CERAMIC-SYNTHETIC MATERIAL

Dr. William W. Shaver

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Reviewed by Col E. J. Ingmire, USA on 30 December 1963.

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MR. MUNCY: Good morning, Gentlemen: The scientific search is on for new materials to withstand the extreme temperatures of aerospace and the extreme pressure of hydrospace.

Our speaker this morning has spent all his professional life in this search. During the past two years he has visited the principal research laboratories in the Far East and also in Europe. In fact he has just returned from a trip to Europe.

It is my privilege this morning to introduce Dr. William W. Shaver, Director of International Research for the Corning Glass Works, Corning, New York, who will speak on the subject, "Ceramic-Synthetic Material."

Dr. Shaver, we welcome you to this podium.

DR. SHAVER: Thank you very much, Mr. Muncy. I assure you it is a pleasure to be here and to spend a little time talking about the thing that we found very interesting, at least, so interesting that you pursue it no matter where it leads.

I think with that as a policy it describes our company's philosophy, because our general thinking is that we ought to be able to answer problems in industry and in general, shall I say? either defense or civilian living as far as they can be answered by inorganic, nonmetallic materials.

The name, Corning Glass Works, does not describe adequately the general philosophy and interest of the company.

Perhaps I might take just a minute or two to give you a little sketch of the entire industry. The glass industry in this country amounts to a total of about #2 billion per year, at the present time. One-half of that is in containers--bottles, jars, and so on--and last year I believe there were 25 billion of these made. That leaves $1 billion for other fields. The other fields are, generally, flat glass, fiber glass, and general technical glassware.

Flat glass is somewhere around $370 million per year. The fiber glass is somewhere in the same area of volume, and the technical glassware is around probably $300 million a year, making the other billion.

Corning is in this field of technical glassware. As I say, even that does not describe the philosophy of the company as far as limits are concerned, because we feel that anything in the field of generally inorganic nonmetallics is part of our interest.

In this course of pursuit, the company has been going in the direction of more and more research for many years.. The laboratory began in 1908. It is one of the oldest industrial laboratories in the country. At the present time we are spending 5 percent of our income on research and development.

So much for the general background. I should like now to speak particularly about some of the new developments in this particular field of glass ceramics. Some years ago we had a development work going on in the field of photo-sensitive glasses. These are glasses are sensitive to ultra violet light. If I may have the screen raised for a little while, I have some things behind the screen that I would like to show you.

In this field glasses can be made that will/sensitive to ultra violet light so that on exposure to sunlight or the carbon arc you will be able to develop a picture or an image of some kind on heating after such exposure. This is what I want to show you.

This picture, which you probably cannot see very well, is in a glass that has been exposed and developed by heat. The picture is in the body of the glass. The glass itself is photo-sensitive. By the way, this work was done by Dr. Stookey, who has been in this field for about 20 years.

This second type is one that develops a white opal after exposure and heat treatment. This is also a photo-sensitive glass. The white areas that you see are crystalline, lithium, metasilicate. Now, you can take various kinds of pictures, and you also can do another interesting experiment, in that, if you expose and then heat treat--and in this case it was a 10-cent store paper doily as a negative--you can then acid etch and remove the areas that have been exposed and develop into the lithium silicate, leaving the unexposed area. That means you can make a pattern, and this is a glass doily--no market, unfortunately.

So that it is only a stepping stone to this kind of thing. And of course margatrol is important. This one is made the same way as you saw that paper doily, but it is made as a circuit board, and this is the use for this particular field of materials.

Now, having gotten to this point, Dr. Stookey, by accident, actually, when an experiment went wrong, found that if he exposed and heated a lot hotter than he ever thought was possible, the whole thing became crystalline. So, while in the glass field you stay away from crystalline--that's devitification, and the crystals are large and usually unmanageable, and reduce your strength so that you are in trouble--in his case he found that by his light system, when he nucleated by a combination of cerium oxide and silver or gold or palladium, he could control the size of the crystals, and he had materials that were interesting.

Having reached this point, as I say, by accident, when he heated it too hot, he found that he had a ceramic material. By the way, right at this point I'd like to just define the difference between what we call glasses and ceramics, although ceramics very often are used to cover both the glass field and the crystel field.

Glasses are amorphous, without ordered structure. Ceramics generally are crystalline. He found that he had a mass of crystals with controlled size. Since he reached that point with photo-sensitive materials, he said, "Why should I depend on light for nucleation, and then heat treatment with subsequent crystal growth." So he devised compositions which would spontaneously, on heating, become crystals. That is the field of glass ceramics.

Now, I should say that you can make glasses out of practically everything in the atomic table except rare gases. They escape. In fact, most glasses contain some water, so hydrogen is present. So you have, by choosing 2, 3, or 4, or more components from the 90-odd or 100 elements that are possible for use, an infinite possibility as far as the numbers of possible glass combinations are concerned.

