500^{\circ}\text{C}$ , and proceeding from there with protective clothing and a long necked torch.

While the oven was reaching temperature, the blanks were cleaned and dried and the equipment readied. The blanks were arranged on a clean towel and handled with gloves. The vacuum pump holds the blanks in place after all the fixture holes are covered. They can then be gently slid into position. Figure 5.

As soon as the annealing oven reached  $500^{\circ}\text{C}$ , the fixture was placed into the oven on

a piece of high temperature glass fabric. Figure 6. The glass fabric insured that no dust from the vermiculite traveled into the spaces between the glass and the carbon, since the vacuum pump would continue to run for the duration of the process.

After ten minutes, the blanks and fixture were uniformly warmed enough to make the first seam. Figure 7. It is important that the glass be worked inside the oven, and that the oven be opened as little as possible. The idea is to maintain the temperature of both the glass and the fixture, as well as that of the oven. The fixture was held in one hand by the vacuum hose, and the flame brought directly across the corner. It is critical that the flame be directed at the flat of one corner and melted to the edge of the adjacent blank. An attempt in the other direction results in the edge shrinking away from the face, and no seam can be made.

After the first seam was completed, the fixture was placed back on the fabric and the oven was lowered once again. It was then left for another ten minutes or so, until the oven temperature again approached 500°C. At that point, the next seam was made in the same manner, and so forth until the last seam was completed. A carbon paddle was used to free the completed tube from the fixture. Figure 8. The oven was then closed, the annealing temperature set and the square section was then put through a full anneal.

## Problems

As with most glass blowing projects, there is no dearth of ways in which things can go wrong. A few observations may spare others a few frustrations. First, it is important to keep in mind that the object is to provide a cell with optical quality surfaces. Perturbations and unevenness will distort the laser beams. Toward this end, it is important to minimize the flame splash across the surfaces. Figure 9 shows a condition to avoid. Remember that the glass is almost at the annealing temperature when the work is started, and so is the carbon fixture. Spending too much time working the seam raises the temperature of the carbon to the point where the glass will start to sag into the vacuum holes. This leaves the unfortunate predicament of how to liberate the finished tube from the fixture. If the oven temperature is allowed to drop too far (below 400°C), or if one attempts two seams in succession without re-warming, then one can expect to hear that maddening little "tink!", familiar to all glass blowers. There's no saving one of these. For this reason it is advantageous to cut, lap and clean four or five sets of blanks and makes as many as work out. The successfully finished tube is fragile in any case, and it makes sense to have a back-up or two. Figure 10 shows the difference in optical quality between the fabricated tubing and drawn tubing.

## Completion of the Cell

Once the square tube was annealed, it was held on the inside by means of a quartz tube wrapped with asbestos-substitute tape or glass fabric, as in figure 11. It is important to heat the entire tube slowly and evenly. Twenty minutes to half an hour is not too much time to spend with a bushy annealing flame, held ten inches away at the start, to gently warm the square section before working. Once the familiar sodium yellow appeared, the end was tooled out and attached to a 35mm tube. The quartz fixture was then removed

and a 25mm tube was placed in the chuck. Before the square section was allowed to cool, its other end was tooled and attached to the 25mm tubing, which was subsequently flame cut in preparation for attachment of the 25mm window. The 25mm tubing was then removed from the chuck, and the usual vacuum fixture to hold the window in place was quickly mounted in its place. The window was glassed on and then the whole assembly was again put in to the annealing oven for a full anneal. Next, the stainless-to-glass seal was machined to length and welded into the flange. Finally, the ring seal was made, completing the cell.

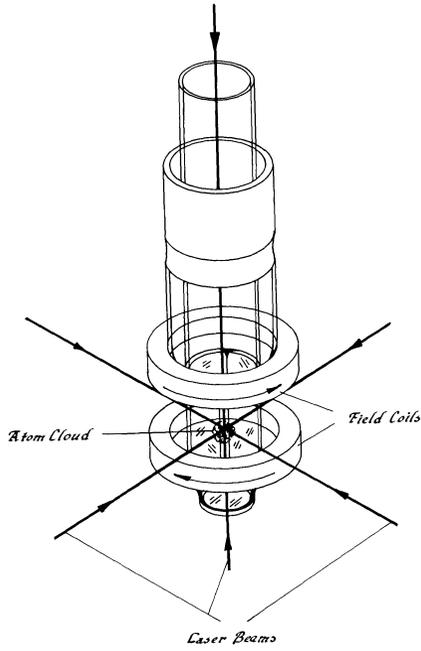
## **Summary**

With the use of a carbon vacuum fixture, it was possible to make a section of square tubing with optical quality surfaces sufficient to create an atom trap capable of trapping and cooling atoms to below a millionth Kelvin. The diffusion rate of the borosilicate glass was sufficiently low, and provided not only for ultra-high vacuum, but also for a trapped atom life of over 1000 seconds, once the rubidium source was turned off. Figure 12 shows the cell on the system in situ.

## **Acknowledgments**

The author is indebted to Doctors Eric Cornell, Mike Anderson and Wolfgang Petrich, for their helping me to understand the nature of their research; the "real" glass blower in the Chemistry Department, Gene Lutter, for his consultation; and my colleague, George Bryce, for his expert photography.

