

American Glass Practice

A practical book devoted to actual glass factory conditions,
with problems discussed in a manner that will be
readily understood by the layman.

By Harry Bastow

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DEDICATED
to the men in the
AMERICAN GLASS INDUSTRY
who are not satisfied to stand still.

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FOREWORD

In presenting this book we feel confident that it will fill a very definite and long-felt need in the glass industry. There is a decided paucity of real practical trade literature that deals in terms of today and is directed to a clean-cut statement and discussion of conditions as they are and as they should be.

Mr. Bastow has had over twenty years actual factory experience, and has handled practically every position in a glass plant, in addition to which he has made a special study of chemistry as applied to glass making. He uses terms in vogue in the trade and also discusses the technical side of the matter in technical terms, in the hope of interesting the practical, but non-technical man in the technical side of his work, and interesting the technical man in the practical side of his work.

The reluctance of the average old-line glass factory manager in the matter of accepting suggestions of a technical nature is proverbial, and the author has therefore endeavored to present his argument in a manner that will appeal to this class as well as to the technical man. Assistant factory managers, heads of departments, and employees who possess initiative and have ambition to succeed in the glass industry will find this book invaluable as a stepping stone to success.

Mr. Bastow's experience covers glass made in pots and in tanks, glass made for high grade purposes and for cheap quantity production; it covers in fact probably ninety per cent of the glass made in America outside of window and plate glass. In addition he spent a part of the war period in the service of the government in charge of the inspection of optical glass, and in this connection was in close touch with many innovations which are being gradually extended to general glass practice, and which have opened practically a new field of improvement.

The tests on the value of opalizers as given in full detail under opaque glasses illustrate Mr. Bastow's possession of the true research type of mind, and the conclusions derived from those tests are valuable. The chapters on annealing and the table of reactions and losses in melting illustrate the practical nature of the book and its recognition of the economic as well as the technical side of the business.

Historical matter has been eliminated and the book is confined to a crisp, concise statement of the subject matter covered. We present it as a real contribution to practical glass trade knowledge.

THE PUBLISHERS. Pittsburgh, Pa.

AUTHOR'S STATEMENT

From an experience of more than twenty years in the manufacture of glass the outstanding conclusion, to my mind, is the lack of real knowledge of the forces at work in the process of making glass, and consequently an inability to intelligently and economically direct those forces.

This condition is aggravated by the age-old custom of secrecy, and I am sure a majority of my brethren in the business will bear me out in the observation that the most narrow-minded and bigoted demonstration of this policy of secrecy is encountered where there is the least of real knowledge. Oftentimes this condition condemns a man and a manufacturing plant to the wasteful use day after day of an uneconomical formula, simply because that formula was acquired under conditions that tended to throw a halo of sacredness over it.

Among the remedies that suggest themselves I have long thought that research by governmental agencies, such as was practiced by the Germans, would be the most practical. Factories would submit their problems to such an agency and the most intelligent research possible would be made by actual test, step by step, until the answer was reached, and the result made available to all factories.

The growing tendency toward having chemists at the plants is a step in the right direction, and while there is a natural clash between the practical man and the theoretical man, it is naturally to be expected that the next generation will produce a combination of the two, which is ideal.

Meantime the writer humbly submits this book as his contribution to the fund. The formulas given are actual working formulas that have been used commercially by him, and the observations as to the reactions between the different ingredients and as to the effect of increasing or lowering the percentages of each are in most cases the result of personal investigation and test and largely independent of old accepted ideas. When I found the conclusions made from my experience at variance with old standards I have not hesitated to state the facts from which I draw my conclusions, and leave the matter up to the reader to judge.

It will be noted that in the set of standardized formulas given the ingredients are so proportioned that the glasses will work together. In a factory where but one or two grades of glass are made day in and day out it is possible to shade costs by careful tests, as well as to better the quality. In a plant, however, where standardization is necessary, any such changes would involve corresponding changes all along the line, otherwise an apparent saving might turn out to be a loss. The table of reactions and shrinkages or losses in melting are designed to enable the cost accounting department to keep closer track of the glass actually produced. I desire to acknowledge with thanks my debt to the rather extensive circle of practical men in the glass trade with whom I have "swapped" information for many years. A number of them will recognize their own pet ideas, and this compilation of ideas will doubtless be helpful to all. That is the spirit in which the book is offered.

I also wish to acknowledge the valued services of Mr. Henry W. Gauding, for many years editor of *The Glassworker* and staff representative of *China, Glass and Lamps*, Pittsburgh, Pa., one of the best known men in the glass industry. Mr. Gauding made many practical suggestions and edited the matter in such a way as to insure that it is stated in a clear and understandable manner—a point that will be highly appreciated by all readers.

HARRY BASTOW.
Pittsburgh, Pa., May, 1920

REACTIONS IN MELTING GLASS

The simile which may be most helpful in absorbing and understanding the reactions which take place during the melting of glass is to liken it to a quantity of water in a tumbler or beaker, to which we add, say, one-fourth of its volume of some clear, transparent acid, for example, nitric acid, so as to have a transparent acid solution.

Glass when molten is a transparent acid solution in exactly the same sense that the liquid above described is a transparent acid solution at ordinary temperatures. In the case of the glass, the acid is silicic acid or silica (SiO_2). This acid is inert at ordinary temperatures, but is sufficiently powerful at high temperatures to decompose most oxides or oxygen combinations. It might be more accurate to state that the oxides and oxygen combinations are weakened in their bond by the temperatures involved in the formation of silicates, as there is evidence that silica is not a particularly powerful acid.

Now, in our tumbler we have a dilute solution of nitric acid. If we, add to it some crystals of a nitrate, say salt petre, which is the nitrate of potash, what happens? Merely that the nitrate of potash dissolves in the solution, leaving the solution as transparent as before. This is equivalent to adding a clear transparent glass or silicate to the pot of clear glass. Neither reaction would change the appearance of the solution, nor would there be any evolution of gas or other evidence of chemical change. The dilute nitric acid solution is not saturated, that is, it has not taken up to its limit of capacity of holding material in solution.

Next in our tumbler we will place a small quantity of soda ash, which is sodium carbonate (Na_2CO_3), and immediately an effervescence takes place. The acid in the solution has combined with the sodium oxide in the soda ash, and has liberated the carbon dioxide contained in it in the form of gas, which passes up through the solution and escapes into the air. When the effervescence has ceased, the solution is as clear as ever. This reaction compares strikingly with the reaction with the same material in making glass. The soda ash is attacked by the acid silica, which appropriates to itself the sodium oxide (with which it forms sodium silicate), and the carbon dioxide is freed as a gas, which passes up through the glass in bubbles (the "plaining" of the glass), and when this is complete the glass is clear.

It is unnecessary to carry the simile further to make it easily understandable that the addition of other carbonates or nitrates whose oxides form transparent silicates would act in a similar way, and that the resulting glass would be a compound silicate or a mixture of silicates. Where oxides are added direct there is no formation of gas.

ACTION OF LIME AND LEAD

There is evidence that lime has a greater affinity for silica than has soda or potash. If to a solution of soluble sodium silicate or potassium silicate there be added calcium chloride, the calcium will unite with oxygen in the silicate of soda, forming lime; and this will again unite with the silicic acid, forming silicate of lime, while the chlorine will unite with the sodium, forming chloride of sodium or common salt. It is also significant along this line, that calcium oxide in the form of burned lime will unite directly with silica, while the sodium oxide will not so unite, and the carbonate is used instead.

A soluble lead salt will displace soda or potash in the soluble silicate, in the same manner as indicated above for the lime, indicating that lead also has a greater affinity for silica than has soda or potash.

INTERESTING EXAMPLES CITED

The making of glass is governed by a number of rules which are very well established. To begin with, it is practically impossible to render silica viscous and commercially workable with any means and equipment now available. If it were possible to work silica with the same ease that glass is worked into the various articles of every-day use, it would be the ideal material for almost every one of those uses. It would be much stronger and less brittle, would not break so easily from either shock or sudden heat or cold, and would be more resistant to the effect of acids, alkalies and the weather than even the best commercial glass.

If to the silica should be added an alkaline base, for example, sodium in the form of carbonate or nitrate, and this mixture be melted and then allowed to cool, it would be found that the sodium silicate formed would be soluble in water.

If two alkaline bases should be added to the silica, say the carbonates or nitrates of sodium and potassium, and the mixture melted, it would be found that this sodium-potassium-silicate would be soluble in water also.

If one or two alkaline bases, as cited above, and an earthy base, say the oxide of calcium (lime), be added to the silica and the mixture melted, a sodium-potassium-calcium silicate would be formed, or a mixture of the silicates of sodium, potassium and calcium, and the glass would-not be soluble in water, but would be durable within the ordinary limits attributable to glass.

If a metallic base, say lead oxide, be substituted for the earthy base calcium oxide in the combination named in the preceding paragraph, the result would be a durable glass in the same sense as the foregoing. In this event, the glass would be a mixture of the silicates of sodium, potassium and lead.

RULE: Silicates of the alkalis alone are soluble in water. The addition of earthy or metallic bases is necessary before the mixture of silicates becomes durable.

MULTIPLE OR MIXED SILICATES

In making multiple, or mixed silicates, it has developed that a double silicate will melt at a lower temperature than either of the simple silicates of which it is composed. It has further been proven that a triple silicate will melt at a lower temperature than the double silicates of the same bases. Figures of the exact temperatures required for the fusion of different mixtures, bearing out the above statements are given on another page under the heading Magnesia.

RULE: In a mixture of silicates, the greater the number of different silicates included in the mixture, the lower the temperature at which they melt.

A number of very good authorities add to the above rule the statement that the more complex mixture of silicates, while more readily fusible, is of poorer quality as to homogeneity, etc. The author's experience has been that the more complex mixtures have produced glass which has been better from the standpoint of appearance, resistance to breakage, and freedom from the ordinary defects to which glass melted in clay vessels is heir.

It is easily conceivable that the addition of *some* silicates whose characteristics are well known, would detract from, rather than add to, the quality of any given mixture of silicates, but it seems safe to say that the addition to a mixture of silicates of another

silicate whose characteristics are not inconsistent with the result desired or with the characteristics of the silicates already present in the mixture, would improve the quality.

VARIATION AND ITS CAUSES

In the matter of homogeneity, other and probably more important factors enter. It has been found that in bottle glass made in a continuous tank, for instance, analyses of samples of glass taken at different times or from different parts of the tank, using one standard batch mixture, varied greatly in the proportions of the different elements. This is doubtless due to the physical conditions. The melting chamber of the tank is a lake of partly melted glass which is denser than the loosely mixed batch that is introduced usually through the "dog-house" or protruding bay at the rear of the tank, which is kept piled up with batch as fast as it is taken up by the molten mass already in the tank.

The most probable explanation of the variation in composition is that the tendency of the molten glass is to absorb the alkaline constituents of the raw batch with which it is in contact before it absorbs the less fusible silica, and it would seem logical that the action on the inner surface of the batch would be a series of steps rather than a continuous and uniform erosion or solution.

These steps would consist first of the absorption of alkali from the layer immediately in contact with the molten glass, which absorption would reach deeper and deeper into the surface until the added weight of the adhering molten glass on that face together with the gradual lowering of the level of glass in the tank by working out the glass at the working end, would slough off a considerable cake of partly fused substance which would float away and expose a new surface of raw batch to the action of the molten mass. The mixing of large quantities of batch in advance of the time it is used tends toward a settling to the bottom of the heavier grains of sand.

ACTION ON POT GLASS

Glass made in pots wherein the batch for each pot is made and mixed separately and the entire contents of the pot held together until complete fusion is attained, would not be subject to the changes of composition referred to above. If glass made in pots were composed of ingredients some of which had a much greater density than the others, there would be some tendency in the heavier silicates to stratify at the bottom of the pot and the lighter silicates above, but practically, with present practice of sufficiently hot furnaces, pure materials and the use of a sufficient proportion of gas-forming materials, which give a stirring action during the melt, the glass, when used without delay, is homogeneous to all practical intents and purposes.

It is only in optical glass that mechanical stirring has been introduced for the purpose of promoting homogeneity, and this has been directed at the absorption into the glass melt of the clay eroded from the pot rather than any tendency to stratify through differences in the densities of the different silicates.

EXPANSION AND CONTRACTION

The statement earlier in this chapter that silica, if it were possible to work it with the facility with which glass is worked into articles of every-day use, would be the ideal material for almost all such purposes, relates to the fact that silica has a very low rate of contraction and expansion. It is obvious that if a material such as silica or glass did not contract or expand under differences of temperature, then the full strength of that material would be available in resisting shock of all kinds, and the factor which decreases

its power to resist shock is internal strain between the layers of the material, due to inequalities in the rate of cooling and corresponding inequalities in the rate of contraction.

The rate at which such a material conducts heat is a factor in the matter of strain through inequalities in contraction between the outer and inner layers. It will readily be understood that if the outer layer conducted its heat readily to the inner layers, the inner layers would promptly respond and would adjust their rate of expansion or contraction to that of the outer layer, and keep the strain between the layers to the minimum.

HEAT RESISTING GLASS

The special glasses which have recently been developed to resist heat sufficiently to be used for cooking purposes have been based on the principle of approaching silica in their coefficient of expansion as nearly as possible. It has been found that the alkalis soda and potash add greatly to the rate of expansion and contraction in the glasses of which they form an ingredient, soda giving a greater coefficient than any other material commonly used in glass making, and potash being a fairly close second. For this reason their use is kept down to a minimum in such glasses, and where possible to provide sufficient heat and heat-resisting vessels to melt the glass, they have been omitted entirely.

In some cases the alkali lithium, which imparts a much lower coefficient of expansion and contraction than soda or potash, has been substituted, but with what success the author is not informed. There is a tendency toward crystallization or devitrification in the use of this alkali, and it is necessary to use it only with equivalent proportions of soda to avoid this tendency, and this of course depreciates its value in reducing contraction and expansion.

EFFECT OF BORIC ACID

A glass without alkali, because of the large rate of expansion and contraction imparted by the use of alkalis, is therefore one direction that the development of these heat-resisting glasses takes. The use of boric acid in this connection has been the largest single factor in getting results, because of the fact that boric acid promotes fusion and makes the glass melt at a lower temperature than without its use, in addition to which it imparts a low rate of expansion and contraction to the resulting glass. In fact, the coefficient imparted by the use of boric acid is the lowest of any of the known glass-making materials.

The use of boric acid, however, has its limitations. A large proportion used in a glass renders that glass less viscous, and therefore more difficult to "gather" than other glasses. Further, glasses containing large proportions of boric acid have a surface which tends to absorb moisture, and when subjected to heat, this moisture-saturated surface splits and peels off. The use of metallic oxides, such as those of zinc, barium and aluminum, offsets this tendency, but lead oxide must be avoided, as it increases the tendency.

ACTION OF ZINC AND BARIUM

Oxides of zinc and barium are valuable in such glasses not only for their tendency to increase the durability of the surface of the glass, but also because they tend to increase the conductivity of heat in the glass in which they are used, and thereby reduce the strain between layers.

STRAIN ON FURNACES AND POTS

The present-day status of the manufacture in the United States of heat-resisting glass for cooking purposes is that the furnaces and pots are tested to their limit of resistance to temperature, and the glass is so stiff as to be worked with great difficulty. Any modification of the composition of the batch designed to ease those conditions is necessarily in the direction of adding materials that tend to add to the expansion coefficient of the glass and thereby make it more liable to break when subjected to cooking temperatures.

LABORATORY GLASS

In the manufacture of laboratory glass, the requirements are first that the surface must be insoluble to the action of acids and alkalis to the highest degree, and next that it shall, when made into the beakers, flasks, bowls, etc., required by the chemist, stand sudden heating over the blast lamp and sudden cooling without breaking. It will be seen that the requirements are somewhat similar to those for the cooking ware referred to above, but inasmuch as the vessels are blown and are usually thin, and that the shock of the application of heat is broken by the placing of iron gauze under the vessels, it is possible to make the batch more fusible and still have a glass that will be sufficiently resistant in this respect.

