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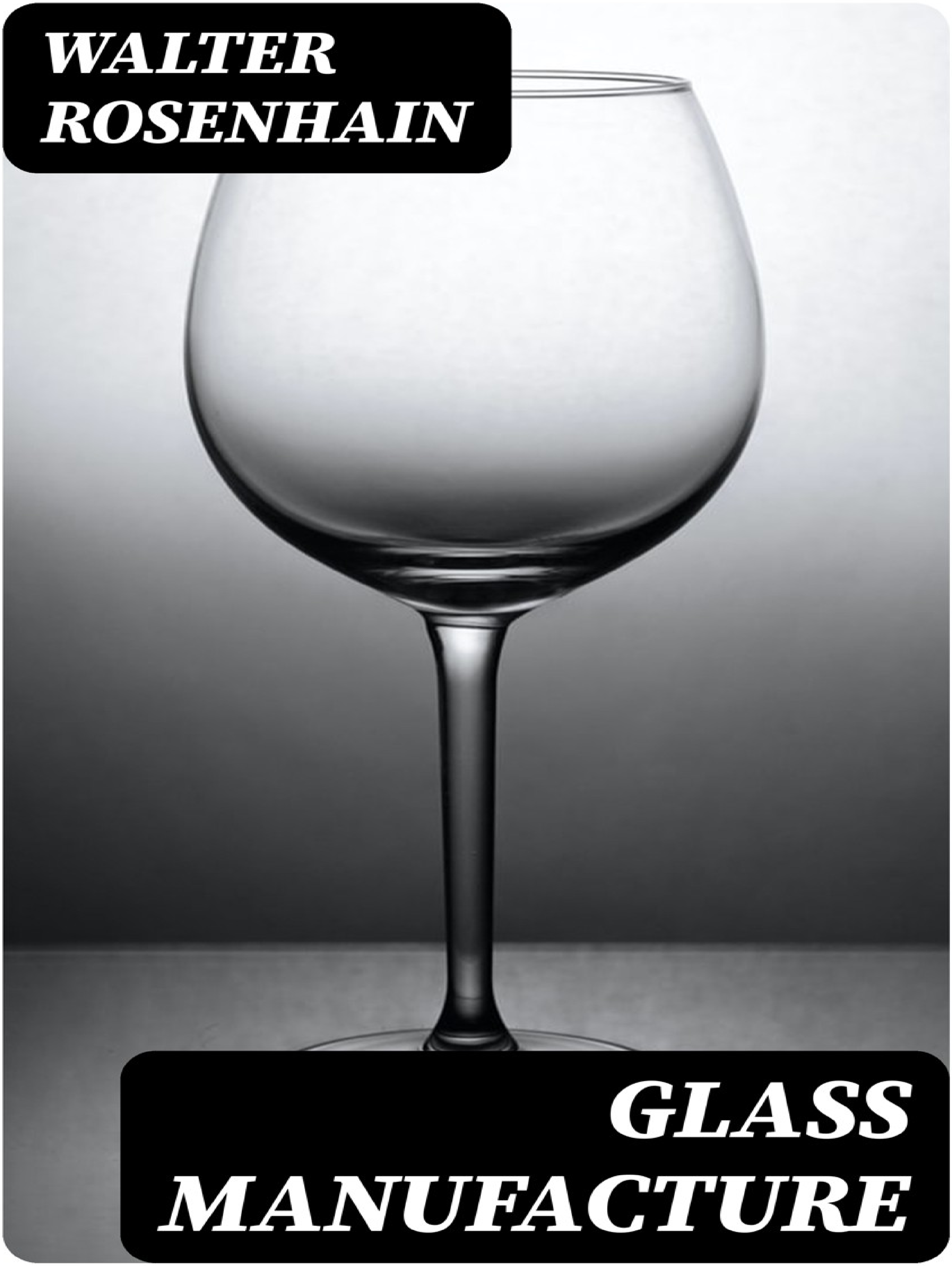

