submitting the portions to be etched or bitten to the influence of hydrofluoric acid, the remainder of the glass being stopped off or protected by a coating of wax or some pitchy compound.[1]

Pressed Glass.—The most brilliant effect is produced by cutting, but moulding or pressing is much cheaper, and this branch of the art has now reached a high state of excellence. Glass formed by pressing in moulds, known distinctively as pressed glass, is peculiarly an English industry, principally because it is only flint glass, or glass possessed of similar properties, that can with advantage be formed in that way. Although moulded glass has existed from early Roman times, it is only within the present century that the modern industry has been developed, and of late years the trade has assumed important dimensions. A metal that melts at a comparatively moderate heat, and does not quickly pass from the plastic state, is essential for success in pressed glass making, because it has not only accurately to fill all the intricacies of the mould, but it must also be susceptible of fire-polishing. This operation consists of a reheating sufficient to melt a thin superficial stratum of the glass, whereby the roughness and obscurity of surface incidental to moulding is removed, and a smooth brilliant effect brought out, inferior only to the sparkling appearance produced by cutting. The moulds for pressed glass are made of iron or bronze; with great accuracy of surface; and they are, in use, kept a little under a red heat. The various segments of the mould are so hinged or connected as to close and leave internally a space representing the form and size of the article to be made, the internal hollow not being produced by blowing but by the plunger of the press under which the mould is placed. The required quantity of metal being dropped into the mould. the plunger descends and forces it into all parts of the cavity, completing immediately the formation of the article, which is then fire-polished by reheating, and afterwards annealed. In this way glass with elaborate facets, bosses, flutings, or other bold ornaments can be produced with rapidity and ease; and the only bar to great cheapness is the heavy cost of the lead and potash in flint glass. Several manufacturers both in England and on the Continent, where the pressed glass industry is extending, now partially supply the place of these costly materials by lime and baryta; and indeed English pressed glass of excellent quality is now in the market containing neither lead nor potash to any appreciable extent.

Baryta Glass.—The high price of red lead, and various disadvantages connected with its use, have given rise to many efforts to find an efficient substitute for it in the manufacture of table and ornamental glass. Barium compounds, principally the native sulphate (common baryta or heavy spar) and the artificially prepared carbonate, have been more or less experimentally tried ever since 1830; but of late years the use of baryta has attracted much attention, and in several French and Belgian glass-works it is understood to have taken its place as a raw material, without, however, much being publicly said regarding the subject. H. E. Benrath, the scientific director of the Lisette glass-works near Dorpat has investigated the application of baryta in glass-making with great fulness. Baryta, it appears, can be used as a partial substitute for the alkalies in glass-making; and indeed it was affirmed by Peligot that carbonate of baryta could altogether supplant either potash or soda, and yield a glass perfectly free of alkali. Such a glass is, however, shown by Benrath to be without practical value; but he has demonstrated that baryta may be used in the place of either lead or lime, to produce an easily fused dense glass much more brilliant than common glass, and in appearance and properties intermediate between that and flint glass. The qualities of the glass and its usefulness for various purposes can be modified by using both baryta and lime in varying proportions. There seems little doubt that baryta will occupy an important place in the future of the glass industry.

Bottle Glass.—This department of glass manufacture is of importance on account of its enormous extent; and although the raw materials employed in the trade are coarse and impure, and though the finished product has little appearance of excellence, the quality of the glass is in the highest degree important. Glass bottles, for example, are used for storing and preserving all manner of liquid substances for food, some of which undergo active chemical change, throughout a period of many years. In such a case it is of the highest consequence that the glass should be capable of resisting the solvent and corrosive action of acids and other substances which may be imprisoned or generated within the bottle, and such an object is attained by the high proportion of alumina which is found in bottle glass. Bottle glass varies in tint from the dark-green, almost black, semi-transparent claret bottles to clear and transparent qualities such as are employed for bottling aerated waters. The difference in colour is partially due to the varying purity of the materials used, and partly to the action of bleaching or oxidizing agents. The materials ordinarily employed are common sand, gas-lime, brick-clay, common salt, and soap-boilers' waste; but local circumstances have much influence in determining the class of materials used. In Continental bottle works lava, basalt, and similar rocks of volcanic origin were formerly employed; and in Denmark and Sweden fluoride of calcium, left as a waste product of the manufacture of soda from cryolite, is used with marked advantage.

For bottle-making the tank furnace with or without compartments as already described is much used; but pot furnaces also continue in use. The arrangements of a common bottle house are seen in fig. 19, which is a ground-plan indicating a bilateral

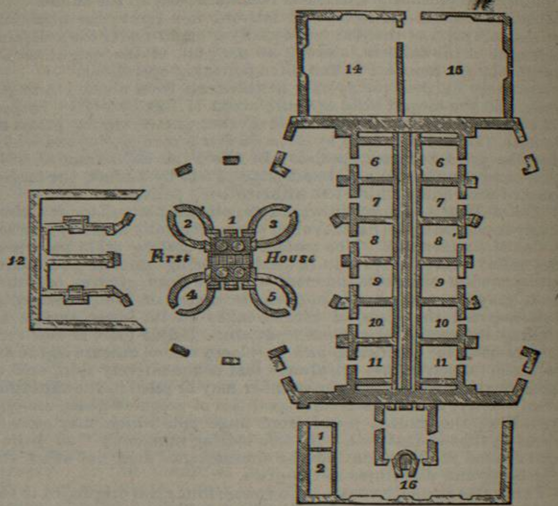

Fig. 19.—Plan of Bottle House.

arrangement of a double bottle house, with the complete plan of a four-pot furnace and ash arches. The furnace is oblong, similar to the crown furnace, but arched over in a barrel shape. It is erected in the centre of the brick cone, above a cave, which admits the atmosphere to the grating. The working holes of this furnace, opposite each pot, for putting in the materials and taking out the liquid glass, are each about 1 foot in diameter. At each angle of the furnace there is also a hole about the same size communicating with the calcining arch, and admitting the flame from the main furnace, which reverberates on and calcines the materials in the arch. In the figure, 1 shows the main furnace; 2, 3, 4, 5, the ash arches for calcining the materials; 6, 7, 8, 9, 10, 11, annealing arches; 12, two-pot arches; 14, clay-house for picking, grinding, sifting, and afterwards working the clay into paste for the purpose of manufacturing pots; 15, mill house for grinding clay; 16, a building containing a calcar furnace for experiments, or for preparing the materials, when the ash arch attached to the main furnace is under repair, including 1, a sand crib, and 2, an ash crib for sifting and mixing the materials, sufficient for two houses.

