PHILOSOPHICAL TRANSACTIONS.

# I. The Bakerian Lecture.—*On the manufacture of Glass for optical purposes.*

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## *Introduction.*

PERFECT as is the manufacture of glass for all ordinary purposes, and extensive the scale upon which its production is carried on, yet there is scarcely any artificial substance in which it is so difficult to unite what is required to satisfy the wants of science. Its general transparency, hardness, unchangeable nature, and varied refractive and dispersive powers, render glass a most important agent in the hands of the philosopher engaged in investigating the nature and properties of light; but when he desires to apply it, according to the laws he has discovered, in the construction of perfect instruments, and especially of the achromatic telescope, it is found liable to certain imperfections, not essentially existing, but almost always involved during its preparation, and fatal to its use. These are so important and so difficult to avoid, that science is frequently stopped in her progress by them; a fact fully proved by the circumstance that Mr. Dollond, one of our first opticians, has not been able to obtain a disc of flint glass four inches and a half in diameter, fit for a telescope, within the last five years, or a similar disc of five inches in diameter within the last ten years.

It must be well known to the scientific world, that these difficulties have induced some persons to labour hard and earnestly for years together, in hopes of surmounting them. Guinand was one of these: his means were small, but he deserves the more honour for his perseverance and his success. He commenced the investigation about the year 1784, and died engaged in it in the year 1823. FRAUNHOFER laboured hard at the solution of the same practical problem. He was a man of profound science, and had all the advantages arising from extensive means and information, both in himself and others. He laboured in the glass-house, the work-shop, and the study, pursuing without deviation the great object he had in view, until science was deprived of him also by death. Both these men, according to the best evidence we can obtain, have produced and left some perfect glass in large pieces: but whether it is that the knowledge they acquired was altogether practical and personal, a matter of minute experience, and not of a nature to be communicated; or whether other circumstances were connected with it,—it is certain that the public are not in possession of any instruction, relative to the method of making a homogeneous glass fit for optical purposes, beyond what was possessed before their time; and in this country it seems doubtful whether they ever attained a method of making such glass with certainty and at pleasure, or have left any satisfactory instructions on the subject behind them.

The philosophical deficiencies referred to above, induced the President and Council of the Royal Society in 1824, to appoint a Committee for the improvement of glass for optical purposes, consisting of Fellows of the Royal Society and Members of the then Board of Longitude. The Government on being applied to, not only removed the restrictions to experiments on glass, occasioned by the Excise laws and regulations, but undertook to bear all the expenses of furnaces, materials, and labour, as long as the investigations offered a reasonable hope of success. In consequence of these facilities, a small glass-furnace was erected in 1825, and many experiments both upon a large and small scale were made with flint and other glasses. During their continuance, Messrs. GREEN and PELLATT gave every instruction and assistance in their power, and evinced the most earnest desire for success. The researches, however, soon showed themselves to be a work of labour, which, to be successful, would require to be pursued unremittingly for a long period; and on May 5, 1825, a sub-committee was appointed, to whom the direct superintendence and performance of experiments were entrusted. This committee consisted of Mr. HERSCHEL, Mr. DOLLOND, and myself; but in March 1829 was reduced to two, by the retirement of Mr. HERSCHEL, who about that period went to the continent. From the respective pursuits of the three persons appointed upon this committee it may be easily gathered, that though all were to do what they could in every way for the general good of the cause in which they were jointly engaged, yet a distinction in the duties of each existed. It was my business to investigate particularly the chemical part of the inquiry; Mr. Dollond was to work and try the glass, and ascertain practically its good or bad qualities; whilst Mr. Herschel was to examine its physical properties, reason respecting their influence and utility, and make his competent mind bear upon every part of the inquiry.

The experimental glass-house was erected on a part of the premises of Messrs. Green and Pellatt, at the Falcon Glass-works; whilst my duties as Director of the Laboratory of the Royal Institution, required my presence almost constantly at the latter place, nearly three miles from the former. As I found it impossible under these circumstances to make the numerous experiments and pay that close attention which appeared essentially necessary to produce any degree of success, the President and Council of the Royal Society applied to the President and Managers of the Royal Institution, for leave to erect on their premises an experimental room, with a furnace, for the purpose of continuing the investigation. They were guided in this by the desire which the Royal Institution has always evinced to assist in the advancement of science; and the readiness with which the application was granted, showed that no mistaken notion had been formed in this respect. As a member of both bodies, I felt much anxiety that the investigation should be successful. A room and furnaces were built at the Royal Institution in September 1827, and an assistant was engaged, Sergeant Anderson of the Royal Artillery, whose steady and intelligent care has been of the greatest service to me in the experiments that have been proceeding constantly from that time to the present. At first, the inquiry was pursued principally as related to flint and crown glass; but in September 1828 it was directed exclusively to the preparation and perfection of peculiar heavy and fusible glasses, from which time to the present continual progress has been made.

I have thought it right to give this brief explanatory statement of the manner in which it has happened to become my duty, on the present occasion, to give an account of what has been done in the improvement of glass for optical purposes by the Committee of the Royal Society, working at the Royal Institution. I would willingly have deferred this account until the inquiry were more complete than at present; for though glass has been made, and telescopes manufactured, yet I have no doubt that much more of improvement will be effected. It may be said that a long time has elapsed since the experiments were first instituted; and that if any thing could be done, it should have been effected in so long a period. But be it remembered, that it is not a mere analysis, or even the developement of philosophical reasoning, that is required: it is the solution of difficulties, which, as in the cases of GUINAND and FRAUNHOFER, required many years of a practical life to effect, if it was ever effected. It is the foundation and developement of a manufacturing process, not in principle only, but through all the difficulties of practice, until it is competent to give constant success: and I may be allowed to plead the acknowledged difficulty and importance of the subject as a reason, both why it may not yet have obtained perfection, and why it should still be pursued.

My wish, however, to delay the account of the researches until I could have carried the experiments further, is overcome by the conviction that much more time must be expected to elapse before I shall consider the investigation finished; by the consideration that a decided step has been made in the manufacture of glass for optical purposes; and by the feeling that the Royal Society which instituted, and the Government which defrays the expenses of the experiments, have a right to an official account of the present state of the investigation. Although much useful information has been obtained respecting flint and other glasses, yet as that train of research is very imperfect, uncertain, and will probably be resumed, I shall confine my present statement altogether to the heavy optical glass already referred to. It will be impossible for me to describe all that has been done on this subject; but I shall endeavour to give such an account of the glass, and the process by which it is obtained in a homogeneous state, as shall enable other persons to do what has been done at the Royal Institution, without incurring the laborious prefatory experiments and investigations which we have had to undertake; only introducing so much of the latter, and the principles of the process, as are necessary to make the descriptions clear to a practical man, and enable him to avoid those circumstances which might otherwise occasion failure. That the paper may appear long and tedious I am aware; but it should be remembered, that it can have no other utility than as containing efficient instructions to the few who may desire to manufacture optical glass; and that to render whatever of this character it may have, imperfect, for the sake of giving to it a more abbreviated and popular form, would have been doing injustice to the objects and motives of those who have instituted and supported the experiments.

## § 1. *Process of Manufacture, &c. &c.*

1. The general properties of transparency, hardness, and a certain degree of refractive and dispersive power, which render glass so valuable as an optical agent, are easily obtained: but there is one condition essential in all delicate cases of its application, which is not so readily fulfilled; this is, a perfectly homogeneous composition and structure. Although every part of the glass may in itself be as good as possible, yet without this condition they do not act in uniformity with each other; the rays of light are deflected from the course which they ought to pursue, and the piece of glass becomes useless. The streaks, striæ, veins or tails, which are seen within glass otherwise perfectly good, result from a want of this equality; they are visible only because they bend the rays of light which pass through them from their rectilinear course, and are constituted of a glass having either a greater or a smaller refractive power than the neighbouring parts.