GLASS MANUFACTURE

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Glass Manufacture

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PREFACE

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The present volume on Glass Manufacture has been written chiefly for the benefit of those who are users of glass, and therefore makes no claim to be an adequate guide or help to those engaged in glass manufacture itself. For this reason the account of manufacturing processes has been kept as non-technical as possible; no detailed drawings of plant or appliances have been given, and only a few illustrative diagrams have been introduced for the purpose of avoiding lengthy verbal descriptions. In describing each process the object in view has been to give an insight into the rationale of each step, so far as it is known or understood, and thus to indicate the possibilities and limitations of the process and of its resulting products rather than to provide a detailed guide to the technique of the various operations. The practical aim of the book has further been safeguarded by the fact that the processes described in these pages are, with the exception of those described as obsolete, to the author's definite knowledge, in commercial use at the present time. For this reason many apparently ingenious and beautiful processes described in earlier books on glass have not been mentioned here, since the author could find no trace of their employment beyond the records of the various patents involved. On the other hand the reader must be warned to bear in mind that the peculiar conditions of the glass manufacturing industry have led to the practice on the part of manufacturers of keeping their processes as secret as possible, so that the task of the author who would give an accurate account of the best modern processes used in any given department of the industry is beset with great difficulties. The author has endeavoured to steer the best course open to him under these circumstances, and he would appeal to the paucity of glass literature in the English language as evidence of the difficulty to which he refers.

In addition to these difficulties, which arise largely from considerations of a commercial nature, the writer of a book on glass is further confronted with technical difficulties of no inconsiderable order. As already indicated, the aim of the present author has been to describe processes from the point of view of principles and methods rather than as mere rule-of-thumb descriptions of manufacturing manipulations, but in doing this he is met at every turn by the fact that from the scientific side the greater part of the field of glass manufacture is a "terra incognita." In making this statement the labours of many eminent scientific workers are by no means forgotten, but the entire field is so large and beset with such great experimental difficulties that even the labours of a list of investigators that includes the names of Fraunhofer and Faraday, Stokes, Hopkinson, Abbé and Schott, have resulted in little more than an accumulation of empirical data which, while they have been productive of great direct practical results, have left the science of glass still in a very elementary condition. To take two examples in illustration of this fact we may mention the question of the connection between chemical composition and any of the physical properties of glass, such as refraction and dispersion of light, and on the more mechanical side the question why all processes, such as rolling or moulding, which involve the contact of hot glass with metal result in a roughening of the glass surface. The former question has been studied by several of the investigators named above, Schott and Abbé having particularly devoted an enormous amount of labour and money to the study of the question with results which have proved disappointing from the scientific point of view. By prolonged experimenting and the employment of a costly system of trial and error an important series of novel and useful glasses has been produced by these workers, but no law by whose aid the optical properties of a glass of given chemical composition could be predicted has yet been discovered, and as a summary of the known facts only the vaguest general principles are available for the guidance of those who wish to produce glasses of definite properties. The same applies in a similar degree to most of the other properties of glass, with the exception, perhaps, of density and thermal expansion; attempts to generalise from the known data of a limited number of glasses generally meet with unqualified failure. The conclusion which one is forced to admit is that the fundamental principles underlying the nature and constitution of glasses have yet to be discovered. A study of the other question mentioned above as an example of the limitations of our knowledge leads to the same conclusion; an almost endless succession of inventors have busied themselves with devices for overcoming the roughening action of rollers and moulds upon glass, but without any real success. A long list of other examples of the same kind could be given, our knowledge of the physical and chemical principles underlying many of the phenomena met with in glass manufacture being deplorably deficient. It will thus be seen that to write a truly scientific account of glass manufacture is at the present time impossible, and the reader is asked to bear this in mind if he should find the chemical or physical explanations given in this book less frequent or less adequate than could be desired.