**FIGURE 1.**



**FIGURE 2.**

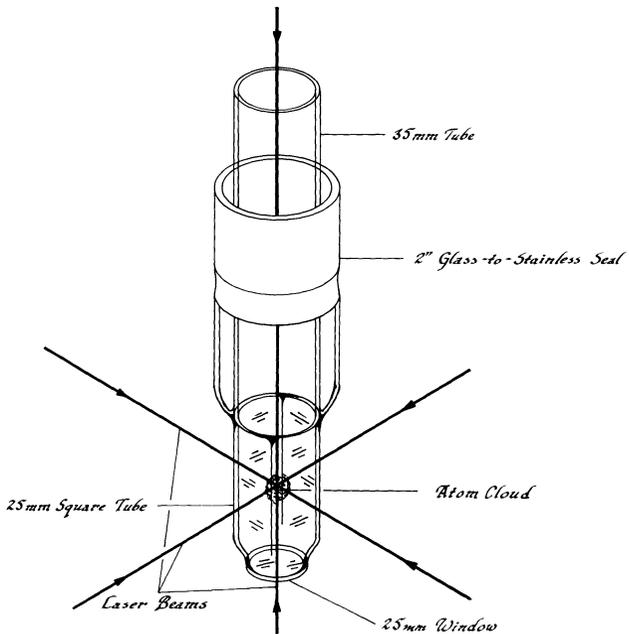


FIGURE 3.

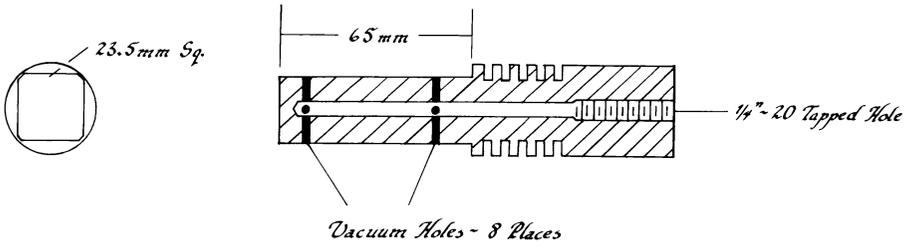
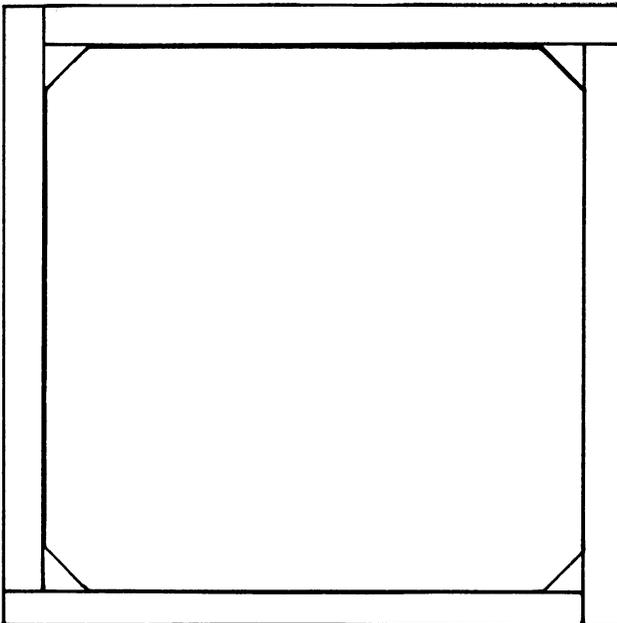


FIGURE 4.



**FIGURE 5.**



**FIGURE 6.**



FIGURE 7.



FIGURE 8.



**FIGURE 9.**



**FIGURE 10.**

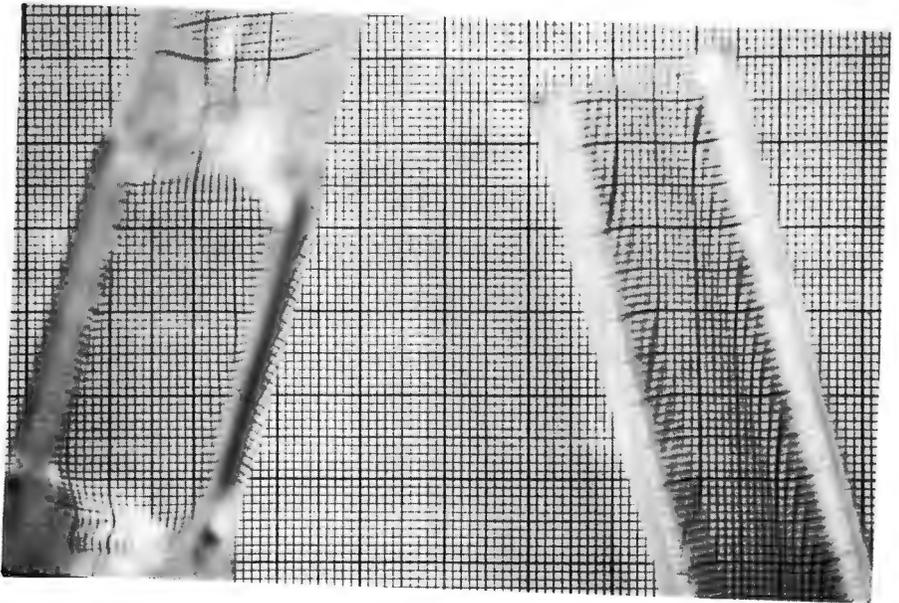


FIGURE 11.