2. When these irregularities are so powerful as to render their effects observable by the naked eye, it may easily be supposed to what an injurious extent their influence must extend in the construction of telescopes and other instruments of a similar nature, where these faults are not only magnified many times, but where the effect is to give an equally magnified erroneous representation of the object looked at, when the very point to be attained is to examine that object with the utmost accuracy; and it is accordingly found that these striæ are the most fatal faults of glass intended for optical purposes. Besides this, not only do the striæ themselves occasion harm, but there is every reason to believe that they rarely occur in glass otherwise homogeneous. Sometimes, it is true, a grain of sand, in passing through and at the same time dissolving in glass, will give a streak of different composition to the rest of the substance; and at others, a bubble ascending may lift a line of heavy or more refractive matter into a lighter and less refractive portion above. But very often, and especially as glass is usually manufactured and collected for use,

striæ are merely the lines or planes where two different kinds of glass approximate; and even if the striæ could be covered so as to produce no bad effect, yet the other parts, not being in every respect alike, would exert an unequal action on light, and the piece be therefore improper for the construction of a telescope. Many a disc, which upon the most careful examination has appeared perfectly free from striæ and quite uniform, has, when worked into an object-glass, been found incapable of giving a good image, on account of the existence of irregularities in the mass, which, though not sudden or strong enough to occasion striæ, still produce a confused effect; and if this happens with glass approaching so near to perfection, it happens still more frequently and to a much stronger degree with such as contain visible irregularities.

3. It must not be imagined that striæ, or those fainter differences, are, according to an expression sometimes used, due to impurity. The glass, either of the streak or of the neighbouring parts, would be equally good for optical purposes were it all alike. It is the irregularity that constitutes the fault; and hence, in this respect, a particular composition is of very little importance. As glass is always the result of a mixture of materials having different refractive and dispersive powers, it is evident that striæ must exist at one period during its preparation; and the point required is not so much to seek for a difference of composition, or for those proportions which are found by analysis to exist in specimens of tried and acknowledged good glass; as to devise and perfect a process by which the striæ period should be passed over before the glass is finished, and the formation of fresh striæ be prevented.

4. Besides these, there are other faults in glass. Sometimes it is said to be wavy, when it has the appearance of waves within its mass; but this is only a variety of that irregularity which has just been explained as constituting, when in a stronger degree, streaks and striæ. Occasionally appearances are observed in it, which seem to indicate a peculiar structure or crystallization, or an irregular tension of its parts: these, there is every reason to believe, may be avoided by careful annealing. Again: the glass sometimes includes bubbles, which, when small and numerous, render it what is called seedy. Bubbles are not usually considered as of much consequence to the performance of the glass, but objectionable only because of their appearance when the glass is looked at, rather than when looked through. They each act like a very

powerful but very small double convex lens of a rare substance in a very dense medium, or as equally deep double concave lenses of glass would do in air; they rapidly, therefore, turn the rays impingeing on them on one side, and occasion a loss of light, just as so many opaque spots would do. But as even when numerous their united area may amount to only a very small proportion of the area of the plate of glass required for a telescope, this loss of light is usually of but little consequence. In practice, it is said that no other real evil than such loss of light is dependent on them.

5. Of all these faults, that of the irregularity constituting streaks, striæ, and waves, is the most difficult to avoid, and the most injurious in its effect. It is not an improvement only beyond what is ordinarily done in this respect that is required, but absolute perfection, a homogeneity equal to that of pure water. In the two kinds of glass required to render a telescope achromatic, namely, crown or plate glass, and flint glass, it is the latter which is obtained perfect with the greatest difficulty, and to which therefore the greatest attention has been paid. The reason of this will be evident, if the general composition of the two glasses be taken into account. The required difference between them in refractive and dispersive power is found to be at command, by attention to composition; and it has been also ascertained, that crown and plate glass answer exceedingly well for the one variety, and flint glass for the other. Crown glass consists of silica, lime, oxide of iron, sometimes a little alkali, and small quantities of other matters: these substances are not very different in their refractive powers, and when fused do not produce very strong streaks, even though a little difference in the composition of different parts of the glass may exist. The glass also is not a very powerful fluxing agent upon the crucible in which it is melted; so that although it is in contact with it in a fluid and heated state for many hours, it does not dissolve much from it; and what it does dissolve having a refractive power little different from that of the glass itself, proportionately less harm is occasioned. Again: the specific gravity of the different materials used is not very different; so that the mixing agencies which affect the contents of the pot,—such as the ascent of bubbles, the ascending and descending currents from difference of temperature,—are more energetically exerted, and the whole mass approaches nearer to uniformity in a given time, or acquires it sooner than would happen were greater differences to exist.

6. With plate glass the same circumstances hold nearly in an equal degree. This substance is composed of silica and alkali essentially, other elements being only in small quantities. Its action upon the crucible is greater than crown glass, but then it has a second application of heat in such circumstances as are calculated to give a very uniform temperature to the contents of a whole pot, and it is delivered into its final form in the manner least likely to cause mixture of the different parts.

7. With flint glass many circumstances are altogether different. Oxide of lead enters into its composition to the amount of one third of its weight, or more, and by its presence gives that proportion of refractive and dispersive power, which makes the glass valuable in conjunction with crown or plate: this it does in consequence of its own powerful action on light; and it makes the glass heavy also, because of its own great specific gravity. A third property belonging to it, namely its high fluxing or dissolvent powers, it also confers upon the glass. Now these three properties are unfortunately very conducive to the formation of striæ. If the least difference in composition exists between one part and another it becomes evident, because of the great difference between the qualities of the oxide of lead and the other ingredients; and a variation in proportions which in crown or plate glass would produce no sensible effect to the naked eye, would in flint glass form strong striæ. Hence it is required that the mixture be in this case far more perfect than in the other glasses; and yet it unfortunately happens that every thing tends to make it much less so. The oxide of lead is so heavy a material, and at the same time so fusible, that it melts and sinks to the bottom, leaving the lighter materials to accumulate at the top: and so imperfect are the means of mixture, under ordinary circumstances, that glass of very different specific gravity is procured from the bottom and top of the same crucible. The following are some cases of this kind, from pots containing glass not more than six inches in depth, made from the usual materials, and retained at a full heat for twenty-four hours:—

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|---|---|---|---|---|---|---|---|---|---|---|
| Top...... | 3.38 | 3.30 | 3.28 | 3.21 | 3.15 | 3.73 | 3.85 | 3.81 | 3.31 | 3.30 |
| Bottom... | 4.04 | 3.77 | 3.85 | 3.52 | 3.80 | 4.63 | 4.74 | 4.75 | 3.99 | 3.74 |

These differences are great, and selected for illustration; but from appearances there is little reason to doubt that the same state of things, though not to such an extent, occurs in every pot of flint glass made in the ordinary way.

8. Another curious illustration of the predominance of oxide of lead at the bottom is shown in many of our specimens, which have been broken through vertically: they have been affected by sulphuretted vapours and tarnished; but the tarnish has occurred only at the bottom, where the lead is abundant, and is there very strong, whilst there is no appearance of it towards the top.

9. Whilst the crucible is in the condition described, it is clear that all those circumstances, as currents, bubbles, &c., which tend to mix the glass, form abundant striæ and veins of enormous strength, and do harm unless they are continued in activity until the mixture is nearly complete; a state rarely if ever acquired in the ordinary flint glass pot. But even if this could be the case, there is a constant cause of deterioration, arising from the highly fluxing and dissolving quality given to the glass by the oxide of lead. In this respect, flint glass far surpasses crown or plate glass, and it is also during one stage of its preparation more fluid: it consequently is continually exerting a solvent power upon the crucible to a considerable extent, occasioning that very irregularity in composition which produces striæ, whilst the comparative levity of the matter dissolved at the sides and bottom, and the ascending currents at the hottest parts of the crucible are constantly mixing this deteriorating portion with the general mass.

10. The difficulties which are thus introduced into the manufacture of flint glass fit for optical uses appeared to the committee, who, however, were none of them practical glass-makers, to increase, as the scale upon which the inquiries were carried on diminished: and the enormous expense of large experiments,—the time required for each,—the number necessary to give that experience which should render any one who undertook the charge of this part of the inquiry an ordinary practical workman,—and the uselessness of the resulting glass for any other purpose than the one directly contemplated,—compelled the sub-committee to consider seriously on the possibility of making other glasses than those ordinarily in use, which, at the same time that they had the high dispersive power enabling them to replace flint glass, might have also such fusibility as would allow of their being perfectly stirred and mixed, and might be

retained, without alteration, in such vessels as could be procured of any desired size.