Having dwelt somewhat emphatically on the limitations of our present scientific knowledge as applied to glass manufacture, it is perhaps scarcely necessary at the present time to emphasise the fact that this state of affairs should act as the strongest incentive to further investigation of the whole subject. The difficulty, however, lies in the fact that such investigation can scarcely be carried on by voluntary workers in ordinary laboratories, but must be undertaken with the active help of glass manufacturers at their works. Glass is essentially a substance that cannot be satisfactorily handled in small quantities, particularly so far as all the phenomena connected with its production and manipulation while hot are concerned; the influences of containing vessels, of furnace gases and of rapid cooling are all enormously exaggerated if ounces instead of hundredweights or tons of glass are used for experimental purposes, and these influences and others of the same nature vitally affect all the results of small-scale laboratory operations. The progress of our scientific knowledge of glass —and the consequent development of the glass industry from its present state where rule-of-thumb and “practical experience” still hold excessive sway—lies in the hands of those concerned in the industry itself. It must be admitted that to undertake such work involves the expenditure of much time and money on the part of a manufacturer, while the field is so large and the problems so complicated that any adequate return cannot be promised for the *immediate* future; on the other hand the very size of the field and the difficulty of the problems offers the promise of the greatest ultimate reward; a really important scientific discovery in connection with glass would be certain to bring in its train industrial developments whose limits it is impossible to foresee. The industrial success of the glass-works of Schott in Jena is often quoted as a brilliant example of commercial success resulting from purely scientific investigations in this actual field; an example of still greater magnitude is furnished by the success of the aniline dye works of Germany which are built up on purely scientific achievements. The glass industry as a whole, supplying some of the absolute necessaries of modern life, should be capable of offering the greatest rewards to success, and the example of other industries has shown that *ultimate* success is bound to reward properly-conducted and perseverant scientific research. Nowhere is this more urgently needed than in the whole field of glass manufacture.

The author is indebted to Mr. W.C. Hancock for valuable assistance in the reading of proofs and various suggestions in connection with the contents of this book.

GLASS MANUFACTURE

CHAPTER I.
THE PHYSICAL AND CHEMICAL PROPERTIES OF GLASS.

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Although the term “glass” denotes a group of bodies which possess in common a number of well-defined and characteristic properties, it is difficult to frame a satisfactory definition of the term itself. Thus while the property of transparency is at once suggested by the word “glass,” there are a number of true glasses which are not transparent, and some of which are not even translucent. Hardness and brittleness also are properties more or less characteristic of glasses, yet very wide differences are to be found in this respect also, and bodies, both harder and more fragile than glass, are to be found among minerals and metals. Perhaps the only really universal property of glasses is that of possessing an amorphous structure, so that vitreous bodies as a whole may be regarded as typical of “structureless” solids. All bodies, whether liquid or solid, must possess an ultimate structure, be it atomic, molecular or electronic in character, but the structure here referred to is not that of individual molecules but rather the manner of grouping or aggregation of molecules.

In the great majority of mineral or inorganic bodies the molecules in the solid phase are arranged in a definite grouping and the body is said to have a crystalline structure; evidences of this structure are generally visible to the unaided eye or can be revealed by the microscope.

Vitreous bodies on the other hand are characterised by the entire absence of such a structure, and the mechanical, optical and chemical behaviour of such bodies is consistent only with the assumption that their molecules possess the same arrangement, or rather lack of arrangement, that is found in liquids.

The intimate resemblance between vitreous bodies and true liquids is further emphasised when it is realised that true liquids can in many instances pass into the vitreous state without undergoing any critical change or exhibiting any discontinuity of behaviour, such as is exhibited during the freezing of a crystalline body. In the latter class of substances the passage from the liquid to the crystalline state takes place at one definite temperature, and the change is accompanied by a considerable evolution of heat, so that the cooling of the mass is temporarily arrested. In the case of glasses, on the other hand, the passage from the liquid to the apparently solid condition is gradual and perfectly continuous, no evolution of heat or retardation of cooling being observed even by the aid of the most delicate instruments. We are thus justified in speaking of glasses as “congealed liquids,” the process of congealing in this case involving no change of structure, no re-arrangement of the molecules, but simply implies a gradual stiffening of the liquid until the viscosity becomes so great that the body behaves like a solid. It is, however, just this power of becoming exceedingly stiff or viscous when cooled down to ordinary temperatures that renders the existence of vitreous bodies possible. All glasses are capable of undergoing the change to the crystalline state when kept for a sufficient time at a suitable temperature. The process which then takes place is known as “devitrification,” and sometimes gives rise to serious manufacturing difficulties.