The following is an outline of the process of making a common bottle. After the metal has been skimmed, the person who begins the work is the gatherer, who, heating the pipe, gathers on it a small quantity of metal. After allowing this to cool a little, he again gathers such a quantity as he conceives to be sufficient to make a bottle. This is then handed to the blower, who, while blowing through the tube, rolls the metal upon a stone, at the same time forming the neck of the bottle. He then puts the metal into a brass or cast-iron mould of the shape of the bottle wanted, and, continuing to blow through the tube, brings it to the desired form. The patent mould now in use is made of brass, the inside finely polished, divided into two pieces, which the workman, by pressing a spring with his foot, opens and shuts at pleasure. The blower then hands it to the finisher, who touches the neck of the bottle with a small piece of iron dipt in water, which cuts it completely off from the pipe. He next attaches the punty, on which is a little metal gathered from the pot, to the bottom of the bottle, and thereby gives it the shape which it usually presents. This punty may be used for from 18 to 24 dozen of bottles. It is occasionally dipped into sand to prevent its adhering to the bottle. The finisher then warms the bottle at the furnace, and taking out a small quantity of metal on what is termed a ring iron, he turns it once round the mouth, forming the ring seen at the mouth of bottles. He then employs the shears to give shape to the neck. One of the blades of the shears has a piece of brass in the centre, tapered like a common cork, which forms the inside mouth; to the other blade is attached a piece of brass, used to form the ring. The bottle is then lifted by the neck on a fork by a boy, and carried to the

[1] A large proportion of the obscuring of the commoner varieties of glass and of the obscured ornamentation on plate and sheet as well as on flint glass is now produced by means of Tilghman's sand blast described below.

annealing arch, where the bottles are placed in bins above one another. This arch is kept a little below melting heat, till the whole quantity, which amounts to 10 or 12 gross in each arch, is deposited, when the fire is allowed to die out.

Slag Glass.—Under a patent obtained by Mr Bashley Britten, a manufacture of bottles has recently been established with every prospect of success, the leading peculiarity of the process being the use of blast-furnace slag, molten as it issues from the furnace, as a principal ingredient. The use of slag in bottle-making is by no means new, but the catching of the intensely hot liquid mass and its immediate use for glass-making had not before been attempted; and therein results the great saving in fuel and consequent economy of the manufacture. A company formed to work the process has erected glass-works in Northamptonshire in the immediate neighbourhood of a set of blast furnaces, and these works are now in constant and successful operation. A regenerative gas furnace applied to a glass tank working on Dr Siemens's continuous principle is used, and in it the ingredients of the glass are fed at one end of the tank, where they are fused and fined, and the fused "metal" flows through a bridge to the other end of the tank, whence it is worked out, blown into bottles, and annealed in the usual way. The tank is from time to time fed with fused slag taken as it flows from the blast furnaces, and with it is introduced the required proportion of the other ingredients. The slag furnishes more than half the total material of the glass, and, as it is already melted, its use effects a saving of about half the heat or fuel and also half of the time necessary for the production of the "metal." Thus the prime cost of the glass as it is worked out is considerably less than that of glass made in the ordinary way. The natural tint of the glass thus produced is greenish, but it can be coloured to any required tint, and by careful fining and bleaching it can be produced almost as colourless as common window glass. The working qualities of the glass are excellent; it comes from the furnace in that beautifully plastic condition which renders it capable of being blown, cast, pressed, or otherwise moulded into any desired form, and the company expects to manufacture other articles besides bottles from a material so cheaply produced.

Optical Glass is of two principal kinds—flint and crown—the combination of these two, with their different refractive powers, being necessary to produce perfect achromatism in the lenses of telescopes. For astronomical telescopes, for microscopes, and for all delicate scientific instruments in which optical glass occupies a place, glass of the utmost purity, transparency, freedom from colour, streaks, and striæ is of the highest importance; and to secure these qualities to the fullest extent much care, trouble, and expense are requisite. The first really successful maker of optical flint glass was M. Guinand of Solothurn in Switzerland who succeeded in making discs 9 inches in diameter free from striæ. Guinand died in 1823, and from his son, M. George Bontemps learned his secret, and at Choisy-le-Roi, near Paris, further improved the manufacture. In 1848 M. Bontemps was induced by Messrs Chance of Birmingham to establish the art in their great works. In the hands of that eminent firm the preparation of optical glass has attained a perfection not approached by any other glass workers, and the *chef d'œuvre* of optical glass hitherto made consists of a pair of flint and crown glass discs, 29 inches in diameter, exhibited by Chance Brothers at Paris in 1855. Regarding these Sir David Brewster said, "I have entertained the hope that the English Government would purchase these discs and construct with them the grandest achromatic telescope that ever was contemplated by the most sanguine astronomer." They were, however, purchased by the French Government in 1867.

Optical flint glass contains more lead, and is consequently heavier and more refractive, than the quality used for common purposes. It is made in a furnace having a single covered pot, and Guinand's secret consisted in constantly stirring the mass while it is in a molten condition so as to keep the heavier lead silicate from falling to the bottom. For the very highest qualities of optical glass, the contents of the pot are most scrupulously cleared, and the stirring is continued after the heat is lowered till the contents are cooled down to little more than a red heat. The furnace is then closed and the metal is allowed to cool and anneal gradually in the pot within the furnace. When withdrawn the pot is broken, and the mass of glass is polished on two opposite sides so that any imperfections may be detected by examination. From the mass, cut horizontally, perfect discs of such size as can be formed are then obtained. Optical glass is also blown into thick cylinders, and cast in slabs from ¼ inch to 1 inch in thickness.