In the matter of increasing the insolubility of these glasses, alumina appears to be the most valuable factor.

LIME FLINT GLASS BATCH

Herewith is given a typical formula for Lime Flint Glass such as is used for bottles, tableware and a great variety of other articles of commerce:

| | |
|--------------|-----------|
| Sand | 1500 lbs. |
| Soda Ash | 550 lbs. |
| Lime (burnt) | 150 lbs. |
| Nitre | 65 lbs. |

To this batch is added the amount of decolorizer found by experience with the raw materials to be necessary to chromatically neutralize the particular shade and depth of green imparted by their impurities. This matter is covered more fully in the chapter on decolorants, which will be found in succeeding pages.

By applying the table of Losses in Melting, carried elsewhere in this book, it will be noted that the glass making constituents total 1954 lbs. out of the 2265 lbs. of batch, leaving a loss or shrinkage of 311 lbs., of which 272 lbs. is definite loss as gas in the reaction, and the remaining 39 lbs. is loss as moisture, which will vary somewhat in materials from various manufacturers. The percentage of loss is 13.73%.

If the nitre were to be omitted entirely and an addition made to the soda ash of 41 lbs. to compensate for the sodium oxide content of the nitre displaced, then the shrinkage or melting loss would be 296 ½ lbs. or 8%.

The formula given above gives a glass which melts in about 22 to 24 hours in closed pots in a furnace running around 2400° F, which is a convenient temperature for this purpose, considered in relation to its wearing effect on pots and furnaces and also the number of melts per week. In tank practice the temperature would be maintained at a point required to maintain completely melted glass at the rate at which it is withdrawn from the furnace; that is, a tank which is being pulled hard and kept close to its capacity

will naturally be kept hotter, so as to keep that capacity as high as possible and prevent the working out of imperfectly melted glass.

This temperature will usually run within a few hundred degrees of the 2400° used in the pot furnace, but the author knows of one plant where a temperature of 3000° F. was maintained, because of the elimination of nitre from the batch and in an effort to minimize "seedy" glass. It is doubtful if this was a net saving, when the extra wear on tank blocks and their more frequent renewal is considered, as well as the greater tendency of the tank block to "throw stones" at the higher temperature.

CONCERNING THE USE OF LIME

Lime, being the cheapest material in the batch outside of the sand, it is proper to inquire to what extent it would be economical to increase the proportion of this material. First, the melting point of glass with any considerable increase over the proportion given in the batch herewith is higher, and the tendency to "throw stones" due to heat erosion on the pot or tank block, consequently is greater.

In the early days of lime glass, the natural mistake was made of using as large a percentage as possible of this new cheap substitute for lead oxide, and for a long time it was used in proportions as high as one-sixth of the weight of sand in the batch, but it was found that the increased heat required, the excessive stiffness and brittleness and the tendency to devitrification stones was such that it was more economical to reduce the proportion to about ten per cent of the weight of the sand.

In the event of using ground limestone in place of the burnt lime a greater proportion should be used in the ratio of 100 of limestone to 56 of burnt lime, to allow for the carbon dioxide content of the limestone, which passes off as a gas.

In many cases in making imitation cut patterns or other patterns with sharp outlines where it is desirable to fire polish the glass and still keep the outlines as sharp as possible, the percentage of lime is placed around eleven per cent of the sand, or even slightly higher.

In this connection, the well known fact that a hot flame in the glory-hole with a sufficient admixture of air to give almost perfect combustion will melt down the outstanding edges of such patterns without giving a good surface polish, whereas a smoky flame, with insufficient air and an evident surplus of carbon, gives a perfect polish with a minimum amount of melting off of edges, seems to indicate a reduction of the silica on the surface of the glass to silicon.

As to the minimum quantity of lime that might be used in commercial glass, if from the batch given at the head of this chapter the lime is entirely removed, leaving only sand, soda and nitre, the glass, being a simple silicate of soda, is soluble to so great a degree as not to be fitted for most purposes.

In varying the lime contents between the upper and lower limits, one other factor enters into the calculation, and that is the annealing. When the lime exceeds ten per cent of the sand it adds to the stiffness and brittleness of the glass and keeps the solidification range of annealing temperatures in the lehr or oven higher, and it is therefore likely to be less perfectly annealed with ordinary lehrs or ovens.

MAGNESIA (MAGNESIUM OXIDE) (MgO) AND MAGNESIUM CARBONATE

These materials are never introduced into the batch except as impurities in the burnt lime or limestone. The burnt lime, which is Calcium Oxide, carries Magnesium Oxide, and the limestone, which is Calcium Carbonate, carries Magnesium Carbonate.

The proportions in either form vary greatly between a small fraction of one per cent up to forty-five per cent of the lime or limestone.

The effect of the presence of a large percentage of magnesium oxide or carbonate in the glass is a tendency to devitrify, usually in evidence as large opaque stones in the glass, which are lumps of devitrified glass.

Magnesia or Magnesium Carbonate also increases the temperature necessary to melt the glass. Silicate of Lime ($\text{SiO}_2 \text{ CaO}$) melts at 3810° to 3900° F, while Silicate of Magnesia ($\text{SiO}_2 \text{ MgO}$) requires 3990° to 4080° F. Silicate of Lime and Magnesia ($\text{SiO}_2 \text{ CaO MgO}$) while it melts at a lower temperature than either the Silicate of Lime or the Silicate of Magnesia at 3630° F, following the principle of multiple silicates (see preceding pages for Multiple Silicates), requires 100° to 150° higher temperature than the Silicate of Lime and Alumina ($\text{SiO}_2 \text{ CaO Al}_2\text{O}_3$), in spite of the fact that aluminum combinations are notoriously hard to melt. The above temperature figures are for the melting of molecular equivalents of the different materials, which means a higher proportion of the bases to the silica than is usual in glass making practice. For this reason the figures must be considered only as indicating comparative results.

The conclusion from the foregoing facts is that Magnesia or Magnesium Carbonate should not be present in the Lime or Limestone beyond a small percentage, say 5%. Evidence seems to point to Magnesium combinations as being inert or at least much less active than other bases, and beyond the 5% above referred to, the author's opinion is that it is merely taking up room that should be devoted to a better material. Engineering practice has decreed that no Portland Cement shall contain over 5% magnesia, for the same reason given above, namely, that it is inert.

THE EFFECT OF SODA ASH

Next, in the economic analysis of lime glass, it is in order to inquire as to the effect of a greater or smaller proportion of soda ash in the batch.

In a pot furnace, when it is desired to make an article that requires much softer glass when it reaches the mold than the average of the articles made from the other pots in the furnace, the first thought of the glassmaker is to soften his batch by the addition of more soda ash. Of course he has a considerable range of control of his working temperature by means of turning a stream of wind in the pot and holding it there, in the case of wanting the glass very stiff for gathering large articles, or turning on the air for a time and then leaving the stopper wide open where it is not necessary to have quite such a degree of stiffness, and so on to the point of leaving the smallest possible opening for gathering where the glass is wanted as soft and therefore as hot as might be.

Beyond this point he turns to the composition of the glass, and as stated, his first thought is naturally toward an increase in soda ash because of its fluxing action. In one plant where the glass is wanted extra soft for the manufacture of cup-foot ware, where the glass must travel through a considerable area of restricted passages in the mold, the soda ash is increased to the proportion of 675 lbs. to 1500 lbs. of sand. The objection to attaining softness by increasing soda ash is that the coefficient of expansion of the glass is considerably increased, thereby increasing the tendency to breakage. As stated in another section of this book, the greater the coefficient of expansion of a given glass the greater the difficulty of annealing and therefore the greater likelihood of less nearly perfect annealing. Further, the tenacity and elasticity of the glass are decreased as the content of soda is increased.

SODA ASH IN TANK PRACTICE

In tank practice, an increase of soda ash beyond the normal proportions has a tendency to erode the tank blocks more rapidly, giving rise to "stones" and also reducing the life of the tank and requiring more frequent relining.

At the other extreme, where the soda ash is reduced to the limit for the purpose of making a fire-resisting or "oven" glass, this is based on the principle of reducing the coefficient of expansion, and it requires an increased temperature for melting in direct proportion to the reduction of soda ash. The reduction of soda ash by indirectly increasing the proportion of silica, improves the quality of the glass.

NITRATE OF SODA (NITRE) NaNO_3

This material, so well known as an oxidizing agent, breaks up under the heat of the glass melt into sodium oxide (Na_2O), which is the glass forming constituent, and nitric oxide (NO) and oxygen (O), both of which escape as gas. Of pure dry nitrate of soda, 36 ½% of its weight goes into making glass, while 63 ½% forms gases which escape. The following representative analysis of commercial nitrate of soda shows a moisture content of about 2 ½%, so that the total shrinkage in this material in making glass is 66%.

| | |
|------------------|---------|
| Nitrate Soda | 96.46% |
| Chloride Sodium | 0.78% |
| Sulphate Sodium | 0.25% |
| Insoluble Matter | 0.09% |
| Humidity | 2.42% |
| | 100.00% |

Obviously nitre, which is produced in Chile and always commands a much higher price than soda ash, is not used for its value in glass making constituents, but for the property which it has of "plaining" the glass promptly and completely by assembling the entrapped air and the gasses formed during the melt into large bubbles with sufficient lifting power to float to the top of the molten mass and escape into the air, leaving the glass free of bubbles.

When any loosely mixed material such as glass batch is filled into a pot, there is inevitably a great deal of air between the particles of the batch. The first action of the heat of the furnace is to seal over the top of the pile of batch by the fusion of the top layer, thus entrapping the air from the start.

This air must remain entrapped until the mass fuses into a liquid, when it appears as bubbles or seeds. If nitre is not used in the batch these seeds are small, the so-called "pinhead boil" instead of the "open boil" resulting from the use of nitre, and it is difficult to rid the glass entirely of these small seeds, obviously because small bubbles have less lifting power than larger bubbles.

FORMATION OF CARBON DIOXIDE

The carbon dioxide gas (CO_2) formed by the breaking up of carbonates used in the batch, such as soda ash, the carbonate of soda, or crushed limestone, the carbonate of lime, while it adds to the gaseous content of the melting batch, does not replace nitre in its power to form large bubbles, and unless nitre is used in conjunction with these materials there is almost invariably a formation of small seeds, which can only be boiled out by the application of a considerably greater degree of heat, so as to make the glass more thinly fluid.

This greater temperature carries with it several disadvantages, which subject is treated in another chapter, and it is doubtful whether it is really economical to entirely eliminate nitre where a clear lime flint glass is wanted.

The fact that nitre fuses at 600° F and parts with its gases around that temperature, while the carbonates fuse at around 1500° F is doubtless significant in analyzing the differences in their action. Also the fact that nitric oxide gas (NO) and oxygen, (O) are lighter than carbon dioxide gas (CO₂) in the ratio of 30 for the nitric oxide, 32 for the oxygen and 44 for the carbon dioxide, will undoubtedly give the bubbles formed by the nitre the greater lifting power.

THE PRESENCE OF IRON

As to the oxidizing action of the nitre, particularly on the coloring property of iron present, which has been featured as the chief function of the nitre, the writer has proven, to his own satisfaction at least, by making glass entirely without nitre and without any oxidizing agent, that there is no appreciable difference in the color imparted by the iron, and this color may be neutralized chromatically in precisely the same way and with the same amount of decolorant as when nitre is used.

Further, inasmuch as most of the iron in any but the poorest grades of glass is introduced from the clay of the pot or tank block, in which it already exists in the form of the higher oxide of iron, Fe₂O₃, it is obvious that there is no oxidizing action on this iron. The oxygen gas would have the effect of burning such organic matter as small sticks or pieces of paper as might be accidentally mixed into the batch, but it is believed that in present-day practice there is little of this material to be oxidized, and it is very probable that most of the oxygen formed passes out as oxygen gas.

The above discussion is with reference to a sand-soda-lime glass, and does not refer to such glasses as are made with salt-cake, in which the reactions take on a different character. While the proposition has been made with reference to melting in a closed pot, the same will hold good with reference to the same type of glass melted in either an open pot, a day tank or a continuous tank.

While the physical movement of the unmelted batch is different in a tank from that in a pot, yet the same condition prevails in that the top surface is glazed over and therefore sealed before the imprisoned air particles have attained sufficient lifting power to force their way out, so that the same conclusion will apply to tank practice as well as to the practice of melting in the closed pot.

It would seem that a cheaper material might be found that will part with its gaseous content at the proper stage of the melt (if that should prove finally to be the governing factor) or that will form a gas sufficiently lighter than the carbon dioxide gas furnished by the carbonates, and the author is convinced that a material that will fulfill both of these conditions, or possibly a material that will fulfill one of the two conditions, will entirely displace nitre, regardless of whether it has any oxidizing action or not.

OTHER INGREDIENTS OF CLEAR GLASS POTASH AND SALT PETRE

The use of carbonate of potash and nitrate of potash (salt petre) parallels so closely the use of soda ash and nitre, both being alkaline bases and the nitrates oxidizing agents, that it will suffice to call attention briefly to their points of difference. First in economical importance, perhaps, is the fact that in lead glass the use of potash and salt petre gives a better color, or rather higher degree of colorlessness than is possible with

the use of soda ash and nitre. Recent tests have developed further that a soda glass is more durable than a potash glass, and that a soda-potash glass is more durable than either.

As pointed out in the chapters on opal and opalescent glass, potash and salt petre have a tendency to reduce opacity in glass of any given composition if substituted for soda ash and nitre. The coefficient of expansion of any glass is increased by the addition of soda or potash, the soda giving a higher coefficient than the potash. The density of potash is also somewhat greater than that of soda, the figures being 2.6 for the soda and 2.8 for the potash.

BARYTA-CARBONATE OF BARIUM

Baryta, the carbonate of barium (BaCO_3), is usually prepared from the sulphate of barium, which is the form in which it most commonly occurs in nature. Baryta is used as a base as a substitute for lead or lime. In substituting it for lead, its density is usually the quality which is desired. A small quantity of this material added to an ordinary lime-soda batch such as that given in the first part of this chapter will tend to soften the batch somewhat, on the principle of multiple silicates. In large proportions it gives opacity. Its coefficient of expansion is lower than that of lime, hence in substituting for lime it would tend to reduce the coefficient of the glass.

ALUMINA-ALUMINUM OXIDE

Alumina, aluminum oxide (Al_2O_3), as an intentional addition to clear glass is a development of comparatively recent years. As an accidental ingredient taken in through clay occurring in the sand or clay eroded from the pots or tank blocks it has been with us always, and until recently was considered a bugaboo to be avoided as far as possible. Exhaustive tests have proved that a glass containing alumina is stronger as a rule and its surface much less liable to attack by acids or alkalis than a glass without it. Its principal point of superiority is the increased elasticity it imparts to the glass, and in this respect it is superior to any other of the commonly used glass making materials.

The reason its light was so long hidden under a bushel is that its source in glass, the clay of the pot or tank or the clay in unwashed sand, always contained iron, and the iron-alumina mixture always gave a green color to the glass.

Moreover the clay so eroded from the pots or tank block is frequently eroded in lumps which, being almost insoluble in molten glass, retain their identity and form the stones, cords, reams, etc., referred to under "Faults in Glass." As pointed out elsewhere, the addition of alumina increases the melting point of the batch.

ZINC OXIDE

Zinc oxide (ZnO). This material in small proportion makes a good addition to a lime-soda glass. It imparts tenacity to the glass and at the same time considerably reduces its coefficient of expansion. It lowers the melting point of the mixture.

BORAX -- BORIC ACID

Borax, Boric Acid. -- These materials are used in glass making for two principal purposes, promoting fusibility and reducing coefficient of expansion. If it is intended for the reduction of coefficient of expansion, the boric acid should be used rather than the borax, as borax is the borate of sodium, and the sodium content tends to offset the reduction of coefficient of expansion due to boric oxide. Boric acid, H_3BO_3 , breaks up into

boric oxide and water ($\text{H}_3\text{BO}_3 = \text{B}_2\text{O}_3 + 3 \text{H}_2\text{O}$), the water of course passing off as a vapor and the boric oxide remaining in the glass. This means 56 ½% glass making material and 43 ½% loss as vapor. Borax ($\text{Na}_2\text{B}_4\text{O}_7 + 10 \text{H}_2\text{O}$), has a much greater vapor loss, as well as the sodium content above referred to.