But now we have just doubled infinity, because you have, by getting into this field of glass ceramics, where you melt as glasses are melted, fused completely into homogeneous materials, and worked as glasses are worked, into products, and then by a subsequent heat treatment you convert to crystal materials, doubled your possibilities as far as the atomic table is concerned.

This is a glass dish which was made as a glass. If this were heated, let's say, well above 1,000 degrees Centigrade, it would become opal and crystal in structure. The interesting thing is that the properties of the finished material after heat treatment are quite different from the glass properties. Actually, in looking for materials or working with the atomic table to see what you can do with it you are always looking for new and different combinations of properties, because by such new combinations you may be able to solve problems that haven't been solved before, or create new ones. You also may be able to lower costs. In other words, you may have materials that will prove useful in this great economy that we have in which we are living.

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So/this new field of glass ceramics, which we have trade-named Pyra-Ceram, as I say, we have doubled the infinite possibilities of compositions

in thie inorganic, nonmetallic field.

Now, I would like to show you some slides which I use to illustrate the development of one of these materials into the glass ceramic state. The first slide will show you the rough composition of the material we are dealing with--silica, magnesia, alumina, titania. By the way, in the glass ceramics, in the photo-sensitive glass, at least, the key to the whole situation was a means of nucleating so that you had billions of nuclei per CC and therefore you could control the size of crystals that you grew by subsequent heat treatment after the light exposure.

So in these Pyra-Ceram materials we need a nucleating agent, and one such nucleating agent is titania. If you look at it this way, I think this is one way to look at it, at least, which makes some sense as far as the process is concerned.

Taking this set of materials with these proportions roughly and melting these at temperatures of the order of, say, 1500 degree Centigrade or above, or 1600 degree Centigrade, you can get, you might say, a homogeneous solution of those oxides, and if you extrude or feed this material through some type of feeder which can chop and give you gobs which you can use for pressing dishes, such as what I showed you, you can quickly cool the material and have a glass. Then by your subsequent heat treatment you develop an opaque at times-- it can also be transparent, by the way-- ceramic or crystalline material which has entirely different properties from the glass.

The next slide shows you the micra structure and properties influenced by the manufacturing process. In other words, we set out with that set of constituents, and in micra structure the porosity, the crystal size, the crystal concentration, the crystal composition, the crystal structure, the crystal orientation, and the uniformity can be controlled from this homogeneous material. In properties the strength, the optical properties, the electrical properties, the thermal properties, and the chemical properties can all be affected by the manufacturing process, that is, by the subsequent heat treatment.

This set of slides illustrates the difference that you have between the conventional ceramics, where you may take alumina clay of some kind and add certain other additions, and form it in its original oxide state, mixing it, and then find some temperature where it centers. The usual ceramic process is quite different from this one where you homogenize and then convert by subsequent heat treatment after forming.

As I say, this set of slides illuatrates the differences that are present between these two particular methods of making ceramic products.

The crystal compounds in the glass ceramic, or Pyra-Ceram, heat to a thousand degrees Centigrade. In this particular case, the ones we have found and identified are cordurite, spinel, magnesium metasilicate, quartz, rutile, magnesium-aluminum titanate. Now, there are probably others that we have not recognized and others that we don't know. In other words, with this method, you see, of making a crystalline body, you can put together combinations that never have occurred in nature, and so you end up with crystal types that are thus far unrecognizable.

You also affect properties by the heat treatment, and in this case these various samples were all nucleated, in other words, heated, at 740 degrees Centigrade, which is somewhere near the mean temperature, to give you the first-phase separation. In other words, this titania, magnesia, silicate, and so on, which is entirely homogeneous, at, say, 1600 Centigrade, when it is heated at 740 degrees Centigrade, there is a separation, almost like oil and water would separate, so you have a phase coming out, and that is the nucleation, a nucleated phase, which gives you the centers on which you grow your crystals. By heat treatment at 1,000 degrees after nucleation, for various times up to 220 hours, you can get these various densities. So you see you have eight different kinds of material depending on the way you finish it.

This slide shows you the range of crystal sizes that you find in that set of samples heated for various times up to about--well, it's 10 to the 2.8--roughly, a thousand hours. This crystal size you see lies between a tenth and really a hundredth of a micron, when you begin, and the maximum size you get is around 4/10 of a micron, or half a micron, say, when you get up near the thousand hours of treatment. So you see you are dealing with very fine crystals, very tiny crystals, and by the heat treatment, as you see, you have control, if you take into account the combination of the nucleation and your time of heat treatment, and also temperature. This applies for only one temperature, you see, 1,000 degrees Centigrade.

Now, this is a rather striking example of differences in properties that you have in the same chemical composition but different heat treatments, BDQ 115, a thermal expansion coefficient of 115, zero to about 200 degrees Centigrade. The 9606--I think it will go hotter than that--material is the one that is used in radomes, and that has an average expansion coefficient of 54. I have seen steel 120 treated at the same scale. You see you have widely different materials depending on the heat treatment.

