(*Domestic Architecture of the Middle Ages*, by Hudson Turner, p. 78).

In Spain glass was made at Barcelona in considerable quantities in 1324; and Almeria, according to an Arab author of the 13th century, was famous for its manufacture of glass. In the 15th century the export of glass from Barcelona was considerable; Jeronimo Paulo in 1491 says that glass vessels of various sorts were sent thence to many places and even to Rome.

In the 16th century the fashion of using glass vessels of ornamental character spread from Italy into France, England, and the Low Countries. Henry VIII. had a large quantity, chiefly or wholly, it would seem, of Venetian manufacture (see inventory in 1542, *Archæological Journal*, vol. xviii.). This increasing use of glass led to the reflexion that large sums of money went annually to Venice for such wares, and to the question whether the manufacture might not be carried on at home. We therefore find that about the middle of this century attempts were made to introduce the Venetian methods of manufacture into the several countries; Henry II. of France established an Italian named Mutio at St Germain-en-Laye, and Henry IV. in 1598 permitted two "gentilshommes verriers" from Mantua to settle themselves at Rouen in order to make "verres de cristal et autres ouvrages qui se font à Venise." A like attempt was made in England about 1550, for in that year eight glass-makers from Murano addressed from London a petition to the Council of Ten at Venice praying to be excused from the penalties decreed by that body in 1549 against Venetian subjects who taught the art to foreigners (*Cal. State Papers*, Venetian, No. 648). The council allowed the eight workmen to remain until the end of the term for which they had engaged themselves. Other attempts followed: Stow says (*Chron.*, p. 1040) that Venice glasses were first made in London by one Jacob Vessaline about the beginning of the reign of Queen Elizabeth, and in 1565 one Cornelius de Lannoy (or Launoy) was working in the pay of the Government (*Cal. State Papers*, Dom.). Others, as Carre or Quarre, and Becku *alias* Dolin, from the Low Countries, were engaged in similar undertakings during the latter part of this century, but it does not seem that any great success was attained, as the importation of glass from Venice continued until long after.

These attempts to rival Murano seem to have been most successful in the Low Countries and in Spain. Ambrozio de Mongarda had a privilege in the former country to make "voirres de cristal à la faschon de Venise," which in 1599 was continued to Philippe de Gridolphi; his glass-house was at Antwerp. Glass-works also existed at Liége. Much glass in the 16th century was sent from Antwerp to England (Houdoy, *Les Verreries à la façon de Venise*). This manufacture went on during the following century, and many examples remain, more or less resembling the products of Murano.

In Germany Ferdinand I. established a glass-house at Weidlingen near Vienna, which was to work in the Italian manner; but no great success it would seem attended these efforts, partly no doubt because about the same time the native glass-makers struck out a new and original style of ornamentation for the great cylindrical beakers, sometimes 20 inches in height, usually called wiederkom (come again), but which M. Peligot says ought to be called willkomm (welcome). This was a somewhat coarse but very effective system of painting in enamel such subjects as the emperor and electors of Germany, or the imperial eagle bearing on its wings the arms of the states which composed the empire, &c. The earliest example which has been met with bears the date 1553, but the system had great vogue, and continued in use until about 1725.

Spanish writers have not as yet acquainted us with the precise means by which the Venetian methods of working were brought to their country; but Gaspar Baueiros in his *Chronographia*, published in 1562, says that the glass made at Barcelona was almost equal to that of Venice, and during this and the next century large quantities were exported. Venetian glass was imitated in several other places in Spain, and with considerable success, as several examples in the South Kensington Museum testify. The native forms and methods of working, however, went on contemporaneously, and it would appear do so down to the present day.

The branch of glass-making in which the greatest results were obtained in France during the 17th century was that of the manufacture of mirrors. In 1665 the services of eighteen Venetians were obtained, and a factory established in the Faubourg St Antoine at Paris, and another factory was founded at Tour-la-Ville near Cherbourg. These were united and worked with great success; the plates which ornament the "Galerie des Glaces" at Versailles were made at Tour-la-Ville. In 1688 the process of casting plates of glass was first adopted in modern times (for the window glass of Roman times was cast); and thus it became possible to make mirrors of dimensions which could not be attained as long as the plates were produced by blowing. The manufacture was carried on at St Gobain, still the seat of an immense production of glass.

English glass-making of the 17th century is distinguished by one of the most important innovations in the practice of the art which has at any time been introduced, that of using a large proportion of oxide of lead in combination with potash. Glass so made is more brilliant than other kinds, and is known in England as "flint glass," in France as "cristal." The employment of lead as one of the ingredients of glass was not a discovery, for it had been practised to a small extent and for certain purposes, as in the imitation of gems by the Romans, and through the Middle Ages. Neither the date when flint glass was first made nor the inventor of the process is known.

Sir William Slingsby before 1611 (*Cal. State Papers*, Dom.) had obtained a patent for making glass with sea coal; and in 1615 the use of wood for that purpose was forbidden by royal proclamation. How far this proclamation may have been obeyed does not appear, but Sir R. Mansel, who held a patent of monopoly for glass-making from 1616 until about 1634 (and perhaps even later), states in 1623 that furnaces erected in London, the isle of Purbeck, Milford Haven, and on the Trent, had all failed, but that he had established them successfully at Newcastle-on-Tyne. Probably coal was used at this last place, and it seems not unlikely that flint glass may have been first made there. Merret, however, writing about 1665 (in his edition of the *Ars Vitraria* of Neri), says that glass made with lead was not in use in the English glass-houses on account of its too great fragility; but in 1673 Evelyn notes in his diary a visit to the Italian glass-houses at Greenwich "where glass was blown of finer metal than that of Murano," and in 1677 a visit to the duke of Buckingham's glass-works (at Lambeth), "where they made huge vases of metal as clear, ponderous, and thick as crystal, also looking-glasses far larger and better than any that come from Venice." From this time much glass was made in England, and Dr Pococke, who travelled in Germany in 1736, gives the preference in point of quality to English glass over Bohemian.