Boric oxide has the lowest coefficient of expansion of any of the known glass-making materials. It also lowers the melting point of the glass. In large quantity it gives a surface which absorbs moisture and tends to flake off as it is subjected to even moderate changes in temperature. This is especially true in lead glasses. The tendency toward flaking surface is increased with increased alkalies and decreased by the addition of alumina, zinc oxide or barium oxide or carbonate.

Optically, boric oxide lengthens the red end of the spectrum, and is quite important for this property.

LEAD OXIDE

Lead Oxide -- Red Lead (Pb_3O_4) and Litharge (PbO) are the forms in which this material are used. Its use for making heavy, rich, brilliant cut glass and the rarer colors is well known, as well as its use for optical purposes, which depends on its density. Lead is the densest of the ordinarily used glass-making materials, and has a coefficient of expansion about one-third as great as that of the alkalies and little more than half of that of lime. It promotes fusibility and its surface is also soft as against the action of abrasives, which is a valuable quality economically in the cutting of glass.

The "Best Lead Batch" given under the heading, "Casing Colors," is a typical rich lead glass, and the cheapening of the glass for commercial purposes is accomplished by reducing the lead content or substituting a percentage of lime or baryta for lead, or both. This cheapening is carried through all the gradations down to the point where the glass amounts to merely a lime glass with a slight percentage of lead so as to justify the use of the term "lead glass."

TRANSPARENT COLORS

With the exception of the ambers produced by the various forms of carbon, the following colors are produced by adding the colorants named to the lime batch given under the heading of Lime Flint Glass, or to any lime batch reasonably near this one in composition. In the case of the carbon amber colors the nitre is omitted because the oxygen freed by the break-up of the nitre under the heat would combine with the carbon to form carbon dioxide, which would pass out as a gas, thereby making a colorless glass.

The coloring imparted by carbons is due to the finely divided carbon permeated throughout the glass, which is indicated by the fact that the carbon may be added to the batch in comparatively large particles, but the color will be invariably distributed evenly throughout the mass of the glass without any particles existing that are visible to the naked eye. It is an interesting angle on the question of reducing and oxidizing conditions that this carbon coloring burns off very slowly despite an exposure to heated air on its surface.

In a "dry" mass, if it were given the stirring action to which the melting batch is subjected, the carbon would be oxidized (burnt) off as fast as the surface was exposed, while in the case of glass, the sealing action of the glass in protecting its enclosed particles of carbon from access to the air, slows up the oxidizing process to such an extent that it is doubtful if the amber coloring would be completely burnt out in a month of exposure under the fire in contact with plenty of heated air.

COLORED GLASS BATCHES

Amber

| | |
|------------|--------------------------------|
| Batch-Sand | 1500 |
| Soda Ash | 600 |
| Lime | 150 |
| Sugar | 28 1/8 (1 ¼ lbs. to 100 batch) |

This gives a beautiful shade of amber when made in a closed pot.

Oats, corn, powdered coal and powdered coke may be substituted for the sugar for different shades of amber.

Amber (In Tank)

| | |
|------------------|-----------|
| Batch-Sand | 1500 lbs. |
| Soda Ash | 525 lbs. |
| Ground Limestone | 315 lbs. |
| Coal | 4 ½ lbs. |

This batch has not been actually used by the author, but the information seems reliable, and the batch proportions are in accord with the author's ideas. This is a rather dense amber. used for bottles.

Amethyst

| | |
|-------------------------------|----------|
| Regular Lime Batch with nitre | 100 lbs. |
| Red Oxide Iron | 1 ½ lbs. |
| Manganese Oxide | 1 lb. |

This glass must be made in closed pots, otherwise the color is burned out. Also it must be used without being allowed to stand too long in the pot before being gathered, for the same reason.

***Blue**

| | |
|-------------------------------|----------|
| Regular Lime Batch with nitre | 100 lbs. |
| Copper Scales | 3 oz. |

The above is a peacock blue, slightly tinging toward the green.

| | |
|-------------------------------|----------|
| Regular Lime Batch with nitre | 100 lbs. |
| Cobalt Oxide | 1 ½ oz. |

The above is a rich, deep blue.

| | |
|-------------------------------|----------|
| Regular Lime Batch with nitre | 100 lbs. |
| Cobalt Oxide | ½ oz. |
| Copper Scales | 1 ½ oz. |

The above is known as Royal Blue.

***Black**

| | |
|-------------------------------|----------|
| Regular Lime Batch with nitre | 100 lbs. |
| Red Oxide Iron | 3 lbs. |
| Manganese Oxide | 3 lbs. |
| Cobalt Oxide | 1 oz. |

***Canary**

Regular Lime Batch with nitre 100 lbs.
Oxide Uranium 4 oz.

***Green**

Lime Batch - Salt Petre instead of nitre 100 lbs.
Oxide Chrome 1 ¼ oz.
Copper Scales ¾ oz.

Above is a beautiful full green; if wanted yellowish, omit the Copper Scales.

Regular Lime Batch with nitre 100 lbs.
Chromate Iron 1 oz.
Uranium Oxide ¾ oz.
Copper Scales ¼ oz.

Above is a beautiful light green.

* Can be made in tanks same as in pots. Black colorants should be increased if made in tanks.

OPALESCENT GLASS.

The following series of opalescent colors are based on the same lime batch as is used in connection with the casing colors given on another page, and the crystal opalescent can be cased with the series of casing colors for making ruby opalescent or any other colors which it is desirable to case.

The lime batch used as a basis is as follows:

Sand 1500 lbs.
Soda Ash 560 lbs.
Burnt Lime 150 lbs.
Nitro 100 lbs.

Crystal (or Flint) Opalescent

Above base batch 100 lbs.
Bone Ash 3 lbs. 1 oz.
Arsenic 3 lbs. 1 oz.
Fluor Spar 1 lb.

Add slightly more than the usual amount of manganese for decolorizing crystal glass.

Blue Opalescent

Above base batch 100 lbs.
Bone Ash 3 lbs. 1 oz.
Arsenic 3 lbs. 1 oz.
Fluor Spar 1 lb.
Copper Scales 5 oz.

Green Opalescent

| | |
|------------------|--------------|
| Above base batch | 100 lbs. |
| Bone Ash | 3 lbs. 1 oz. |
| Arsenic | 3 lbs. 1 oz. |
| Fluor Spar | 1 lb. |
| Chromate Iron | 3 oz. |

Canary Opalescent

| | |
|------------------|--------------|
| Above base batch | 100 lbs. |
| Bone Ash | 3 lbs. 1 oz. |
| Arsenic | 3 lbs. 1 oz. |
| Fluor Spar | 1 lb. |
| Uranium | 4 oz. |

Chrome oxide cannot be used as a colorant with the base batch on account of the presence of nitre. Substitution of salt petre for nitre in the above batch prevents the clean "striking" that is characteristic of this particular opalescent glass. Other chrome compounds may be used, however, for example the phosphate of chrome, in combination with the lime batch containing nitre.

This opalescence is sensitive to changes in the proportion of soda ash in the batch as well as to the substitution of salt petre for nitre as indicated above. Batches should be made separately for each melt of this glass to insure that the proper proportion of soda ash is present. Changes in the proportion of lime or the analysis of the lime are not so important, and may vary considerably without affecting the clean striking.

The author found at one time that he was having considerable breakage in light blown opalescent articles, and that this breakage was materially reduced when the amount of lime in the batch was reduced to 135 lbs.; further that a reduction of the lime to 130 lbs. made the glass "sandy," indicating incipient devitrification. This, however, was doubtless due to the high magnesia content of the lime, and the breakage would not occur when a lime is used that is low in magnesia content.

CASING COLORS

In the following series of casing colors, that is, colored glasses formed by casing or plating a thin coating of colored glass inside of colorless glass, except for the ruby glass, the articles may be formed either by gathering first the colored glass, then cooling somewhat and gathering the clear glass over it, or the colored glass may be worked out into rolls, reheated and placed on the end of the pipe by the "caser" and then the clear glass gathered over it. In the case of ruby glass, the latter method only will apply, as the rolls must be kept under the heat until the color develops, as the glass is a rather deep yellow when first gathered.

STANDARD LEAD AND LIME BATCH

The following standard "Best Lead Batch" is used as the basis of this entire series of casing colors:

| | |
|------------|----------|
| Sand | 500 lbs. |
| Lead Oxide | 355 lbs. |
| Pearl Ash | 175 lbs. |
| Salt Petre | 33 lbs. |

The casing colors made with this batch are used for casing inside of crystal glass made from the following standard lime batch, for the reason that they have been found to stand together without breakage due to undue strain between the two glasses:

| | |
|----------|------------|
| Sand | 1500 lbs . |
| Soda Ash | 560 lbs . |
| Lime | 150 lbs . |
| Nitre | 100 lbs . |

It might seem superfluous to interject here that it is unnecessary to use decolorizer with the above lime batch when the glass is intended to be cased with a colored glass, as the decoloring effect will be entirely lost in the deeper coloring effect, but as a matter of fact the author knows of cases where hundreds, probably thousands of decoloring "doses" were thus wasted.

In comparing the composition of the lead and lime batches above given with the expansion co-efficients of their several components, it is found that the rules for compound glasses are carried out, though these batches were found thus compatible with each other long before the rules for compound glass were formulated.

The author finds an old note made in connection with the manufacture of ruby which shows a recognition of forces which were later organized into the rules for making compound glass, as follows: "When ruby stands on the outside and breaks on the inside, it is short of soda." It was known then, over twenty years ago, and had been known for quite a long time before, just as we know now, that a remedy for this "ruby which stands on the outside and breaks on the inside" is to add more soda to the outer glass.

We know now that the improvement is accomplished through the fact that the increased soda content of the outer glass increases its coefficient of expansion, and thereby makes it contract faster than the inner or casing glass, and thus compresses the surface of the latter, strengthening it in its power to withstand shock. With our present knowledge of the principles involved it would, of course, be more logical and economical to decrease the alkali content of the inner glass and thereby decrease its expansion coefficient to more nearly correspond with that of the outer glass.

Briefly, the rules for making compound glass require a difference in the coefficient of expansion of the two glasses involved, the inner or casing glass having the smaller coefficient and being considerably less in thickness than the outer glass. This means that in cooling the outer glass contracts at a more rapid rate than the inner or casing glass and has the effect of compressing the surface of the casing glass, in which condition it is much more resistant to strain or shock than if the two glasses had precisely the same coefficient. It is easily understood that if this condition were reversed, so that the surface of the inner glass were under a pull or tension instead of compression, it would tend to fly to pieces with the slightest shock or scratch on its surface.

It is important that the outer glass be much heavier than the inner glass, for two reasons. (1) that it may have the greater strength to resist the tension rising from the compression of the inner layer and (2) that it may also have the greater strength to stand up under the natural tendency in its own outer skin to cool and harden first and thereby set up a compression strain in its own outer surface at the expense of a corresponding tension strain in the inner layers.

As indicated above, the casing glass was not calculated to meet the rules laid out. The rich lead batch, however, is soft and much more flexible than the lime glass, and the richness of the batch helps to intensify the color and give a richer effect in many cases.

CASING GLASS BATCHES

Amber

| | |
|-----------------|----------|
| Best Lead Batch | 100 lbs. |
| Borax | 1 lbs. |
| Red Oxide Iron | 4 lbs. |
| Manganese | 13 oz. |

Amethyst

| | |
|-----------------|----------|
| Best Lead Batch | 100 lbs. |
| Manganese Oxide | 2 lbs. |

Amethyst

| | |
|-----------------|----------|
| Best Lead Batch | 100 lbs. |
| Oxide Nickel | 4 oz. |

Blue (Royal)

| | |
|-----------------|----------|
| Best Lead Batch | 100 lbs. |
| Cobalt Oxide | 6 oz. |

Black

| | |
|-----------------|----------|
| Best Lead Batch | 100 lbs. |
| Red Oxide Iron | 10 lbs. |
| Manganese Oxide | 4 lbs. |
| Cobalt Oxide | ½ oz. |

Green (Citron)

| | |
|-----------------|----------|
| Best Lead Batch | 100 lbs. |
| Oxide Chrome | 5 oz. |

Green (Olive)

| | |
|-----------------|----------|
| Best Lead Batch | 100 lbs. |
| Copper Scales | 2 ½ lbs. |
| Iron Scales | 2 ½ lbs. |

Ruby

| | |
|--|---------------|
| Best Lead Batch | 300 lbs. |
| Red Oxide Iron | 9 oz. |
| Manganese Oxide | 1 lbs. 12 oz. |
| Borax | 2 lbs. 8 oz. |
| White Ox. Antimony | 2 lbs. |
| White Ox. Tin | 2 lbs. 8 oz. |
| Regulus Antimony | 3 lbs. |
| Gold coin at the rate of \$20 for 500 lbs. | |

DIRECTIONS FOR RUBY: Dissolve the gold in a solution of 16 oz. hydrochloric acid and 8 oz. nitric acid, with one-half teaspoonful of red oxide iron added to the solution. Use a warm sand-bath to promote the solution, which will take about one-half hour to accomplish. Mix the batch and the coloring ingredients separately; scoop a hole in the pile of batch and put the coloring ingredients in the hole, then pour the gold solution

slowly into the coloring ingredients, mixing thoroughly, and when all is poured in, mix the batch and coloring ingredients well together and fill into the pot. When the glass melts plain, gather out and marver into rolls, let the rolls cool and then place in moderately hot lehr and allow to soak in the heat until the deep ruby color develops. For casing, "stick up" a roll, warm it in the glory-hole, cut off a suitable size piece and stick it on the red hot end of a pipe, pressing it on tightly with a casing tool and blowing slightly so that it does not stop up the pipe. Then gather the crystal glass over it.

As indicated earlier in this chapter, this formula has been in use for a great many years and was originated under the rule-of-thumb conditions then existing. It is entirely possible that there is considerable dead wood in the formula that might be eliminated by careful research work, which would involve a considerable amount of time and trouble. For instance, gold coin contains ten per cent copper, which almost certainly exerts some coloring influence in this glass; if so, and that color is ruby, then how far could we go in increasing the copper and decreasing the more expensive gold?

The author spent a great deal of time and work in trying to so readjust the proportions of materials in this batch as to have the color develop in the working or in the annealing operation immediately after working, and as a matter of fact did actually accomplish it at the first attempt in a small crucible, but the balance of conditions required for this is so delicate that it could not be repeated in quantities.

Gold ruby depends for its color on the finely divided metal in suspension in the glass, and in its progression from the combined (and therefore non-coloring) form to the extremely finely divided metal, and from that point on to the less finely divided metal, the particles gradually coalescing into larger and larger units, the period over which the fineness of division is right for the production of the ruby color is comparatively short.

Obviously in a glass which is gathered before the reduction has progressed to the proper coloring point and allowed to solidify, and the further development of the color brought on slowly by soaking in a moderate heat, the control of the proper coloring point is much more complete than in a glass in which the reduction is brought on rapidly with the intention of developing the color during the working period while the glass is soft.

Gold ruby glass which has just passed the proper coloring point exhibits a "liver" color, and, curiously, transmits the rays that it absorbed when at the proper point for the production of ruby color. That is, a glass that transmits the typical gold ruby color absorbs the balance of the spectrum, which is a greenish-blue mixture and this same glass, when the reduction, or more properly speaking, coalescing of particles, has progressed beyond that point, precisely reverses its coloring effects, absorbing the red and transmitting the greenish blue.