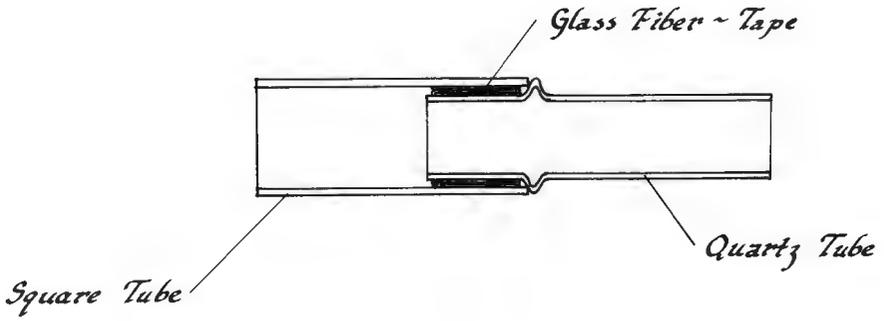
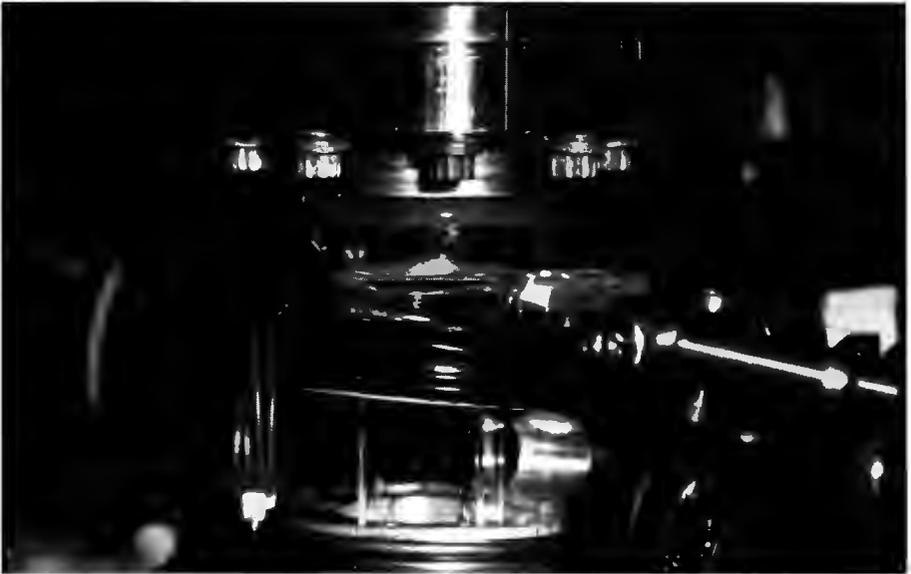


FIGURE 12.



# Drilling Holes in Glass and Ceramics

by Barry Shaw

Glass, because of its brittle and abrasive nature, poses serious machining problems, especially when drilling straight, clean holes through glass components. Chipping, cracking, drill burn-out and excessive wear will occur, unless great care is taken.

A steel or carbide twist drill that may be used routinely on steel, aluminum or wood will not work on glass! The ideal tool is without question the diamond-edged drill which actually abrades away the glass particles instead of drilling the glass itself.

There are two basic drill types: solid and core. It is universally accepted that diamond core drills are superior in performance to solid drills because of the importance of through coolant in drilling. With a core .031 inch (.75mm) or smaller, however, it is impossible to force sufficient coolant through the tiny orifice. Hence, most units under .031 inch are of the solid type.

A diamond drill is essentially a metal shank to which diamonds have been affixed in one of three ways: impregnation, plating, or electro-deposit.

**Type I: The impregnated (or sintered) diamond drill.** The diamond section consists of a prescribed quantity of natural or synthetic diamond, sieved to the desired size, mixed with a holding matrix and bonded to the steel shank. The depth of diamond is usually 1/8, 1/4 or 3/8" relative to diameter.

**Type II: The Plated Diamond drill.** A single layer of diamond particles, generally synthetic because of uniformity of shape, is plated with nickel or another material to the end of a metal shank or tube. The diamonds are more exposed than those of impregnated drills and consequently, cut faster. However, once the single layer of diamond wears off, the drill must be discarded.

It should be remembered when using plated drills, that only the top, or crown, of the drill does the actual cutting. Although diamonds may be visible on the side of the drill when the crown area is worn clear of diamond, the drill will no longer cut. Some machine operators look at the drill and, seeing diamonds on the side, attempt to continue drilling and are usually puzzled when the drill fails to penetrate the glass.

**Type III: The electro-deposited drill.** Here, the diamond section is built up in layers on a ceramic core by means of an electrolytic process. The core is then discarded, leaving a hollow drill with the advantages of a sintered drill plus, because of its thinner wall, an increase in the penetration rate of the drill, and increased drill life due, to the multiple layers of the diamond section. This, however, is disadvantaged by the weakness of the unit itself.

## The Diamond

In a paper presented some years ago we stated that synthetic diamonds were slowly taking the place of natural diamonds in drill applications. Today, virtually all drills are

made with synthetic diamonds. There are special types that have been engineered for this purpose.