Chance Brothers make six kinds of optical glass, of which the average densities and refractive indices for the three hydrogen lines and for the sodium line are given in the following table:—

	Density.	C.	D.	F.	G.
Hard crown	2·485	1·5146	1·5172	1·5232	1·5280
Soft crown	2·55	1·5119	1·5146	1·5210	1·5263
Light flint	3·21	1·5700	1·5740	1·5839	1·5922
Dense flint	3·66	1·6175	1·6224	1·6348	1·6453
Extra dense flint	3·85	1·6450	1·6504	1·6643	1·6716
Double extra dense flint	4·45	1·7036	1·7103	1·7273	...

In 1830 Faraday proposed the use of a compound silicate and borate of lead glass, with a density of 5·44, for optical use; and Maez and Clemandot have successfully introduced a boro-silicate of zinc. An optical glass of higher refractive and dispersive power than any previously known has been made by Lamy from a mixture of silica, red lead, and carbonate of thallium. The glass is perfectly homogenous, but of a yellow tint—an evil, however, said to be avoidable by the use of the sulphate instead of the carbonate of thallium. The extraordinary refractive power of the glass renders it peculiarly adapted for the fabrication of imitation precious stones.

Strass.—Remarkably faithful imitations of every kind of precious stone can be made from suitably prepared and, when necessary, coloured glass. The transparent basis from which artificial precious stones is prepared is called *strass* or *paste*, a material which must of necessity be the purest, most transparent, and most highly refractive glass that can be prepared. These qualities are combined in the highest degree in a flint glass of unusual density from the very large percentage of lead it contains. Among various mixtures given by Donault-Wieland as suitable for strass the following is an example:—powdered quartz 300 parts, red lead 470, potash (purified by alcohol) 163, borax 22, and white arsenic 1 part by weight. Special precautions are adopted in the melting of the materials, and the finished colourless glass is used for imitating diamonds. When employed to imitate coloured precious stones the strass is melted up with various metallic oxides, to which reference will be made under coloured glass. Artificial precious stones are, of course, easily distinguished from real stones by their inferior hardness, and by chemical tests. They may also be generally detected by a comparatively soft warm sensation they communicate when applied to the tongue.

Glass Tubes, used for gauge glass for steam boilers and for many other purposes, are made by a very simple process; but as the manufacture is a separate department of industry it demands some notice. A gathering of glass is made on a blow-pipe, which is marvered, and slightly blown, so as to form a thick-walled elongated globe. To the end of this globe opposite the blowing pipe a pontil-rod is attached by an assistant, and the two workmen move backwards the one from the other, drawing out the tube as they recede. One or two boys watch the process of elongation, and when the tube reaches the desired gauge they fan its surface so as to "set" the glass, and thus prevent further attenuation at that particular point. The relation of the mass of metal to the original cavity determines the comparative stoutness and bore or internal diameter of the tube, and it requires much dexterity to make a tube at once straight and of uniform gauge and diameter. In drawing out tubes of large gauge the operatives recede from each other at a slow rate; and in proportion as the size of tube decreases the rate of drawing out increases. In the Venetian factories, where small tubes for beads are made, the workmen move at a smart walking pace.

Massive Glass.—Under this term may be conveniently noticed the manufacture of various familiar solid glass objects which do not acquire their form either by blowing or pressing in the ordinary sense. *Glass Rods* form the basis of many of these objects; and the formation of a plain rod of glass is accomplished by a manipulation in all respects similar to that described under the head of glass tubes, the only difference being that the rod is drawn from a solid instead of from a hollow or blown gathering as in the case with tube drawing. From solid rod glass, glass buttons of various forms are "pinched" by heating the rod till it softens, and immediately pinching it in heated moulds made and worked like ordinary pincers, but having moulds of suitable form in place of the gripping surface of the pincers. The small facets of glass lustres and girandoles and glass marbles, are made by an analogous process.

Spun Glass.—Certain qualities of glass in the plastic condition are capable of being drawn out to threads of great tenuity, which, while possessing much brilliancy and beauty of colour, are perfectly flexible and elastic, and feel to the touch soft and smooth like fine wool. A good deal of attention has been given to glass spinning in Vienna and in the Bohemian glass-works, the thread produced being woven into many textiles for upholstery and wearing purposes. The material is specially useful in millinery ornaments owing to the fine colours in which it may be produced, and to the fact that it is unalterable in and unaffected by all kinds of weather.

A remarkable and novel application of glass was patented in 1878 by Mr J. B. Hannay. It consists in making glass a cementing or binding substance in the manufacture of emery wheels, now so much used instead of files. For preparing the wheels any broken fragments of glass are utilized. These are reduced to powder, mixed with proportions of powdered flints and emery, and in the form of a cake introduced on a layer of paper into a furnace where the material is submitted to a heat sufficient to fuse it into a compact ringing mass. The resulting cake is of intense hardness and durability, and cuts through ordinary emery wheels with ease. As the glassy emery wheels can be made very much cheaper than those at present in use, there is little doubt that this material will come into extensive use, in the rapidly increasing applications of emery to grinding, smoothing, and cutting.