Molten glass may be regarded as a mutual solution of a number of chemical substances—usually silicates and borates. When cooled in the ordinary way these bodies remain mutually dissolved, and ordinary glass is thus simply a congealed solution. The dissolved substances have, however, natural freezing-points of their own, and if the molten mass be kept for any length of time at a temperature a little below one of these freezing-points, that particular substance will begin to solidify separately in the form of crystals. The facility with which this will occur depends upon the properties of the ingredients and upon the proportions in which they are present in the glass. In some cases this devitrification sets in so readily that it can scarcely be prevented at all, while in other cases the glass must be maintained at the proper temperature for hours before crystallisation can be induced to set in. In either of these cases, provided that the glass is cooled sufficiently rapidly to prevent crystallisation, the sequence of events during the subsequent cooling of the mass is this: as the temperature falls further and further below the natural freezing-point of one or other of the dissolved bodies, the tendency of that body to crystallise out at first rapidly increases; as the temperature falls, however, the resistance which the liquid presents to the motion of the molecules increases at a still greater rate, so that two opposing forces are at work, one of them an increasing tendency towards crystallisation, the other a still more rapidly increasing resistance to any change. There is thus for every glass a certain critical range of temperature during which the greatest tendency exists for the crystallising forces to overcome the internal resistance; through this range the glass must be cooled at a relatively rapid rate if devitrification is to be avoided; at lower temperatures the crystallising forces require increasingly longer periods of time to produce any sensible effect, until, as the ordinary temperature is approached, the forces of internal resistance entirely prevent all tendency to crystallisation.

The phenomena just described in reality constitute the natural limit to the range of bodies which can be obtained in the vitreous state: as we approach this limit the glass requires more and more rapid cooling through the critical range of temperature, and is thus more and more liable to devitrify during the manufacturing processes, until finally the limit is set when no industrially feasible rapidity of cooling suffices to retain the mass in the vitreous state.

While the range of bodies that can be obtained in the vitreous state is very large, only a comparatively small number of substances are ordinarily incorporated in industrial glasses. With the exception of certain special glasses used for scientific purposes, such as the construction of optical lenses, thermometers and vessels intended to resist unusual treatment, all industrial glasses are of the nature of mixed silicates of a few bases, viz., the alkalies, sodium and potassium, the alkaline earths, calcium, magnesium, strontium, and barium, the oxides of iron and aluminium (generally present in minor quantities), and lead oxide. The manner in which these various elements enter into combination and solution with one another has been much investigated, and the more general conclusions have been anticipated in what has been said above. It is abundantly evident that glasses are not definite chemical compounds, but rather solutions, in varying proportions, of a series of definite compounds in one another. In many cases the actual constitution of industrial glasses is so complex as, for the present at all events, to baffle adequate chemical expression.

One of the factors that limit the range of possible compositions of glasses has already been indicated, and two others must now be discussed. For industrial purposes, the cost and rarity of the ingredients becomes a vital bar at a certain stage; thus the use of such elements as lithium, thallium, etc., is prohibitively costly. In another direction the glass-maker is very effectively restrained by the limitations of his furnaces as regards temperature. The presence of excessive proportions of silica, lime, alumina, etc., tends to raise the temperature required for the free fusion of the glass, and when this temperature seriously exceeds 1600° C., the manufacture of the glass in ordinary furnaces becomes impossible. Thus pure silica can be converted into a glass possessing very valuable properties, but the requisite temperature cannot be attained in regenerative gas-fired furnaces such as are ordinarily used by glass manufacturers. The production of this glass has accordingly been carried on upon a small scale only by means of laboratory furnaces heated by oxy-acetylene flames, while latterly a less perfect variety of silica glass-ware has been produced on a large scale by the aid of electric furnaces.