For plated drills, many manufacturers use GE Synthetic Diamonds of the MBG (T) type in 120/140 grit or DeBeers ECD type synthetics. For impregnated type drills, DeBeers SDA or GE MBS are used.

Combinations of some or all of the above types are not uncommon and are often used to produce drills for special materials.

We believe that, beyond better availability and lower cost, the main reason for the switch to synthetic diamonds is uniformity in grit, shape, and size. This is important not only in obtaining close tolerances in size, but also in avoiding the problem of the "High Diamond", a problem we will cover later. It is possible to produce a fairly thin wall drill with synthetics, an important factor when high penetration rates are required.

## **Diamond Grit**

Diamond grit is available in sizes ranging from a coarse 60/80 to a fine 270/20 mesh. Choice of mesh is largely determined by the size of the drill and the material being drilled. It is highly important that the correct grit size be used. A coarse 60 mesh diamond drill will not give the same performance as a 150 mesh unit. Generally speaking, coarser grit sizes are used for faster stock removal (i.e., higher productivity) without much concern for surface finish.

## **Diamond Concentration**

Although the term "diamond concentration" may be familiar to many users of diamond tools, its meaning and significance are not widely understood. Concentration refers to the quantity of diamond in the drill matrix. Consider, two drills with 120 mesh-size diamond grit. One has a 100 concentration, the other a 50. The 100 concentration drill contains twice as many diamond particles as the 50 unit. It is understandably more expensive. High concentration does not, however, automatically lead to better performance. Correct concentration depends upon the material being drilled, feed rates, and other variables.

## **Drilling Equipment**

When the goal is to drill chip-free holes consistently, every component in the drilling process is important. The basic equipment required is a sturdy, vibration-free and well-made drill press, capable of developing the proper speeds and, at the same time, allowing sensitive feeds. The drill press must be mounted on a firm base and its spindle must be periodically checked for run-out. The workpiece should be securely held when positioned. Moreover, the spindle bearings must be in good condition and the feed sensitive enough for the operator to 'feel' the cut.

Not too long ago there were a few machines capable of quality drilling small holes (under 1/8 inch or 3.18mm). Then we developed our SL-1 drill press which was capable of

drilling holes down to, .031 inch with coolant passing through the drill center.

This machine was manually controlled, but then we developed the Lunzer CL-1A, an automatic drill press which, following set up, drills a hole at the touch of a button, and then automatically retracts at completion of the operation. In the past we had always recommended drilling by the "pecking" method, where the operator constantly lowers and raises the drill to ensure a steady supply of coolant at the cutting point.

Now, with the CL-1A automatic drill press, we can drill straight through the workpiece. The operation is faster and the drill lasts longer. This mainly applies to core drills; because it is still necessary to use the pecking method with solid drills.

## **Ultrasonic Drilling**

When small, deep holes are required, say, in the range of 1mm to 2.6mm diameter and as deep as 12", we recommend an ultrasonic rotary drill of the type manufactured by Sonic Mill Co. This machine is also very efficient for trepanning or grinding.

## **Pecking Method**

Many operators favor a pecking action when drilling holes in glass. There are pros and cons to this method. When using a solid diamond drill, it is essential that a good supply of coolant can at least be directed at the drill head. The up and down motion of the drill, in and out of the hole, helps to pump out the abraded waste material from the hole. This is highly desirable. Moreover, since the drill is flooded by coolant, it remains relatively cool and, hence, lasts longer. The pecking method does, of course, slow down drilling time.

When using a conventional core drill, constant pressure of the drill along with the correct speed of rotation, produces favorable results.

In the past we had also recommended a pecking action for core drilling, but we have learned that when good coolant pressure (60/80 psi) is maintained through the center of the drill, the drill will remain cool, debris will be forced out of the hole and core hang-up will be minimized. One of the main reasons for not using pecking method with core drills is that the pecking action itself often breaks the core from the workpiece. This can lead to clogged or broken drills, or to damaged workpieces.

## **Core Hang-Up**

This is an important subject. Core hang-up generally takes place just at the point of break-through. As the core breaks away from the workpiece, especially when the workpiece is not properly supported, there is usually a rim of unground or unabraded glass at the very bottom of the core. Being unground, it is wider than the core drills I.D. This unground rim causes the core to stay firmly within the drill.

By waxing down the workpiece with a minimum of wax adhesive and by properly supporting the workpiece under the drilling point, it is possible to drill completely through the workpiece, have the core remain in position and also obtain clean holes.

Remember, good coolant pressure, a suitable coolant type, and a minimum of pressure, at break-through will help to prevent core hang-up problems. Whenever possible, a dial gauge should be used so that the operator knows exactly the point of break-through, and can reduce the downward pressure of the quill and ease the drill through its last few thousandths of an inch of travel.

Finally, a "disintegrating" core drill with the drills I.D. offset to one side (of the drill) also helps to prevent core hang-up. With this type of design, the actual core material is smaller than the drills internal diameter, and can easily be washed away by coolant pressure.