If a very dilute solution of chloride of gold in distilled water be placed in a perfectly clean bottle, and a few drops of ether, in which phosphorous has been dissolved, poured into it, a beautiful ruby-colored liquid is obtained, the color of which is due to metallic gold in an extremely finely divided state, and on allowing it to stand for some months, the metal subsides as a purple powder, leaving the liquid colorless. If any saline impurity be present in the gold solution, the color of the reduced gold will be amethyst or blue. This illustrates very strikingly the use of gold for imparting ruby and purple tints to glass and the glaze of porcelain.

The amber color in this lead batch is, of course, the iron-manganese amber; the carbon amber would be impossible in a lead batch, as the carbon would reduce the lead to a metallic state, and it would be found in metallic buttons in the bottom of the pot or tank.

The amethyst (a mixture of red and blue) is made from manganese oxide or nickel oxide, and neither of these oxides gives a chromatically correct imitation of the color of the natural stone, although nearly enough for most practical purposes. It has not yet been found possible to make the color synthetically by mixing a blue-coloring oxide with a red-coloring oxide, because the reducing conditions required for the production of the reds will not permit the formation of a blue; or conversely, a batch which is correct for the production of a blue color is not correct for the formation of a red color at the same time. Even so strongly coloring an oxide as cobalt oxide will not work in even a moderately reducing batch; that is, a batch with even a small amount of carbon or other reducing agent.

The black, of course, is made up of an excess of colorants, some of which absorb one section of the spectrum colors and others of which absorb the remaining spectrum colors, the total result being the absorption of all rays of light and the transmission of none. A thin sliver of black glass will usually show some one color predominating, and if it is desirable that the absorption of the rays be evenly balanced, the oxide or oxides responsible for the predominating color can be reduced and the others increased until a balance is reached so that even a thin sliver will show a neutral gray.

The Citron Green with oxide of chrome is possible with this batch only on account of the presence of salt petre; if nitre, the nitrate of soda, were substituted the color would be a muddy, brownish green.

OPAQUE WHITE

For Use With Casing Colors. (Outside.)

The following is an opaque white to be cased with the foregoing series of casing colors:

| | |
|------------------|-----------|
| Sand | 1500 lbs. |
| Soda Ash | 300 lbs. |
| Lead Oxide | 300 lbs. |
| Fluor Spar | 300 lbs. |
| Feld Spar | 250 lbs. |
| Kryolith | 50 lbs. |
| Nitrate Soda | 100 lbs. |
| Manganese | 3 lbs. |
| Arsenic | 10 lbs. |
| Carbonate Potash | 50 lbs. |

OPAQUE WHITE

For Use as Casing Glass. (Inside.)

The following is a white opaque glass, to be used as a casing inside of the standard Lime Crystal Glass:

| | |
|--------------|----------------|
| Sand | 50 lbs. |
| Soda Ash | 14 lbs. |
| Lead Oxide | 35 ½ lbs. |
| Nitrate Soda | 3 lbs. 5 ½ oz. |
| Arsenic | 3 lbs. 8 oz. |
| Bone Ash | 3 lbs. 8 oz. |

OPAQUE GLASSES

Opacity in glass can be likened to the stirring of an inert finely divided material, say powdered chalk for an example, into clear water. In the water, of course, it would settle down to the bottom in a short time, which would not be the case in the glass, on account of the relative densities and the viscosity of the glass, but in both cases it is merely the suspension in a liquid of a more or less foreign material which does not completely, if at all, lose its identity or suffer chemical change. In opaque glass, as a rule, the suspension of the foreign matter has a tendency to weaken the bond of the particles, and makes a more fragile material.

Opaque glasses are of two general types, the alabaster type of glass and the so-called "opal" (accented on the last syllable by an old glass-house custom). The chief differences in appearance between the two glasses are that the alabaster glass is not so dense a white as the opal is usually made, and that on holding up a thin section of the opal glass to the light a "ruddy glow" is transmitted, which is not the case in the alabaster type of glass.

The difference in the reactions that take place in the melting is that the opal glasses are more nearly permanent in their coloring power during the melt as well as afterwards, while the alabaster, depending for its peculiar type and density of color upon an incomplete reaction, is subject to irregularities in its density of color, due to the difficulty of stopping the process at precisely the right point. This difficulty is increased by the use of cullet, or waste glass, and if this cullet were to be rejected, of course, the cost of the glass would be very considerably increased. An excess of cullet gives a tendency toward transparency in the glass, proving that the opacity is dependent on a temporary condition which, when completed makes a more nearly, if not quite, transparent glass.

ALABASTER GLASS

The following is the formula for an alabaster glass used in 1894, which was adapted from an older English formula:

| | |
|---------------|----------|
| Sand | 480 lbs. |
| Carb. Potash | 120 lbs. |
| Soda Ash | 72 lbs. |
| Lead Oxide | 40 lbs. |
| Carb. Baryta | 12 lbs. |
| Salt Petre | 4 lbs. |
| Fluor Spar | 16 lbs. |
| Arsenic | 4 lbs. |
| Plaster Paris | 14 lbs. |

The ingredients outside of the fluor spar and plaster Paris (which is calcium sulphate) would give a transparent glass, and this proportion of fluor spar without the plaster Paris would be too small to make a completely opaque white.

In the manufacture of clear transparent glass with Sulphate of soda (salt cake) it is found necessary to add a portion of carbon to the batch, usually in the form of powdered coal, in order to complete the reaction and thereby form a clear transparent glass. The carbon combines with a portion of the oxygen in the sulphate of soda to form carbon dioxide, which passes off as a gas, and which leaves the glass making portion of the remainder, the sodium oxide (Na_2O) combined with (SO_2) gas, which latter passes off

at a much lower temperature than would be required to drive off (SO₃) gas without the aid of carbon to break it up.

The alabaster type of glass, when made with sulphates, is made with a batch that will melt at a comparatively low temperature, so that there will be a minimum of reduction of the sulphates, and the presence of carbon is avoided for the same reason, and on the contrary, nitre or salt petre are used for their oxidizing value.

As indicated in a preceding paragraph, there was considerable difficulty experienced in getting glass that was approximately uniform in density of color, and the plan of using one fourth cullet and three-fourths batch was adopted in order to make the conditions as nearly uniform as possible. Undecomposed sulphates always appear on the surface of this glass at the end of a melt. There may be some reduction of the calcium sulphate to calcium oxide with the consequent formation of (SO₃) gas, but the main reaction depends on comparatively low temperature for melting, evidently to avoid the complete reduction of the calcium sulphate, and so that as much of it as is required might remain in suspension in the glass.

FLUOR SPAR

Fluor spar, calcium fluoride, (CaF) is a common component of both types of glass. A typical analysis is as follows:

| | |
|------------------|--------|
| Calcium Fluoride | 97.91% |
| Alumina | 1.90% |
| Silica | 0.11% |
| Oxide Iron | 0.04% |
| Moisture | 0.04% |

This is a natural glass which fuses at about 1655° F. When introduced into glass batch as an opalizer there is a tendency toward a combination between the silicon of the sand and the fluorine of the fluorspar, to form silicon fluoride (SiF₄) which passes off as a gas.

It has been proven that in enamels made with fluor spar the above reaction takes place and is almost complete, and it is almost certainly true that it takes place to some extent in the reaction of glass making, but it seems equally certain that a large portion of it remains in the glass as suspended matter, largely retaining its identity as calcium fluoride.

In this connection it might be stated that any opalizer used in small proportions will fail to impart opacity to glass, and it is a case of adding more and more of the same or other opalizers until the saturation point has been reached and the glass loses its transparency and takes on a degree of opacity.

FELD SPAR

Feld Spar, which is a silicate of alumina and either potash or soda (or both), is a natural glass which approaches normal glass much more closely than or spar. It melts at 2160° F. Typical analyses are as follows:

| | Soda Feld Spar | Potash Feld Spar |
|------------|-------------------|---------------------|
| Silica | 64.14 | 65.95% |
| Oxide Iron | 0.87% | 0.12% |
| Alumina | 20.63% | 18.00% |
| Lime | 1.19% | 1.05% |

| | | |
|----------|--------|--------|
| Soda | 10.27% | 2.11% |
| Potash | 0.43% | 12.13% |
| Magnesia | 2.06% | trace |
| Moisture | 0.35% | |

To use an indirect method of analyzing the opalizing value of this material, if it were made up synthetically from sand, aluminum oxide, potash, soda, etc., and the proportion of alkalis were doubled and the silica decreased to a corresponding point, leaving the proportion of alumina the same as shown above, the mixture would be transparent, but would be at the point where a small addition of opalizer would be required to acquire a degree of opacity.

In other words, alkalis tend to reduce opacity, potash reducing opacity more than soda, and the alumina content appearing to be a matter of saturation, that is, up to certain percentage of alumina in the presence of a given percentage of alkali will leave the glass transparent, and beyond that point it takes on opacity.

KRYOLITH

Kryolith, or Iceland spar, is a double fluoride of sodium and aluminum, (6NaF , Al_2F_6). It melts at 1800°F . A typical analysis is as follows:

| | |
|----------|-------|
| Aluminum | 13% |
| Sodium | 32.8% |
| Fluorine | 54.2% |

This material is a powerful opalizer. It resembles fluorspar in its tendency to erode the clay of the pot or tank, kryolith being more corrosive in its action than fluorspar. This undoubtedly relates to the fact that both are fluorides and seems to indicate that the tendency in fluorides is to attack silicate of aluminum combinations, possibly with greater readiness than they attack free silica.

It is well known, or at least widely accepted among glass makers, that the addition of a silicate of alumina, such as china clay, to an opaque glass containing fluorides will reduce the erosion on the pot or tank, evidently by saturating or partially satisfying the tendency of the fluorides to attack silicate of alumina combinations.

TIN OXIDE

Tin oxide, on account of its high cost, is not often used now in opaque glasses. It is a powerful opalizer, apparently through retaining its entity while in suspension in the glass, and authorities state that glass with 7% to 20% of oxide of tin, when slowly cooled becomes opaque, and under the microscope shows long, needle-shaped crystals which, upon separation and analysis, are found to consist of pure tin oxide.

BONE ASH

Bone Ash, calcium phosphate $\text{Ca}_3(\text{PO}_4)_2$, is very similar in its action to tin oxide, and its property of precipitating or crystallizing under cooling and reheating is the basis of opalescent glass, making it possible to "strike" patterns in opaque white on a background of clear glass. Under certain conditions, and possibly to some extent under all conditions in glass making, the presence of bone ash tends to bring about devitrification in the glass. An instance in the writer's experience is cited under the heading of Opalescent Glass. It is used in opal glass for decorating because of its property of standing up under the heat, which property is doubtless related to its tendency to devitrify.

CHINA CLAY (KAOLIN)

China clay, or kaolin, is a silicate of alumina, and melts at 3326° F. It is apparently an inert filler or opalizer except insofar as it furnishes a material which, on account of its finely divided state, absorbs the attack of the fluorides and thus relieves the strength of the attack on the pot or clay vessel. This material is a definite chemical compound, and is used for Seger Cone No. 35.

Aluminum oxide would differ from china clay in its action only in that it would combine with silica to form silicate of alumina during the melting of the glass, while the china clay is a silicate of alumina already combined before being introduced into the batch. This is an important difference, however, because in its nature it would not attack the silica of the clay (either china clay or the clay of the pot or vessel), but would combine with the sand of the batch, and would thus have an important bearing on the ability of the mix to absorb opalizers before showing opacity. A significant clue to its effect on melting temperatures is that Seger Cone No. 36; with a melting point of 36° F. higher than the No. 35 cited above, is made by the addition of pure aluminum oxide to the china clay which composes the No. 35 Cone.

Sulphate of alumina which is sometimes used as an opalizer, is somewhat similar in its action to plaster paris in that it is a sulphate and tends to break up under the reaction. In this reaction the oxide of alumina formed by the break-up would act in a similar manner to oxide of alumina when added directly to the batch, as described in a previous paragraph.

RELATIVE VALUES OF OPALIZERS

On account of their value in illustrating the relative value of opalizers, and at the same time the conditions which affect the developing of a gold ruby color, the author cites the following tests from a series of 129 melts in small crucibles. This was following up the attempt referred to under the heading of Ruby in Casing Colors. The balance of conditions required to secure a ruby color which would develop during the working or annealing just after working were found to be very delicate in a batch made up from the Best Ruby Batch quoted in the chapter on Casing Colors, and the author had found that Rose Pinks, that is, opaque white glasses with a gold content for the developing of a pink color, were much more hardy, so to speak, and could be produced from several batches varying rather widely in composition.

This suggested the idea of taking such a Rose Pink batch as a basis and gradually reduce the opalizers while endeavoring to hold on to the ruby coloring, and thus possibly retain the hardness, or lack of delicacy of balance until the opalizers might be eliminated entirely, leaving a transparent ruby. The test with the notations of results on each are as follows, the original batch being designated A, the next batch B, then followed by 1, 2, 3, etc., (realizing that here might be a month' s job it actually took 20 days)

COMPARATIVE TESTS

| | A | B | 1 | 2 |
|------------------|-------------|-------------|-------------|-------------|
| Sand | 30 oz. | 30 oz. | 30 oz. | 30 oz. |
| Soda Ash | 7 ½ oz. | 7 ½ oz. | 7 ½ oz. | 7 ½ oz. |
| Lead Oxide | 2 ¼ oz. | 2 ¼ oz. | 2 ¼ oz. | 2 ¼ oz. |
| Potash | 2 ½ oz. | 2 ½ oz. | 2 ½ oz. | 2 ½ oz. |
| Feld Spar | 5 ¼ oz. | 2 ½ oz. | 5 ¼ oz. | 2 ½ oz. |
| Fluor Spar | 6 oz. | 3 oz. | 0 oz. | 3 oz. |
| Kryolith | 10.63 grams | 5 grams | 0.63 grams | 5 grams |
| Nitre | 21.26 grams | 21.26 grams | 21.26 grams | 21.26 grams |
| Oxide Tin | 11.54 grams | 12.54 grams | 14 grams | 14 grams |
| Oxide Antimony | 11.54 grams | 12.54 grams | 14 grams | 14 grams |
| Regulus Antimony | 15.39 grams | 16.39 grams | 17 grams | 17 grams |
| Manganese Oxide | 3.85 grams | 3.85 grams | 3.85 grams | 3.85 grams |
| Red Oxide Iron | 3.85 grams | 3.85 grams | 3.85 grams | 3.85 grams |
| Gold | 0.05 grams | 0.05 grams | 0.05 grams | 0.05 grams |

A. Good warm pink, developed on edge only by "warming in" in pot mouth. Somewhat harder than usual to develop the color. Very opaque.

B. Semi-opaque or translucent. No pink. Cutting feld spar, fluor spar and kryolith in half has reduced opacity about half, and has lost the pink color.

1. Bright green, transparent. Both opacity and color lost through elimination of fluor spar, though feld spar and kryolith were restored in full, and tin and antimonies slightly increased to help the development of the ruby coloring.

2. Green, very slight trace of opacity.

COMPARATIVE TESTS (CONTINUED)

| | 3 | 4 | 5 | 6 |
|------------------|-------------|-------------|-------------|-------------|
| Sand | 30 oz. | 30 oz. | 30 oz. | 30 oz. |
| Soda Ash | 7 ½ oz. | 7 ½ oz. | 7 ½ oz. | 7 ½ oz. |
| Lead Oxide | 2 ¼ oz. | 2 ¼ oz. | 2 ¼ oz. | 2 ¼ oz. |
| Potash | 2 ½ oz. | 2 ½ oz. | 2 ½ oz. | 2 ½ oz. |
| Feld Spar | 5 ¼ oz. | 0 oz. | 0 oz. | 0 oz. |
| Fluor Spar | 6 oz. | 6 oz. | 5 oz. | 6 oz. |
| Kryolith | 10.63 grams | 10.63 grams | 10.0 grams | 0 grams |
| Nitre | 21.26 grams | 21.26 grams | 21.26 grams | 21.26 grams |
| Oxide Tin | 14 grams | 14 grams | 17 grams | 17 grams |
| Oxide Antimony | 14 grams | 14 grams | 17 grams | 17 grams |
| Regulus Antimony | 17 grams | 17 grams | 20 grams | 20 grams |
| Manganese Oxide | 3.85 grams | 3.85 grams | 3.85 grams | 3.85 grams |
| Red Oxide Iron | 3.85 grams | 3.85 grams | 3.85 grams | 3.85 grams |
| Gold | 0.05 grams | 0.05 grams | 0.05 grams | 0.05 grams |

3. Turned a nice warm pink; very opaque. This is the same as A except the increase in the tin and antimonies, which made the color develop more easily. Same as 1 except restoring the 6 oz. fluor spar, which meant the difference between completely transparent and very opaque.