During this century much art and labour were employed in Germany in the ornamentation of vessels for drinking, such as goblets and wiederkoms. Sometimes they were painted in grisaille, the subjects being battles, processions, and the like, sometimes engraved or etched; common subjects are escutcheons with arms, views of cities, ciphers, &c. Many excellent artists worked in these various styles (Beckmann, *Hist. of Inventions*, iii. 209; Doppelmayr,

Nürnbergische Künstler, p. 231, 233, &c.), and their works brought high prices. Dr Pococke mentions seeing some at Rispen, to which the glass-works formerly carried on at Potsdam had been removed, which cost from £100 to £150. Excellent material for these artistic efforts was furnished by the Bohemian furnaces; the art was patronized by several German princes; the celebrated Kunkel was in 1679 director of the glass-houses at Potsdam, which were carried on at the cost of the elector, and where the beautiful ruby glass was produced. Etching and engraving on glass was also much practised in Holland.

In Spain glass was made in 1680, at San Martin de Valdeiglesias, in imitation of Venetian; and Barcelona, Valdemaquada, and Villafranca are named in a royal schedule of the same date, fixing the prices at which glass was to be sold in Madrid, as places where wares imitative of Venetian were made. There was also an important manufactory at La Granja (see Introduction to *Cat. of Spanish Glass in South Kensington Museum*, by Señor Riano). Some of the products of the Spanish furnaces closely resemble those of Murano, but rarely exhibit much beauty or much originality. Others again, attributed to the factory of San Ildefonso and to the 18th century, bear a very close resemblance to some of the Dutch glass of that period.

Although during the 18th and earlier part of the 19th century progress was made both in the purity and in the beauty of the material (especially in the case of glass for optical purposes), and in the organization and working of factories, it was a period marked in no country by much of novelty or of artistic effort in the manufacture of glass. M. Labarte even goes so far as to say (*Hist. des Arts Industriels*, iv. 597) that in France in 1759 the fabrication of "vases de verre" had so completely fallen into decadence that the Academy of Sciences offered a prize for an essay on the means by which the industry could be revived. In the beginning of the present century cut glass was much in vogue, and was produced in England of great brilliancy, though the forms of the objects often left much to be desired in point of elegance.

The manufacture of coloured glass for windows was a consequence of the revival of Pointed architecture, and England, France, Belgium, and Germany have in this century rivalled each other in its production.

The Exhibition of 1851 did not perhaps produce a more marked effect on any of the industrial arts than on that of glass. The progress made since that date in the fabrication of artistic glass wares (the verrerie de luxe of the French) has been surprising, and at the present moment enlightened and enterprising manufacturers of glass are in every country studying the products of the furnaces of all times and all countries, as their predecessors at Murano in that great period of the art—that of the Renaissance—did the relics of Roman glass-working (Biringuccio, *Pirotechnia*, lib. ii.) in order to glean from them lessons and suggestions of further advance in their art. (A. NE.)

THE MANUFACTURE OF GLASS.

Glass, in its ordinary signification, is a brittle, transparent compound produced by the fusion, at a very high temperature, of silica (silicic acid) with one or more basic substances, one of which, in all cases, must be an alkaline metal. But the silicates of sodium and potassium, whether separate or combined, being soluble in water, and also readily acted on by other agents, are not in themselves suitable for most of the purposes to which glass is ordinarily applied. When, however, to these silicates, or to either of them, a silicate of an alkaline earth is added, the resulting body is not sensibly affected by water or ordinary solvents; and it is the fused amorphous mass thereby obtained that alone is glass in the restricted technical sense. Thus the definition given by Dumas that glass is a silicate of at least two metals belonging to different groups, one of which must be an alkaline metal, strictly embraces and limits all varieties of ordinary glass. Boracic acid, a substance closely allied in chemical properties to silica, has a similar influence on the alkalies and alkaline earths, producing by their mutual fusion a transparent amorphous compound; and indeed, for certain special purposes, a glass in which borates to a certain extent supplant silicates is used for optical purposes. The substances, however, which form the essential basis of all varieties of common glass are (1) silica as the acid element; (2) soda or potash as the alkaline base; and (3) lime and oxide of lead as the alkaline earths. To the alkaline earths commercially employed there ought also to be added baryta and alumina, the former being used in the place of lead, and the latter being a common ingredient in certain kinds of glass.

The following tabular statement shows the bodies capable of yielding transparent glass:—

Acid	Alkaline.	Earthy.	
		Colourless.	Coloured.
Silica. Boracic acid.	Oxides of Potassium. Sodium.	Oxides of Calcium. Lead. Barium. Strontium. Magnesium. Aluminium. Zinc. Thallium.	Oxides of Iron. Manganese. Copper. Chromium. Uranium. Cobalt. Gold.