Such methods are, however, obviously limited to very special products commanding special prices.

A further limitation in the choice of chemical components is placed upon the manufacturer by the actual chemical behaviour of the glass both during manufacture and in use. As regards chemical behaviour during manufacture, it must be borne in mind that, although glasses are of the nature of solutions rather than of compounds, yet these solutions tend towards a state of saturation; thus a glass rich in silica and deficient in bases will readily dissolve any basic materials with which it may come in contact, while, on the other hand, a glass rich in bases and poor in acid constituents such as silica, boric acid or alumina, will readily absorb acid bodies from its surroundings. During the process of melting, glass is universally contained in fire-clay vessels. These are chosen, as regards their own chemical composition, so as to offer to the molten glass a few of those materials in which the glass itself is deficient; yet a limit arises in this respect also, since glasses very rich in bases, such as the very dense lead and barium glass made for optical purposes, rapidly attack any fire-clay with which they may come in contact. The finished glass also betrays its chemical composition by its chemical behaviour towards the atmospheric agents, such as moisture and carbonic acid, with which it comes in contact; glasses containing an excessive proportion of alkali, for example, are found to be seriously hygroscopic and to undergo rapid decomposition, especially in a damp atmosphere.

Within the limits set by these considerations, the glass manufacturer chooses the chemical composition of his glass according to the purpose for which it is intended; for most industrial products the cheapest and most accessible raw materials that will yield a glass of the requisite appearance are employed, while for special purposes the dependence of physical properties upon chemical composition is utilised, as far as possible, in order to attain a glass specially suited to the particular requirements in question. Thus the flint and barium glasses used for table and ornamental ware derive from the dense and strongly refracting oxides of lead and barium their properties of brilliancy and weight. The fusibility and softness imparted to the glass by the presence of these bases further adapts it to its purpose by facilitating the complicated manipulations to which the glass must be subjected in the manufacturing processes.

Taking our next example at almost the opposite extreme, the hardest “combustion tubing,” which is intended to resist a red heat without appreciable softening, is manufactured by reducing the basic contents of the glass to the lowest possible degree, especially minimising the alkali content, and using the most refractory bases available, such as lime, magnesia, and alumina in the highest possible proportions. Such glass is, of course, difficult to melt, and special furnaces are required for its production, but on the other hand this material meets requirements which ordinary soda-lime or flint glass tubing could never approach. Another instance of these refractory glasses is to be found in the Jena special thermometer glasses and in the French (Tonnelot) “Verre dur”; the best of these glasses show little or no plasticity at temperatures approaching 500° C., and have thus rendered possible a considerable extension of the range of the mercury thermometer. Further modification of chemical composition has resulted in the production of glasses which are far less subject to those gradual changes which occur in ordinary glass when used for the manufacture of thermometers—changes which vitiated the accuracy of most early thermometers. A still more extensive adaptation of chemical composition to the attainment of desired physical properties has been reached primarily as a result of the labours of Schott and Abbé, in the case of optical glasses. The work of these men, and the developments which have followed from it, both at the works founded by them at Jena and elsewhere, have so profoundly modified our knowledge of the range of possibilities embraced by the class of vitreous bodies, that it is not at all easy at the present time to realise the former narrow and restricted meaning of the term "glass." The subject of the dependence of the optical properties of glass upon chemical composition will be referred to in detail in Chapter XII. on "Optical Glass," but the outline of the influence of composition on properties here given could not be closed without some reference to this pioneer work of the German investigators.