11. The borate of lead, and the borate of lead with silica, were the substances which, after some trials, were found to offer such reasonable hopes of success as to justify a persevering series of experiments; and the metal platina was looked to as the material out of which to form the vessels intended to be used. It was soon ascertained that the borate of lead could be readily formed from dry materials, and that silica might be added with great advantage to the resulting glass; a range of proportions between the three ingredients being permissible, which gave much command over the properties of hardness, colour, weight, refractive and dispersive power, &c., and yet remained within the required range of fusibility. Platina also was ultimately found to answer perfectly the purpose of retaining the glass: for though at first it was continually liable to failure, yet it was ultimately ascertained that neither the glass nor any of the substances entering into its composition, separate or mixed, had the slightest action upon it. Finally, it was found that several kinds of glass formed of these materials, were in their physical properties fitted to replace flint glass in the construction of telescopes, in some cases apparently even with advantage; since which time the experiments have been unremittingly pursued.

12. The great proportion of oxide of lead in these glasses rendered attention to very minute points essential; for otherwise striæ were inevitably formed, and even the destruction of the apparatus involved. For this reason, after a certain number of trials upon composition had been made, one unvarying set of proportions were adopted, and the attention given altogether to the discovery and establishment of a process which should yield constantly good results. This, as far as it has been carried into effect and proved, it is now my object to describe.

13. The glass with which I have principally worked is a silicated borate of lead, consisting of single proportionals of silica, boracic acid, and oxide of lead. The materials are first purified, then mixed, fused, and made into a rough glass, which is afterwards finished and annealed in a platina tray.

14. *Purification of materials. Oxide of Lead.*—The oxide of lead at first used was litharge; but this source occasioned frequent destruction of the platina trays, in consequence of the existence of particles of metallic lead, which

alloying with the platina, rendered it fusible. When red lead was substituted for litharge, the same effect took place, due to the presence of particles of carbonaceous and reducing matter. Both these substances also contained so much iron and other impurities, as to give a deep colour to the glass, far beyond what was expected from the quantity of impurity present; this was afterwards explained. Carbonate of lead was also found to be too impure. Finally, all the oxide of lead necessary was purified, by being converted into a nitrate, and crystallized once or twice, as occasion might require.

15. For this purpose litharge is first washed, by which many black carbonaceous and ferruginous particles are separated; it is then dissolved in diluted nitric acid, so as to form a hot saturated solution, the operation being performed in clean earthenware vessels. Both the perfectly pure and the moderately pure acid have been tried without any sensible difference in the results: a little sulphuric acid does not seem injurious; and I find that sulphate of lead will dissolve perfectly in the glass; but muriatic acid has been always avoided. As the acid, water and litharge are made to act on each other by heat, either purposely applied or resulting from the chemical action going on, it will be found that when approaching towards neutrality the liquid will become very turbid. The hot saturated solution is then to be poured from the remaining litharge and undissolved nitrate of lead, and after standing a few moments, again poured from the sediment, and set aside to crystallize in a cool place. Before it is left, however, it is to be examined as to its acidity: if strongly acid to litmus paper, it is in a right state; if not, a little nitric acid should be added, for the crystals of nitrate have always been compact and pure under such circumstances, and more readily separable from insoluble matter.

16. After eighteen or twenty-four hours, the basins of crystals are to be examined; the clear mother liquor carefully poured off; the crystals broken up in the basins; and then repeatedly washed in fresh clear portions of the mother liquor, that any insoluble deposited matter may be removed. There will generally be a portion of this deposit; but if the process has been well performed, the crystals will be quite free. If they appear perfectly white or bluish white, they need not be recrystallized; but if yellow, they must be dissolved in water, a little nitric acid added, and the crystallization repeated. The nitrate in the mother liquors and washings should be purified by repeated processes.

17. The good crystals are to be washed in three or four waters, to remove the last portion of deposit and adhering soluble impurities: but to prevent excessive solution of the nitrate, the same portions of water may be used for several basins of crystals washed at the same time, by making it pass from one to another in succession. Being thus cleansed, they are to be drained, put over the sand bath, stirred and dried, and finally preserved in glass bottles. By this process much iron and sulphate of lead are excluded; and the purified nitrate is found to yield a glass very far superior in colour to that prepared with the ordinary oxides of lead, and to exert not the slightest action on the platina: its use put an end to all the accidents and failures which resulted from the presence of metallic lead in the oxide. 166 parts by weight are to be considered as equivalent to one proportional or 112 parts of protoxide of lead.

18. *Boracic acid.*—The boracic acid for these experiments was obtained pure from the manufacturer, but before being used was carefully examined. It was rejected unless it was in white or bluish white crystals, clean and entirely soluble in water. Its solution was tested for iron by the ferro-prussiate of potash and a drop of sulphuric acid, and also for other metallic impurities by a little solution of sulphuretted hydrogen. An ounce or two were heated and dissolved in a little water; and when cold, the soluble part separated and examined for sulphuric acid, by a few drops of nitrate of baryta and a little nitric acid. It was also examined for soda by dissolving three or four ounces in hot water, adding ten or fifteen drops of sulphuric acid, and allowing the whole to cool and crystallize, expressing the mother water from the crystals; concentrating it; again crystallizing, and then acting upon the mother liquor, obtained at the second time by strong alcohol, and continuing to wash with the latter fluid until all was dissolved, or an insoluble part left. If the latter circumstance occurred, the insoluble substance was examined for sulphate of soda, which if in any sensible quantity occasioned the condemnation of the boracic acid. The care respecting alkali in boracic acid was taken in consequence of observing certain bad effects produced in glasses which appeared referrible to its presence.

19. When the boracic acid was acknowledged as pure, 36 parts by weight of the crystals were considered as equivalent to 24 parts, or one proportional of the dry substance.

20. *Silica.*—This material is in its most convenient state when it forms part of a combination consisting of two proportions silica, and one oxide of lead. As yet, the silica I have used has been the flint glass-maker's sand, obtained from the coast of Norfolk, well washed and calcined. The silicate has been prepared by mixing two by weight of this sand with one of litharge, or with such quantity of nitrate of lead as is equivalent to one of litharge (16); the mixture is put into a large Hessian or Cornish crucible, which being covered over, has been put into a furnace and raised to a bright red heat for eighteen or twenty-four hours. On taking out the crucible, the charge has been found diminished somewhat in bulk, and of a porous structure and appearance like loaf-sugar. It has been freed from the crucible, the outside portions removed, and the pure parts carefully pulverized in a clean Wedgwood mortar. The powder has then been washed over in water, so as to obtain the whole in a fine state of division; after which it has been dried, and preserved in bottles. No sieve should be used in these comminuting operations, nor any reducing or metallic matter brought in contact with the substance. Every care should be taken to avoid contamination: 24 parts by weight of the silicate are equivalent to 16 parts, or one proportional of silica, and 8 parts of protoxide of lead.

21. The advantage of the silica in this combined state depends upon the known composition of the substance, its comparatively easy pulverization, and ready fusion with the other materials. That there is iron in the silica (and the litharge when used) is objectionable; and the trials for its removal have only been delayed that the investigation of a more important point, namely, a successful process, might proceed. From some brief experiments, I am led to believe that an unexceptionable source of silica will be obtained by acting upon this silicate, in a state of fine division, by nitric acid and water, or else by the use of rock crystal.

22. On some occasions I used pulverized flint glass, as the source of silica, conceiving that being already in a fusible state, it must possess an advantage over other silica, in allowing rapid mixture with the other materials. Allowance was made for the oxide of lead present, and the alkali was permitted to pass, as a substance that would probably do no harm. But a striking effect took place, which at once showed the necessity of perfectly pure materials. The glass when finished and cold was of a deep purple colour: this was immediately

referred to the manganese in the flint glass; a supposition proved by repeating the experiment with other flint glass, and then with flint glass of our own manufacture in which no manganese was used: the latter glass gave no purple colour; the former, a colour as deep as the first flint glass.