Various authorities who have investigated the constitution of glass have endeavoured to establish a chemical formula for what they term normal glass. The results arrived at, however, by different investigators disagree among themselves; and the balance of opinion is in favour of the view that no such substance as normal glass exists, and that glass does not result from any definite chemical compounds, but is simply a mixture of silicates, with usually an excess of uncombined silica. The proportions in which the ingredients of glass are present, however, have not only a very great influence on the fusibility of the mass; but these conditions also very materially affect the qualities of the substance. In general the more nearly the proportion of silica approaches the amount necessary to form definite compounds with the basic ingredients, the better and the more stable is the quality of the glass. The conclusion of Otto Schott in his investigation of the constitution of glass, that the simplest formula for glass is represented by $\left.\begin{matrix} xNa_2O \\ yCaO \end{matrix}\right\} zSiO_2$, may be accepted as a safe statement.

The phenomenon of devitrification, which is exhibited most readily by glass of inferior quality, has important bearings on the chemical constitution of glass, as well as on the working of the material. Devitrification is a change which may be induced in all varieties, but only with difficulty in the finer kinds of potash glass—either by slowly cooling the glass from the state of fusion, or by heating it in a mixture of sand and plaster of Paris till it softens, and then allowing it to cool by very slow degrees. Thereby it partly or entirely loses its transparent amorphous form, and by the formation of innumerable minute crystals it becomes opaque. When such a change penetrates the entire mass it assumes a milky and porcelain-like appearance, whence it is in this condition known as Réaumur's porcelain—the phenomenon having been first investigated by that observer. Devitrification renders the material much harder and less fusible than the same glass in a transparent condition; and it is less subject to fracture on the application of heat. According to Pelouze, Splittgerber, and others, devitrification results simply from a rearrangement of the molecules into the crystalline form while the mass is soft, no alteration in the proportions of the constituents taking place concurrently; but Dumas and his followers maintain, on the contrary, that in undergoing the change the glass loses part of its alkali, and that crystallization takes place through the formation of compounds infusible at the temperature existing at the moment of crystallization. These compounds may result either from the dissipation of alkaline matter or from the separation of the mass into two strata,—that most highly alkaline retaining its amorphous condition more persistently than the other more siliceous portion.

The physical properties upon which the great value and utility of glass principally depend are (1) its well-known prevailing transparency combined with a brilliant lustre and great hardness; (2) its fusibility at a high temperature; and (3) its softness and viscosity at a red heat, whereby it can be moulded and otherwise worked with facility into any shape desired. Of great value also is its resistance to the influence of common solvents. Properly-made glass is not sensibly acted on by any of the acids except hydrofluoric acid, which attacks it powerfully, combining with and removing its silica. Water affects glass so feebly that for practical purposes its action may be disregarded; but when it is submitted for a prolonged period to water at a high temperature, it is slowly dissolved. Even prolonged exposure to moist air so acts on glass, particularly on highly alkaline varieties, that the surface becomes clouded and obscure, and the beautiful iridescent scaling off observable in ancient glass is due to the exposure of the substance for long ages to the influence of moist air or damp earth.

Glass is an extremely bad conductor of heat, and from that property springs, in great measure, its brittleness. Owing to this imperfect conductivity it necessarily results that a mass of glass, or a glass object cooling from a state of fusion, becomes cooled and set or solidified on its outer surface before the internal molecules have parted with their heat, contracted, and established themselves in a stable relation to each other. The solidification of the superficial stratum thus necessarily hinders the contraction of the internal portion of the mass, and as the internal molecules cool down a state of tension is created, the central portion tending to draw the surface stratum inwards with a force held in check by the strain in the contrary direction of the outer range of molecules. In this condition a very moderate impact is sufficient to determine the fracture of the glass. The high degree of brittleness which results from unequal cooling is exhibited in a very marked manner by the philosophical toy known as "Rupert's drops." Such pear-shaped masses of glass are prepared by allowing molten glass to fall, drop by drop, into cold water, when the drops assume a more or less spheroidal form, with a finely tapering point. Of course a very sudden and rapid cooling of the surface takes place, while the interior is still at a high temperature, and correspondingly much dilated, the consequence of which is that a state of great tension is established between surface and centre. The breaking off of a small portion of the tail is sufficient to destroy the equilibrium established between the hard superficial and the dilate internal molecules; and immediately the whole mass is shattered to dust with explosive violence. Excessive brittleness is overcome by the operation of annealing to which glass is submitted,—a process which has been explained under ANNEALING, and which will be further referred to in dealing with a method of tempering or hardening glass which has been introduced by M. de la Bastie within the last few years.

It is difficult to give a consistent and systematic view of the manufacture of glass, because not only chemical constitution, but the mechanical operations by which glass is prepared, and the purposes to which the material is applied, have also to be taken into consideration. A good classification, from a chemical point of view, is that given by Stein (in Bolley's *Technologie*), who distinguishes three classes:—

(1.) Glass containing one or two bases belonging to the same group. This class embraces only the soluble silicates which do not fulfil the ordinary functions of glass.

(2.) Glass with several bases which belong to different groups, comprehending two classes:—(1) calcium glass, under which come sodium-calcium glass and potassium-calcium glass; and (2) lead glass, which constitutes ordinary flint glass or crystal and strass.

(3.) Coloured and opaque glass, of which there are also two classes,—the first embracing the varieties of transparent coloured glass which may belong to any of the above classes, with the addition of colouring oxides, and the second being devoted to the various kinds of opaque glass.