The chemical behaviour of glass surfaces, to which we have already referred, is of the utmost importance to all users of glass. The relatively neutral chemical behaviour of glass is, in fact, one of its most useful properties, and, next to its transparency, most frequently the governing factor in its employment for various purposes. Thus the entire use of glass for table-ware depends primarily upon the fact that it does not appreciably affect the composition and flavour of edible solids or liquids with which it is brought into contact—a property which is only very partially shared even by the noble metals. Again, the use of glass windows in places exposed to the weather would not be feasible if window-glass were appreciably attacked by the action of water or of the gases of the atmosphere. For these general purposes, it is true, most ordinary glasses are adequately resistant, but this degree of perfection in this respect is only the outcome of the centuries of experience which the practical glass-maker has behind him in the manufacture and behaviour of such glass. When, however, a higher degree of chemical resistance is required for special purposes, as for instance when glass is called upon to resist exposure to hot, damp climates, or is intended to contain corrosive liquids, the rules which are an adequate guide to the glass-maker in meeting ordinary requirements are no longer sufficient, particularly when the glass is expected to meet other stringent requirements as well. It has, in fact, frequently happened that a glass-maker, in striving to improve the colour or quality of his glass, as regards freedom from defects, brilliancy of surface, etc., has spoilt the chemical durability of his products. The reason lies in the fact, long known in general terms, that an increased alkali content reduces the chemical resistance of glass, while at the same time such an increase of alkali is the readiest means whereby the glass-maker can improve his glass in other respects by making it more fusible and easier to work in every way.

This subject of the chemical stability of glass surfaces attracted much attention during the later part of last century, and careful investigations on the subject were carried out, particularly at the German Reichsanstalt (Imperial Physical Laboratory) at Charlottenburg. Here also the labours of Schott and Abbé proved helpful, until at the present time such glass as that used by the Jena firm in the production of laboratory ware, and certain other special glasses of that kind, are fitted to meet the most stringent requirements.

Leaving aside the inferior glasses, containing, generally, more than 15 per cent. of alkali, the behaviour of glass surfaces to the principal chemical agents may be summed up in the following statements. Pure water attacks all glass to a greater or lesser extent; in the best glasses the prolonged action of cold water merely extracts a minute trace of alkalies, but in less perfect kinds the extraction of alkali is considerable on prolonged exposure even in the cold, and becomes rapidly more serious if the temperature is raised. Superheated water, *i.e.*, water under steam pressure, becomes an active corroding agent, and the best glasses can only resist its action for a limited time. For the gauge-glass tubes of steam boilers working at the high pressures, which are customary at the present time, specially durable glasses are required and can be obtained, although many of the gauge-tubes ordinarily sold are quite unfit for the purpose, both from the present point of view and from that of strength and "thermal endurance."

In certain classes of glass, the action of water, especially when hot, is not entirely confined to the surface, some water penetrating into the mass of the glass to an appreciable depth. The exact mechanism of this action is not known, but the writer inclines to the view that it arises from a partial hydration of some of the silica or silicates present in the glass. If such glasses be dried in the ordinary way and subsequently heated, the surface will be riddled with minute cracks, some glass may even flake off, and the whole surface will be dulled. As such penetrating action sometimes takes place—in the poorer kinds of glass—by the action of atmospheric moisture when the glass is merely stored in a damp place, it is often mistaken for "devitrification." This latter action, however, is not known to occur at the ordinary temperature, although glass when heated in a flame frequently shows the phenomenon; it is, however, entirely distinct from the surface "corrosion" just described. Water containing alkaline substances in solution acts upon all glasses in a relatively rapid manner; it acts by first abstracting silica from the glass, the alkali and lime being dissolved or mechanically removed at a later stage. Water containing acid bodies in solution—*i.e.*, dilute acid—on the other hand acts upon most varieties of glass decidedly less energetically than even pure water, and much less vigorously than alkaline solutions; this peculiar behaviour probably depends upon the tendency of acids to prevent the hydration of silica, this substance being thereby enabled to act as a barrier to the solvent action of the water upon the alkaline constituents of the glass. The better varieties of glass are also practically impervious to the action of strong acids, although certain of these, such as phosphoric and hydrofluoric, exert a rapid action on all kinds of glass. Only certain special glasses, containing an excessive proportion of basic constituents and of such substances as boric or phosphoric acid, are capable of being completely decomposed by the action of strong acids, such as hydrochloric or nitric, the bases entering into combination with the acids, while the silicic and other acids are liberated.