Be sure to tell your supplier the material you will be drilling. He can then deliver the correct diamond size and matrix. Also ask for the drill to be made to your largest tolerance - i.e., if ordering, say, a 1 inch drill with a given tolerance of +/- .005 inch, request that the drill be made 1 inch +.005 inch and -.000 inch. This will give you longer drill life, as drill wear is spread over the /.010 inch tolerance.

## **Coolant**

Coolant is as important as the drill bit itself. We do not recommend drilling dry with diamond drills.

Coolant serves two purposes: first to keep drill and glass cool; and second, to flush away abraded glass particles that could otherwise impede the operation of the drill. With the use of an additive, coolant viscosity and lubricity is increased, thus aiding in carrying away the abraded material.

The ideal procedure is to supply coolant under controlled pressure through the center of the drill. Next best is to drill with the workpiece submerged in coolant. With solid drills, a copious flow of pressurized coolant to the outside is good. The practice of "squirting" coolant onto the workpiece and drill point is utterly useless.

In our experience, oil-based coolants keep the drills cleaner than water. We use and recommend Lunzer Coolant Concentrate, distributed by Lunzer, Inc.

The smaller the drill, the greater the coolant pressure should be. Water direct from the mains gives 40/60 psi, which is not adequate for small drilling, such as 1mm. It is also difficult to introduce additives when taking water from a faucet, so, when possible, a pressure tank should be used to enable additives to be introduced and to control the coolant pressure flow.

As a rule of thumb, we recommended an approximate pressure of 80psi for a 1mm core drill. For a 1 inch drill, 20-30 psi is adequate.

## **Drill Speeds**

Experience has taught us through the years there is no set speed for drilling. Drill speed depends on the glass, the operator, the pressure and other variables. Today, we recommend a variable speed control for the drill press.

The operator will soon determine the best speed for the specific job he or she is doing.

## **Chipping and Break-Out**

Care, experience and good equipment are required to minimize chipping. The most successful method of avoiding chipping is to flip-drill. This, however, is not always feasible. It also presents additional problems, such as realignment of the workpiece. In some instances, drilling with an undersized drill followed by reaming with a reamer of finer grit size not only enables you to hold tight tolerances but also removes any small amount of chipping. This method is costly and is not always practical.

Dual size drills have also been successful. Here, the drill portion of the head is below required finish size, while the section immediately behind or above the head tapers out to the correct finish size. This results in a hole reamed to finish size while at the same time removing any chipping. With this type of drill a 'catchment' is required beneath the workpiece to trap and return the coolant to the outside of the drill during the reaming action. If a catchment is not provided, the coolant will escape and the reamer section of the drill will run dry with disastrous results to both workpiece and drill.

## **Holding Hole Size Tolerances**

Most manufacturers produce drills to a plus or minus .002 inch tolerances. Tighter tolerances can be obtained on request. It is nonetheless often found that while the drill measures "on size", the resultant holes over size. This is brought about either by bad drill alignment, machine run-out or a badly ground drill or simply 'High Diamond'. First, check the machine spindle head to be sure there is no run-out. Check that the drive belt is not too tight or too slack since either condition affects spindle motion. Also be certain there is no foreign matter on the drill seat, when fitting the drill to the spindle as this could cause misalignment of the drill.

Check the drill for head concentricity. If the head is not absolutely concentric with the tail or mounting portion of the drill, it will produce oversize holes. The fact that the head size "mikes" correctly means little.

A single high diamond will also produce oversize holes, but may not be detected when the drill is "miked". So it is prudent to check the drill head with a loupe. If a high diamond is found, switch on the drill press and very lightly touch the drill head with a fine diamond file, to chip off the high diamond without damage to the drill surface. You have, no doubt, often heard it said, "Just drill into a scrap piece of glass and your drill will align itself."

This is correct to some extent. The drill appears to be running true. To be certain, place a dial indicator against the head of the drill and rotate the spindle by hand to be sure there is no run-out. Be sure the dial indicator is fitted with a nylon-protected finger.

Finally, if you must drill straight through with no backing, drill carefully! Watch your dial gauge, and when you come near the depth break through point, ease up the pressure and increase your drilling speed.

There is no substitute for experience. An operator's first holes can be ragged and drill life short. As he or she proceeds and gains an understanding of speeds and pressure, the quality of the holes improve and drill life is lengthened.

# **A Glass Bellows Mercury Manometer**

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## **Abstract**

The fabrication, filling, and operation of a glass bellows mercury manometer are described. The instrument uses fundamental vacuum measurement without contaminating the system with mercury. Special considerations for bellows construction, introduction of mercury, and calibration are discussed.

## **INTRODUCTION**

The use of mercury in the laboratory has declined in recent years due to a heightened awareness of the health hazards associated with it. In some laboratories it is still used in simple U-tube manometers because this type of gauge is irreplaceable in its relatively low cost and high degree of reliability in the 0 to 760 millimeters of mercury range. This gauge uses the fundamental principal of displacement of a column of mercury; there are no black-box erroneous measurements as are inherent to so many electronic gauges. The prime disadvantage of this manometer, however, is that a surface of mercury is exposed to the system to which it is attached.

An exposed mercuric surface is undesirable because mercury reacts chemically with some gases, especially halogens, and it allows for the possibility of mercury contamination of the system in vapour and liquid form. A drop or two of high vapour pressure oil such as silicone oil placed on top of the column of mercury replaces the mercury interface with an oil one. This remedy is limited though, as an oil interface also has undesirable characteristics.