4. Nice warm pink; turned deeper and more easily than 3; slightly less opaque than 3, from omission of feld spar.

5. Very hard to develop color; opaque.

6. Developed easily; nice warm pink; opaque. In connection with 5 indicates that fluor spar seems to be most important factor in controlling the developing of the color, and that opacity due to fluor spar is stronger than that due to feld spar, and possibly stronger than that due to kryolith (both feld spar and kryolith have been omitted in this test, and still opacity persists).

COMPARATIVE TESTS (CONTINUED)

| | 7 | 8 | 9 | 10 |
|------------------|------------|------------|------------|------------|
| Sand | 30 oz. | 30 oz. | 30 oz. | 30 oz. |
| Soda Ash | 7 ½ oz. | 7 ½ oz. | 7 ½ oz. | 7 ½ oz. |
| Lead Oxide | 2 ¼ oz. | 2 ¼ oz. | 2 ¼ oz. | 3 oz. |
| Potash | 2 ½ oz. | 2 ½ oz. | 2 ½ oz. | 2 ½ oz. |
| Feld Spar | 0 oz. | 0 oz. | 0 oz. | 0 oz. |
| Fluor Spar | 4 oz. | 3 oz. | 4 oz. | 3 oz. |
| Kryolith | 0 grams | 0 grams | 0 grams | 0 grams |
| Nitre | 21 grams | 21 grams | 15 grams | 10 grams |
| Oxide Tin | 25 grams | 30 grams | 35 grams | 45 grams |
| Oxide Antimony | 25 grams | 30 grams | 35 grams | 45 grams |
| Regulus Antimony | 35 grams | 40 grams | 45 grams | 55 grams |
| Manganese Oxide | 3.5 grams | 3.5 grams | 0 grams | 3.5 grams |
| Red Oxide Iron | 3.3 grams | 3.5 grams | 3.5 grams | 3.5 grams |
| Gold | 0.05 grams | 0.05 grams | 0.05 grams | 0.05 grams |

7. Very slightly pink; hard to develop; opaque.

8. No pink; semi-transparent.

9. No pink; slightly opaque.

10. No pink; almost transparent.

Comparing 7 and 9, each with 4 oz. fluor spar and no feld spar or kryolith, 7 being opaque and 9 only slightly opaque, this difference in degree of opacity is apparently due to the decrease of nitre and manganese oxide or the increase in the oxide of tin and the antimonies. The color has been lost also through the same changes.

Have eliminated feld spar and kryolith from above equation.

COMPARATIVE TESTS (CONTINUED)

| | 11 | 12 | 13 | 14 |
|------------------|------------|------------|-------------|-------------|
| Sand | 30 oz. | 30 oz. | 30 oz. | 30 oz. |
| Soda Ash | 7 ½ oz. | 7 ½ oz. | 7 ½ oz. | 7 ½ oz. |
| Lead Oxide | 2 ¼ oz. | 2 ¼ oz. | 2 ¼ oz. | 3 oz. |
| Potash | 2 ½ oz. | 2 ½ oz. | 2 ½ oz. | 2 ½ oz. |
| Feld Spar | 0 oz. | 4 oz. | 5 ½ oz. | 6 ½ oz. |
| Fluor Spar | 4 oz. | 3 oz. | 4 oz. | 3 oz. |
| Kryolith | 0 grams | 0 grams | 0 grams | 0 grams |
| Nitre | 21 grams | 21 grams | 21.26 grams | 21.26 grams |
| Oxide Tin | 17 grams | 30 grams | 17 grams | 17 grams |
| Oxide Antimony | 17 grams | 30 grams | 17 grams | 17 grams |
| Regulus Antimony | 20 grams | 40 grams | 20 grams | 20 grams |
| Manganese Oxide | 3.85 grams | 3.5 grams | 3.85 grams | 3.85 grams |
| Red Oxide Iron | 3.85 grams | 3.5 grams | 3.85 grams | 3.85 grams |
| Gold | 0.05 grams | 0.05 grams | 0.05 grams | 0.05 grams |
| Calcium Chloride | 8 ½ oz. | | | |

11. Did not melt properly (characteristic of chlorides) ; transparent. green.
12. Almost white opaque; no pink.
13. Developed nice pink in one heating; opaque.
14. Pink, harder to develop than No. 13; opaque.

No. 11 not only confirms that calcium chloride acts similarly to the attempts to use salt (sodium chloride) direct in glass making, but being transparent proves what seemed obvious, that the fluorine content is the opalizing factor.

Comparing No. 13 and No. 12, the increase of fluor spar brought the pink coloration back in spite of a decrease of almost half of the oxide of tin and antimonies.

Comparing No. 13 and No. 14, the only difference being 1 oz. of fluor spar and the one with the greater quantity of fluor spar being the harder to develop the color, seems to indicate that the proportion of fluor spar in No. 13 is the critical percentage, and increase or decrease of this proportion hurts the coloring condition. The percentage of fluor spar figures 10.85% in this batch -- later tests indicate that 10% is more nearly the exact critical point.

The development of the elimination of the opacity from this point on showed that it was necessary to increase the Lead Oxide and alkali contents before the Fluor Spar could be reduced to a point that would leave the glass transparent and at the same time develop the ruby color. From this and the fact that the color was developed in several mixtures varying somewhat in percentages of the tin oxide and antimonies as well as fluor spar, the author is persuaded that control over the point in the process at which the color shall develop is more largely a factor of the fusibility of the mixture than of these materials.

COLORED GLASSES

The most important and most obvious property of glass is transparency but for some purposes this transparency is modified or even eliminated. Transparency in its strict definition means perfect transmission of light without any interruption or loss by absorption, and no glass fulfills this definition, but in the optical glasses this condition is approached with some degree of nearness, and so far as appears to an uncritical glance by the naked eye, the great majority of the commercial glass in use may be said to be transparent.

As stated in the chapter on Decoloration, the addition of decolorants, which are really colorants chromatically opposite to those colors inherent in the glass which are to be neutralized, always means an absorption of some of the spectral rays of which white light is composed. For instance, if we wish to color a transparent glass green we do not add a material which creates green rays or which converts the other rays into green rays, but merely a material which absorbs the rays other than green and allows the green rays to pass through unobstructed or almost completely so.

If we could assume the spectrum as mathematically divided into the seven primary colors, red, orange, yellow, green, blue, indigo and violet, it will be seen that a green glass would be one in which red, orange, yellow, blue, indigo and violet were absorbed; in other words, six-sevenths of the rays must be absorbed to a greater or less degree to allow one-seventh to predominate, and the glass is less transparent in proportion to the absorption of those six rays, and chromatically pure as it approaches extinction of the six other colors.

A mathematical division of the light rays is of course out of the question, for the reason, among others, that the rays which are most distinct to the eye are near the red end of the spectrum and have little or no effect on the photographic plate, while the rays most active on the photographic plate are near the violet end of the spectrum and have little effect on the human eye. As a matter of fact, photographs have been taken in a room completely dark to the naked eye by means of ultra-violet rays, which are rays beyond the violet end of the spectrum, and which are invisible to the eye.

EXPERIMENTS IN COLORS

To revert to the simile of the transparent liquid described in the chapter on Chemistry of Glass in which we have a vessel containing a colorless solution of nitrate of potassium and nitrate of sodium with an excess of nitric acid still unused; if we now add a metallic oxide whose nitrate gives a blue coloring, for instance, the whole solution will be colored blue as soon as it has been added and has had time for the free nitric acid to convert the oxide into the nitrate which gives the blue coloring.

Similarly in making colored glass, where the acid is silica or silicic acid, if the oxide of cobalt be added, the glass will be colored blue when the melt has been completed and the oxide has had time to be converted into the silicate of cobalt, which imparts a blue color, that is, absorbs the other rays of light to a greater or lesser extent and is transparent to the blue rays.

Again reverting to the colored liquid, if an oxide be added whose nitrate gives a yellow color, when the oxide has been in the solution sufficiently long to be converted into the nitrate, the solution will be green by mixture of the blue and yellow colorants, in other words the result of the absorption by the two different colorants will be that the greatest transparency will be for a color in the spectrum between the blue and the yellow, or green.

The similarity again applies to glass making; if to the glass already colored blue by the addition of cobalt oxide, there be added a small quantity of uranium oxide which by itself would produce a yellow coloring in the glass, a green will result as soon as the melt is complete and the uranium oxide converted into the silicate.

In making colored glass the use of the principles of mixing colors is practiced as well as the use of single colorants for the colors characteristic to them. The process, however, is not so simple as mixing paints in which a chemical change is not involved, because some glass colorants require oxidizing conditions in the batch while others require reducing conditions, and others are best developed in neutral conditions as regards oxidation.

Obviously a red color which required reducing conditions for its production could not be modified to a purple by the addition of a blue colorant which required oxidizing conditions for its production.

DECOLORATION

In the present-day production of "crystal" glass tableware, decorative articles, and the better grades of bottles, a better standard of color, or rather colorlessness, is required than has been the case at any previous time in the extensive history of the art of making glass.

This may appear to be a rather broad statement, especially in view of the "lost art" epoch in the history of glass, but that it is true is indicated first by the fact that the present standard of purity in raw materials is only made possible by distinctly modern

methods (including chemistry in particular) and modern machinery, and second by the failure to find specimens of colorless glass amongst the thousands of fragments of ancient examples of the glass-maker' s art.

However, with even the present high standard of purity of raw materials, there still remains in them a small but troublesome quantity of materials having a coloring effect, besides which working conditions, both as to mixing, melting and remelting cullet have a decided effect on the colorlessness of the resultant glass.

IMPURITIES IN SAND

Sand, the principal ingredient, comprising roughly two-thirds of the finished product, is usually a large factor and sometimes the largest factor in introducing foreign and objectionable matter into the batch. It will be easily understood that in a material used in such large proportions, even a small percentage of foreign matter will total considerably larger than would be the case of a material used in smaller quantities.

Glass sand occurs as a silica rock, and there are numerous deposits in the United States of a very high degree of purity. In some deposits the rock is quite hard and difficult to crush, while in other deposits it is very loosely bound and tends to disintegrate as soon as exposed to the action of the air.

The presence of organic matter and clay due to seepage is a matter that necessitates the rejection of the layer of rock nearest the outcrop, a layer of greater or less thickness according as the rock is more or less porous. In the better grades of glass sand, even the cleaner covered portion of the rock is washed after being crushed in order to reduce clay and organic matter to a minimum.

However, while there are numerous deposits of sand in the United States whose silica content runs 99.9% and even better, and iron, the principal coloring impurity, probably only one-half of the remaining .1%, by the time that same rock has been crushed between the chilled iron or steel jaws of the crusher and has next come into contact with the iron or steel surface of the dryer, the shovels, wheelbarrows or chutes, the abrasion natural to such a sharp-grained material has brought a small, but certainly not negligible quantity of iron into the batch.

In the manufacture of glasses where the degree of colorlessness, meaning the freedom from absorption of light, is essential, magnetic separators are used to remove such iron from the sand and other materials. It should be stated in this connection that optical glass is not "decolored" in the sense in which crystal glass for other purposes is decolored, but only in the use of the purest raw materials and melting receptacles and the exclusion of any material or action in the working that will hinder the most nearly perfect and unobstructed transmission of light.

In second grade sands, which are usually not washed and not handled so carefully, the percentage of iron is of course somewhat higher, as is also the clay and organic matter, which have not been removed by the washing which the better grade of sand receives.

SODA ASH IMPURITIES

The soda ash, while it is second in proportion to sand in the sand-soda-lime glasses which constitute the great bulk of the glass in the classes under consideration, is much more nearly chemically pure than any of the other materials used. This purity is a development of comparatively recent years, since the abandoning of the old LeBlanc

process of making soda ash by roasting salt-cake, the sulphate of soda, on iron plates in contact with carbon in the form of coal or coke.

In this process the contact of the moist sulphate, always containing some free sulphuric acid, which the iron plates under the action of heat, always produced a greater percentage of iron oxide. The author has plunged a magnet into a cask of this imported soda ash and brought it out fairly bristling with long flakes of iron oxide.

Present-day soda ash is made by the ammonia process or a modification of it, in equipment which gives the minimum of any contact which could introduce iron into the material, and consequently the improvement noted in the soda ash produced, although there is not complete freedom from iron.

LIME IMPURITIES

Next in importance is lime, usually introduced into the batch as ground burned lime, but in some cases as slacked or hydrated lime and in other cases as ground limestone, which is the carbonate of lime. While the lime in any form may contain magnesia in quantity from a trace up to forty percent in the dolomite limes, neither the magnesia nor the lime itself have coloring properties in glass, so that we are concerned with the other impurities.

These consist of iron and clay introduced in the material as it occurs in nature or in the operation of mining, burning and crushing in a manner similar to the introduction of similar impurities into the sand as referred to earlier in this chapter.

IMPURITIES IN NITRE

The nitre, or nitrate of soda, whose action as an alkali, oxidizer and "boiler" is referred to in a separate chapter, is also a source of introduction of foreign matter, usually as sulphate and chloride of sodium, which have a greening tendency in the glass, or organic matter, together with minute percentages of iron. A considerable portion of the impurity in nitre is introduced by its handling in jute sacks in which it is shipped from Chile, these sacks being continually moist from the wet crystals of nitre, and therefore taking up dirt whenever handled.

In the better grades of tableware, it is the practice of the manufacturer to purify the nitre by dissolving it in hot water in a suitable vessel, removing the organic matter forming into a scum on the surface, and rejecting the insoluble portion which settles down to the bottom. In this way clear transparent crystals are formed, which are obviously much purer than the crystals as they reach the factory in the jute bags, when they vary in color from dirty gray to a deep salmon pink.

SCALE FROM PIPES AND PUNTIES

One other source of bad color in glass is the glass from pipe ends in blown-ware factories, where particles of iron scale or rust peel off the pipe and remain with the glass knocked off. This also applies, but in a much smaller degree, to glass from the "punties" in pressed-ware factories, because the glass in contact with the iron is removed only a very few times during a turn. Obviously, the remedy in these cases is to keep such iron-contaminated glass separate from the clear cullet, and either reject it altogether or use it in the manufacture of colored ware, or such glass as need not be decolorized.

EFFECT OF MELTING CONDITIONS

Next, as to the melting conditions in their effect on the color. The greatest degree of freedom from color imparted by melting conditions is given by the use of the closed pot, which utilizes in melting the batch into glass, only such heat as is transmitted through the wall of the pot. This, while there is a loss in heating efficiency through lack of direct contact between the flame and the batch, obviates the coloring effect which such direct contact gives, and in localities where coal is the fuel used, the closed pot prevents the introduction of flying particles of coal ash into the glass, which ordinarily would have a trifling effect as to color.

The open pot, the day tank and the continuous tank, in the order given, tend to impart color to the resulting glass, and, while this action is usually stated as being the "reducing" action of the flame, it would appear questionable whether this is a proper designation for the actual condition. As a matter of fact, in metallurgical operations it has been found that the melting of metals in similarly shaped furnaces at temperatures corresponding fairly closely to those used in melting glass indicates a strongly oxidizing effect on the molten metal.