23. Thus it appears that this very heavy glass, the silicated borate of lead (and I find it to be the case with other heavy glasses), has the power of developing the colour of mineral substances far beyond what flint glass possesses; just as flint glass surpasses in the same property plate and crown glass. In the case in question, the manganese, which did not give a sensible tint to the flint glass, produced a strong colour when diluted eight or nine times by the heavy glass, for the proportion of flint glass used was only $\frac{10}{85}$ths of the whole. On making a few experiments with iron, I find that the same strong development of colour is produced with it in these heavy glasses; so that the utmost care is necessary to preserve all the materials during their preparation, and the glass in every part of the process, from metallic contamination.

24. The use of flint glass even without manganese was also objectionable, because of the alkali in it, which, as before stated, was found to produce bad effects, and rendered the glass containing it very liable to tarnish.

25. Such are the materials from which the heavy optical glass has been latterly manufactured. When the composition has been determined upon, the proper proportions and quantities of each are weighed out in a clean balance and vessels; thus, for the silicated borate of lead glass, consisting of single proportionals of each substance, 24 parts of the silicate would be taken, for they contain a proportional of silica equal to 16 parts, and in addition 8 parts of protoxide of lead: the proportional of oxide of lead has been taken as 112 parts; but there being 8 in the silicate, the quantity of nitrate of lead equivalent to 104 parts only are required, and this is 154.14 parts: the equivalent of dry boracic acid is 24, which being contained in 42 parts of the crystals, that quantity is the one required. These proportions when heated and submitted to mutual action will leave only 152 parts of glass, or thereabout, for

| | | | |
|---|---|---|---|
| 154.14 | nitrate of lead contain . . . . . . | 104 | protoxide of lead. |
| 24.00 | silicate of lead contain . . . . . | 8 | ditto. |
| | | 16 | silica. |
| 42.00 | crystallized boracic acid contain . . . | 24 | dry boracic acid. |
| | | 152 | glass. |

Hence the materials for any quantity of glass can be easily calculated; and if the above parts be ounces, about 9lbs of glass will result. The nitrate of lead is then to be broken small in a clean mortar, and the other ingredients well mixed with it in basins, the use of metal or dirty implements being carefully avoided.

26. The mixture is next melted, and made into rough glass. This preparatory operation is necessary, because from the quantity of vapourable matter which is disengaged in this part of the process, the materials, if put at once into the finishing vessel and furnace, might boil over and do injury; and the acid nature of the vapours themselves, if it did not occasion harm by acting on neighbouring iron and other parts of the furnace, would at least cause inconvenience. It is effected in a furnace, which will be particularly described in the Appendix to this paper. It will be sufficient here to state, that being a close furnace, the part immediately beyond the fire-place forms a horizontal chamber, covered above by an iron plate having large circular holes; these allow crucibles to pass through them, and to stand supported on the bottom of the chamber, whilst their edges rise above the upper iron plate. In this way the fire is applied very generally to the crucibles, whilst their mouths are altogether exterior to the furnace, so that the introduction of any reducing or colouring impurity from the fire is prevented, and the greatest facility in introducing the mixture, of watching its fusion, of stirring the glass, and finally of ladling it out, is obtained. The holes through which these crucibles are inserted are five or six in number; they are never all in use at once, and those out of use are covered by crucible covers. The heat is not given altogether by flame; but whilst coal is used in the fire-place, coke is applied between the crucibles, being introduced for that purpose, and arranged through the unoccupied holes. The iron top of the furnace is covered by a second iron plate, or, what is better, by earthenware plates, to retain the heat. The crucibles are of pure porcelain ware, and as thin as they can be obtained. The covers for them are evaporating dishes, considerably larger than the mouths of the crucibles: being turned upside down, they rest, when in their places, upon the neighbouring earthenware plate; not touching the crucibles, but preventing any thing from falling into them, and preventing the vapours from passing into the room. The latter are by the draught of the chimney drawn through by the sides of the crucible into

the furnace, and carried away up the flue, so as to occasion no annoyance to the operator. The covers are slung by a piece of platina wire, which being passed across the middle on the outside, is bent at each end round the edges, so that a rod of iron slightly curved at the extremity, easily suffices to remove them when the crucible is to be opened. Great care is always taken to put them in clean situations, and that in their removal nothing shall fall from them into the glass.

27. This furnace is found to be very effectual in its action; being connected with a high flue governed by a damper, great command of the temperature is obtained. The crucibles before being used are examined as to soundness, and then their temperature is raised gradually, and should not be above a dull red heat when the operation commences. The mixture already described (25) is then introduced, and the crucible covered; decomposition of the nitrate of lead instantly commences; the boracic acid loses its water, all the fixed elements unite; and it is remarkable that though a considerable quantity of boracic acid usually sublimes with the water when the latter is driven off from its crystals unmixed with other substances, yet scarcely a trace seems to evaporate in the present instance, in consequence of the presence of the oxide of lead.

28. The heat should not be raised too high or the operation hastened, and then the ebullition will proceed very gradually and favourably, the rough materials being by degrees converted into glass. Before the first charge is entirely melted a second is put in, and when that is fused down, sometimes a third, according to the quantity of glass present and the soundness of the crucible. When all is fused, the temperature is allowed to rise, but not too much, lest action upon the crucible to a serious extent should occur; the glass is then well agitated and mixed by a platina rake or stirrer, to be described hereafter. Finally the glass is either transferred by a platina ladle into trays roughly turned up out of old platina foil, or into a clean deep white earthenware vessel containing much distilled water. In the lattter case it is obtained in a divided state, and when drained, is dried on the sand-bath, and put up in clean bottles.

29. When a crucible has been emptied of its first portion of glass, it will serve, if carefully used, for a second, third, fourth, or for many operations; but

it should be watched for cracks and casualties, that the running of the glass into the furnace may be prevented, and, if necessary, another vessel taken.

30. The rough glass thus prepared is in the next operation to be converted into an annealed and finished plate. The size must therefore be determined upon, and we will assume it as 7 inches square, and 8 tenths of an inch thick, that being the dimension of the largest plate as yet made. For the purpose of making a competent platina vessel, a plate of that metal will be required at least 10 inches square; but if larger, it should not be cut, but either made into a tray with higher sides than is absolutely needful, or else used first in the manufacture of a larger plate of glass than the one to be described. It should be of such thickness as to weigh at least 17·5 grains to the square inch; and it is important that in its preparation a good ingot or the good part of an ingot of platina has been selected, and that it has been rolled very gradually and carefully without the formation of any holes by the adhesion of dirt or hard particles, or by the dragging of the metal in the mills. The desired perfection is, I understand, best obtained by rolling the platina between two clean plates of good copper.

31. The plate, being laid upon clean paper or a cloth on a smooth table, is to be cleansed with a cloth and a little water or alcohol, and then to be ignited at every part by a large spirit lamp. It must next be carefully examined as to its state and the occurrence of places upon its surface where holes are likely to exist. If the metal seems dragged in any place, an effect indicated by a roughness upon the surface, or by short lines parallel to each other but perpendicular to the course of rolling, such place should be noted or marked, for which purpose a dot of ink will be convenient. If a scale appears, or a small portion is apparently folded over, it should also be marked; and if a black spot is visible, (and they are sometimes formed by the adhesion of a particle of dirt or grit,) it should be examined, and removed by the point of a knife, if necessary, and its place also marked. All these places and the whole surface of the plate should then be examined for holes by a still stronger test, namely, by holding the sheet of metal before and close to a bright light, as a candle or lamp, in a dark room, and every hole observed marked. In making this examination, it must be done carefully and minutely, holding the plate in different directions to the light (for sometimes the holes are oblique),

and being careful that no reflection from illumined objects, as the hands, on to that side towards the face shall give deceptive indications. In the marking, too, the indicating spot should always be made at a certain distance from the hole, as the fourth or the third of an inch, and on the same plate constantly in the same direction or towards the same edge; the holes are then easily found again, and the mark remains during the soldering to guide the operator.