Ideally a gauge would provide the benefits of a simple mercury manometer while allowing the system to contact inert surfaces only. A modified U-tube mercury manometer with a flexible glass interface would perform as such a gauge provided the glass could be made flexible enough.

## **GLASS BELLOWS**

Glass flexibility is achieved by the use of glass bellows. The bellows in this case are a closed-end series of very thin hollow glass discs centrally attached to each other. A pressure differential between the interior and the exterior causes the thin glass in the flat part of the discs to flex, changing the internal volume of the bellows. The relationship between external pressure and internal volume of these bellows is the basis for a glass bellows mercury manometer.

In the manometer shown in figure 1, bellows are encased in a glass tube. At the base of this tube the bellows are connected to a capillary U-tube. The U-tube and the bellows are completely filled with mercury using a special filling procedure. The exterior of the bellows is exposed to the annular space of the encasing tube which is in turn connected to a vacuum system. A change in pressure in the system from  $P$  to  $P'$  causes the bellows to flex and change in internal volume from  $V$  to  $V'$ . This change in volume causes a displacement in the column of mercury in the side arm of the U-tube from  $h$  to  $h'$ . The correlation of the system pressure change  $P$  and the column displacement  $h$  provides a transfer of information of the quality of the vacuum in the system across a glass interface.

## **CALIBRATION**

A conventional U-tube mercury manometer with one arm fully evacuated, and the other arm at atmospheric pressure, will displace a column of mercury 760 millimeters or so, depending on the day's barometric conditions.

Operated in the same way a glass bellows mercury manometer displaces only a fraction of this amount as it is limited by the flexibility of the bellows. The more flexible the bellows, the closer the displacement will be to 760 millimeters. Ideally, the displacement would be linear for all pressures between full vacuum and atmosphere. In order to establish this linearity the instrument must be calibrated. The results of this calibration, whether in the form of a graph, a mathematical formula, or a direct reading scale, are unique to the instrument and should be kept with it.

## **FILLING PROCEDURE**

The filling of the instrument with mercury requires the simultaneous evacuation of three zones; the interior of the bellows and a U-tube, the exterior of the bellows bounded by the annular space of the encasing tube, and the reservoir of mercury. The reason for this is as follows. One cannot successfully evacuate the interior or the exterior of empty bellows independently from the other. The thin glass of the bellows would simply flex so much it would break. The filling procedure requires the evacuation of the empty bellows adjacent to a mercury reservoir (which also must be evacuated), and therefore also requires the evacuation of the exterior of the empty bellows.

Once these zones are evacuated, the whole assembly is sealed off under vacuum and manipulated in such a way as to tip mercury from the reservoir into the U-tube/bellows portion. Atmospheric pressure is then allowed in behind the mercury. This is done slowly to ensure that there are no sudden pressure differentials. Once the manometer is filled, the mercury acts to cushion the bellows; sudden pressure changes are dampened by the mercury.

## **CONSTRUCTION**

A piece of 7 millimeter outside diameter standard wall Pyrex tubing, free from seeds, stones, striations, and airlines, and as uniform as possible in wall thickness, was selected and chucked in a lathe. Using constrictions of 4 millimeter outside diameter, six 14

millimeter sections were made. (see figure 2)

Heating with a bushy flame, a section was stretched out while being blown up, making a very thin-walled football shape. Reheating with slight tailstock pressure produced a sphere shape. Continuing down the length of the tube, six 28 millimeter outside diameter thin-walled spheres were made. (see figure 3)

Discs were made by reheating and pushing up the spheres. The flame was then passed between each disc and its neighbour, reducing the constriction diameter, bringing the discs closer together (but not touching each other) and slightly reducing the internal disc volume. (see figure 4)

The series of discs were then closed off at one end in such a way as to leave a slight tip. This tip was later used in centering the bellows. The other end was cut to approximately 40 millimeters.

The performance of the bellows was tested by applying slight positive and negative pressures through a blow hose while watching for expansion and contraction. Further testing was done by dropping the bellows on the tip from a height of approximately two feet onto a hard surface and watching them bounce. This ensured the bellows were flexible and free from flaws. Testing procedures involving mechanical pumps, tesla coils and moisture were avoided. It was felt that the empty bellows would crush under full vacuum and that a tesla coil might punch a hole in the thin glass. Water or other solvents inside the bellows were thought to be too difficult to remove as they tend to freeze under vacuum which may crack the fragile discs.

The approximate volume of bellows was measured by submerging the closed end into a beaker of water. It was found to be about 20 millilitres. (see figure 5)

The bellows were then sealed into an encasing tube of 41 millimeter outside diameter (using the tip as a centering device) and attached to a 760 millimeter capillary U-tube as in Figure 1.

A reservoir such as the one shown in figure 6 was used to contain the mercury. It had three necks; one for attachment to the instrument and vacuum line, a ground glass joint for the addition of mercury, and a narrow tip for the slow re-introduction of air to the system after filling was complete. It was attached to the instrument and vacuum line as shown in Figure 7, allowing for the glassblowing to be complete before any mercury was added. (see figures 6 and 7)

In excess of 25 milliliters of mercury were added to the reservoir before it was capped off. A cold trapped mechanical pump was left to evacuate over a period of twenty hours at which point the arrangement was sealed off.