EFFECT OF DIRECT FLAME

Further, in the manufacture of optical glass it has been demonstrated that it is possible to gain an extreme degree of colorlessness by the use of pure materials even with such intimate and prolonged contact direct with the flame as is given by melting in the open pot, and that the use of closed pots did not measurably increase this colorlessness. That this is related to the fact that no "decolorants" are used, and particularly no manganese, makes a strong case for the belief that the "reducing action of the flame" bugaboo is largely the reducing or oxidizing or whatnot action of the flame on the oxide of manganese which has been used so long as a decolorizer, and that when the use of manganese is abandoned it will be found that the flame has little or no measurable effect on the colorlessness of the glass. The action of the flame is principally on the manganese.

EROSION OF POTS AND TANK BLOCKS

The composition of the pots and tank blocks is a source of introduction of iron into the glass through the erosion due to the contact of the alkali of the batch with the silicate of alumina and iron of the clay. Until this subject was investigated closely in working out the manufacture of optical glass, it was supposed that these clays were comparatively free from colorants, or at least that the percentages were small, and when divided by the slowness of erosion were negligible as to their coloring effect on the glass. It was found that this source of color was far from negligible, and moreover that clays containing one-fourth to one-tenth of the iron in the old clays which had been standard for so many years could be used, with surprising results in the light-transmitting properties of the glass melted in such vessels.

IRON PERSISTENTLY PRESENT

To summarize the color-producing materials introduced into the glass we find that iron in the form of the oxide or the finely divided metal is the material most persistently present. As the finely divided metal is quickly oxidized in the usual batch, we have only to consider the coloring effect of the oxides of iron, which extend from a full green to almost pure yellow, according to the degree of oxidation, and it is found that

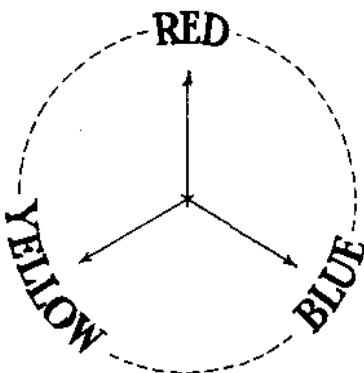
glass melted from commercial materials without decolorants exhibits color within this range.

Organic matter, first burning to carbon by the drying out of its moisture, then combining under the continued heat with the oxygen available, has a reducing effect by using up that oxygen and forming carbon dioxide, which passes off as a gas, without any direct coloring action. However, it will be realized that the introduction of any considerable quantity of organic matter through carelessness will bring with it some materials which will have a coloring effect, and cleanliness therefore is much to be desired.

MANGANESE OXIDE EFFECT

Now, as to the correcting or decolorizing, the old theory that manganese oxide decolorized through its oxidizing effect has been thoroughly exploded. The effect is purely one of chromatic neutralization. The study of light teaches that each color has its complement or opposite. For instance, taking the three primary colors, red, blue and yellow, it is found that an equivalent mixture of any two of these gives the complement of the third color; that is, green, which results from the mixture of blue and yellow, is the complement of red.

If these primary colors be represented as equi-distant points in the circumference of a circle (thus:)



A straight line drawn through the center of the circle from any given color will indicate its complement. Thus, if the green color imparted by the impurities involved in making glass were the pure spectrum green, it would represent a point midway between the blue and the yellow on the circumference of the circle, and its complementary color which we should have to produce for its neutralization would be the spectrum red.

However, the green to be neutralized in this case is a yellowish green, and is represented by a point closer to the yellow than the spectrum green would occupy, and therefore the complementary color would be represented by a point to the left of the red and toward the blue, which would be a violet. It happens that manganese oxide gives a violet coloring, and for many years it has been accepted as the proper material for decolorizing, although, as stated above, the greatest prominence was given to its oxidizing power, and its coloring power was considered secondary. In some cases it was found that the color imparted by the manganese was not sufficiently blue, and a small quantity of powdered blue, a dilute cobalt silicate, was used for this correction.

This action is similar to the familiar "bluing" operation in the washing of white cloth for the purpose of neutralizing the yellowish white that would otherwise be in evidence.

The use of manganese has its drawbacks, and it is being gradually withdrawn in favor of materials not subject to these drawbacks. In the first place, manganese is a "fugitive" colorant, that is, under varying conditions of heating and flame contact it varies markedly in its coloring properties, and where there is a large surface of glass materials containing manganese subject to continued contact with the flame, it is found that a large quantity is required, and the resulting glass is dark-colored and absorbs a great proportion of light, even when it is so balanced that the color is neither violet nor green, but a neutral gray.

It should be explained that chromatic neutralization in the manufacture of glass is not strictly decoloring, but really the opposite, the introduction of additional color, which, however, is so chosen as the chromatic opposite of the resident color, so that the color in the glass is a neutral gray, or as nearly so as possible for the glass maker to attain. Obviously, pure materials, by introducing less coloring and therefore requiring the introduction of less additional colorants for "decoloring," leaves the glass clearer and more transparent than would be the case if impure materials were used. It is possible by the addition of large quantities of these same coloring and decoloring materials in the same proportion to each other, to make a black glass, which absorbs practically all the light reaching it.

Manganese has a further draw-back, which is related to this same "fugitive" coloring quality. It is found that not only is the manganese sensitive to changes in the melting conditions, but that a glass must come out of the furnace a trifle "high" or violet colored in order to compensate for the burning out effect of the heat of the lehrs or annealing ovens, so that the glass when cool may be properly balanced as to color.

And this same principle extends still further; it is found that gas and electric light globes, for instance, made of glass "decolored" with manganese, gain a decidedly violet tinge after continued exposure to sunlight.

Efforts have been made, by the use of manganese in the granulated form, to delay its solution into the glass, and therefore introducing its coloring effect as late in the melt as possible, to reduce the burning out action of the flame.

Summarized, the use of manganese as a "decolorizer" is an asset only when used in small quantities, which involves the use of comparatively pure raw materials, and in closed pots. In tank furnaces, either day tanks or continuous tanks, the quantity that must be used, together with the action of the open flame makes even a fair balancing of color only an occasional incident between an inevitable swing from "high" to "low" color, and even the best of it has an absorption of color that excludes its use from any but the cheaper grades of ware.

THE USE OF SELENIUM

Selenium, either as the powdered metal or as seleniate of soda, has been rapidly gaining favor in the past few years as a substitute for manganese. Selenium is a metal rather closely allied chemically to sulphur, and consequently the conditions best for its use in glass are considerably different from those conducive to best results with manganese.

In the first place, nitre must be kept at a minimum, or a wasteful amount of the more expensive selenium will be required. On a test in a closed pot it was found that the

use of more than 6 lbs. of nitre to 1500 lbs. of sand diluted the coloring power of the selenium very appreciably, while the addition of charcoal in the proportion of 3 lbs. to 1500 lbs. of sand practically doubled the coloring power of the selenium.

TANK GLASS DECOLORIZER

Many manufacturers of tank glass have adopted selenium as a decolorizer and have discontinued the use of nitre with remarkably good results so far as uniformity of color is concerned. Their chief difficulty has been the boiling out of the "seeds" and to the present time their efforts to obviate this trouble have been along the line of increasing the melting temperature. The author is of the opinion that a small proportion of nitre would be helpful and would be economical as balanced against the extra fuel and extra wear on tank blocks occasioned by the extra temperature.

The use of salt cake in the proportion of 10 lbs. to 1000 lbs. of sand gives good color result with a small quantity of selenium, but has a tendency to increase the "seeds." The author believes a combination of materials might be worked out that would give the best results in selenium coloring and at the same time obviate the trouble with "seeds"

VALUE OF POLISHED SURFACE

Finally, it might be added that the polish of the glass, while not strictly a color effect, has a decided effect on the distinctness with which any color in the glass may be detected. If the surface of the glass is dull and unpolished, such as in the "unfinished" ware, this condition of the surface has a diffusive effect on the light striking it which makes the color stand out more distinctly, besides giving a much less agreeable appearance than a nicely polished surface. It is worthy of comment that the manufacturers who are most successful in producing high grade colorless glass pay the most attention to the polishing of their molds and to the thoroughness of the fire-polishing when "finishing" the glass.

LOSSES IN MELTING

| Material | Chemical Formula | Combines With Silica | Loss as Gas | Other Loss | Function |
|----------------------|---------------------------------|-----------------------------|---|-------------------|-------------------------|
| Sand | SiO ₂ | | none | moisture 1% to 5% | Acid |
| Soda Ash | Na ₂ CO ₃ | Na ₂ O + 58% | CO ₂ 42% | moisture 1% | Alkaline base |
| Lime (burned) | CaO | CaO | none | moisture 1% | Earthy base |
| Limestone | CaCO ₃ | CaO + 56% | CO ₂ 44% | moisture 1% | Earthy base |
| Nitre (Nitrate Soda) | NaNO ₃ | Na ₂ O + 36 1/2% | N ₂ O* 63 1/2% | moisture 2 1/2% | Oxidizer; Alkaline base |
| Potash (Carbonate) | K ₂ CO ₃ | K ₂ O + 68% | CO ₂ 32% | moisture 2 1/2% | Alkaline base |
| Salt Petre | KNO ₃ | K ₂ O + 46 1/2% | N ₂ O ₃ * 53 1/2% | moisture 2 1/2% | Oxidizer; Alkaline base |
| Salt Cake | Na ₂ SO ₄ | Na ₂ O + 43 1/2% | SO ₃ + + 56 1/2% | moisture 2 1/2% | Alkaline base |
| Red Lead | Pb ₃ O ₄ | PbO + 97 2/3% | O 2 1/2% | moisture 1/2% | Metallic base |
| Litharge | PbO | PbO | none | moisture 1/2% | Metallic base |
| Carbonate Baryta | BaCO ₃ | BaO + 77.6% | CO ₂ 22.4% | moisture 1% | Earthy base |

*N₂O₃ is really 2NO + O.

+ + SO₃ is really as SO₂ + O by addition of carbon to combine with one atom of oxygen

Moisture percentages are estimated to cover average conditions, and each plant should checkup actual figures covering their conditions.

APPLICATION OF THE TABLE OF LOSSES IN MELTING

Take the case of a lime batch as follows:

| | | |
|--------------|-----------------|---|
| Sand | 1500. | If test of your sand shows say 2% moisture, then the loss is 30 lbs., and the net in glass is 1470 lbs. |
| Soda Ash | 550. | Apply the 42% gas plus 1% moisture, makes 43% of 550 lbs. or 236 1/2 lbs. loss, netting in glass 313 1/2 lbs. |
| Lime (burnt) | 150. | Moisture loss only, 1 % or 1 1/2 lbs., netting in glass 148 1/2 |
| Nitre | 65. | Apply 63 1/2% gas loss plus 2 1/2% moisture, makes 66% of 65 lbs. or 43 lbs., netting in glass 22 lbs. |
| Total | 2265 lbs. | Total loss 1954 lbs. |
| | Batch filled in | 2265 lbs. |
| | Glass resulting | 1954 lbs. |

Loss in melting 311 lbs. or 13.75%
Decolorizers, being in small quantities, are ignored in this calculation.

VALUE OF LIMESTONE AND BURNED LIME

In comparing the value of limestone and burned lime, it must be borne in mind that limestone has a gas loss of 44%, while burned lime has no gas loss, therefore the price of limestone should be 56% of the price of burned lime.

OPTICAL GLASS

Inasmuch as the governmental agencies or those agencies which worked in conjunction with the government in the organizing and perfecting of methods of manufacture of optical glass during the period of the world war have in contemplation the publishing of a full and complete history of the various steps taken and methods evolved, as well as the results obtained, courtesy demands that this treatise be confined to those aspects of the optical glass practice as relate to factory practice and improvements that may be adapted to other branches of the manufacture of glass, leaving the strictly optical features for exposition by those able organizations, the Bureau of Standards and the Geophysical Laboratory of the Carnegie Institute. With this point in view we will enter into the optical problems only sufficiently to make the explanation of the processes intelligible.

QUALITIES REQUIRED

The qualities required in optical glass are: first, the highest degree of transparency, giving a maximum of transmission of light, or to state it from the opposite angle, the smallest absorption; next, varying degrees of the index of refraction, corresponding roughly with the density or weight of the glass; next, varying degrees of dispersion of light, especially in relation to the index of refraction; and last, by the use of materials having special qualities, swinging the dispersion towards different points of the spectrum.

The transparency required in optical glass goes to a degree considerably beyond the best of the ordinary requirements for other purposes, and as stated in the chapter on Decolorants, it is not permissible to add to the absorption of the glass by adding so-called decolorants, and transparency must depend upon purity of materials together with refinements of the manufacturing process which in other types of glass add to the color or absorption of the glass.

After a careful checking over of the raw materials, their degree of purity as relating to freedom from color-forming elements and methods of improving them in this respect, including, for instance, the magnetic separator for the removal of iron, it was found that the greatest source of color in glass is in the clay absorbed from the pot in which it is melted.

It was found that the ordinary pot clay batches contained iron in proportions around two to four per cent, and a new mixture of china and ball clays was evolved having an iron content in the neighborhood of .4%. By an application of the principles of colloid chemistry an ingenious method of pouring pots was

adopted, and at the same time avoiding the excessive shrinkage that would result in the drying of the pot if made with the amount of water ordinarily required to make the clay soft enough to pour.

Inasmuch as almost all the optical pots so made were allowed to cool and were broken up with the glass melted in them, thereby each pot giving service for one melt only, it was not demonstrated just how far such a composition for pots is consistent with long wear such as would be required in regular plate glass practice of lifting out the pot and pouring the contents on the table, or even in pot practice such as in tableware factories, where pots remain in service four to six months without being removed from the furnace.

POTS FOR OPTICAL GLASS

These pots were all of the regular plate-glass shape, being open, cylindrically-shaped vessels with a thickened band around the middle for engaging the tongs of the lifting crane. The size mostly used was 36 inches in diameter and 36 inches in height, with walls tapering in thickness from a little over two inches at the top edge to about three to three and a half inches in the bottom.

THE FURNACE

The pots, after being gradually brought up to the temperature of the furnace in regulation "pot arches," were transferred to the melting furnace, which was a square chamber of such size as to allow a margin of about one foot on each side of the pot used. These were fired with natural gas mixed with air and blown in under close regulation by means of an electric fan, being introduced at opposite sides of the middle of the furnace.

The front of the furnace consisted of a lifting door or "tuile," containing an opening in its middle through which the batch could be inserted in ladles and the stirring operation conducted, while the door could be raised to allow the introduction or removal of the pot. The temperatures best suitable for the melting of the different compositions of glass, the time during which the melt should proceed before stirring, the point to which the temperature should be dropped before and during the stirring operation, the time and temperature after the stirring is completed when the pot should be removed from the furnace, and the methods of cooling to get the greatest evenness and therefore the least strain, were all worked out from experience from day to day.

THE STIRRING MACHINE

The stirring machine is an ingenious affair which imparts a spiral motion to the glass in the pot by means of an electric motor and elaborate set of gears connected to a clay stirring-rod in the pot by means of a water-cooled iron pipe, the stirring rod being of a tapered shape about four inches in diameter at the top and two and a half inches at the bottom having a hole in its top end to engage the end of the water-cooled pipe.

COOLING THE GLASS

The pot of glass when removed from the furnace is placed on fire-brick or on the factory floor, surrounded by a Sheetmetal jacket containing insulating material, and the top surface of the glass being also covered with an insulating material and the whole allowed to stand for three days to cool before breaking the pot away and breaking the glass into chunks suitable for remelting into slabs, in which form the glass passes on to the next process.

It was found that for many purposes the glass could be rolled, ground and polished by regular plate glass methods, and at a considerable reduction in cost from that entailed in the regular optical process herein described, but the great majority of the glass produced in the United States during the period of the world war was made by regular optical methods and not the plate glass method.

CAREFUL COOLING ESSENTIAL

While at first glance it would appear that slow cooling and annealing of the glass in the pot is unimportant inasmuch as the glass is reheated for shaping into slabs, yet it is found that a poorly annealed or quickly cooled pot of glass breaks unevenly and with far greater waste than when properly annealed. This matter was found to be of sufficient importance to justify many experiments aimed at the uniformity of cooling of the different parts of the pot.