The raw materials of the glass manufacture embrace the following principal ingredients. (1.) Silica is used in the forms of pure quartz (for very fine qualities of glass), crushed sandstone, pulverized flints, and especially sand of degrees of purity varying in proportion to the quality of the glass to be made. The finest iron-free sand in the United Kingdom is obtained from Alum Bay in the Isle of Wight, from Lynn, Norfolk, and from Leighton Buzzard, Bedfordshire; but much pure sand is imported into the United Kingdom from Fontainebleau in France, from Belgium, and other localities. (2.) Lime is employed in the form of chalk or marble, either burned or unslaked, and it also must for colourless glass be free from iron impurities. Of (3.) potash and (4.) soda any of the ordinary salts except chlorides, but especially the sulphates and carbonates, are indifferently utilized, the point of real importance being here also the freedom of the compound from contamination when fine glass is being made. At no very remote date kelp was the principal source of soda alkali in glass, but this is now entirely disused, and the principal source of potash is the salt mines of Stassfurt and Leopoldshall in Prussia, and at Kalusz in Galicia. Both potash and soda are frequently constituents of the same glass; but glass made from potash is free from the decided sea-green tinge which invariably is seen in soda glass, although the latter is the more brilliant in lustre. (5.) Lead is the characteristic ingredient of a distinct class of glass of which ordinary flint glass is the type. It is usually employed in the form of minium or red lead ($2PbO,PbO_2$), partly on account of its fine state of division and partly because by giving off oxygen it helps to purify the metal. (6.) Baryta and witherite or baric carbonate have been introduced with much success as a partial substitute for alkali in soda or potash glass, and for a part of the lead in ordinary flint glass, and in all probability barium compounds are destined to occupy a much more important place in glass manufactures than hitherto they have done. (7.) Cullet or waste and broken fragments of the special kinds of glass to be made is an important and essential ingredient, being added to the extent of about one-third of the whole charge in the melting and preparation of glass. These materials constitute the essential ingredients which go to the formation of glass. In coarse varieties, such as bottle glass, alumina and iron are present, but their presence simply results from the inferior and impure nature of the raw materials employed, and are neither essential nor desirable. Some portion of alumina too is taken up from the pots in which the materials are melted. Bleaching or oxidizing agents are also employed to produce a high degree of colourlessness in

clear glass, and for this purpose peroxide of manganese, arsenious acid, and nitrate of potash are the materials generally used. These bodies oxidize carbon compounds which may be present, and neutralize to a large extent the colour yielded by iron by converting its protoxide into peroxide. Too much manganese, however, gives the glass a reddish tinge, and excess of arsenic produces a milky cloudiness. The various substances employed to produce coloured and opaque varieties of glass will be enumerated when these special kinds are described. The requisite proportions of the raw materials ground and prepared are intimately mixed with the aid of a mixing apparatus, and in this form constitute the "batch." Formerly it was the habit to frit or partially decompose and fuse the ingredients in a form of reverberatory furnace called a calcar arch, but since the use of kelp was abandoned that operation is no longer essential, and generally the well-mixed batch is placed at once in the melting pots, or the tank in the case of tank furnaces.

Melting Pots.—These pots or crucibles are made of the finest fire-clay, that from Stourbridge in Worcestershire being exclusively used for glass pots in Great Britain. Great care is requisite in the selection, and in cleansing the clay from extraneous particles, the presence of which, even in the smallest degree, will injure the pot. A fine powder procured by grinding old crucibles is generally mixed, in a proportion seldom larger than a fourth, with what is termed the virgin clay. This mixture dries more rapidly, contracts less while drying, and presents a firmer resistance to the action of the fire and alkali used in the composition of glass than the simple unmixed clay. These ingredients, having been mixed, are wrought into a paste in a large trough, and carried to the pot loft, covered in such a way as to exclude dust and other minute particles. Here a workman kneads the paste by trampling it with his naked feet, turning it from time to time until it becomes as tough as putty. It is then made into rolls, and wrought, layer upon layer, into a solid and compact body, every care being taken to keep it free of air cavities, which would, by their expansion in the furnace, cause an immediate rupture of the pots. After pots are made, very great care is necessary to bring them to the proper state of dryness before taking them to the annealing or pot arch. In drying they commonly shrink about 2 inches in the circumference. When pots are made during summer, the natural temperature is sufficient for drying them; but in winter they are kept in a temperature of from 60° to 70° Fahr. They remain in the room where they are made for a period varying from nine to twelve months. Being afterwards removed to another apartment, where the heat is from 80° to 90° Fahr., they are kept there for about four weeks. They are then removed for four or five days, more or less, according to their previous state of dryness, to the annealing arch, which is gradually and cautiously heated up till it reaches the temperature of the working furnace, whither, after being sufficiently annealed, they are carried as quickly as possible. Pots last upon an average from eight to ten weeks, and they form a costly item in the manufacturing operations, as each pot is worth on an average about £10; and many of them, notwithstanding all care, crack and give way as soon as they are placed in the melting furnace. For all varieties of glass, excepting lead glass, open pots in the form of a truncated cone, as represented in fig. 1, are employed; but for flint glass a covered pot with an opening at the side, as shown in fig. 2, is essential. Dr Siemens proposed a form of melting pot divided into three compartments, the materials being melted in the first, and passing into the second by an opening at the lower part of the partition, where the metal was to be fined and freed from included air-bubbles, and afterwards to pass by a like opening to the third compartment, whence it was to be drawn for working. The specific gravity of the charge in the first compartment would rise in proportion as the materials melted and became homogeneous in structure. Therefore the metal would sink in proportion as it melted;

Fig. 1.—Crown-Glass Pot.