32. The holes discovered by these examinations are to be closed by little patches of platina soldered with gold; for gold, like platina, may be safely used in these experiments, when reducing matter is absent. The gold has been used in the finely divided state in which it is obtained by precipitation from its solutions by means of sulphate of iron, but it must be washed perfectly pure: the patches are formed by cutting a piece of clean new platina foil into small square or rectangular plates: a sufficient heat can usually be obtained by the use of the spirit lamp and mouth blowpipe. In the process of soldering, a little of the powdered gold is heaped upon the hole and slightly flattened by some clean instrument, the spirit lamp is applied underneath for a moment, which causes the gold to adhere slightly, a selected patch of platina is laid delicately upon the gold, and then the heat of the spirit lamp, urged by the blowpipe, is directed beneath against the place. Usually the gold will melt and run instantly, the platina patch will come into close contact with the plate, and the operation will be completed. If well done, the fused gold will appear all the way round in the minute angle formed by the edge of the patch, and also faintly at the hole on the opposite side of the plate.

33. Sometimes when the patch is large, or in the middle of a plate, the heat obtained as above is hardly sufficient to melt the gold freely and cause perfect adhesion. In such cases, a single or double piece of platina foil loosely laid over the part, prevents loss of heat from the upper surface, and frequently causes such increased elevation of temperature as to render the soldering perfect and effectual. In the few cases where this expedient has not succeeded, I have resorted to the oxyalcohol blowpipe, using a small bladder of oxygen with a little attached jet for the purpose. This has never failed to produce an effectual heat, and 15 or 20 cubical inches of oxygen are sufficient for many operations.

34. This application of patches and soldering is only secure for small holes,

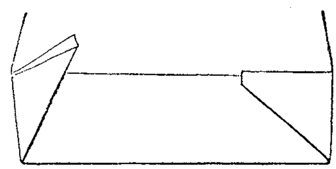
i. e. such as a pin might pass through, and smaller. The patches are always to be applied on that surface of the plate which is to constitute the outside of the tray; and therefore, before the soldering begins, the two surfaces should be examined, and the most polished and perfect selected as that intended for the inside. The patches are valuable in their use far beyond what the mere application of gold to the hole would be; for the heat afterwards applied to the tray when charged with glass, is abundantly sufficient to melt gold; in which case, if unsupported by the platina patch, the weight of glass and the action of stirring would probably force the gold out of the hole and cause the tray to run; whereas the patch of platina, although the gold holding it to the plate is liquid, still adheres by so strong a capillary action as to be sufficient to retain its place, and being outside is not disturbed by the motion of the stirrer. Besides, after a long application of heat, the gold and platina combine so perfectly as to become one piece of white alloy, infusible at the heat applied.

35. The plate is now to be folded into a tray, preparatory to which, a piece of thin board is to be provided as a guage, which in the present instance must be 7 inches square. This laid upon the plate and held tightly down, directs the foldings of the sides, and would, if placed in the middle, leave sufficient for edges one inch and a half high all round; but as the plate should serve for use several times, it is advantageous to apply the guage a little eccentric; for then, when used for a second and third operation, its place may be shifted, and the folds not occurring where they did before, there is less chance of holes being broken through the platina. The folds necessary at the corners of the tray are especially likely to render the same parts unable to bear a second and third bending; but the necessity of having them in the same place may be usefully obviated by placing the guage oblique to the sides in one direction and in another, on different occasions, and moreover gives other advantages in finishing the folding of the corners (36). These attentions, tending to the preservation of the platina for repeated service, are very needful, in consequence of the great expense of the material: the value of the plate in question is about 6*l.* 10*s.*, and when worn out, it may be sold for about half that sum. Whether it be used therefore once, twice, thrice, or four times, makes considerable difference in the expense of the resulting plates of glass.

36. When the guage is properly placed on the platina, the sides are raised

perpendicularly: this produces four projecting folded triangular corners, which being pressed close, are then turned against the sides, and a square tray is finished, which has no aperture or orifice below its upper edge. The folding of these corners is a matter of much more consequence than might be anticipated. The plate is seldom so regular that the parts of two neighbouring sides which come together at a corner are exactly of equal height; neither is it desirable that it should be so, and the unsymmetrical position of the guage to the plate, already recommended (35), is almost sure to prevent it. In that case, of the two sides of the folded corner, one will be higher than the other, and if the corner be so folded that its lower side is towards the tray and beneath its edge, a kind of syphon is formed which becomes charged with fluid by capillary action, and continues to discharge glass from the tray during the whole time of heating, notwithstanding that all the edges are much above the level of the fluid within. This in a long experiment is competent to occasion serious injury.

37. I have found, even when the edges of a corner have been of equal height, but below the edge of the side against which they are disposed, that still this capillary and syphon action has gone on, and the reason is not difficult to comprehend; the corners therefore have always been folded in such a manner, that their highest edge has been inwards, and both their edges above the level of the corresponding edge of the tray. To effect this, the line of their lateral flexure is not perpendicular to the bottom of the tray, but a little outwards above, and the proper degree of inclination is easily given by using a mould upon which to bend the corners. This should be a thick square piece of wood, having the four corners cut with different degrees of obliquity: when the corners of the tray are first imperfectly formed, it will be easy to ascertain by trial, which corner of this mould will give the obliquity and position already described as necessary, after which the folding may be easily finished upon it. The accompanying sketch represents first a good and then a bad folding.



38. All occasion for changes in the folds, especially at the corners, should be avoided. The folds should be decided upon as the work proceeds, so advantageously as to make alterations unnecessary. The closer the corners

are pressed, the smaller is the quantity of glass contained in them, and the less risk is there of the platina being broken when the finished glass is taken out; but it is proper to avoid general contact between the corners and the sides against which they are disposed, otherwise welding is likely to occur during the stirring, and the platina is injured for future experiments.

39. The tray being formed is again to be examined for holes, first by a light as before (31), and then in the following manner. Being laid upon a sheet of bibulous paper, alcohol is to be carefully poured in until the fluid is within the fourth or the sixth of an inch of the lowest edge of the tray, so as to occasion no running over at the sides or corners. If a large hole exist, it will be rendered visible immediately; but if none such appear, a large basin or some other cover is to be placed over the tray to prevent evaporation, but without touching the vessel or its contents; and the whole is to remain undisturbed for some hours. Being then examined, the wetting of the paper will indicate a hole or a badly folded corner, and will point out the faulty place: the tray may easily be shifted from one part of the paper to another for the discovery of any moistened places beneath. Sometimes holes occur so small that alcohol will not run in a sensible quantity through them. Suspected places of this kind and suspicious corners also should be examined by a clean dry point of bibulous paper, which soon shows, by its change of appearance, the transmission of any fluid: but attention is required that no false indication be produced by carelessly bringing the paper near the upper edges of the platina, especially in the folded places. These minute holes do not occasion much harm in the furnace, but no fault should be allowed to pass which care can correct.

40. When the tray is faulty, the alcohol must be removed by a small syphon, the holes soldered in the manner before described (32), and the tray again tried. When it proves good, it is, after the removal of the alcohol, to be heated red hot in every part by the flame of a large spirit lamp, and then reserved with care in a clean place until required.

41. If the platina has been used before, it should first be ascertained that none of the glass from the former experiment remain on it. If there be any portion, the plate must be returned to the weak acid or pickle out of which it has been taken. If free from glass, it should then be examined as to any

chemical injury it may have suffered. Any part which is altered in appearance, *or has been attacked by the acid, or which tarnishes when heated to redness by the spirit lamp, has been thus affected; and it will depend upon the* extent of the action whether the plate is unfit for further use. No chemical injury is occasioned by the proper and successful performance of an experiment.

42. An examination for holes by the candle or lamp must next be made, especially in the folds at the corners and where adhesion of the platina from welding may have occurred, and any that are discovered are to be marked as before (31). The plate should then be flattened by being put between two sheets of writing paper upon a smooth table, and the edge of a folding knife or some other smooth substance drawn over it; but if this be done whilst old glass adheres to the plate, it is almost certain to produce injury. The holes are then to be soldered and mended, the patches being applied upon the same side as before. The guage for the new tray is to be applied to the plate, shifted, if there be occasion, from its old position, as before intimated (35), and the folding of the tray, its completion and examination, to take place as before.

43. It is desirable never to cut the platina smaller than can be helped, but always to make the largest plate upon it for which it is competent. Then, when operated with a second or third time, smaller guages may be used, and the folds will not be repeated in the same place; and if injury occurs to the metal, being generally at the sides of the tray, the middle part will still be left for the preparation of smaller plates of glass.