Enough mercury was then tipped over into the manometer to fill the bellows and U-tube. The narrow tip on the reservoir was snapped off allowing air to enter behind the mercury very slowly. The reservoir was cut from the instrument as were the upper parts of the side arms.

After attaching the manometer to a vacuum system, it was calibrated against a conventional U-tube manometer.

## RESULTS

The calibration curve shown in figure 8 shows the linear relationship of the glass bellows manometer's displacement to the conventional U-tube manometer. The slope of the straight line is 1.2 and can be used in the formula

$$P = 1.2h$$

where P is the pressure in millimeters of mercury and h is the height in millimeters of the mercury in the side arm of the glass bellows mercury manometer.

## DISCUSSION

The glass bellows mercury manometer provides the reliability of a U-tube mercury manometer while eliminating the possibility of system contamination. The instrument does use mercury, but the system it is attached to remains mercury free. This is particularly beneficial to a glassblower doing a repair or modification to the system. Even the smallest bead of mercury, when heated, is dangerous, especially when the system is vented directly to a blowhose.

The ability of the instrument to have an inert interface hinges on the flexibility of the glass bellows. The procedure for making the bellows described in this paper yields very flexible ones as evidenced by the linearity of the calibration curve and its modest slope. Less flexible bellows would have shown a steeper slope. The linearity and reproducibility of the instrument should perhaps be re-checked in a few months.

The filling procedure involved the connection of the interior of the bellows, the exterior of the bellows, and the mercury reservoir to a common pumping port. Perhaps some investigation should be done to determine if the "system" part of the instrument (the annular space of the encasing tube) is contaminated during this procedure. If so, this part should be evacuated by attachment to a separate, cold-trapped part of the evacuating line.

At the open end of the manometer, mercury is exposed to the laboratory environment. Although the cross-sectional area of the interface is small, mercury is toxic and exposure constitutes a health hazard. Additionally, this interface provides a site for the formation of mercuric oxide. This oxide, or "dirty mercury", is undesirable because it tends to stick to the glass walls of the manometer. Perhaps an intermediate interface of silicone oil would solve this problem.

The accuracy of this instrument could be enhanced by the use of a cathetometer or travelling microscope. A cathetometer is used for accurate measurements of vertical displacements to the nearest 0.05 millimeter<sup>1</sup>. Employing such a device would increase

the range and accuracy of the glass bellows mercury manometer although for many purposes measurements to the nearest 0.1 millimeter are sufficient.

It is not the author's intention to be credited with the design or invention of this instrument. The glass bellows mercury manometer has enjoyed popularity in laboratories at the National Research Council of Canada for decades. For a number of reasons, many of these instruments are being replaced with other types of gauges. Still they are demonstrative, novel instruments and there seems to be a void of information concerning the fabrication, filling, and operation of these gauges.

Properly used, the instrument's health hazards can be reduced to a minimum. While a revival of its popularity is not expected, the principles on which the glass bellows mercury manometer are based are interesting and worthy of documentation.

## **ACKNOWLEDGMENTS**

I am very grateful to my father, James Vandenhoff, whose technical ability and knowledge of the fabrication of the glass bellows mercury manometer are unsurpassed by anyone I know. I would also like to thank, Lyne Séguin and Jerry Sebesta, in the design office for their computer aided drafting and photographic efforts, and Colleen Cameron for her efforts in the preparation of this paper

## **LITERATURE CITED**

Shoemaker, Garland, Steinfeld and Nibler, "Experiments in Physical Chemistry" 4th ed., 1981.

<sup>1</sup> Shoemaker et al, "Experiments in Physical Chemistry" 4th ed., 1981, pp 648-649.