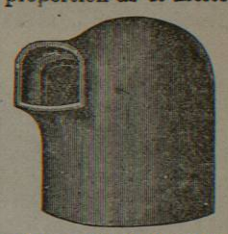


Fig. 2.—Flint-Glass Pot.

and the best melted portions pass into the second compartment, in which, under the influence of the direct furnace heat, it would be cleared. There, similarly, the perfectly fined glass falling to the bottom would pass into the cooler working compartment, which is protected by a covering cap. Dr Siemens's idea has been practically developed in his continuous tank referred to below.

Furnaces.—A glass-melting furnace or oven is a modified form of reverberatory furnace, which assumes many different shapes and arrangements according to the kind of glass to the manufacture of which it is devoted, and the nature of the fuel used. As regards the latter cause of difference it may be noted that, while coal is the principal fuel employed in Great Britain, dried wood and peat are extensively consumed in Germany, and in modern times gas furnaces on the Siemens and other principles are being freely introduced. In the construction of a furnace the principal objects to be kept in view are not only the production and maintenance of an intense heat, but its uniform distribution throughout the furnace, and the bringing of the charges of glass materials directly under its fusing influence. The form assumed by melting furnaces is, in general, square or oblong for sheet and plate-glass making, and circular in English flint-glass making. The fire-space or grate occupies the centre of the furnace, and the fire, when fuel is used for direct heating, is either fed or stoked from both ends, or raised from under the bars by a patented method The fire-grate is usually on a level with the floor of the house in which it is erected, but under it is an arched subterranean passage forming the "cave" or ash-pit, both ends of which extend to the open air outside the glass-house. The fire-grate bars are placed in the top of this arched passage, which thus serves as a canal for the atmospheric air required to maintain combustion within the furnace; and for regulating the admission of air, and so controlling the heat, there are doors at both ends of the archway. In some cases two such arched passages at right angles to each other, and intersecting at the fire-bars, are constructed, so that either can be used according to the prevailing direction of the wind, &c. In general no flue or chimney is directly connected with the furnace, the only exit for the products of combustion being the working holes, and thus the heat is directed around and over each pot placed opposite a working hole in the furnace. Within the furnace, around the grate space in the case of circular furnaces, or on both sides of it in quadrangular furnaces, is a raised bank or narrow platform termed the "siege," on which the melting pots are placed. The number of pots arranged in a furnace vary from four to ten, and each is reached, either for charging or for working off the prepared metal, by means of "working holes" in the side of the furnace situated directly over the pots. The general form and construction of a six-pot crown-glass furnace, which also may be taken as the type of sheet and plate-glass furnaces, is shown in Plate V., where fig. 3 is a ground plan at the level of the siege of a common form of furnace, while in fig. 1 is seen a front elevation of the same furnace, 1, 2, and 3 being the working holes, 4, 5, 6, and 7 pipe-holes for heating the blowing pipes, and 8, 9, and 10 foot-holes for mending the pots and sieges. The furnace

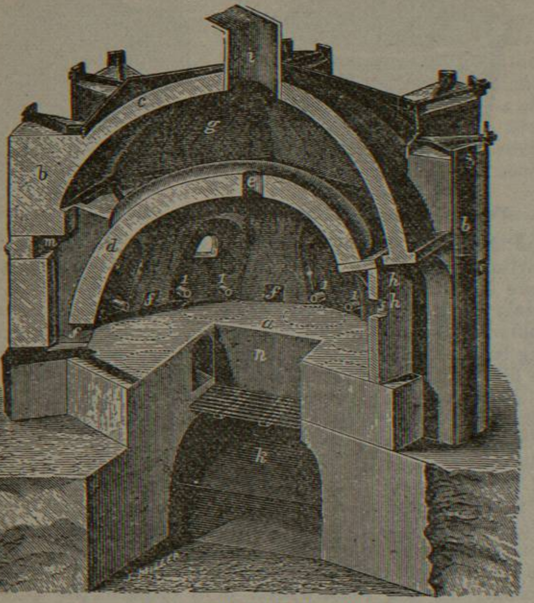
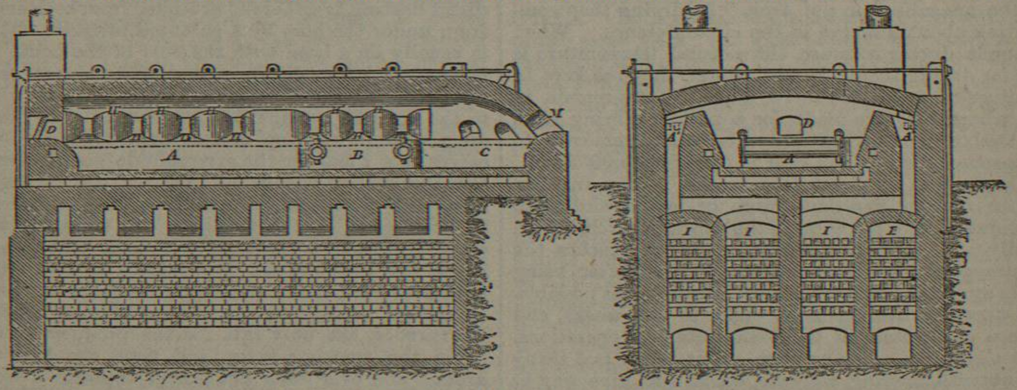


Fig. 3.—Section of Flint-Glass Furnace.

is covered with a low-roofed crown or dome, and the whole structure is bound together with a system of iron bars. The materials used in the construction and lining of all furnaces must be selected with the utmost care, and built with special regard to the enormous temperature to which they are subjected. Formerly a fine-grained purely siliceous sandstone was much used, but now the principal materials are large moulded bricks or blocks of fire-clay of the most infusible and refractory description. For the crown of the furnaces used in plate-glass melting Dinas silica blocks are employed. In laying the blocks and throwing the arches no mixture containing lime can be used, but only fire-clay or Dinas sand, in as small quantity as possible. Should any of the materials of the crown of the furnace gradually fuse under the influence of the heat, the dropping of the molten matter into the glass-pots is the cause of most serious annoyance and loss to the manufacturer.