This slide shows you the difference in thermal conductivity. I didn't stop long enough to point out the difference in density, but that BDQ 115 has a density of nearly 3, whereas the material that is heated for longer times goes to a density of about 2.6. This shows the difference in thermal conductivity.

Now, here is the comparison of the bending strength on the glass ceramic, Pyra-Ceram materials, of the kind that we have been talking about, as compared with the same type of material made by the conventional method of centering oxides. Centered cordurite, for example, has a bending strength of 5 to 15,000 pounds per square inch. The glass ceramic has a bending strength of 25,000. That is the material we talked about on the previous slides. The betaspogemine, 5 to 10,000, made by the conventional method, 20,000 with glass ceramics, is one that was not shown on the previous slides. The betiacriptite is 2,000 pounds per square inch as against 16,000 pounds when made by the glass ceramic conventional method of using a nucleated agent and subsequent heat treatment.

Now, what are we doing with these things? The glass ceramic field is being worked on by--I was going to say--every laboratory interested in this field of nonorganic, nonmetallic materials around the world. There was a symposium on glass ceramics a year or two ago and a number of countries sent their people with papers in this field. Obviously it is a new field and it has other possibilities, of course, that have not been discovered as yet because of the possibility of getting new combinations of properties.

For example, the dish that I showed you in the glassy state has a thermal expansion coefficient of 45 x 10 to the minus 73 degree Centigrade. Now, that is what we would call a heat-resisting glass. You could bake in that dish. It would do fairly well. It might give you some trouble because it is on the borderline of the resistance to heat shock. Heat shock, by the way, is really mechanical breakage that is brought about by differences in temperature in a product.

So there are two factors that affect heat shock very materially. One is the mechanical strength--in other words, how far can the material be bent or stressed before it will break. The second is what is the thermal conductivity and the expansion coefficient. The expansion coefficient is the one property that you can vary over a wide range. It may be an expansion coefficient of fused silica, about 5½ times 10 to the minus 73 degree Centigrade, up to the one that will seal two coppers, say around 175. When you get beyond that and you've got glasses that are not of very durable type.

That dish, when heat treated has a thermal expansion coefficient of about 10, fused silica about 5½. Now fused silica is a material that we would use for many things if we could make it inexpensively and in quality. Fused silica can be made by taking good sea sand and melting it, but you have a mass that you really can't do much with, because it is so viscous at elevated temperatures where you can melt that the bubbles stay in. You make your best quality fused silica by choosing very find quartz crystals the size of your thumb or bigger and then heating under vacuum, finally heating under pressure. And you have a pretty good product, but expensive.

So that you would like to have the properties of fused silica but you can't afford the cost. Now, these materials, particularly the 9608, the one I am speaking about, the dish I have here, can be made, you see, by conventional means and then, by heat treatment, you end up with an expansion coefficient of 10, which means you can take that dish from red heat to ice water and it won't break. That is the dish that you see in the stores, under the name, Corningware. Oddly enough, its properties are such that it has been sought after, I should say, by housewives in considerable quantity.

If you move around a bit and talk to people in the laboratories, there are two things that they speak of. One is the Corningware, glass, because of its particular ability to resist heat shock. There is a way, you see, of arriving at a material that is practical for a variety of applications where heat-shock resistance is important.

Another one of these is in the field of glass ceramics, again, in the field of the heat exchanger.

This last slide gives you a summary of the values that we had on the previous slides. Young's modulus, you see, also changes by heat treatment as low as from 14.2 to 19.6 times 10 to the 6 PSI. In making tests we abuse the surface. Glasses are fundamentally very strong materials, with the strength to the order of a million pounds per square inch on fibers and above that, but you must have good surfaces. The surfaces must be perfect.

When you deal with products you cannot maintain perfect surfaces in service, and so you've got to deal with abused surfaces. Hence, in making our tests and evaluating materials, we abuse the surface by either carborundum paper or sometimes tumbling the samples in a barrel with carborundum grit. These results, which you see are abraded, going from 8 to 20, times 20,000 PSI, are on abraded or abused samples. The polished samples give you somewhat higher values.

This brings me to the second product I would like to show you that has come out of this field, and this is a heat exchanger. This heat exchanger from where you sit looks like a block of wood. It is ceramic material, but it actually is a honeycomb structure. If you picture the gas turbine engine and its problem of a heat exchanger, you know you need there something that will withstand heat shock, something that will cool off the exhaust gas and heat up the incoming air to improve efficiency. We think this material can be an answer to that particular problem.