**FIGURE 1: Glass bellows mercury manometer**

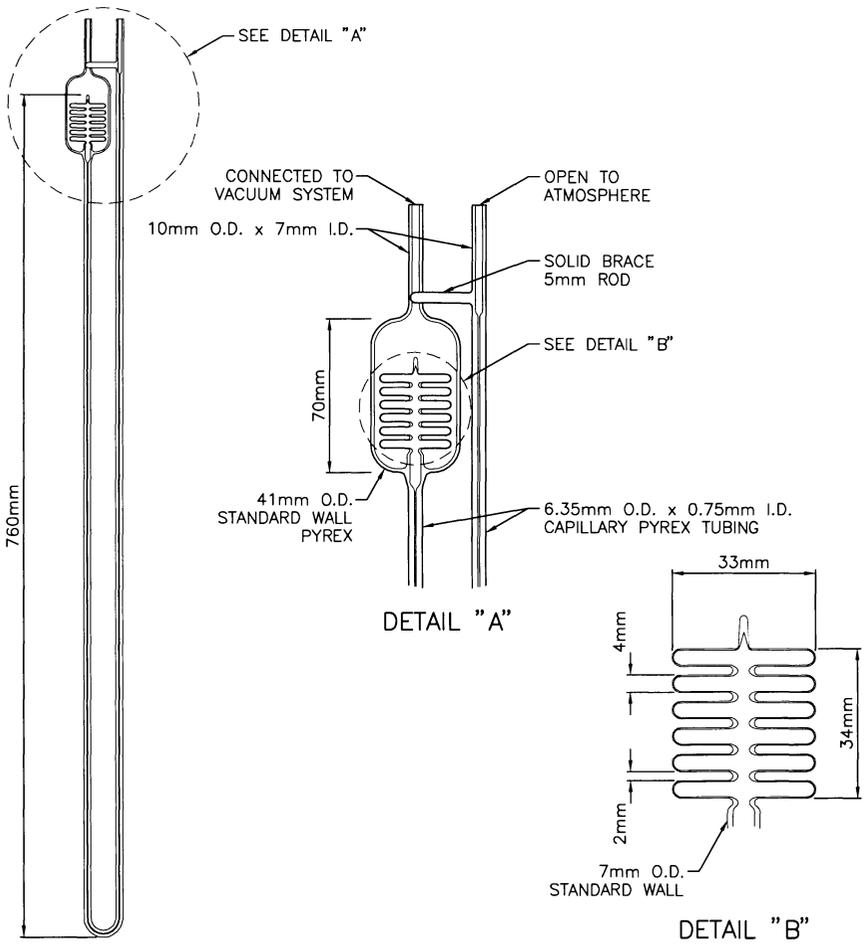


FIGURE 2: Six sections bound by constrictions



FIGURE 3: Thin-walled spheres



**FIGURE 4: Discs made from spheres are pushed close together**



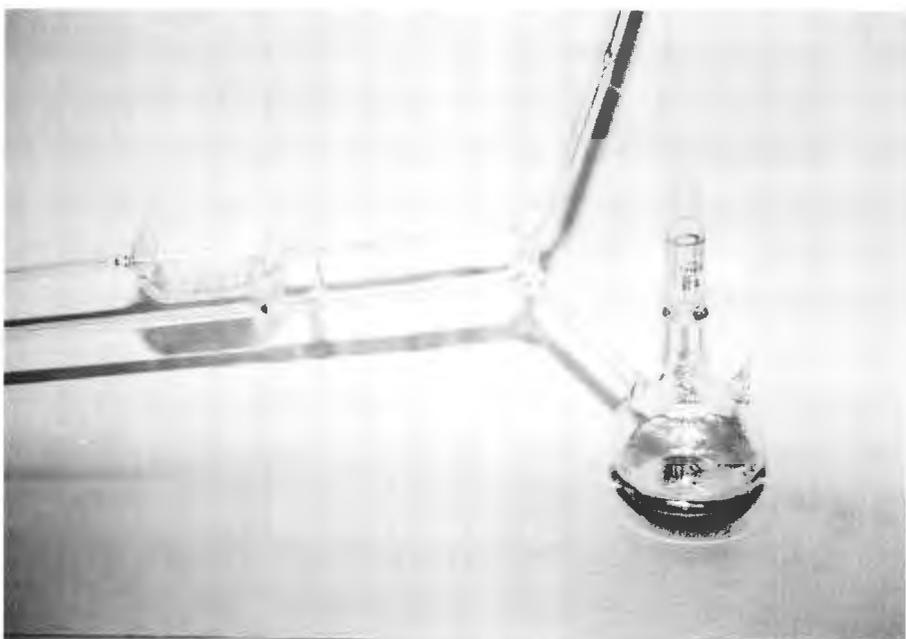
**FIGURE 5: Measuring approximate volume**



**FIGURE 6: Mercury reservoir**

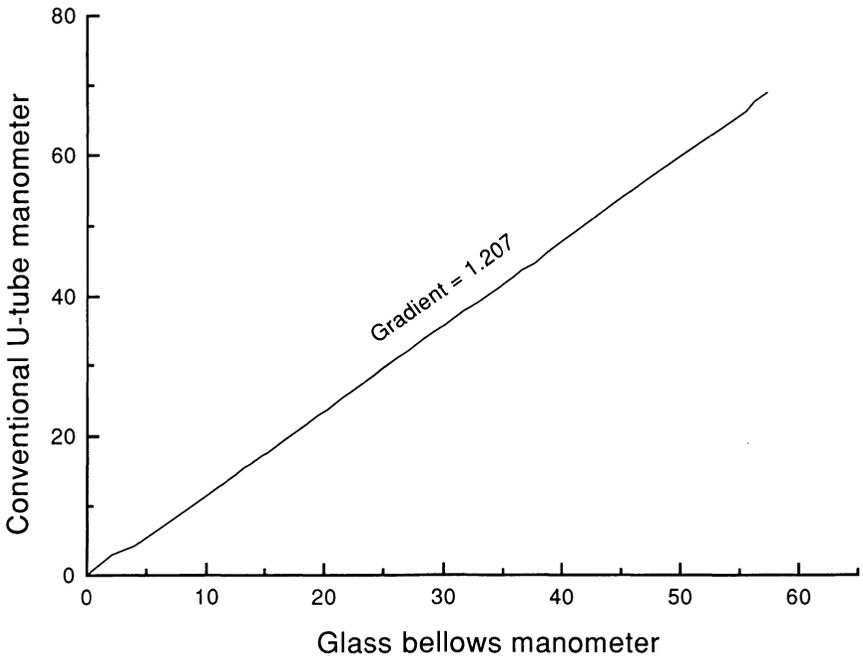


**FIGURE 7: Pumping arrangement**



**FIGURE 8: Calibration curve**

**Calibration curve**



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