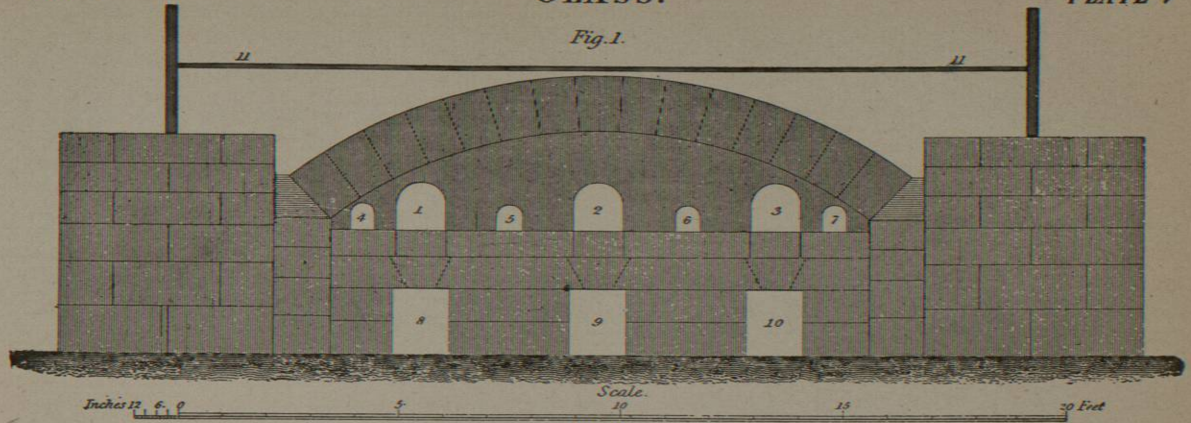
An English flint-glass furnace furnishes the type of circular furnaces. Usually a large number of pots, sometimes ten, are provided for in such a furnace, because, the objects made in flint glass being in general of small size, the metal is worked off only slowly, and a large number of glass-blowers can be accommodated at the separate work-holes. The arrangements of the cave and fire-grate are the same as in the case of square or oblong furnaces, but flint-glass furnaces differ from the prevailing rule in others by being provided with a system of flues and chimneys, one flue being placed between each pair of pots. The general appearance presented within a flint-glass house is illustrated in Plate VI. fig. 1; and the accompanying woodcut (fig. 3) is a sectional illustration showing the construction and internal appearance of a seven-pot furnace. The furnace is composed of a double arch or vault springing from strong pillars or abutments *bb*. The space *c*, between the outer arch and the vault proper of the furnace *d*, is a common receptacle for the flues *ff* led from within the furnace, and the products of combustion escape by the chimney *i*. The work-holes are at *h*, and at that place the furnace wall is taken down when a pot requires to be removed and renewed. The "cave" or air canal is seen at *k*; *n* is the fire-grate, stoked in this case from one side only; *l* shows openings at which the blowing tubes are heated; *m* is an opening for cleaning the flues; and *a* is the bank or siege with the position of the pots indicated. Frequently instead of being arched the outer portion of the furnace is carried up in the form of a wide truncated cone or open chimney stalk, and in other cases short separate chimney stalks are built for each flue terminating within the glass-house, which itself forms such an open-topped



Figs. 4 and 5.—Siemens's Continuous Tank Furnace.

cone or chimney. Of course in cases where such separate small chimneys are provided no second or outer vault is required.

In the year 1861 Dr C. W. Siemens introduced a form of furnace in which the use of melting pots was altogether abandoned, and the batch was introduced into, melted in, and worked from a tank which occupied the whole bed of the furnace. This furnace he heated from the sides by means of his well-known regenerative gas system described under Furnace and Iron. In 1872 he effected a further development of the tank furnace by dividing the tank, on the principle of his melting pot, by means of two floating bridges or partitions into three compartments, and thus he elaborated what is termed Siemens's patent continuous melting furnace. Of this improved furnace fig. 4 shows a longitudinal section, and fig. 5 is a transverse