If you would picture this material, which, by the way, can be made with an expansion coefficient of plus or minus 1 times 10 to the minus

73 degrees Centigrade, that wonderful fused silica that I spoke about has an expansion coefficient of 5½, times 10 to the minus 73 degrees Centigrade. This is plus or minus 1, but it can go negative. If you picture this in the form of a disc, say 30 inches or so, in diameter and 3 inches thick, this disc is now smooth on top and has two manifolds riding on it side by side. The one manifold is the exhaust manifold, which will push the exhaust gases down through this honeycomb structure. The other manifold right beside it is the air intake manifold which pulls air up through the structure. This is rotating. So you see it is alternately heated and cooled. With a zero expansion coefficient the material loves it. It lives this way. It is an answer to that particular problem.

I have a torch here and water. I don't know whether I can get it as hot as it should be heated to give you a good demonstration, but I'll try it. This material can take abuse up to about 1,000 degrees Centigrade. May I have the lights out.

(Demonstration) Now, we'll stick it in water. Light up, please. This suffered no damage. In fact, it is an excellent water pump. Just imagine--for you Navy people here--it can be used as a bailer.

This is another example of a new possibility, a new answer, because of this field of materials.

There is another field where these materials are involved. By the way, I should like to tell you this. The expansion coefficient of these materials can run from negative minus--oh, I suppose--200, times 10 to the minus 73 degrees Centigrade, up to plus 600. So there are all kinds of possibilities of expansion coefficientwise. This one, as I say, is around zero.

One thing you like to do when you are making glasses is to make them strong. You may have heard of Chemcore glasses. Chemcore is a blanket name for glasses that have unusual mechanical strength. The unusual strength is obtained by a variety of methods. Chemcore, as I say, is a blanket term for these products.

I'll give you an example. Let's begin with the ordinary tempered glass. There you are dealing with a sheet of glass, say, that's 1/4 inch or so thick, heated to the point where it can bend easily. Then you cool it by dipping it in a bath or by blowing air, or something of this kind, so that you introduce a temperature grading in the glass before it has reached a condition of rigidity. In other words, you introduce temperature grading while it is still soft enough that the surface can yield with respect to the interior, and you develop, you see, a temperature grading without stress. You bring this piece now down to room temperature, and you still have no stress as long as the temperature grading doesn't change. But when the surface reaches room temperature the core is still hot and then, as the entire block cools and the entire plate cools, the core continues to cool and, of course, attempts to contract, but being attached to the exterior zone this is impossible to do, so you have sudden stresses set up with tension in the core and compression in the surfaces. Glasses do not fail under compression. Professor Bridgman at Harvard has squeezed glass up to 400,000 pounds per square inch and, while a steel tube under such conditions collapsed and the bore was gone, a glass tube stayed as it was. So, the surface compression in a tempered piece gives you a built-in, desirable pre-stress, so that, when you come to bend this glass--and glass breaks from tension not from compression--you have to overcome the surface compression before you get any tension at all. Hence you have just lifted the level of usage, the level of strength, by whatever compression you put on the surface.

It is practical in tempered glass, tempered safety glass, which is used in automobile windows, to have stresses of the order of, I should say, 15,000 to 20,000 pounds per square inch in the surface, compression. Hence, you get bending strength to the order of 25,000 pounds per square inch.

Now, in this new Chemcore field you can pre-stress up to about 100,000 pounds per square inch and so, as far as rupture is concerned, you have materials that are stronger than steel. This pre-stressing is done in various ways. One method is to choose a composition which, on exposure to environment, where you can get an ion exchange--in other words, you can actually exchange ions in the surface--you introduce, say, soda polythia, or potash, soda, and so on, and you can modify the surface composition of the glass by such an ion-exchange treatment. By choosing your composition to begin with, you can produce a new composition of the surface which is actually in the field, again, of these glass ceramics, and that new composition can have a thermal expansion coefficient that is negative.

Now let's do this at elevated temperatures and you've got a new material with your composite, again, with a thermal expansion coefficient of some negative value on the surface and a positive one in the core. You see this gives you tremendous opportunity for pre-stressing, and that is part of the Chemcore story.

There are other ways of doing it. This (demonstrating) is a piece of Chemcore material--glass. It is about .008 thick or so. It is curved this way so that you can easily demonstrate it. You can bend it, you see, without undue stress, or undo distress, and it lends itself to the manufacture of products where light weight and high strength are required. So at the present time this is going into the rear windows of the Ford Galaxie convertibles. The glass window is going in there to replace the plastic window. It is thin enough and very strong. The modulus of that is about 12,000 pounds per square inch. This gives you a very desirable factor. This is an illustration of where this kind of thing belongs, where you have high strength and light weight requirements.

Now, another example of another application for these glass ceramics is in this field of missiles. These are just two dummies. This is glass ceramic after heat treatment. These are being made in sizes up to about this height as radomes for some of the Navy missiles. The material has excellent mechanical properties and it has extellent heat-shock properties. It is very hard, erosion resistant, and all the rest.

Dialectrically it makes the window for radar devices that may be on the inside for various purposes, as self-guidance or with direction from an outside source, and so on. This is the 9606 material that is going into that field.