COLOURED GLASS.—When to the ordinary materials in the melting pot small quantities of various metallic oxides and other mineral substances are added, coloured but still transparent glass is produced. The colours yielded vary in intensity according to the proportion of oxides used; and the temperature at which the fusion is effected, the length of time the molten glass remains in the melting pot, not only modify, but actually change altogether, the resulting colour. Indeed, it has been asserted by M. Bontemps that all the colours of the spectrum may be obtained by the use of one oxide alone, if employed in varying proportions and at different temperatures. The materials, temperatures, and other conditions employed by manufacturers for producing certain of their colour effects in glass are kept as trade secrets; although, in a general way, the substances which produce particular colours are perfectly well known. Blue is obtained by the use of cobalt,—the ordinary blue pigment smalt being a powdered cobalt glass. Yellow glass can be prepared from several sources: uranium yields a beautiful opalescent yellow; salts of silver are the source of fine shades of yellow; a different tone of the same colour may also be obtained from oxide of antimony; and a dull yellow is produced from powdered charcoal. Green was at one time prepared chiefly by the use of cupric oxide and of ferrous oxide; now oxide of chromium—which produces a beautiful emerald green—is much employed, that substance being mixed with other oxides when modified colours are desired. For red glass, cuprous oxide is employed to produce an intense ruby tint; and the purple of Cassius—a compound of gold with tin oxide—yields magnificent shades of ruby, carmine, and pink, while oxide of iron also is the source of a brownish-red colour. For the production of violet tints the black oxide of manganese is depended on, and a mixture of the oxides of manganese and cobalt is employed for black. The deep-black glass prepared at Venice for making glass beads contains a large percentage—about 11·40—of manganese. Avanturine an imitation in glass of the mineral bearing that name, is a warm, brown, opaque glassy body, studded with innumerable minute spangles having a metallic lustre. It was originally made in the Venetian glass-houses, but can now be manufactured generally throughout the Continent. According to Von Pettenkofer, the metallic spangles consist of cuprous oxide, and one means of preparing the glass consists of melting equal parts of cuprous oxide and ferrous oxide with the glassy mass. The other opaque varieties of coloured glass are obtained by using the various metallic oxides with the compounds that produce milky or white glass.

The uses of coloured glass are various, the most obvious and usual being for ornamental windows, for signal lights, for imitation precious stones and ornamental table glass, &c. For the imitation of precious stones the strass already alluded to forms the basis, and both flint glass and Bohemian (potash) glass are much used for coloured domestic glass. Window and signal coloured glass are made both as rough plate and as sheet glass. In the case of plate glass the metal is, of course, uniformly coloured throughout, but coloured sheet glass may either be composed of "pot metal" or it may be "flashed colours." Pot metal consists of glass uniformly coloured throughout; but in flashed colours the body of the glass is transparent sheet metal covered on one surface only with coloured glass. It is very simply made: the workman, taking up on the end of his blowing tube a gathering of clear metal from one pot, dips this into a pot of coloured metal, thus gathering over the transparent mass a uniform stratum of coloured glass. The whole is then blown in the ordinary manner, and according to the original relative proportions of clear and coloured metal will be the thickness of each in the finished sheet. It is obvious that this process admits of many variations, such as gathering the coloured metal first, or making alternate gatherings of coloured and clear metal so as to have clear within coloured, coloured within clear, and so on.

IRIDESCENT GLASS.—Ancient glass, which has for ages been submitted to the slow disintegrating influence of the damp of the earth and other gently operating agencies, in many instances displays an iridescent play of colours of a most magnificent description. The iridescence thus shown, it has been long known, is due to a process of decomposition resulting in the formation of excessively thin scales of glass. Numerous attempts have been made to imitate by artificial means, the gorgeous display of colours thus produced by the slowly acting influences of many centuries, and a certain amount of success has attended some of these efforts. The Venetian glass workers possess the means of giving the surface of their glass a kind of metallic iridescence; and in certain Hungarian glass houses iridescent glass has been made for at least about 20 years. But in 1873, at the Vienna Exhibition, iridescent glass formed a prominent feature, and since that time it has become very common. The iridescent glass now generally seen is a plain flint glass having a slightly metallic tinge and a play of colours like a soap bubble. It is probable that several methods of producing iridescence in glass are practised, as the nacreous lustre in different examples varies considerably. The subject was investigated by MM. Fremy and Clemandot; and under a patent obtained by the latter gentleman, one method, commonly practised, has been made public. It consists in submitting the object to be iridized to the influence of a weak acid solution—such as water with 15 per cent. of hydrochloric acid—under the combined influence of heat and pressure. The effect certainly falls immensely short of the iridescence of ancient glass, but the glass assumes permanently a pearly iridescence, and, though the effect is tiresome, the process will doubtless continue to occupy a place among the methods of ornamenting table glass, &c.

OPAQUE GLASS.—Absence of transparency in glass may be due to any of three causes—(1) to the grinding, or roughening by other means, of the surface of ordinary clear glass; (2) to devitrification or crystallization of the substance; and (3) to the mechanical intermixture of an opaque substance in the glassy mass. Obscured glass was formerly principally prepared by a process of grinding the surface,—the means employed in the case of sheet and plate glass being simply the smoothing process, which forms an intermediate stage in the operation of polishing plate glass. Now the greater part of ordinary obscured glass is prepared by the agency of Tilghman's sand blast, an apparatus by which a fine stream of sand is blown with great violence against the glassy surface. The impinging grains of sand abrade the surface with extraordinary rapidity, and by protecting certain portions with suitable stencils, elaborate patterns in clear glass are produced in a very simple manner. Alabaster glass, so called on account of its resemblance to that substance, is an opaque variety of glass which has been long known and used. Its opacity is due to a process of devitrification it readily undergoes, favoured by the excess of uncombined silica used in its preparation. The material is prepared from a combination such as 100 parts of sand, 40 of potash, 5 of borax, and 5 of talc (silicate of magnesia). Into the composition of this glass it will be observed no lime enters, although sometimes bone-earth is added to the materials. For enamel glass a mixture of varying proportions of lead and tin oxides is prepared by calcining the two metals together, and using the compound in the preparation of a mixture for fusing, of which the following is an example:—sand 100 parts, pure potash 80, and mixed oxides 200 parts. The proportion of tin varies within wide limits, and oxide of antimony may be substituted for the tin. Bone glass, milk glass, and opal glass, differing in degree of opacity, are made by adding to the materials of clear glass large proportions of bone-ash, or of oxide of tin, or both together, and with these substances white arsenic may also be combined. The following is an example of a batch for opal-flint glass:—sand 100 parts, bone-ash 30, potash 30, borax 5, and red lead 5 parts. Such a glass was formerly in extensive use for the opal shades of gas lights and moderator lamps, &c.; but the ruddy glow possessed by the rays passing through the imperfectly opaque glass was an objectionable feature in the resulting material. During recent years an opal or milk glass free from such a defect has been introduced, and it is now in extensive use for globes. This preparation, which diffuses light from its surface in a clear pure white glow, owes its milky opacity to the use of cryolite—a mineral substance consisting of a double fluoride of aluminium and sodium (Al_2F_6, 6NaF) obtained from Greenland. The cryolite glass was first brought prominently into public notice by the Hot-Cast Porcelain Company of Philadelphia, by whom it was made on a large scale, although the material had been in use in Bohemian and Silesian glass-works for some years previous to the commencement of the manufacture in America. For milk white glass the materials used are—sand 100 parts, cryolite 40, and zinc oxide 10 parts. The finished glass, which is remarkably strong, hard, and indifferent to acids contains about 15 per cent. of undecomposed cryolite, to which its opacity is due. The copious evolution of fumes of hydrofluoric acid during the melting, which continues even in the working, is the source of serious difficulty in the manufacture of cryolite glass.