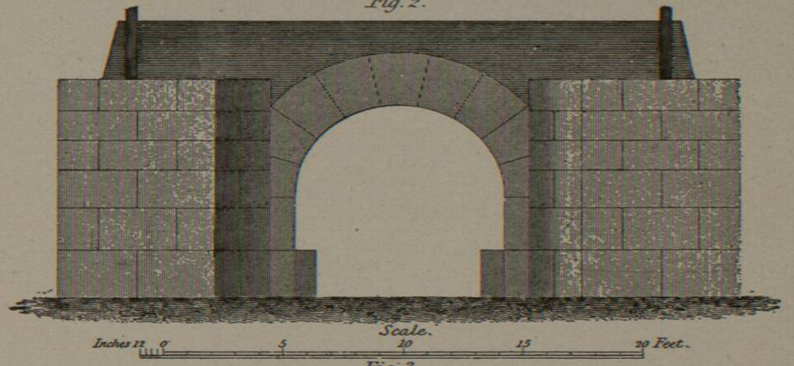
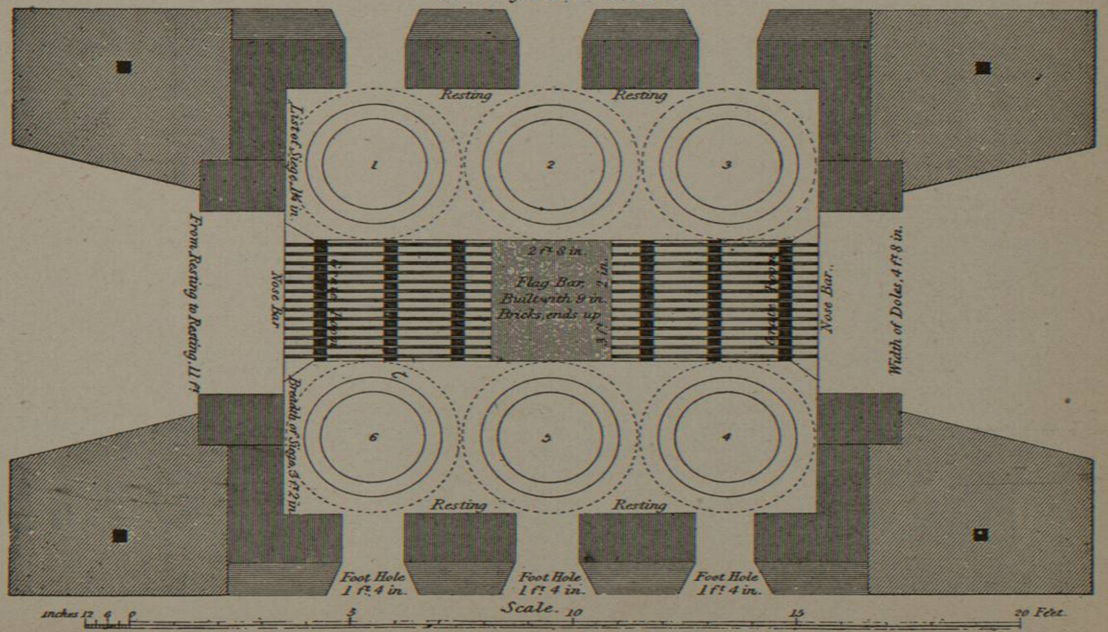


Fig. 3.
Inside Length of Furnace, 12 Feet.



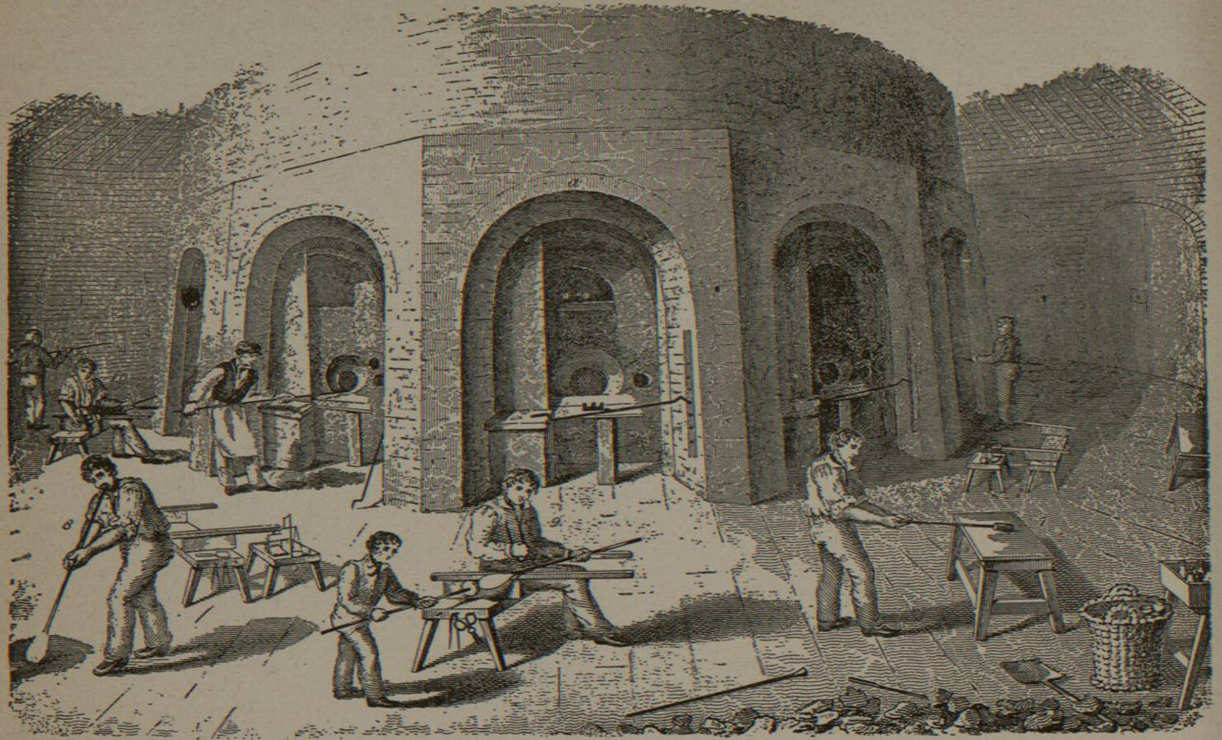


Fig. 1. FLINT-GLASS MANUFACTORY

Drawn by W. Cowper, Edinr. Fig. 2. INTERIOR OF A CROWN-GLASS HOUSE. Engd by G. Aikman