If such large plates of platina are required for trays as can hardly be rolled at once, there is no difficulty in making a folded joint and rendering it tight by soldering with gold.

44. A kind of furnace, unlike the former, is now required for the completion of the glass, and its delivery in the state of an annealed plate. This furnace shall be described accurately in the Appendix. It may here be sufficient to state that it consists of a fire-place in which coals are burnt; of a part beyond, acting both as furnace and flue, in which coke is used; and of a chamber above, to be heated by the fire, though out of the course of both flame and smoke. It is in this chamber that the glass is made; so that, by the arrangement adopted,

at the same time the substances are fused and access for stirring allowed, the essential condition of excluding impurity or reducing matter is also fulfilled.

45. The fire-place itself is of the ordinary construction, and fed with fuel by an aperture in front in the usual way. I have found abundant reason to be satisfied that the passage of steam beneath the bars of the grate is of considerable use; for which reason an iron trough charged with water occupies the lower part of the ash-pit. The bars are by this arrangement preserved very cool and do not burn away; they are easily kept open and clear of clinkers; the free passage of air to the fire is permitted; and the action of the furnace retained at a high point for any number of hours together.

46. That part of the furnace beneath the chamber requires peculiar and careful arrangement; for at the same time that such a heat as will soften the neighbouring materials is produced there, the bottom of the chamber in its softened state and charged with several pounds of materials, has to be firmly supported for many hours together without change of position.

47. The coke necessary in this part is introduced by two or more holes in the side of the furnace, which, when necessary, are stopped by bricks. The bottom of the chamber is supported on ledges at the sides, and upon the ends of fire bricks in the middle, firmly placed at intervals so as neither to stop the passage for smoke and flame, nor the cross passages for the introduction of coke.

48. The value of the coke arrangement in this as in the other furnace is very great. The heat obtained by the united action of the coke and the flame from the fire-place, is abundantly sufficient; and whilst obtained at the necessary point does not involve that degree of mechanical action required for stoking and stirring, which is necessary with coals, and would risk the destruction of the soft thin bottom of the glass chamber. It further occasions the perfect combustion of the smoke produced in the coal fire, which at first was so considerable in quantity that, had it continued unaltered, the experiments must have been removed from the Royal Institution; in which case they would probably have been discontinued altogether.

The flue is the same as that connected with the former furnace, and has a damper for regulating the heat, especially useful during the annealing operation.

49. The chamber was at first of cast iron, that material being selected as one which would bear a sufficient temperature without melting, would conduct and transmit the heat freely to the substances within, and could be easily obtained of the requisite form. The upper aperture was closed by plate iron covers, and in the first trials all appeared to answer well ; but when large experiments were made, and the heat was continued for a long time, the bottom gave way and became irregular ; and upon endeavouring to rectify this, and place the tray of glass level by means of sand, the transmission of heat to the glass was prevented, the temperature of the iron rose, and the bottom melted. Besides these injurious liabilities, if the smallest portion of glass passed out of the tray, the moment it touched the iron it was reduced, the lead immediately caused fusion of the platina, and in an instant the tray was destroyed, the experiment stopped, the glass rendered black and useless, and the bottom of the chamber covered with lead and rendered unfit for another operation.

50. Finally, one very curious action of the iron was discovered, which immediately caused its rejection. Plates of glass, which seemed very good in other respects, were frequently so discoloured by dark smoky clouds as to be useless. These could not be referred to any impurity which had been left in the materials or had entered accidentally, and, as the platina was in all such cases altered and injured, was at first supposed to be occasioned by some particular action exerted between it and glass at high temperatures. But upon every fair trial to verify such chemical action, the proofs failed, however high the temperature used, or however minutely the metal was divided. At last the cause was discovered. To understand it, it must be known that the platina tray, with the glass in it, was either placed directly upon the bottom of the iron pan, or, for greater security, with only a plate of platina intervening; and that the whole was covered by an evaporating basin turned upside down, forming a sort of inner chamber within the large one. In this confined state the oxygen of the portion of air present was soon abstracted by the heated metal, an oxide of iron being formed in consequence, and at the same time also, a portion of carbonic oxide from the carbon in the cast iron. At the high temperature to which the experiment was raised, this carbonic oxide was competent to reduce a portion of the oxide of lead in the glass to the metallic state, itself becoming

carbonic acid; but as soon as the carbonic acid so produced came in contact with the heated iron, it was again converted, according to the well known condition of the chemical affinities at these temperatures, into carbonic oxide, and went back to the glass to repeat its evil operation and produce more metallic lead. In this way it was that the glass became sullied by smoky clouds consisting of metallic lead. It was the lead thus evolved also, that, by alloying with the platina, had produced the appearance of chemical action always visible in these cases; and now I knew how to account for the failure of many experiments in consequence of the formation of holes in the trays in a manner before quite inexplicable: for in the experiments purposely made to investigate this point, sometimes the glass was darkened only at the surface, the lower part being quite clear and good; and then, though the platina tray was frequently cut through as with a knife all round level with the surface of the glass, it was quite unaltered below. At other times the superficial stain was in a greater quantity, and had collected together into little drops like fat upon hot water, and upon examination each little globule was found to be soft metallic brilliant lead. At other times a much larger globule hung from the middle of the surface into the glass, barely sustained there, and ready to sink by the least agitation when in a heated state, and in some instances the bottom of the tray was alloyed and perforated by globules of lead which had thus been formed and deposited, and the glass just running out, whilst another globule was in progress of formation at the surface exactly over the place of the hole.

51. When iron was dismissed as the material of the chamber, earthenware was resorted to. The sides were built up of brick, and the bottom formed of tiles, which resting at the sides upon ledges, and at the middle upon the fire brick supports (47), could be replaced at pleasure. The same iron covers were used for the upper aperture of the chamber as before.

52. The use of earthenware as the material, made it far more difficult to apply a sufficient heat to the contents of the chamber than before, because of its inferiority to the iron as a conductor of heat; and a series of investigations were required to discover that substance, which, at the same time that it had sufficient strength and exerted no injurious influence, was also a sufficiently good conductor. Reigate fire-stone, recommended by the builders, did not answer the purpose, and moreover in thin plates was liable to fuse and slag.

Slate, however carefully heated, shivered and split, not only across, but parallel to its structure, and then, as soon as air intervened, it transmitted too little heat. It also softened, became curved, and let in air and smoke, and at last gradually fused, becoming unable to bear the weight of a large experiment. Yorkshire stone rubbed down into plates $\frac{5}{8}$ths of an inch thick, answered moderately well, if the application of heat was carefully made and gradually raised. It cracked in a few places, but did not fall to pieces; and it was more difficult of fusion than the former substances. Fire tiles of various kinds were tried; those made of Stourbridge clay answered the best, and when about $\frac{3}{4}$ths of an inch thick and carefully heated, might be successfully used; but that which we finally arrived at was the use of plates made of the materials from which Cornish crucibles are manufactured. These we obtained through the intervention of our President; they were purposely manufactured for us by Mr. Michell of Caleneck in Cornwall, a gentleman who has been ever willing and anxious to assist us in our inquiries, by supplying us with vessels of any size or form, or any other article which it was in his power to produce.

53. The Cornish plates have not much cohesion, and feel tender in the hand. They may be rubbed down to a flat surface, and resist any heat which can be applied to them in these or in much more powerful furnaces. They are therefore readily brought to any thickness, and when of about $\frac{5}{8}$ths of an inch, and supported in the furnace as before described (47), have strength to bear any weight required to be placed upon them. They do not crack, nor do they force themselves to pieces by expansion; but they are porous, as indeed are in a greater or smaller degree all the materials of which the chamber and its sides are now composed.