In connection with the action of acids upon glass, mention should be made of certain special actions that are of practical importance. The dissolving action of hydrofluoric acid upon glass is, of course, well known. It is used in practice both in the liquid and gaseous form, and also in that of compounds from which it is readily liberated (such as ammonium or sodium fluoride), for the purpose of "etching" glass, and also in decomposing glass for purposes of chemical analysis. Next in importance ranks the action of carbonic acid gas upon glass, especially in the presence of moisture. The action in question is probably indirect in character; the moisture of the air, condensing upon the surface of the glass, first exerts its dissolving action, and thus draws from the glass a certain quantity of alkali, which almost certainly at first goes into solution as alkali hydrate (potassium or sodium hydroxide); this alkaline solution, however, rapidly absorbs carbonic acid from the air, and the carbonate of the alkali is formed. If the glass dries, this carbonate forms a coating of minute crystals on the surface of the glass, giving it a dull, dimmed appearance; this, however, only occurs ordinarily with soda glasses, since the carbonate of potassium is too hygroscopic to remain in the dry solid state in any ordinary atmosphere. Potash glasses are, as such, no more stable chemically than soda glasses, but they are for the reason just given less liable to exhibit a dim surface. If the dimming process, in the case of a soda glass, has not gone too far, the brightness of the surface of the glass may be practically restored by washing it with water, in which the minute crystals of carbonate of soda readily dissolve, while separated silica is removed mechanically. An attempt made to clean the same dimmed surface by dry wiping would only result in finally ruining the surface, since the small sharp crystals of carbonate of soda would be rubbed about over the surface, scratching it in all directions.

The dimming process in the case of the less resistant glasses is not only confined to the formation of alkaline carbonates; the films of alkaline solution which are formed on the surface of glass form a ready breeding-ground for certain forms of bacteria and fungi, whose growth occurs partly at the expense of the glass itself; the precise nature of these actions has not been fully studied, but there can be little doubt that silicate minerals—and glass is to be reckoned among these—are subject to bacterial decomposition, a well-known example in another direction being the “maturing” of clays by storage in the dark, the change in the clay being accompanied by an evolution of ammonia gas. In the case of glass it has been shown that specks of organic dust falling upon a surface give rise to local decomposition. In this connection it is interesting to note the effect of the presence of a small proportion of boric acid in some glasses. The presence of this ingredient in small proportions is known to render the glass more resistant to atmospheric agencies, and more especially to render it less sensitive to the effects of organic dust particles lying upon the surface. It has been suggested—probably rightly—that the boric acid, entering into solution in the film of surface moisture, exerts its well-known antiseptic properties, thus protecting the glass from bacterial and fungoid activity.

The durability of glass under the action of atmospheric agents is a matter of such importance that numerous efforts have been made to establish a satisfactory test whereby this property of a given glass may be ascertained without actually awaiting the results of experience obtained by actual use under unfavourable conditions. One of the earliest of the tests proposed consisted in exposing surfaces of the glass to the vapour of hydrochloric acid. For this purpose some strong hydrochloric acid is placed in a glass or porcelain basin, and strips of the glass to be tested are placed across the top of the basin, the whole being covered with a bell-jar. After several days the glass is examined, and as a rule the less stable glasses show a dull, dimmed surface as compared with the more stable ones. A more satisfactory form of test depends upon the fact that aqueous ether solutions react readily with the less stable kinds of glass; if a suitable dye, such as iod-eosin, be dissolved in the water-ether solution, then the effect upon the less stable glasses when immersed in the solution is the formation of a strongly adherent pink film. The density or depth of colour of this film may be regarded as measuring the stability of the glass; the best kinds of glass remain practically free from coloured film even on prolonged exposure. A test of a somewhat different kind is one devised in its original form by Dr. Zschimmer, of the Jena glass works; this depends upon the fact that the disintegrating action of moist air can be very much accelerated if both the moisture and the temperature of the air surrounding the glass be considerably increased. For this purpose the samples of glass are exposed to a current of air saturated with moisture at a temperature of about 80° C. in a specially arranged incubator for one or more days, means being provided for securing a constant stream of moist air during the whole time. On examining the glass surfaces after this exposure—any wiping or other cleaning of the surfaces being avoided—various qualities of glass are found to show widely varying appearances. The best and most stable glasses remain entirely unaffected; less stable kinds show small specks, which merge into a generally dulled surface in unstable kinds. There is no doubt that this test gives a sharp classification of glasses, but it yet remains to be proved that this classification agrees with their true relative durability in practice; the writer is inclined to doubt whether this is really the case, since certain glasses that have proved very satisfactory in this respect in practical use all over the world were classed among the less stable kinds by this test.