Now, as I said, the field is new. I think probably we announced this about 1957 and it is in the laboratory yet. So that there will be more and more things coming out of it, I am sure. I think our chief problem at the present time is to find someplace where there is a real demand which will justify the production in volume, because you don't produce these things in quality in small lots. You would like to find a field somewhere where the requirement would be, say, 50 tons a day. Then you can do business. But, propertywise, and characteristicswise, the material has very interesting possibilities--this field of materials, I should say. We cannot tell today what we will be doing tomorrow with it, because of the variety of things that can come out of it.

Now, there are other things I could talk about, but I think at this point I would like to give you a chance to think about this a bit. Is this the time for the break, Professor Muncy? Then we can come back and have questions later.

Thank you very much.

MR. MUNCY: Dr. Shaver is ready for your questions.

QUESTION: Doctor, this glass you see that has exploded in the rear windows of cars, is that a tempered glass?

DR. SHAVER: That's right. Tempered glass with stresses of the order of 8,000 or 9,000 pounds per square inch, tension, and surface stress of the order of 20,000 pounds, compression, 1/4 inch thick, when fractured--if you take a punch at one you will break it--will give you dicing. You get fractures of the order of the size of your little finger in size, and in general they are not sharp cutting edges. That constitutes another kind of safety glass, another, differing from the laminated glass with the vinal buterol in between the two sheets of annealed glass.

Now, you can make a million of these things. Remember, you have loaded on the inside core a stretching or a tension of the order of 8400 pounds per square inch, and if you have an inhomogeneity, like a stone, or a crystal of some kind, the strength is less than that, or at least it is of that order. Actually, as you heat treat by heating very hot blowing air you will get some breakage spontaneously on the line. But put your million pieces in stock and the next morning you will find you have maybe 2 or 3 that have spontaneously broken because the stress in the core combined with a little flaw has just been too much and you've got a fracture. This has then gone all through the place, because, once you expose such a surface to tension, it will continue to move.

In your rear window that has been sitting around in use for some time, it might be that it has had a blow of some kind or it might be just a delayed fracture that has been increasing in size over a period of some months, and finally it goes. But the number is very small. It is quite a practical kind of desirable window.

In these large doors, very often--I don't know how much of it is now--the glass used to be all tempered to this degree also.

QUESTION: Doctor, I saw a slide up there, a chromatograph. Will you discuss that please, sir?

DR. SHAVER: Well, how much of this can you stand? These stories get longer and longer, you know. Actually, this is a porous glass with pores of the order of 25 to 40 angstroms--one-fifth of a millionth of an inch. It's made, again, by a phased separation kind of thing. You melt a glass that isn't much good and then you heat treat it, and it begins to separate in boiling water again. You can dissolve out one of the phases, which is dissolved away, and leave your porous structure with a surface area of 1-1/4 acres per ounce of material, 1-1/4 acres surface per ounce of glass. That's a porous glass state and the composition is 96 percent silica. This is what we call our Vitcorgran glasses. We have a number of them. We do that because it is a low-cost way of getting at glasses that approximate and even are somewhat better than fused silicas and properties.

This particular plate is a sheet of this porous material between two covers. We have in our laboratory a man who is a crytoalist by avocation. He acts as a scientific witness on criminal cases. He wanted to have some way of distinguishing inks one from another. So he took a piece of this porous glass, which will absorb water, of course, very easily, and he put five dots of ink on it and set it in a bath of water. The water diffused upwards and carried various portions of the ink with it. So he had a glass chromatograph. This has been published and he offered it to the scientists, but they haven't run very high for it. But it is available, and it gives you a permanent record, you see. You can consider it a paper chromatograph which you can use for your analysis by this system, if you will. It is an interesting thing that the fusion is such that this is a way that you do have of identifying various inks.

QUESTION: Sir, I understand that there has been some talk about using glass for submarine hulls, maybe down to about 5,000 feet. Will you comment on that?

DR. SHAVER: Glasses fundamentally are very strong under pressure. We have taken little cylinders of glass, 1/2 inch in diameter or so, and polished the ends between hardened steel blocks and you get loads under such conditions on the order of 200,000 or 250,000 pounds per square inch. When you have complete hydrostatic loading--I spoke about Professor Bridgman at Harvard having tested a closed glass tube to 400,000 pounds per square inch without damaging the glass-- and can take a symmetrical structure, such as a sphere, and subject it to hydrostatic pressure, it will take a tremendous load, depending on the precision of the finish of the sphere. In other words, if it is an actual, perfect sphere, it should take an almost indefinite load to break it.

This principle seems interesting from the standpoint of what you can do under water, and we are now working with various people in the Navy on preliminary experiments along these lines to study what can be done with such materials under hydrostatic pressure.