TOUGHENED OR HARDENED GLASS.—In the year 1875 the announcement that a French gentleman, M. de la Bastie, had discovered a means of rendering glass practically unbreakable attracted a great amount of attention; and his statements were immediately made the subject of practical investigation throughout the glass-making community. All the experiments made in connexion with M. de la Bastie's process tended to confirm his claim to have discovered a method of rendering glass capable of bearing a shock or strain variously estimated at from 30 to 100 times greater than the same material annealed in the common way. De la Bastie was led to undertake the prolonged series of experiments, which ultimately resulted in his discovery, by the consideration that the brittleness of glass arises from weak cohesion of its molecules; and his efforts were first directed to improving its molecular arrangement, by submitting glass, in a molten state, to forcible compression. This series of experiments led to no practical result; and the line of investigation he ultimately pursued, as well as the merits and defects of his process, are thus succinctly stated by Mr H. J. Powell of Whitefriars Glass Works, with whom M. de la Bastie carried out his first practical experiments with hollow glass. Mr Powell, writing in August 1875, says of the process:—

"That it consists in plunging glass heated to the melting point into a bath containing an oleaginous mixture, at a high temperature, but considerably cooler than the glass itself; and that this, according to the specification of the patentee, is effected by re-heating already manufactured and annealed glass in a kiln, and passing it thence into the bath. After a rough trial of this process, which certainly answers well for flat or solid glass, we decided that it is defective, for hollow flint glass, as hollow vessels, left to themselves in a kiln, are almost certain to collapse on reaching the required heat. To avoid this difficulty, and knowing that a vessel in course of manufacture, however hot, is always under control whilst it remains on the workman's rod, we placed a bath as near the mouth of the working-pot as possible, and directed the workman, instead of sending the finished vessel to the annealing oven, to drop it into the bath. The vessel is caught in a wire net, and is ready for removal as soon as it has acquired the temperature of the bath. For all vessels made in one piece, e.g., tumblers, finger basins, &c., this process answers well; and it is obvious that if it proves to be the best way of treating hollow flint glass, the use, for this description of glass, of the complicated machinery described in M. de la Bastie's specification will be done away with, and the glass will be tempered in the course of manufacture, instead of being re-heated and tempered after it has been already manufactured and annealed. We ascertained, with M. de la Bastie's aid, the right constituents and right temperature of a bath for flint glass; for although the conditions for sheet, plate, and flint glass are nearly the same, there is a difference, and it seems probable that every chemically different glass, and even every different thickness of glass, may require certain variations. In our experiments as to the hardness of the glass, we found that it could be marked, but not cut, with the diamond, and, although it could be smoothed and engraved in the ordinary way, that the disturbance caused by the wheel, when penetrating to any appreciable depth, tended to weaken, or even to cause the destruction of the entire mass. The value of the invention, as far as it concerns flint glass, is at present somewhat modified by difficulties in manipulation. 1. It seems to be impossible to heat a vessel made up of different pieces and of various thicknesses to an absolutely equal temperature throughout, so that the whole may be equally tempered. 2. It seems also impossible to displace the air from a narrow-mouthed vessel quick enough for the inside and outside to be tempered simultaneously. However, setting aside these difficulties, we come to a point which applies equally to all sorts of hardened glass. Hardened glass is not 'unbreakable'; it is only harder than ordinary glass, and though it undoubtedly stands rough usage better, it has the disadvantage of being utterly disintegrated as soon as it receives the slightest fracture, and up to the present, until broken, of being undistinguishable from ordinary glass. This glass is known as 'toughened' glass, and we have seen the terms 'malleable' and 'annealed' applied to it. Nothing can be more misleading than these unfortunate epithets. The glass is hard, and not tough or malleable, and is the very opposite to annealed glass. Annealed glass is that the molecules of which have been allowed to settle themselves; the molecules of hardened glass have been tortured into their position, and until the glass is broken are subject to an extreme tension. It is the sudden change of temperature that 'hardens'; glass heated up together with the oil may be annealed, but decidedly is not hardened. A piece of hardened glass is only a modified Rupert's drop, i.e., it is case-hardened; the fracture of both is identical, both resist the diamond, and both can be annealed. Moreover, in the middle of imperfectly hardened glass a line is plainly visible, which seems to mark the extent of the case-hardening. This line resolves itself under the microscope into a mass of bubbles and striæ; it seems to be the nucleus of breakage, and consequently as soon as the cutting wheel approaches it, utter destruction ensues."

The great anticipations which at first were formed as to the extended use of hardened glass have not been realized. M. de la Bastie has improved several of his processes; but the demand for his productions, at no time great, is understood to decrease rather than to increase. For a short time the process was worked by both Messrs Powell and Messrs Pellatt in London, but both these eminent firms have given it entirely up. Sheet glass hardened by the process does not appear ever to have come generally into the market, the most serious obstacle to its introduction being the impossibility of cutting it with the diamond, after which the utter destruction resulting from fracture is a serious defect. For laboratory purposes—as flasks and beakers, &c.—it has been suggested that the glass has great advantages, but experiments have proved that its great resistance is not absolutely reliable, and that hardened vessels submitted to a high heat lose their distinguishing peculiarities and become as common glass. Thus a glass, partially filled with water and heated considerably above the boiling point at the parts uncovered with water, broke, the bottom of the glass showing the fracture peculiar to hardened glass, while the upper uncovered part was broken into large sharp-edged fragments like common glass. A modified process of hardening, patented by Herr F. Siemens, consists in pressing and suddenly cooling the glass in moulds specially constructed to conduct away the heat with the various degrees of rapidity found to produce the best results.