For instance, it was found, naturally, that the center or bottom of the pot, being shielded from cooling influences by the floor or brick on which the pot rested, was the last part to cool, and to balance this condition the experiment was tried of first dipping the pot hot from the furnace in a shallow vessel filled with water which quickly evaporated into steam after bringing down the temperature of the hot bottom to a point where it would become cool at about the same time as the remainder of the glass. While this particular experiment was to an extent along the right lines, it was not found sufficiently satisfactory to be adopted as standard practice.

CLOSE SEARCH FOR DEFECTS

Next the lumps so broken from the pot of glass were subjected to examination by the eye for such defects as are so visible, such as seeds, bubbles, stones and heavy striae or aluminous accretions from the clay of the pot. Then a further examination through a set of lenses aided by the immersion of the rough lump in a liquid of the same index of refraction as the glass for the detection of striae not otherwise visible.

REHEATING AFTER TESTING

The lumps which pass these tests are next reheated in suitable furnaces to their softening point and pressed into slabs averaging about four by six inches and about three-fourths in thick, which are given the most careful annealing so as to absolutely remove all strain which would interfere with the optical qualities of the glass.

ANNEALING

The critical high point for the annealing of each kind of glass was carefully determined, and the temperature of the ovens used kept safely above this figure until the oven was filled, when the temperature was reduced from this high point down through the period of solidification of the glass at the rate of five to not more than ten degrees Fahrenheit per hour.

In the construction of the ovens special heat-insulating materials were used, not merely for the sake of economy of fuel, but more largely to maintain a greater degree of uniformity of cooling. Obviously with a greatly diminished loss of heat by radiation there is less danger from irregularities in that. radiation loss.

GRINDING AND POLISHING

The dulled surface imparted by the pressing process is next removed by grinding and polishing, which is usually accomplished by assembling the slabs on suitable beds and treating the assembled slabs as one slab in the regular grinding and polishing methods. This grinding and polishing is not for the purpose of furnishing the surface required by the instrument maker for the instrument, but for the purpose of making the next examination for striae and other defects.

DETECTION ON STRIAE

For the detection of striae which have until this stage eluded the eye of the inspector a system of lenses is arranged in conjunction with a source of light through a small hole in a sheet of metal, which gives a very narrow beam of light which is passed through the slab of glass under examination and enables the experienced operator to detect minute interruptions in the homogeneity of the glass which indicates the comet-shaped streak of aluminous glass imbedded in the body of the glass, which is perfectly transparent and invisible to the naked eye.

OTHER FAULTS

Such faults as laps caused by faulty pressing, bubbles in not too great number, occasional stones, etc., are removed by sand-blasting, and again checked up by examination in a liquid of suitable index of refraction which fills up the interstices in the surface of the glass formed by the sand-blasting and makes it possible to see through what would otherwise be an opaque surface.

HEAVY PROPORTION OF LOSS

In addition to the rejections for faults as outlined above, the ordinary proportion of losses through broken pots in the furnace, and the fact that the flint and barium glasses do not run very true to index in spite of the greatest care in uniformity in raw materials and melting and stirring conditions, makes the shrinkage run into rather startling percentages.

As a matter of fact, the average of the various glasses showed a total shrinkage of about eighty-two per cent, leaving a net of optical glass suitable for

high grade instruments of about eighteen per cent. This net, however, could undoubtedly be increased through methods that would naturally suggest themselves in the course of a greater length of time, and especially with the removal of the urge for speed necessary during war times.

As to the glasses themselves, their transparency and freedom from seeds were favored by the use of liberal percentages of nitrates in the batch. The amount of cullet also was very carefully regulated, which was especially necessary in the flints and barium glasses, which were very difficult to keep true to index, while the borosilicate and ordinary crown glasses showed very little difficulty in this respect.

REFRACTION AND DISPERSION

The exact measurement of index of refraction and dispersion was by means of a spectrometer, while approximate measurement of index of refraction sufficiently close to judge in passing from one factory operation to another was by means of a color test in liquids, known as the monochrometer test.

The spectrometer is used not only for the measurement of the index of refraction, in other words the angle of deflection of light, but also for the measurement of certain definite lines in the spectrum which may always be artificially produced by the introduction of sodium and hydrogen into the source of light. The yellow sodium line corresponds with the Fraunhofer line C and the first two of the three hydrogen lines in the spectrum correspond with the Fraunhofer lines D and F.

The distances between these lines vary in the various types of glass, and is known as the dispersion. The relations between these values are reduced to a mathematical formula. Thus the index of refraction of the glass is expressed as the angle of deflection of the D line, designated n_D . Next, the angle of deflection of the line C, designated n_C , which is toward the left or red end of the spectrum, and the angle of the deflection of the line F, designated n_F , which is toward the right or violet end of the spectrum, are determined, and the difference between the n_C and n_F is called the dispersion. The relation of the dispersion to the n_D is designated v , whose

$n_D - 1$
value ($v = \frac{n_D - 1}{n_F - n_C}$) is a necessary factor in optical calculations for the
 $n_F - n_C$ achromatising of lenses.

Even after a standard formula and standard melting and reworking conditions are adopted and maintained, it is necessary to take readings of these values for each melt of glass, as optical calculations require an exactness to the fourth decimal place.

The dense flints or heavy lead glasses possess the greatest density and therefore the greatest index of refraction, while their v is the smallest. It will be noted in the following list of optical glasses that the progression of index of refraction is downward while the progression of the v is upward:

| | | | |
|--------------------|------------------------|---------|------|
| Dense Flint | average ⁿ D | 1.617 v | 30.1 |
| Light Flint | average ⁿ D | 1.570 v | 41.0 |
| Barium Crown | average ⁿ D | 1.577 v | 56.3 |
| Ordinary Crown | average ⁿ D | 1.524 v | 57.5 |
| Borosilicate Crown | average ⁿ D | 1.516 v | 63.4 |

The above assortment of standard types, while not as complete as desired for the purpose of giving full scope of optical effects, was found sufficient to permit the manufacture of the great majority of the instruments of precision required for war-time purposes.

PURITY OF MATERIALS NECESSARY

The developments of optical glass practice which should be adopted into standard practice in other lines are first, purity of materials, which is a matter for the manufacturers of such materials and which has been met by them in very satisfactory degree. Next, such precautionary measures as the use of the magnetic separator to remove not only abraded iron but also such things as nails, bits of wire, etc., which will otherwise occasionally get into the batch.

Third, the composition of pots and tank blocks, particularly as to their iron content, affords one of the largest factors of improvement in making colorless glass, and at this writing the manufacturers of glass melting refractories have commenced the introduction of these.

The exact knowledge as to the annealing conditions and their application to any particular type of glass is of tremendously far-reaching proportions.

THE ANNEALING PROCESS

Annealing is the process of gradually cooling glass during its period of solidification, so that its particles or succession of layers may have time to adjust themselves to each other in such a manner as to minimize or eliminate entirely the strains which are the principal source of the brittleness characteristic of almost all commercial glasses.

This is not to say that glass or any combination of silica is malleable, because there is no authentic evidence that malleable glass-glass which can be hammered into different shapes while cold has ever been made, but perfect annealing by eliminating the internal strain in the article leaves the full strength of the particular combination of silicates available to resist such shocks as glass is commonly liable to.

The extent to which good annealing improves this resistance to shock has been emphasized in the United States more particularly during the war than at any other time, and the results obtained in the war-time practice as developed in the manufacture of optical glass, which must of necessity be to the greatest possible degree free from strain, has pointed the way that improvement in commercial practice must take.

First, as to the principles involved. It is of course well known that glass may be quickly cooled from the temperature at which it is gathered from the furnace, averaging around 1900° F., to a point at which the ordinary article will stand alone, which in tableware practice, is in the neighborhood of 930° to 1000° F., without injury if its cooling is slowly graduated from that point down. In pressed ware practice where many articles are made at the rate of upwards of 2,000 pieces in a turn of four and a half hours, it will be seen that this period in the cooling of the glass is extremely rapid, and as a matter of fact, is hastened by the use of cold air blown into the article while still in the mold and even after being removed from the mold.

In the cooling from this point on lies the value of the annealing process. This means that the period in the cooling of the glass during which the annealing process is effective is the period during which the glass is solidifying, and the rate of cooling above or below that period of solidification is immaterial.

Glass quickly cooled during its period of solidification becomes cold first on its outer skin, and this outer skin reaches the temperature below which it does not contract while the inner layers are still contracting owing to their higher temperature. This higher temperature of the inner layers is due to the fact that glass is a poor conductor of heat, and the outer layer has had the effect of shielding the inner layers from the cooling effect of the air or other medium with which the outer layer is in contact.

This belated contraction of the inner layers in relation to the outer layer produces a pull inward by the inner layers and a corresponding compression in the outer layer. Glass has the power of resisting compression in a high degree, ranking in this property with granite, but its power of resisting pull is very much

less than its power to resist crushing, therefore the weak point - the point from which breakage will originate - is the inner layer, and if the cooling during the solidification is very rapid, the strain set up will break the article into hundreds of fragments.

A solid marble or ball of glass, unless some means is taken to cool it off rapidly, will harden naturally in a way that enables it to resist shock much better than most glass articles of commerce. This is due to two causes. (1) the large inner mass of glass forms a reservoir of heat that lets the temperature of the outer skin down slowly, and (2) the later and continued contraction of the inner layers creates a pull toward the center that compresses the outer layer and thereby strengthens its resistance to shock. At first glance these causes might seem to be inconsistent with each other, but really (1) is a case of automatic self-annealing to a degree which always falls short of one hundred per cent, and (2) refers to the fact that the strains which remain, owing to the nature of the article, are so disposed as to favor the only surface exposed to the shock, which is the outer surface.

If we apply the above rules to the case of a heavy, but hollow ball, a complete hollow globe, the automatic annealing effect (1) will be less marked on account of a smaller mass of glass to act as reservoir of heat, and the compression of the outer layer (2) would prevail in much the same way, but the inner surface of the globe would be in tension as opposed to the compression in the outer surface, and therefore the inner surface would be susceptible to any slight shock or scratch that might be imparted to it.

In a square flat slab of glass, say four inches square by a half-inch thick, if allowed to cool naturally, the edges, having double surfaces exposed, will cool quicker and deeper than the plane surfaces, and the corners, having triple surfaces exposed, will cool still more quickly and deeply. This forms a stiff frame around the hotter and therefore softer central portion of the glass, and the contraction of that central portion gives a pull inward against that frame, which has the effect of bowing in the middle of each side, a slight bowing in around the middle line of the edges of the slab, and a decided thinning of the center of the slab.

If the slab were well annealed, the application of the annealing heat from the outside would reverse the cooling action on the edges and corners first, and would make them hot and soft, with the aid of the heat still emanating from the inner body of the glass. The stiff outer frame being thus removed, the whole of the mass is in position to contract slowly and regularly toward the center and minimize strain. The thinning of the central portion would still persist, but would be so delayed as to more completely give way to the natural contracting effect, and therefore minimize the strain.

Obviously, within certain limits, the thicker the article the greater the strain between the layers, and a very thin piece of glass requires very little annealing because its inner layers are so close to the outer layer as to cool approximately at the same moment. In a very thick piece of glass, on the other

hand, the inner layers are so massive and are so insulated from the outer cooling influence that they form a reservoir of heat which is conveyed back to the outer layer, and if the latter is not in contact with any rapid conductor of heat, a fair degree of annealing is automatically accomplished.

The great majority of the commercial articles of glass, especially in table ware, bottles, packers goods, etc., come between the two extremes cited above, and it becomes necessary to minimize the strain by means of some process of annealing. The shape of the article is a large factor in acquiring strain in the process of manufacture. Sharp, thin corners adjoining thick portions, or stems consisting of heavy bulbous portions divided by narrow contractions, a thin body joined to a thick stem, or a pattern having abrupt changes of conformation from very thick to very thin, all tend to add to the strain in the article over and above that which would exist in an article whose thickness and conformation were more regular and uniform.

THE ANNEALING LEHR

The function of the annealing lehr or oven of whatever form is to so maintain the heat of the outer layer or skin of the article as to permit time for the inner layers to complete their cooling and contracting as nearly as possible at the same time that the outer layer reaches the same point.

This discussion, in order to simplify its statement, is directed at the method of annealing in lehrs, which is the means by which the vast majority of commercial glass articles are annealed. The lehr is a continuous oven in the form of a long tunnel, having a fire-box at the front or end wherein the ware is introduced, and having an endless chain of pans by means of which the ware is gradually withdrawn from the heat imparted by the fire-box.

The temperature at the fire-box end of the lehr in present practice for the articles mentioned above averages in the neighborhood of 950° F., but of course the composition, thickness and shape of the articles must be taken into account in setting the proper temperature for the beginning of the annealing process.

A PRACTICAL HIGH TEMPERATURE TEST

The importance of setting this temperature at the right point and maintaining it with the greatest uniformity has been emphasized in war-time practice, and a plan has been evolved by which the proper temperature for each particular kind of glass may be determined. It is recommended that a rod be drawn from the glass in question about four feet long and $\frac{1}{4}$ to $\frac{3}{8}$ inch in diameter, and placed in the lehr to be used, resting on a brick under its middle,, allowing the ends to extend outwardly without any support. The heat is then gradually increased and the temperature, as shown by the pyrometer, noted at the point where the ends of the rod sink about one inch. This temperature may be noted as the highest temperature at which strain may exist in the glass under test, and may safely be adopted as the standard temperature for the fire-box end of the lehr in annealing ware made of that glass.

Inasmuch as successful annealing depends upon the slowness and uniformity with which the temperature of the articles is reduced, it is just as important to know the lower limit of temperature of the period of solidification, the period below which no strain can be imparted to the glass, as it is to know the high limit referred to above.

MINIMUM TEMPERATURE STRAIN LIMIT

One authority, after testing a number of optical and other special glasses, has concluded that the maximum drop of temperature between the high limit above which no strain can exist and the low limit below which no strain can be imparted to any of the glasses in the group under his observation, is about 175° F., and this drop in temperature was evenly divided over a period of four weeks. The factor of safety in this practice was very high, and American practice in the manufacture of optical glass has developed that dropping the temperature over the period of solidification at the rate of five degrees Fahrenheit per hour is consistent with an absolute absence of any evidence of strain, and further that there is little danger when the rate is made ten degrees per hour.

SOME LEHR PRACTICE SUGGESTIONS

The author makes the suggestion that present lehr practice, which starts at about 950° F. and delivers the article in from five to eight hours at the ordinary temperature of the atmosphere, a drop of almost 900° at the rate of 110° to 180° F. per hour, (eleven to eighteen times the fastest optical glass practice), could be improved with very slight changes in the present equipment.

If the present lehrs were so heated as to drop the temperature at the rate of 50° F. per hour, which is still five times as fast as the fastest optical glass practice, the annealing would be twice as good as it is at present, and the breakage would be reduced and the strength of the articles increased proportionately.

This could be accomplished by merely a rearrangement of the draft by making the main stack opening much further back in the lehr, and dampering off most if not all of the draft from the center of the lehr extending the fire-box back further into the lehr and tapering off more gradually the amount of fuel entering each flue of the fire-box; stopping off the greater part of the air which enters through the openings in the front of the lehr, using self-closing doors for introducing the ware into the lehr; and, most important of all, using the proper temperature for the high point.

It will be obvious in this latter connection that if the lehr is needlessly hot, by say 100°, the time in the lehr until the real critical temperature is reached is lost time and subtracts from the time available for the reduction of temperature in the actual period of solidification.

One factory manager has made curtains for the rear end of his lehrs from a great number of short lengths of asbestos cord reaching down to the pans, which is excellent in checking air currents in the lehr, thus reducing the percentage of breakage.

In an eighty-foot lehr, and taking an average time of eight hours for annealing, the ware would be dropped in temperature over a range of 400°, and the temperature at each successive ten-foot point in the lehr would be 50° lower than the preceding one. If the test of the glass, for instance, showed that the critical high point of annealing is 800°, then the arrangement of the heat and draft should be such as to give a temperature of 800° at the point where the ware first touches the lehr; the pyrometric couple located ten feet back of the first one should be maintained at 750°, the next one 700° and so on until the ware came out at the back with a temperature around 450°, at which point solidification in the glass is absolutely complete and no further strain can be set up in the glass, regardless of how fast it might be cooled from this point down.