QUESTION: Sir, you mentioned meeting with representatives of foreign countries from establishments in your field. Will you comment on their parallel endeavor? Are they about at the same place that we are in the development of these things in considering the criteria?

DR. SHAVER: Well, each country, each firm, each laboratory has its own specialty. I might just mention one or two places where advances have been made outside this country that really are very striking. One that you have probably read about is the flat-glass process which has been developed by Pilkington's for making plate glass by feeding glass from some type of orifice on a bath of molten tin effectively and allowing the glass to be in a bath that is hot enough so that the glass can really settle down and give you a mirror surface which will be parallel, top and bottom. They can draw it off the other end and they have quality in the finish plate that is such that it will take a very large percentage of the plate glass business.

Now, that particular firm has been leading in plate glass manufacture and development for many years. They have a twin grinder which I think has been going for more than a generation grinding and polishing continuously. They rolled a sheet of glass and then put it through a layer and fed the sheet continuously between grinders and finally through the polishers, so that they cut off plate glass at the end. That was developed there and then adopted later in this country.

Another development that the French have led in, I should say, is the use of glass power insulators, tempered glass insulators for power-line installations. The Japs, by the way, are running hard on this too, and very effectively. They are hard workers and they have ideas. They are very active people. They have really taken over the foreign suspension insulator business in electrical enforcement. They are all over the world with that. They have the largest electrical enforcement factory in the world. And the French have developed and are competing with them in electrical insulation with tempered glass insulators, which are very, very strong.

Now, also I was struck with the forward look in Great Britain, particularly, in magneto hydrodynamics. They are looking forward to a very large unit where they will have 200 megowatts of power from the magneto hydrodynamics principle, and 800 from the subsequent use of the exhaust gas, with an input, I think, of 25 pounds of fuel per second. They don't know what they are going to do with the roar that will come about with such consumption, but in any case it is an interesting field which they are very active in. They need heat exchangers.

In Belgium there is a company marketing a heat-reflecting window where they have a thin film of gold deposit on the one side of a glass sheet and it is then used as a part of a pair. In other words, it is a double glazing unit. That gold is so thin that you can see through it. It has a green tint. It has got high reflectants for infra red and in effect for solar heat.

This thing could go on like a brook, but I think those are some of the chief things that might be of interest to you, to know what goes on over there.

QUESTION: Sir, you mentioned the use of the radome in radar, and you just mentioned the heat-reflecting glass in Belgium. Will you stress the optical properties of the infra red or the ultra violet?

DR. SHAVER: You mean the transparency to ways beyond the infra red and below the ultra violet? Materials generally are not transparent. Well there are some. Crystals are transparent down on 1400 angstroms. The best material that I know of that is practical for going below the normal 1850 angstroms ultra violet is fused silicate which you make. This can go down to as low as probably 1700 angstroms or a little bit below that.

In the infra red glasses are limited to about the ones, shall I say? that have workability, around 6 mu. Of course when you get into the exotic ones, the arsenic tellerite and so on, and that kind of thing, you go beyond that. But you are limited in glasses, even silica below this and germania , to around 6 microns, I believe.

QUESTION: Doctor, would you describe the manufacturing process involved in special optical glass? I have in mind the 48-inch reflector mirror. What special quality control do you have to get?

DR. SHAVER: Well now, there is often confusion on mirrors and lenses for telescopes. The large telescopes use reflecting mirrors as light-gathering devices. The optical part of the glass really isn't too important. I mean, it must be reasonably good but it doesn't need to be the kind of optical quality that you need for a very high precision lens. Of course the largest one we made was in 1935 or 1936, the 200-inch Mount Palomar disc, and that was made by actually having a mold which we filled with ladled glass, ladling, I think it was, 500 to 800 pounds of glass at once and then annealing over a period of 10 months, I believe it was. That was then surfaced. You see, the surface is all you use, and so even a bubble or two isn't too important, although you don't want any. But, as a percentage of loss of the useful surface that one bubble would produce, it wouldn't amount to anything.

When you come to optical glass--I have two blocks here which you might take a look at after this is over--there is such a difference between good commercial glass and optical glass that the glass man knows about and so does the optical glass lens designer, but the average individual, who doesn't come in contact with these things, doesn't see this difference, and to him they look alike.

In this case here is a block which is a good, commercial glass. It's for a window in a jail. This shape was designed so that there can be steel bars fit in place. I merely polished the ends so that they can set it on some printed matter, and you can see the difference between a good, commercial glass and a good, optical glass, which is worth probably, let's say, anywhere from 10 to 100 times per pound the price of this one. Yet maybe they both have maybe the same chemical durability and the same mechanical strength. For a jail this is wonderful. You don't need optical glass. For a lens you need optical glass and you don't need the kind of glass that goes in the jail.