Before leaving the subject of the chemical behaviour of glass, a reference should be made to the changes which glass undergoes when acted upon by light and other radiations. Under the influence of prolonged exposure to strong light, particularly to sunlight, and still more so to ultra-violet light, or the light of the sun at high altitudes, practically all kinds of glass undergo changes which generally take the form of changes of colour. Glasses containing manganese especially are apt to assume a purple or brown tinge under such circumstances, although the powerful action of radium radiations is capable of producing similar discoloration in glasses free from manganese. Apart from these latter effects, of which very little is known as yet, there can be no doubt that the action of light brings about chemical changes within the glass, but it is by no means easy to ascertain the true nature of these changes, although they most probably consist in a transfer of oxygen from one to another of the oxides present in the glass. Although it has not been definitely proved, it seems very unlikely that the glass either loses or gains in any constituent during these changes. Good examples of the changes undergone by glass under the action of sunlight are frequently found in skylights, where the oldest panes sometimes show a decided purple tint which they did not possess when first put in place. The glass spheres of the instruments used for obtaining records of the duration of sunshine at meteorological stations also show signs of the changes due to light—the glass of these spheres when new has a light greenish tint, but after prolonged use the colour changes to a decided yellow. The coloured glass in stained-glass windows also shows signs of having undergone changes of tint in consequence of prolonged exposure to light; glass removed from ancient windows usually shows a deeper tint in those portions which have been protected from the direct action of light by the leading in which the glass was set, and it is at least an open question whether the beauty of ancient glass may not be, in part, due to the mellowing effect of light upon some of the tints of the design. This photo-sensitiveness of glass is also of some importance in connection with the manufacture of photographic plates. It has been found that if the glass plate of a strongly-developed negative be cleaned, a decided trace of the former image is retained by the glass, and this image is apt to re-appear as a “ghost” if the same glass be again coated with sensitive emulsion and again exposed and developed. The best makers of plates recognise this fact and do not re-coat glass that has once been used for the production of a negative.

CHAPTER II.
THE PHYSICAL PROPERTIES OF GLASS.

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The Mechanical Properties of Glass are of considerable importance in many directions. Although glass is rarely used in such a manner that it is directly called upon to sustain serious mechanical stresses, the ordinary uses of glass in the glazing of large windows and skylights depend upon the strength of the material to a very considerable extent. Thus in the handling of plate-glass in the largest sheets, the mechanical strength of the plates must be relied upon to a considerable extent, and it is this factor which really limits the size of plate that can be safely handled and installed. The same limitation applies to sheet-glass also, for, although its lighter weight renders it less liable to break under its own weight, its thinner section renders it much more liable to accidental fracture. In special cases, also, the mechanical strength of glass must be relied upon to a considerable extent. Gauge tubes of high-pressure boilers, port-hole glasses in ships, the glass prisms inserted in pavement lights, and the glass bricks which have found some use in France, as well as champagne bottles and mineral water bottles and syphons, are all examples of uses in which glass is exposed to direct stresses. It is, therefore, a little surprising that while the mechanical properties of metals, timbers, and all manner of other materials have