It stands to reason that proper adjustment of the annealing conditions demands the use of pyrometers, and it has been demonstrated beyond question that a very liberal use of pyrometers is one of the very best investments that can be made.

TYPICAL EXPERIENCE OF A MANAGER

One factory manager tells of an experience with an article of such irregular shape that his breakage at the back of the lehr was very heavy, so much so that it was decided to abandon the manufacture of the article unless this condition could be improved.

After trying many different plans, chiefly directed toward getting the article in the lehr as hot as possible, the manager in desperation decided to reverse this plan and try sending them in the lehr as cold as they could safely be allowed to get, so he directed that six of the articles accumulate on the stand before the first two should be carried into the lehr, the next two carried in when two more had accumulated on the stand, and so on.

At the same time he increased the temperature of the front end of the lehr to a point that would have melted down the ware if it had been carried in as hot as had been his former practice. Rather to his surprise, his breakage by means of this plan was reduced to a very nominal percentage, and the item has been successfully made ever since.

The high initial temperature of the lehr had the effect of slowly soaking through the firm outer layer until it acquired the temperature of the still hot and soft inner layers, by which time the ware had been pulled back out of the hottest zone sufficiently to start the flow of heat outwardly after having been held measurably near an equilibrium for a considerable length of time during the critical period in the annealing.

This is a practical demonstration of the operation of the laws governing annealing as outlined above, and further tends to prove that ordinary practice in annealing falls considerably short of what might be accomplished with the same equipment with comparatively trivial changes in arrangements.

CONCERNING ATMOSPHERIC CONDITIONS

It is found that atmospheric conditions have a considerable effect on the results of the annealing accomplished in a given set of lehrs. This is usually due to an insufficiently high stack or its unfortunate location in relation to neighboring high roofs, or even nearby high hills which create swirls in the air which occasionally blow directly down the stack.

In many cases where the direction of the wind has been such that the ware came out of the back of the lehr hot, it has been the cause of alarm to the factory manager, but needlessly so, because as a matter of fact perfect annealing conditions are more nearly approximated when the ware comes out hot than when it comes out cool, as indicated above. The use of swinging ventilator tops to the stacks is the remedy in most cases for reverse drafts.

THE BATCH AND ANNEALING

While on the subject of breakage and annealing, it is appropriate to say that the composition of the glass is a very large factor in the matter of breakage. If the batch is mixed in large units and not thoroughly mixed, obviously each pot or each section of batch entering the tank, if a tank be used, will vary in composition, which is bad from many practical standpoints, but especially the matter of annealing and breakage.

If the composition of the glass is so calculated as to be of better heat-conducting properties, then the annealing is more readily and easily accomplished, because the temperature of the inner and outer layers is more rapidly conducted from one to the other, and the strains thus reduced.

If the composition of the glass be directed toward a reduction of the coefficient of expansion, then the amount of expansion to be adjusted by annealing is reduced, and the danger of breakage from this source correspondingly reduced, but of course the annealing must be over the solidification period of this glass, which is usually much higher than other glasses.

An intelligent revision of the batch along these lines can be made at a very moderate cost per ton, and will show results in reduction of breakage and improved product that will pay the cost many times over. As a matter of fact, the addition of small quantities of the oxides used for the above purposes reduces appreciably the temperature necessary to melt, and gives a product superior in many ways.

ELECTRICALLY HEATED LEHRS

Tests of electrically heated lehrs for annealing glass are under way at this writing and instruments have been perfected whereby any required rate of reduction of temperature can be carried out automatically. This method eliminates draft, which is one of the biggest drawbacks to perfect annealing in the present lehrs.

These tests are being made in lehrs very similar in shape to the present horizontal tunnel-shape lehrs, and also in a type of lehr having several towers through which the ware must travel up and down on a continuous chain, so as to get the amount of time of travel of the ware with as little floor space as possible.

Moreover, the cost of operation of these lehrs will be very moderately, if at all, in excess of the cost of the gas or other fuel now used to heat the lehrs.

FUTURE IMPROVEMENT

As an illustration of the extent to which the available strength of glass can be increased -- meaning by "available" the inherent strength of the glass due to its composition minus the internal strains -- it is common practice in the manufacture of optical glass to remove any portion of a slab of glass by means of a hammer directed against the corner to be removed, the slab of glass resting against a sharp steel anvil edge. The piece breaks off cleanly under a blow that would shatter an ordinary annealed piece of glass into a thousand pieces. The author ventures the statement that the very greatest improvement in glass for general purposes lies in more perfect annealing; that present annealing does not eliminate one-half of the internal strain, and that when that internal strain is eliminated or nearly so, the glasses now made, without any change in composition will withstand shocks, both of sudden heat and cold and of violence that will surprise those who have manufactured them for years without realization of the qualities of the materials that have passed through their hands.

MELTING TEMPERATURES

The practical glassmaker has ever before him the problem of quality, quantity and economy. He must melt his sand with as little of the more expensive ingredients as possible, consistent with the production of the quality of material required in his product. Yet when he reduces the fluxes, soda and potash, he increases the temperature required to melt the batch into glass. If he is making glass in a pot furnace with closed or "covered" pots, the pots themselves will mark his limit in the direction of upward temperatures by the caving in of the crowns of the pots, but usually he will only have attained this condition in an effort to shorten the time required to "plain" his glass.

MELTING TIME FOR CLOSED POTS

All of these factors enter into the problem, and successful management consists in the best compromise between them. Long experience indicates very clearly that the glass should melt in from 22 to 26 hours, preferably the shorter time. Glass melted more quickly is of better quality than glass made of the same ingredients but taking a longer time to melt. It is less likely to be cordy, stringy or seedy.

Also there is obviously an advantage in getting more melts per week per pot. It frequently happens that a difference of an hour in the average melting time for a pot of glass will mean a difference of one melt per week; if the last melt for

the week is just too late for Saturday morning' s work, then it is a loss, and must wait until Monday.

The present-day development of pot-making as regards temperatures is such that the best working temperature for a pot-furnace with covered pots is 2400° to 2600° Fahrenheit. Higher than this is likely to cave in the crowns of the pots, and lower than this, except for glasses requiring low-temperature melts for special reasons, is not economical.

MELTS IN CONTINUOUS TANKS

In glass made in continuous tanks the author knows of one instance where a temperature of 3000° Fahrenheit is maintained in the melting chamber for the manufacture of bottles. The manager arrived at this practice for reasons of supposed economy, chiefly directed at the elimination of nitrate of soda from his batch. A soda-lime batch made without nitre, as explained in another part of this book, requires a considerably greater heat to melt the glass thinly fluid enough to permit the smaller bodies of entrapped air to push themselves up through the viscous mass.

HARD USAGE ON TANK BLOCKS

He accomplished the purpose of making a fair grade of lime flint bottle glass, still containing some seed, however, but at the expense of the tank blocks, especially the spout leading from the melting chamber to the working chamber, which is the point of greatest wear in any continuous tank. His tank blocks had to be replaced once every year, besides frequent mending of the spout, and the cost of this relining, if it had been expended in the softening of his batch by the addition of nitre, or more soda, or better still, by the addition of small quantities of two or three different metallic or earthy bases, would have given him not only a better product, but practically doubled the life of his tank blocks, and very likely have shown a cash saving in addition.

The proper kind of a batch would have been figured so as to melt at 2500° to 2700° and would have softened down the wear and tear on his tank blocks through the high temperature, saving many dangerous leaks and wearing out of the blocks at inopportune times and would have safely given him two seasons' wear out of his blocks. It will be easily perceived that if a tank gives way a month before the end of a fire, the month' s work is lost, as it would be impossible to tear down and rebuild in time to get production in a month.

The effects of the different ingredients on the melting temperatures are treated under the headings of the separate material.

FAULTS IN MELTING

The usual faults that develop in the manufacture of glass are seeds, cords, waves, striae and reams, stones, scum, and so-called "salt water."

Seeds are the small bubbles of entrapped air introduced when the batch was filled in the pot, or bubbles of gas formed by the decomposition of the

carbonates, nitrates or sulphates under the influence of heat in the presence of silica. When seeds are present in the finished article it means that the glass was worked before it had time to thoroughly melt. If the composition of the glass is such as to usually give a clear, plain, silvery glass, then an occasional attack of seediness is most likely caused by a chilling of the furnace during the melting operation.

EFFECT OF INTERRUPTED MELT

Any such interruption of the melting process, it has been shown by repeated experiences, stiffens the batch and makes it impossible for the gases to work their way up and out while the glass is so cooled, and further, that when the higher temperature is again restored, for some reason the bubbles of gas do not have the lifting power to clear the glass, but persist as small bubbles or seeds, which it is almost impossible to get rid of.

Glass which is persistently seedy in spite of proper temperature conditions needs the addition of nitre so as to form the large bubbles constituting the "open boil" which culminates in proper time in perfectly clear, plain glass. This action is treated more fully under "Nitrate of Soda."

The term bubbles merely applies to large seeds, which, however, may be mechanically introduced into the glass instead of in the same manner that seeds are produced. Glass full of large bubbles would indicate that it had been "taken down" and cooled to the working temperature just before it would have "plained up." In optical glass, quite large bubbles are sometimes stirred into the glass when the stirring operation is continued after the glass gets stiffened beyond the proper point.

CORDS, STRIAE, ETC.

Cords, waves, striae and reams are four names for the same thing, or at least names for slightly different manifestations of faults having the same cause, which is the accretion of particles of aluminous clay from the pot or tank block in which the glass is melted, and which because of their high alumina content are almost insoluble in the glass, but tend to float on the surface or streak through the body of the glass, and while transparent, have a different index of refraction from that of the body of glass in which they are imbedded. When they occur on the surface they have sufficient stiffness to interrupt the smoothness of the surface of the glass.

The term cords is applied to distinct streaks on the surface of blown glass which have sufficient prominence that they can be felt when the hand is passed over the surface. When they are less prominent but still visible on the surface of the glass, they are called waves.

Striae is the term used in optical glass to denominate the same character of fault, but means are taken to discover such aluminous accretions even when they occur under the surface and would be invisible to the naked eye. It is especially necessary that optical glass be free from striae, because of the irregular refracting

of the ray of light which would result in inaccuracies in the instrument in which such glass might be used.

The term reams is applied to the same fault when it shows on the surface of plate or window glass. This accounts for the weird distortions of objects when seen through a poor quality of window glass.

REMEDIES DESCRIBED

The means taken to remedy this character of fault have taken three angles. One has been by means of introducing alumina or silicate of alumina in the form of kaolin or china clay in small quantities, with the idea of saturating the batch up to or near its capacity for absorbing aluminous combinations, so that it would have less action on the clay of the pot. All clays are eroded to a greater or less extent under the combined action of heat and alkalis. The reason that cullet is less corrosive on the pots or tank blocks is that the completed glass is acid in its chemical character, the same as the clay, while in the unmelted batch the free alkali has opportunity for contact with the clay and tends to a degree to combine with it.

Another plan which has been used with some degree of success is almost opposite in principle to the above. It consists of the addition to the batch of small quantities of fluor spar which is corrosive in its action, and appears to be especially so in its action on aluminous glass; at any rate, there appears to be good ground for accepting the statement that it seems to dissolve these faults to a sensible degree and tends to make the glass clear and free from cords.

The third angle has had to do with the composition of the pots. Patents have been recently taken out covering a clay into which a quantity of finely ground silica has been thoroughly mixed. It is claimed that while the erosion of the clay continues, that the silica admixture tends to make the erosion uniform and in such small particles as to be absorbed into the glass uniformly instead of in streaks or lumps. While this would seem to increase the rapidity with which a pot or tank block would erode to a point where it would have to be replaced, it is pointed out that the erosion in this case is uniform over the body of the clay, while pots and tank block usually wear through in streaks.

Some glasses are more corrosive than others, and therefore accumulate more strai or cords than others. Some tanks are worked very hard-high temperatures and fast working-which gives more erosion on the tank blocks, particularly on the "spout" between the melting chamber and the working chamber, and the cords, etc., will naturally be greater in number in such cases.

Some of the cords occur in glass which is to be pressed, in which it is practically invisible on the surface, and therefore can be ignored to a considerable extent. Such a fault in an opaque or translucent glass would be practically if not entirely invisible.

SURFACE SCUM AND SALT WATER

The formation of scum on the surface of the glass is usually the result of dirt of an insoluble nature accidentally introduced into the batch, frequently from scraping loose bits of clay into the pot from the breast-wall of the furnace after having filled the pot. Impure materials, such for instance as undissolved sulphate or chlorides in the soda or potash, will form a scum, and if the undecomposed sulphates be in sufficient proportion, the so-called "salt water," which is merely liquified sodium sulphate, will form and float on the surface of the glass, and must be raked or ladled off. In a glass whose composition renders it particularly liable to this difficulty it is found desirable to fill the pot extra full of batch, so that the "salt water" may run off the surface and out of the pot.

Water must not be allowed to come in contact with this liquid sulphate, or an explosion would ensue. In a clear glass, carbon as finely powdered coke may be thrown on the surface, and will break up the sulphate so that its alkaline value may be saved to the glass, but it is doubtful if it is economical to do this, as the tendency is to form a top layer of glass richer in alkali than the body of the glass. In glasses made translucent by means of sulphates, the formation of "salt water" is quite frequent, and carbon must not be added, as it "plains" the glass and boils out the small seeds or bubbles of sulphurous gas which give the translucent effect.

CONCLUSION

In conclusion, the writer wishes to emphasize that this book is not offered as being the "last word" in the sense of leaving nothing more to be said. Far from it; in fact the further investigation proceeds the wider the field appears to be. At any stage developments may appear which bring up new questions.

For instance, take the case of iron oxide. Make an opal glass and color it with iron oxide, and you have a glass that will develop a surface stain (brown) which will not appear on the same glass without the iron oxide. Take an opalescent colored glass and add iron oxide to the colorants and you find that the iron oxide coloring smears through both the transparent and the "struck" or opalescent white portion. Doubtless there is a relation between the two reactions. What is the real explanation, and can it be put to commercial use?

Again, in blast furnace practice in making iron, an excess of lime is used to take the silica away from the iron oxide, and in the presence of coke and the requisite heat the oxygen is removed and the iron precipitated as a metal. That makes the old conception that iron is so intimately bound up with and inseparable from glass forming materials -- a sort of necessary evil -- look ridiculous.

Right along this line also, it comes with a sort of surprise to learn that a number of other bases, including lime, lead, copper and manganese, have a greater affinity for silica than has either soda or potash. In fact, it seems to be a case of the alkalies being more loosely combined with the silica than any other ordinarily used base, which is probably why highly alkaline glasses are poor weather resistants.

These are only a few of the hundreds of questions that suggest themselves for answer, and in the quest of the everlasting "why" something useful and commercially practical quite frequently develops.

If this book is accepted as a successful compilation of the author's experiences and those of his friends among the practical men in the industry, and as a serious attempt to analyze cause and effect, resulting in stimulating thought and bringing out something useful it will have accomplished his aim.

Price \$6.00

American Glass Practice, by Harry Bastow was originally published by *The Glassworker* magazine in Pittsburgh, PA in 1920.

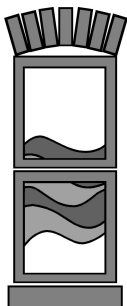
The publisher described it as "A practical book devoted to actual glass factory conditions, with problems discussed in a manner that will be readily understood by the layman."

The book includes:

- 28 glass batch formulae, including one for gold-ruby
- A discussion of glass making materials and impurities
- A series of tests on the value of opalizers
- A chapters on annealing
- A table of reactions and losses in melting

The material will be of general interest to students of glass history, and useful to both studio glass workers and to those concerned about the remediation of former glass factory sites.

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