STATISTICS OF THE GLASS TRADE.—According to a factory report of 1871, there were in that year 240 glass-works in the United Kingdom, employing, in addition to steam-power, 21,434 operatives, of whom 2116 were females. Of these works 213 were in England, 19 in Scotland, and 8 in Ireland. Further, there were at the same date 37 glass-cutting factories, employing 500 people, principally situated in the county of Warwick. The quantities and value of glass manufactures exported were as under in the year 1878:—

Plate glass	1,156,435 sq. ft.	£106,906
Flint glass	93,112 cwts.	239,966
Common bottles	575,160 ,,	308,481
Other glass manufactures	72,209 ,,	99,170
		£754,523

In 1878 the imports of manufactured glass were thus given:—

Window glass	652,325 cwts.	£452,202
Flint glass	143,665 ,,	489,518
Plate glass	91,198 ,,	233,602
Glass manufactures	335,751 ,,	879,733
	1,222,939	£2,055,055

The following table shows the comparative imports and exports of glass in the ten years ended 1877:—

	Imports, Foreign.	Exports of British Glass.	
		Plate Glass.	Other Kinds.
	Cwts.	Square Feet.	Cwts.
1868	609,806	911,330	868,950
1869	601,070	1,076,130	933,475
1870	602,376	1,357,508	799,252
1871	629,472	1,643,575	847,988
1872	688,156	2,131,924	1,002,498
1873	807,410	2,183,106	1,148,640
1874	946,903	1,411,268	1,114,253
1875	983,677	1,609,180	880,983
1876	1,060,361	1,779,628	743,495
1877	1,140,694	1,157,063	792,424

In the *Bulletin de la Société d'Encouragement pour l'industrie nationale* for 1877 there is an elaborate statistical computation of the extent and value of the glass manufacture throughout the world, based chiefly on returns applicable to 1874. The writer, M. Henry de Fontaine, arrives at the conclusion that the annual production of glass has almost doubled in the past twenty years, and estimates the total yearly production throughout the world at a value of six hundred millions of francs.

Bibliography.—The literature of glass-making of English origin is scanty and imperfect. In France and Germany the subject has received much fuller attention. The following list embraces the principal works:—Antonio Neri, *Ars Vitraria, cum Merritti observationibus*, Amst., 1668 (Neri's work was translated into English by C. Merritt in 1662, and the translation, *The Art of making Glass*, was privately reprinted by Sir T. Phillipps, Bart., in 1826); Johann Kunkel, *Vollstandige Glasmacher-Kunst*, Nuremberg, 1785; Apsley Pellatt, *Curiosities of Glass-making*, London, 1849; A. Sauzay, *Marvels of Glass-making* (from the French), London, 1869; G. Bontemps, *Guide du Verrier*, Paris, 1868; E. Peligot, *Le Verre, son histoire, sa fabrication*, Paris, 1878; W. Stein, *Die Glas-fabrikation* (in Bolley's *Technologie*, vol. iii.), Brunswick, 1862; H. E. Benrath, *Die Glasfabrikation*, Brunswick, 1875; J. Falck and L. Lobmeyr, *Die Glasindustrie*, Vienna, 1875. (J. PA.)

GLASS PAINTING.

The manufacture of coloured glass, which is the basis of the beautiful and interesting art of glass painting, originated at a period of remote antiquity, and the use of enamels, to vary or ornament its surface, was known to the ancient Egyptians; but the formation of windows of mosaics of coloured glass upon which the shapes of figures and ornaments are painted with an enamel fixed by fire is mediæval, and emphatically a Christian art. In all probability it was suggested by the mosaic pictures with which churches were adorned from an early period for the instruction of the illiterate, as was shown by the inscription which they bore, "sanctæ plebi Dei." The step from mosaic pictures to glass mosaic windows was merely a question of time; it is not known when the step was taken, but coloured windows existed in St Sophia at Constantinople in the 6th century, whilst the basilicas of St John Lateran and of St Peter at Rome were adorned about the same time in the same manner. In the year 709 Wilfrid, bishop of York, invited workers in glass from France ("artifices lapidearum et vitrearum fenestrarum primus in Angliam ascivit"). The French claim the honour of having invented the process of painting upon the mosaic windows of coloured glass, and of thus transforming them into works of art, and also of teaching this to the English, who in their turn instructed the Germans; but Muratori, in the second volume of his *Antichità Italiche* of the Middle Ages, printed a treatise on mosaic and painted glass written by an anonymous Italian in the 8th century, and probably not later than the 11th was written the interesting essay *Diversarum Artium Schedula Theophili Presbyteri et Monachi*, which details with minute accuracy the process of painted glass as it has been practised with some additions and modifications, throughout the best periods of the art; it may reasonably be assumed that Theophilus describes methods invented before his time. Probably the oldest specimen of glass painting now existing is a window of the 11th century in a church at Neuwiller, in Alsace, representing St Timothy. The figure is rudely designed, but, with the rich border of ornament, shows that the executant knew his art, which in the following century is further illustrated by windows in St Denis, near Paris, erected by the abbot Suger, which are still preserved. It was however in the 13th century, that great age of the revival of art, that glass painting attained its first great development, and notwithstanding the claims advanced by France, it is most probable that as all art radiated from Italy as a general centre of invention and progress, as well as of faith and dogma, so glass painting partook of the general impulse. It has indeed been asserted that glass manufactured in the north was superior to that produced in Italy, and this is admitted by Vasari, but an examination of old Italian windows throws doubt upon this statement, for the Italian glass will be found to be more even in texture, more diaphanous, and certainly not inferior in colour, whilst the beautiful, pearly, white glass of the earliest date in Italy is superior to the pale green representing white in northern glass, and assorts much more harmoniously with the glowing coloured glass with which it is associated. Considered as a branch of fine art, Italian painted glass occupied a very high position at all periods of its history, for the designs were frequently made by some of the most famous of that long roll of immortal artists who have had so few equals elsewhere. In Germany the family of Hirschvogel of Nuremberg and other eminent artists, including, it is popularly believed, Albert Dürer, and in France Jean Cousin, Bernard Palissy, Louis Fauconnier, and others, equalled the Italian glass-painters, whilst both German and French artists excelled them in technical processes.