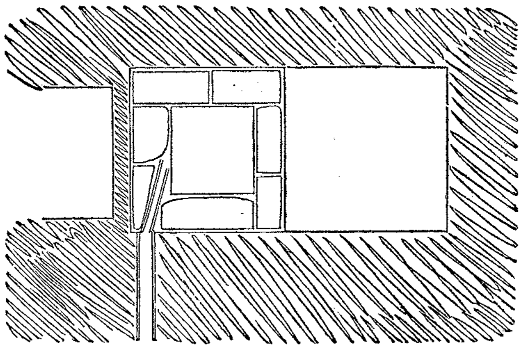
54. The porosity of these materials was of great importance; for it allowed of the passage of gaseous matter, and that even of a reducing nature, from the fire into the chamber. I have frequently had evidence that the sides and bottom might be considered as a very sieve-like partition between the fire, the flue, and the space called the chamber; for when the upper aperture has been closed, there has been a current through the chamber in the direction of the flame, the gaseous matter entering at the extremity nearest the fire, and passing out at the end towards the flue. In one or two cases, oxide of lead was actually reduced, and the glass thus rendered cloudy.

55. Hence it became necessary to use some certain means of maintaining an oxygenating atmosphere about the glass; to obtain which, and also to prevent any other injurious vapours from the fire entering the space beneath and within the earthenware covers (50), the expedient was adopted of allowing a current of fresh air to pass continually into that space and circulate about the glass. To effect this, a clean earthenware tube, glazed within, was let horizontally into the side of the furnace, in such a manner that one extremity was flush with the inside of the chamber, and of such height, that its lower edge corresponded with the level of the bottom upon which the glass in its tray was to be placed, whilst the other end of the tube reached to and was flush with the outside of the furnace. A loose piece of tube, similar in kind but smaller in diameter, being laid upon the bottom of the chamber, and applied at its end to the orifice of the larger one, served as a continuation of it until the inner extremity reached to and was under the cover of the glass experiment. When the furnace was hot, there was always a draught inwards through this tube; but the quantity of air admitted was regulated by a valve (70). The air, by first passing through the hot sides of the furnace, then through the shorter ignited tube serving for connection, was transmitted in a thoroughly heated state to the place where its presence was required, without producing any serious cooling effect; it there maintained a continually oxygenating atmosphere, and, judging from the effects, prevented the draught inwards of any vapours from the fire to the space beneath the glass covers.

56. The next point of importance, in the preparation of the glass, is the arrangement of the tray in the furnace, whose powers have just been described. To understand this, it will be necessary to say that the glass chamber is 25 inches long, 13 inches wide, and 8 inches deep, and that the fire being at one end, the flue is at the other. Plates of glass 7 inches square have been made in it; but it would probably require a larger furnace to make much larger pieces.

57. The bottom of the chamber being perfectly level and clean, the guage board, on which the tray was formed (35), should be placed on the middle of the half next the fire, and then a piece of connecting air tube taken, which being laid on the bottom of the chamber, may extend from the fixed air tube by the side of the guage as far as the middle, or even towards the other side of the chamber. After this, pieces of Cornish tile (53), or other clean

earthenware which will not fly in the fire, contains but little iron, and is free from glaze, are to be prepared, of such size that they will fit in loosely round the guage, covering the rest of that half of the chamber bottom, and serving to support the sides of the tray when in its place. This support to the tray is highly needful; for, otherwise, the weight of the glass, and the action of stirring, would be more than the thin and heated platina could support. The thickness of the pieces should be, for the plate in question, about 1 inch, and they should be all uniform in that respect. They should never rise so high as the edge of the platina, lest glass should accidentally pass from the tray to them, or impurities from them to the glass. An excellent guide to their thickness is, to make it similar to that of the intended plate. When they have been roughly arranged around the guage, the latter should be withdrawn, and the tray itself introduced, the pieces being now finally adjusted about it. They should not be so arranged as to press against its sides; but the latter should be at liberty, though only so much, that upon the least tendency of the sides outwards, they should be supported by the pieces. The assistance thus given should be directed rather to the sides than the corners, and it is better that the latter should not be in contact with these adjuncts, but be allowed to sustain themselves, for they are strong enough for the purpose, and the corners are always those places at which, from one circumstance or another, the glass is most likely to pass outwards.



58. The piece of earthenware which is fitted nearest the mouth of the air tube should have its angle taken off, or some other provision made, as by making the orifice of the tube oblique, that the passage of air may be uninterrupted; and on that side the tube itself may frequently form the support to the tray. If it does, and is glazed on the exterior, a piece of loose platina foil should be wrapped round it at the part where it touches the tray, to prevent adhesion by the glaze when cold. The general disposition of the tray, the tube, and the packings, may be seen in the sketch above.

59. When the first set of packing pieces is properly adjusted, a second series is to be arranged over them; but these are to be removed backward from the tray about the third or half of an inch all round, that accidental contact with its edges may be avoided. Their thickness should be sufficient to raise them level with, or rather above, the edges of the tray. All these adjusting pieces are to be rendered perfectly clean and free from dust before they are applied. Their use is not only to afford support and assistance to the platina tray, but also to sustain the glass covers, and likewise, by retaining the heat upon the bottom of the chamber, prevent much of the inconvenience that would otherwise occur at the times of stirring the glass.

60. The glass covers have, up to this period, consisted of inverted evaporating basins, suspended at pleasure, in the manner before described, by platina wires (26). When the platina trays used have been sufficiently small to admit of the arrangement in our present furnace, two, and even three covers have been used simultaneously, each prepared with its own platina suspension; but of such size, that the larger could be placed over and inclose the smaller, without touching it. In such cases the temperature of the glass, after being lowered by stirring, or in any other way, rose very rapidly; but with the large plate of 7 inches square, the furnace would admit of but one glass cover of sufficient size, and the only additional assistance which could be obtained was that which was given by putting a similar but smaller cover on the outside and above the principal one.

61. The first and important cover is to be selected of such dimensions, that when in its place and resting by its edges upon the packing pieces, it shall fully inclose the platina tray and its charge, not only for the purpose of accumulating heat and confining an oxygenating atmosphere within, but also sheltering the glass, and preventing any oxide of iron from the chamber covers, or dirt from other sources, falling into it. These covers, when hot, are raised and removed by means of clean iron rods, which being sufficiently thick to have abundant strength, and no injurious degree of elasticity, are made taper at one extremity, and slightly curved there. This end is easily introduced beneath the platina suspension wire, and as easily withdrawn when the cover is removed.

62. All these matters being preliminarily arranged, the final disposition of

the tray and its charge is made. The air tube is carefully wiped, and its external aperture closed by a clean loose plug of dry sponge. The tray is for the last time freed from dust by inversion and blowing upon it, and is put into its place. The quantity of rough glass necessary for the required plate, about 8lbs in the present instance (29), is carefully weighed out, and then introduced by an evaporating basin, or some other means which shall not allow of the admission of any reducing or colouring matter, or permit any portion of glass to pass beyond the edges of the tray. The glass covers are then to be arranged in their places; the iron covers of the chamber likewise adjusted, and over all are to be placed a set of thick earthenware tiles, which have been fitted together so as to constitute a general covering to the whole, well calculated to retain heat.

63. The ensuing part of the process is one in which the precise order of, and most advantageous proceedings have not yet been ascertained. Variations have been made up to the very last experiment, and it is only by still more extensive experience that the arrangement will ultimately be settled.

64. A fire being lighted in the furnace, and some coke put beneath the glass chamber, the temperature is gradually raised. In about an hour the bottom of the chamber begins to appear ignited, and in four hours the top iron covers are usually dull red hot. These appearances are useful, as indications of the progress of the operation. When the furnace has been heated for the first half hour, then every care is taken that the temperature may be fully sustained to the end of the experiment; and besides the ordinary kind of attention to the fire, particular care is taken that coke be supplied, by the lateral holes, to the part beneath the chamber; for, if the fuel there be allowed to burn out, the heat soon falls, notwithstanding the flame from the coals. Although the fire may seem quickly to have attained its best condition, yet the temperature continues to rise in the chamber long afterwards; for, from the quantity of lateral brick-work to be heated, it is usually many hours before the sides of the chamber are so hot, that the tray and its contents can attain their highest temperature. At the same time it must be understood that the heat of the glass is very much governed, especially at the early part of an experiment, by the number of covers over it, and rises far more rapidly, and much higher, with two or three covers than with one.