The optical glass was formerly made by stirring in a pot, and that's homogenizing the best you can, because remember, you are dealing with molasses, different kinds of molasses, when you get up to the melting temperature of glasses. If you can imagine mixing various kinds of molasses by just heating it, it is not easy. Then you go in and stir it, you see, and even that isn't easy. The old method used to be to make as much as you could in a pot, stir it with maybe a platinum covered stirrer, then take it out, let it cool, break it up, and you were lucky to save 15 percent. You would break out the undesirable parts and save the rest.

By World War II we had worked for some time on optical glass-making methods. We continued during that time. We built a factory at Frankfort Arsenal for the old system. Before the end of the war we were making optical glass by a continuous process, producing more glass, it what would be about one-half the size of this room, than the entire factory that we had built for optical glass could produce. In this case the glass is homogenized by stirring, and you can make almost any size of product you want by this continuous process.

It is widely used now around the world. The products really are interesting. Perhaps the chief example of changing in this field is that the eye-lens people, the optometry people, wanted optical glass for years and never could get it. With this method of developing we have set up a factory to make this kind of thing. The lenses that you are looking through in your glasses may have come from that factory in optical glass quality.

QUESTION: Sir, would you discuss the influence or the impact of plastics on the glass industry?

DR. SHAVER: Well, the plastics industry has many things to be said for the use of it. You can see the use of it being increased from year to year. Actually, I think the most phenominal increase and the most useful field is a combination of fiber glass and plastic materials. Glasses are fundamentally strong materials. A strength of over a million pounds per inch can be had in fibers. On bending strength I have a couple slides here. We loaded some glass rods just to check the sustained loading strength in 1936. I remember one was loaded at 250,000 pounds per square inch for bending. In other words, the maximum stress at the bottom of the curve was 261,000 pounds per square inch. We unloaded that rod after 25 years. The experiment was not designed to look for permanent distortion. As far as the eye could tell the rod came back, when we unloaded it, after 25 years, to its original position.

Now, fibers are stronger than that, even, you see, and when you protect the surface--because the surface condition of a glass makes all the difference in the world to the strength--you can draw a rod out of molten glass and can have strength to the order, in bending, of say 400,000 or 500,000 pounds per square inch. But if you handle it in your hands, it will come down to maybe 50,000 pounds. If you lay it on the table and roll it around, it will come down to 20,000 pounds. It will get down, finally, if you abuse it, to about 5,000, 6,000, or 7,000 pounds. But now, bury those fibers in plastic and you will protect the surface, and then you begin to develop real, effective strength of glass. Because the glass fiber has a modulus of around 12 million, and the plastic is around 500,000 or something at this time, the load is carried by the glass. That combination is, as you know, a very desirable kind of thing. It is a new field of products.

Now, in answer to your question about glasses versus plastics, of course, plastics will go where they belong, and so will glasses. I just spoke about the Chemcore glass. The Chemcore rear window for those Galaxie convertibles is replacing a piece of plastic.

QUESTION: Doctor, my question relates to the use of glass ceramics in space. I understand that one of the big problems in selecting materials for that application for so long has been an inability to stand up under high vacuum conditions. I wonder how these compare with some of the methods that have been developed recently for that purpose.

DR. SHAVER: You mean inability to withstand high vacuum without evaporation, and that kind of thing?

STUDENT: That's right.

DR. SHAVER: Well, you see, glasses generally have been used--for I was going to say a thousand years, but we haven't had vacuum that long--wherever vacua have been used because they are so often used for envelopes.

The vacuum that you have in space,of course, is beyond what you can easily attain on earth. But I don't see any reason why the materials wouldn't behave themselves as far as any loss from the surface is concerned. If you are talking about friction, such as friction between glass and something else, then I don't know. That is something, of course, that would be quite different with such high vacuum than what would be found under normal conditions.

As far as an envelope is concerned, or as far as materials that would stay in the same shape and not lose by volatilization, I would have no fear about at all.

QUESTION: We understand that at Corning you are formulating a number of types of glasses and putting the information away and not using it at the moment, at least. Movies that we have seen show this. My question relates to the reproducibility of the qualities of whatever formula it is that you put away. Do you feel that you can attain again that particular quality that that sample of glass had?

DR. SHAVER: Generally speaking, yes, but specifically you may find in some cases that the behavior or the property of the thing that you have in that particular mouth depends on a contaminant which you don't know is there. In such cases you may have difficulty in finding what the contaminant is or reproducing it. But generally speaking, yes. Specifically there are cases when we have difficulty reproducing what we have done before.

QUESTION: Dr. Shaver, your Chemcore sample has some precautions on it. It says, "Bend it but don't drill it," or other things. I am interested in the reason for precaution. Also with Chemcore, when you go into mass production how does this stack up competitively with plain window glass, for instance, or with plate glass?

DR. SHAVER: As far as the caution on treatment after the thing is finished is concerned, that is the same situation exactly that you have in thermal tempered glass. In other words, a window that is tempered by heating and cooling cannot be worked afterward. It depends on the degree of tempering, but, when you get a safety glass which breaks into small pieces, if you attempt to drill a hole in that, you will break the whole glass.