The late Mr Charles Winston, author of *An Inquiry into the difference of style observable in Ancient Glass Painting, especially in England*, with his usual accuracy and profound knowledge of his subject, thus classifies the consecutive styles:—the Early English, from the date of the earliest specimens extend to the year 1280; the Decorated, which prevailed from 1280 to 1380; the Perpendicular from 1380 to 1530; and the Cinquecento from 1500 to 1550. The styles successively prevalent in Italy, although they have an affinity with those following each other in northern countries, cannot be accurately designated by the titles selected in England, the last excepted. Like other branches of painting they are most readily divided and understood by centuries; as the 13th century, a style principally influenced by Giunta Pisano and Cimabue; the 14th century, in which the spirit of Giotto and Orcagna and their followers prevailed; the 15th century, the first period of which was transitional, and the second early revival, as illustrated by the designs for windows of Lorenzo Ghiberti, Donatello, Paolo Ucello, Pietro Perugino, Andrea della Robbia, and other great artists of the time. The last age, called by Mr Winston the Cinquecento, lasted in Italy beyond the period assigned by him for its termination, and was characterized by florid magnificence of design and splendour of colour, imitative of the pictorial art of that age, and the ornament resembled that prevalent amongst the ornamentists of the schools of Raphael and Michelangelo.

In this brief analysis of the history and practice of glass painting, the Italian examples of the art are selected for description as being less known than those existing in other parts of Europe, which have been minutely and ably illustrated. Besides being classified by centuries, Italian glass painting may be appropriately arranged under the following heads or schools:—the Pisan, Florentine, Sienese, Umbrian, Lucchese, Bolognese, Lombard, and Venetian; for notwithstanding the lamentable destruction of painted glass in Italy even now in progress, specimens by artists belonging to these schools still exist, and the names of a numerous array of glass-painters of these provinces are preserved. The best examples extant of this art in Italy of the first half of the 13th century are two couplets in the apse of the famous basilica of St Francis at Assisi. In general arrangement and design they resemble windows of the same age in other parts of Europe classed by Mr Winston under the general head of Early English, being divided into panels of varied and admirably designed geometrical forms surrounded by diapers and borders of rich fancy and glowing colour, which, however, are rather more confused than similar details in contemporary glass elsewhere. The panels are filled with scripture subjects, and Italian skill and refinement are obvious in the design of the figures; this may be readily understood when it is considered that Italian artists of this time rendered the Greek art, universally followed, with more sentiment and power than any other people. The ornament shows the influence of Byzantine conventions, but the ornamentists imitated natural forms of foliage sooner than northern artists. A remarkable peculiarity of the early painted windows at Assisi, which are here taken as the best and almost the only specimens of 13th-century glass left in Italy, is that throughout the couplets the backgrounds in each light differ in colour. The subjects for instance in the right light are on a blue ground, on the left on a red ground, in other examples the grounds are alternately blue and green. It might be supposed that all unity of effect must have been destroyed in this way; but such is the skill with which the general harmony of colour is arranged, that the counterchanges are less objectionable than might appear possible. Early Italian glass painting, like that of other parts of Europe, is characterized by an obvious ignorance of perspective on the part of the designers, but there are manifest indications of attempts to represent retreating surfaces and lines; that these have not the effect intended was not due, as some suppose, to the maintenance of a principle appropriate to glass painting, but simply to a want of knowledge of perspective laws common to all, even the greatest artists of the time.

Besides executing panel windows with small figures, the artists of the 13th century painted figures of comparatively large proportions under canopies of simple and primitive forms. These figure windows were placed in positions at a distance from the eye, as above in the clerestory, or at the ends of aisles. At Assisi such figures are painted at the bases of some of the windows irrespective of the idea of distance, the upper portions being filled with panels and small figures. This irrational system gave way to the entire window being filled with large figures placed over each other within canopies or geometric borders, a method of design which survived in Italy to the close of the 15th century.

The coloured windows of the upper and of the lower church are associated with mural paintings which cover every available space on the walls and vaults. It might be supposed that the refulgent painted glass would either obscure the frescos or diminish their effect by contrast; but in the first place the glass is not so thick as that of northern manufacture, nor is it made opaque by the effect of climate, whilst, as already noticed, the white glass is purer, and the brilliant sun of a southern climate illumines the frescos sufficiently, notwithstanding the coloured medium through which the rays are transmitted. Such is the case at Assisi; but at Florence the coloured glass in the cathedral darkens the church too much, from causes which will be explained afterwards. The true method of combining coloured glass in a building with the presence of pictures and sculpture in a less sunny climate will be illustrated in describing glass painting of the 16th century, the subject being important at the present time.