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section. A is the melting compartment, B the refining compartment, and C the working-out compartment. The compartment A is fed with raw material (or batch) through the door D at the back end of the furnace; it is separated from the compartment B by the floating bridge E, under which the partially melted glass passes to reach the latter. In the compartment B the metal, by the influence of the higher temperature maintained on its surface, is completely purified, and sinks to flow under the bridge F in a complete workable condition. Suitable provision is made, by means of air-passages, to keep the sides of the tank of the requisite temperature to prevent any egress of glass through them, and the floating bridges E and F are renewed as often as necessary. The regenerative gas furnace is employed, and the gas and air ports H H′, leading from the regenerators I I′ respectively, are arranged along each side of the tank, so as to cause the flames to play across the furnace. The temperature of the different parts is regulated according to the various stages of preparation of the glass in the several compartments, this regulation being effected by constructing the gas and air ports of larger dimensions, or increasing their number, where the greatest heat is required; it is also facilitated by means of division walls (not shown in the figures) which may be built over the floating bridges to separate the compartments. The temperature of the working-out compartment C is controlled by regulating the draught of the furnace chimney, by diminishing which more or less flame must necessarily pass from B over the floating bridge F into C, and through the working holes M. The principal advantages resulting from the use of the continuous melting furnace are the following:—

1. An increased power of production, as the full melting heat may be employed without interruption, whilst with the old method of melting nearly half time is lost by cooling and settling the metal, the working it out, and the re-heating of the furnace.

2. An economy in working, as only half the number of men are required for the melting operations.

3. A greater durability of the tank and furnace, owing to the uniform temperature to which they are subjected.

4. A much greater regularity of working, and more uniform quality of the product than in other furnaces.

5. For the manufacture of window glass, the compartment C may be so arranged that the blowers can work without interfering with the gatherers; this would do away with the separate blowing furnace now in use.

Although the Siemens regenerative gas firing is generally used with tank furnaces, that system is not essential to the successful working of tanks. Mr Archibald Stevenson of Glasgow has patented a tank furnace fired by common coal from one end, with working holes on the other three sides, and furnaces on this principle are worked in a perfectly satisfactory manner with much economy of coal and working room. Tank furnaces are used principally in bottle works and in the manufacture of rolled plate. The following statement shows the extent to which Siemens furnaces and tanks have been introduced by manufacturers.

Furnaces using Pots.

	Plate Glass.	Window and Bottle Glass.	Flint Glass.
Great Britain	5	5	2
France	7	4	11
Belgium	4	1	1
Other countries	6	10	15

Furnaces with Tanks.

Great Britain	6

Furnaces with Continuous Tanks.

Great Britain	4
France	10
Belgium	1
Other countries	3

Formerly it was the habit that to the sides or wings of the main melting furnace there were attached calcar or fritting arches, annealing ovens, pot-firing arches, and other subsidiary furnaces required in certain stages of glass manufacture. These were heated by flues leading from the fire-space of the principal furnace; but such a practice is now generally abandoned, and distinct furnaces or ovens, arranged and fired according to the necessities of the case, are provided instead. In the manufacture of common bottle glass, however, for which highly impure materials are used, it is still the practice to prepare a frit in a side arch occasionally attached to the melting furnace.

The whole of the pots in a common furnace are charged or filled with the prepared "batch" at the same time. Immediately the heat is forced, and the stoking must thereafter be carefully regulated to maintain the high temperature. As the mass begins to fuse it settles down and occupies considerably less space in the pot, to which thereon a second quantity of material is added, and generally a third portion is subsequently filled in so as to have at the close of the melting process as large a quantity of metal as possible. When the fusion is complete a scum composed of uncombined salts, and known as glass gall or sandiver, rises and collects on the surface. It consists almost entirely of sulphate of soda, with sulphate of lime, and a small percentage of chloride of sodium. This scum of glass-gall is carefully removed with a perforated scoop, and the heat of the furnace is then forced to the most intense degree with the view of rendering the metal as fluid and limpid as possible, so as to free it from all included gaseous bubbles which it still contains. This process of "fining," "refining," or hot-stoking, as it is indifferently termed, involves a temperature which is estimated in certain cases to reach from 10,000° to 12,000° Fahr.; and the operation is sometimes assisted by stirring the molten mass with a pole of wood, in a manner analogous to the poling of copper in the refining of that metal. Throughout the operation of melting, test pieces are periodically withdrawn from the pots for the purpose of observing the progress and condition of the glass. When it is found that the vitrification is complete and the object of refining fully accomplished, the heat of the furnace is considerably reduced, so that the glass may be brought into that condition of viscosity in which it is capable of being worked. In contradistinction to the refining or hot-stoking period, this is known as cold-stoking.

Glass Working.—The means by which melted glass is caused to assume its varied forms for use are (1) by blowing; (2) by casting; and (3) by pressing in moulds—an operation in which the other two processes may be partly combined. Minor manipulative processes which do not fall under any of these heads are called into action; but these are for the most part merely subsidiary to the others, which really comprehend all the lines along which the formation of glass proceeds.

Having regard principally to the forms into which glass is worked and the uses to which it may be applied, the following classification embraces the principal departments of the glass-making industry.

- I. Flat glass.
  - Crown glass.
  - Sheet glass.
  - Plate glass.
- II. Hollow glass.
  - Flint glass, blown.
  - Bohemian glass.
  - Venetian glass.
  - Bottle glass.
  - Slag glass (Britten's).
  - Tube and gauge glass.
- III. Pressed and massive glass.
  - Flint glass.
  - Optical glass.
  - Strass.
  - Rod glass, marbles, and beads.
- IV. Coloured, opaque, and enamel glass, including glass mosaics and hot cast porcelain, &c.