This has the same characteristic. It is a safety glass. You can't drill into it without disturbing the stresses and exposing areas with your drill which are in high tension. That abused or abraded surface will cause fracture, you see.

Now, there are degrees of this. The degree that you have in this particular sample is designed to give you many pieces. It is a finished job, and you don't work it afterwards. But you can get some degree of strengthening and you can still drill holes in it. There is a whole range of things possible in this field.

There was another part to your question wasn't there?

STUDENT: If you wanted to mass produce, how would it stack up pricewise? I had in mind this, Dr. Shaver. The New York City School System has found it necessary to put, I think it is, colored plastic on the lower two floors of their schoolroom windows that get broken so much. I was wondering how some of these products might work there.

DR. SHAVER: This Chemcore glass has a subsequent treatment after forming which would make it more costly than the ordinary window glass if the two compositions were alike. Of course this I think would be a more expensive composition than that in ordinary window glass. So that on both counts this would be more expensive than ordinary drawn sheet.

QUESTION: Doctor, in the manufacture of synthetic quartz crystals are we able to develop the type that will have the same fuse or electric qualities that imported glass has?

DR. SHAVER: I really do not know the answer to that. I would expect that you could but I don't know. I have no experience in that field.

QUESTION: Doctor, I imagine the harried housewife would like to have her ceramic pots and pans cost about the same as her other wares cost now. Is there a chance in the foreseeable future that the price will decrease?

DR. SHAVER: I think that the Corningware is bound to be more expensive. It is a more expensive glass and the processing is more expensive. The whole thing is higher priced. But what it does for you is much more valuable than just baking. So that it's a bargain.

QUESTION: Are we developing a fiber glass that will be competitive with asbestos or replace asbestos?

DR. SHAVER: In what field would that be? Again, I am not in the fiber glass field. I don't really know the answer to your question. I noticed just recently something about the fiber-glass-plastic combinations become more and more competitive with steel for automobile bodies because there was some hope of getting both the plastic materials and the fibers lower in price.

I would think that asbestos, which is a natural mineral, would always be cheaper than a synthetic product which you've got to melt and form.

QUESTION: With the combination of the spectograph and your photographic work is there a possibility of having colored photography which would result by a treatment of this glass?

DR. SHAVER: We tried that in this photo-sensitive glass. We got in that particular picture a range of blue to red, but we couldn't put the red where we wanted it and the blue where we wanted it exactly. We also could get a sepia with palladium, I think it was. But we never had really color photography as a possibility, up to the present time.

STUDENT: I was thinking of the reflection of color due to a measure of transparency.

DR. SHAVER: We haven't been able to do that.

QUESTION: How does glass stand up under extreme high-frequency vibration?

DR. SHAVER: Well, actually, I would think that it is a combination of the frequency and the amplitude. In other words, if you have a test piece and you have a resonance frequency, and you hit that and keep on pumping it, you will probably break it. But if you are not in resonance

I think it would do very well. It would depend so much on the circumstances that I think you would have to take a particular case and actually check it out.

QUESTION: Sir, is there an application of your photo-sensitive glass as a protector against flash blindness and cockpit covers?

DR. SHAVER: Not at the present time. We haven't anything that would answer that. But we know of that problem and we have it in mind. But we do not have an answer at the present time.

QUESTION: Dr. Shaver, you mentioned that glass is not particularly strong in tension but is strong in compression, and yet, when we get down to fiber glass, we find it is strong in tension. I was wondering at what point in the diameter of these things do we begin to develop strong tensile strength, and how do we explain it?

DR. SHAVER: The difference actually is in the surface condition. In other words, fibers are drawn, and we hope they never touch them, until they get a coating on to protect them. I spoke of drawing a rod, a 1/4 inch or a 1/2 inch rod, out of a molten bath. That is also very strong. But just as soon as you begin to handle it or modify the surface by rolling it on a table or any kind of abuse, then down goes the strength. So that you actually have strength comparable to the fibers if it is untouched. It depends on the surface.

What do we have to offer you? We have surfaces to offer you. That's all you get when you buy a piece of glass. The body doesn't matter--it's the surface. So anything we would put on the surface to protect it and maintain this high stremgth changes the surface. We have made tumblers that you could drop off high buildings. We put plastic coatings on them and then we had a plastic tumbler, you see. So that, if you are going to have the quality of glass surfaces, you've got to develop products that will have this high strength in service. Hence we test abuse.

In fibers, when you put them in plastic, then you can begin to take advantage of the real strength, because you protect the surface with the plastic.

MR. MUNCY: Dr. Shaver, we are indebted to you for a very profitable lecture. Your demonstrations here I think attracted a great many people during the period. With your permission perhaps some of them would like to come up to see them during the lunch hour. Thank you very much, sir.