In the next great age of art, that which commences with the triumphs of the genius of Giotto, glass painting evidently shared in the general progress. No windows remain which are associated with his name as designer, but in Santa Croce at Florence, by the will of Count Alberto di Lapo, dated the 9th of July 1348, money was provided for adorning the apse of the church with frescos and painted windows to be completed in three years. The frescos were painted by Angelo di Taddeo Gaddi, and it seems reasonable to suppose that he designed two of the three windows,—that in the centre being of later date. The following extract from the archives of the cathedral of Florence shows that Angelo Gaddi designed for glass-painters: "A window in Santa Reparata"—the ancient name of the cathedral—"over the door towards the street of the Cassettai is commissioned of Antonio of Pisa, master glass-painter, and the design is by Angelo Gaddi." The windows illustrate the system of ranging single figures under canopies over each other. The colouring is harsh; there is too great a prevalence of dark green; and the general design of ornament is meagre and confused. This is increased by the capricious changes of the colours of the canopies, which are not white, these being rare in Italian glass painting. Thus in one of the windows the first two canopies are respectively red and green, which colours are counterchanged in those immediately over; the next two in ascent are green and yellow, the next pair brown and yellow, the fifth order shows both yellow. Thus that variety of colour prevalent in the backgrounds of Italian 13th century work is found in the canopies of windows of the next century, a custom limited to glass painting, and not found as a rule either in mural or other pictures. There are in Santa Croce several windows of the 14th century, but they are generally inferior to those of the same period extant in St Francis of Assisi, where there are important examples of rare beauty of design and workmanship, more harmoniously coloured than those at Florence, and suggesting that the Umbrian excels the Florentine school of glass painting.

Throughout the whole of the painted windows existing in Florence, of the fully developed style of the 14th century, and for a considerable portion of the 15th, the influence of the architectural design of Giotto and Orcagna is very perceptible. The graceful twisted shafts common to the works of both architects, the richly adorned niches and gablets, the dome-like covering of the famous baldacchino in the church of Or San Michele, the work of Orcagna, are features which are imitated in various ways by Italian glass-painters. The colour is especially noteworthy; the canopy, somewhat squat in form, is adorned in every part with rich and diversified colours evidently imitative of the varied marbles and the infinity of marble inlay and mosaics, characteristic of so much of the mediæval architecture of Italy; whilst in northern countries the canopies in windows, with their beautiful details of form showing such rich fancy and such graceful lines, are chiefly white, not that they are altogether colourless, for it is of the perfection of mediæval architecture to associate colour with form. That which in Italy was done by the help of rich stores of marbles of many hues, was effected in the north, where these were not available, by means of polychromatic painting, which was imitated in window design by the glass-painters. Thus the canopies in Italian windows differ as much from those prevalent at the same period in the rest of Europe as the campanile of Giotto differs from the spires raised by the genius of northern architecture.

In the history of painted glass in Italy during the 15th century, the windows of the cathedral of Florence, dating from 1390 to 1503, occupy an important position, not only by reason of their interest as connected with that celebrated church, but also because they were designed and executed by artists of the highest reputation. The cathedral was founded on the 8th of September 1298, the architect being Arnolfo di Cambio di Colle di Valdelsa. In 1334 Maestro Giotto was architect, and commenced the famous belfry. In 1364 the church was vaulted over at its eastern end, and in 1420 Filippo Brunelleschi and Lorenzo Ghiberti, who built the clerestory of the nave with its round windows and Renaissance cornice, were appointed joint architects. Painted glass was introduced into the windows thirty-six years before the completion of the cupola, and thirty before that of the clerestory. These dates are an interesting testimony to the importance attached at the time to painted windows as portions of the design of so great a church. They were erected in the aisles, before the nave was finished, by Don Lionardo di Simone, monk of Vallombrosa, and Niccolo di Pietro della Magna, so early as 1390, and when the nave was roofed over by its architects, Fra Bernardino di Stefano executed the two first windows of the clerestory from designs by Lorenzo Ghiberti.[1] Ghiberti is also alleged to have designed many of the painted windows at the east end of the church; but those now existing, judging by the design and colour, as well as by the technical execution, cannot be his, for they are manifestly of earlier date, whilst the authorship of some of them is recorded in the archives without reference to Ghiberti. One only, on the north side of the apse and in the lower row, suggests the design of this great artist, the suggestion being strengthened by the fact that the diapered ornament on the ruby dress of the figure is made by the wheel, which brings this window within the 15th century, whilst the diapers in the other figures of the same series are executed in an older style. It has been stated that Ghiberti advised the municipality of Florence to invite a celebrated glass-painter of Lübeck, Francesco di Domenico Lievi da Gambassi, by letters, the second being dated October 15, 1436, to settle in Florence with special privileges; he came, and it is assumed that he painted Ghiberti's designs for glass, but of this there seems to be no satisfactory evidence. We find that in 1434, before his arrival, Maestro Domenico di Pisa painted the east window of the drum, representing the coronation of the Virgin, which was designed by Donatello in competition with Ghiberti, and preferred. As it was on the 12th of January 1434 that Brunelleschi completed the dome, evidently no time was lost in commencing the painted windows. Bernardo di Francesco del Boni is recorded in the archives as having executed in 1442 the following windows in the drum, called in Italian

[1] This circumstance has led to the erroneous statement, repeated to the present time in every guide-book and by every writer on the cathedral, and to the still prevalent belief, that the three windows in the façade of the church were designed by Ghiberti, who has himself recorded:—"I designed for the front of Santa Maria del Fiore, for the central round window of the façade, the Assumption of our Lady, and I designed those on each side." The windows which Ghiberti really designed were the great circle of the façade, a noble work still in its place, and the two of the clerestory on each side of it, long since removed and lost. That they were painted by Fra Bernardino di Stefano in 1423 is thus shown in the archives of the cathedral—"Fra Bernardino di Stefano, of the order of the Preachers of Santa Maria Novella, is to execute two round windows in the nave of Sa Maria del Fiore, one to the right and the other to the left,—that to the right representing Joachim driven from the Temple, that to the left the Death of the Virgin Mary, and the designs are by Lorenzo di Bartoluccio (Ghiberti)." It is thus evident that the windows of the clerestory of the nave were to be painted with the life of the Virgin Mary, of which these two were the first and last of the series, whilst the Assumption of the Virgin appropriately occupied the centre. Those in the clerestory having disappeared, it has invariably been supposed that the two remaining at the ends of the aisles are those described by Ghiberti, although they differ in subject and entirely in style from his work. They are in fact thus mentioned in the archives:—"In 1414 Nicolo di Pietro della Magna painted the two windows on each side of the front of the cathedral," which record settles the question.