65. Perhaps the glass may with propriety be examined once, early in the

experiment, for the purpose of ascertaining that the tray and its contents are safe; but usually it is left for six or eight, or a greater number of hours, that the whole may fuse, the temperature rise, and the bubbles escape. When the glass is to be examined, the tile and iron covers are to be removed from over that half of the chamber containing it, by which, consequently, the glass covers are exposed; these are next to be carefully raised, one by one, using the iron instrument before described, for the purpose (61), and, as they are removed, are to be carefully put into the further part of the chamber, which still remains covered, where they will be retained in a heated state. This prevents their cracking and falling to pieces, as they would do if brought into the open air. If the experiment, and consequently the covers, are upon so large a scale that the latter cannot all be placed in this situation, then the exterior ones may be placed upon the top of the heated covers and tiles; but the particular cover, which immediately incloses the glass, being of great importance, must be put into the further safe part of the furnace, that it may be carefully preserved from injury, and ready to be replaced over the glass with the least possible disturbance.

66. The moment the last cover is removed, the glass is exposed to any falling substance from the iron plates, or tiles, or other sources, so that extreme attention is required at such times, to keep the place free from dust, and to perform every requisite operation as quietly as possible. The current of hot air which rises from the chamber, ascending and striking against the ceiling, frequently causes, by change of temperature and mechanical agitation, the separation of small particles of matter, which, descending, cause risk of injury to the glass; for which reason, it may sometimes be needful to have a temporary shelter fixed over the furnace, either of tin plate, clean boards, or some other material which shall not throw off scales or impurities of any kind.

67. If, by any unfortunate accident, a fragment of matter does fall into the glass, it should be instantly removed. It certainly will not sink, because of the great density of the glass, and may be taken out, usually with facility, by touching it, and the glass in its neighbourhood, with the platina stirrer (28), or the bottom of the platina ladle (28). In carrying it and the adhering glass away, great attention should be given, that none of the latter fall over the sides of the tray; since such portion might be a means of introducing im-

purity hereafter, or of cementing the tray and the earthenware together in a very inconvenient and injurious manner.

68. If, also, it should be observed, at this time, that there is a superabundance of glass in the tray, and not sufficient distance between its surface and the edges of the platina, the excess should be ladled out (28), an operation easily performed, but which must be done with care.

69. When the glass is ascertained to be in a proper condition, and that there is no appearance of any portion of it outside the tray, the covers are to be replaced, the chamber closed, and the heat continued. If the covers be glazed, some precaution is required in their arrangement; for on putting the second cover over the first, if they are left in contact by a portion of glazed surface, they will be found, upon their next removal, to adhere at that place. They should never be put in contact therefore with each other, or, if that cannot be avoided, a piece of old platina foil should be laid upon the place where the contact is necessary (58).

70. Whilst the glass is covered and subjected to a high temperature, there is, as before stated, an inward current of fresh air passing continually to and about it through the air tube, during the whole time of the experiment (55).

It was necessary to apply a valve to the external orifice of this tube to regulate the supply; for the draught was so considerable, that the glass was cooled by it, and much dust carried in. Finding reason to believe that even when very much diminished, the quantity of soots and dust in a London atmosphere, and especially in that portion of it taken from an experimental room in which a powerful furnace was at work, were competent to do much harm in eighteen or twenty-four hours, by giving colour and forming striæ, experiments were made on the means of cleansing the entering air. It was found easy to effect this, by the assistance of two or three Woulfe's bottles, or two or three jars, inverted one within another, using at the same time portions of diluted sulphuric acid, or such solutions of salts in the vessels as would not supply any moisture to the air, but rather take water with the dust from it. In these cases the air did not bubble through the liquid, but only passed close to its surface, and had time to deposit its dust during its passage through the inclosed spaces above the fluid: but, finally, a still simpler arrangement was used, consisting merely of a plug of clean dry sponge fitted into the end of the tube, which, at the same time that it allowed sufficient air to pass, seemed, from the appearance of the tube afterwards, to have excluded every impurity.

71. There are two conditions of the finished glass, each of great importance, which it is the object of the process to obtain in this state of the substance. One, and the most essential, is the absence of all striæ and irregularities of composition; the other, the absence of even the most minute bubbles. The first is obtained by agitation and perfect mixture of the whole; the latter, principally by a state of repose: so that the means required to be successful on both points are directly opposed to each other. Were the glass absolutely incapable of change by the long-continued action of heat, it would be easy first to render it uniform by stirring, and then to leave it in a quiescent state, until the bubbles had disappeared; but I am not yet fully assured of the fact which is necessary to this order of proceedings. That the glass as far as proportions are concerned, if changed at all, is altered only in an extremely minute and inappreciable degree, is shown by some experiments, in which, after a portion had been prepared and heated for many hours, and also stirred well, the resulting piece was divided into smaller portions, and these heated at different temperatures, in platina trays, for sixteen hours. Three portions were heated as powerfully as the furnace would admit of; three only to redness, which may be considered as a very low heat; and three to an intermediate degree: all were cooled slowly and annealed for an equal time. The specific gravities of each after the experiments were as follows:

| | | | | | |
|---|---|---|---|---|---|
| Highest heat | 5.4206 | 5.4211 | 5.4203 | Mean sp. gr. | 5.42066 |
| Intermediate heat | 5.4253 | 5.4242 | 5.4255 | ——— | 5.42500 |
| Least heat | 5.4258 | 5.4262 | 5.4235 | ——— | 5.42516 |
| Original glass | 5.4247 | 5.4261 | | ——— | 5.42540 |

72. Here, notwithstanding the irregularities between the similar experiments, there seems, from the comparison of the mean specific gravities, to be a gradual though minute diminution of density, as the glasses have been more powerfully heated; and I found also, that when glass was so well stirred as to leave no doubt that it was thoroughly well mixed, yet being left in the furnace at a high temperature for eight or nine hours, it contained striæ.

73. On the other hand, first to render the glass perfectly free from bubbles and clear, and then to stir out the irregularities of composition, I have not

found to be a practicable process; because the stirring, in the manner in which I have yet performed it, tends to introduce bubbles into the glass; and though these are only small, still they are objectionable. Hence a mixed process has been adopted, which, as I have before stated, is subject to correction from future experiments. To render the process as far as it has been carried sufficiently intelligible to others, I will first describe the circumstances connected with stirring, and their influence upon striæ; and afterwards, the plans adopted for the dispersion of bubbles.

74. It is not a small degree of stirring and agitation which is sufficient to make a fluid of mixed materials homogeneous; especially when the mixture is not exceedingly fluid, but has a considerable degree of tenacity, something like tar or syrup. An idea of the extent to which it must be carried, and of the general nature of striæ in fluids, may be gained by taking a glass full of clear saturated syrup, made from white sugar, putting a few drops of water into it, and stirring the whole together. It may then be remarked how slow the striæ are in disappearing; and when they are apparently destroyed, if the whole be left for some hours, it will frequently happen that a separation will take place into a lower heavy, and superincumbent light portion, which when stirred together again produce striæ. In the glass, the stirring must be in the utmost degree perfect, for if there be the least difference in different parts, it is liable to form striæ: nor are the different portions allowed to arrange themselves by their specific gravities, in which case one part might perhaps be removed from another, after the glass was finished and cold; but the ascending and descending currents which inevitably take place in the fluid matter, are certain to arrange the irregularities in such a manner as to produce the strongest possible bad effect.

75. The instrument used for stirring has hitherto consisted of a piece of plate platina, which for the seven-inch glass, taken as illustrating the process, is $6\frac{1}{4}$ inches in length and $\frac{3}{4}$ths of an inch in breadth. It is perforated with various irregular holes, that, when drawn through the glass like a rake, it may effectually mix the parts. A piece of thick platina wire, about thirteen inches long, is riveted to it, and the extremity of this screwed into the end of a clean iron rod which answers the purpose of a handle. No small or cellular apertures should be allowed in this stirrer; for they will frequently retain air or moisture,

which may cause bubbles in the heated matter and do much harm. A little gold, therefore, should be applied to the part where the stem is attached, and fused, so that all hollows may be filled up. Stirrers of different dimensions are to be provided for different sized plates of glass. Before being used, they should be steeped in dilute nitric acid, and also heated to redness in the spirit lamp, just previous to their immersion in the glass for the first time in each experiment.

76. When a stirring is to be performed, the tiles and iron covers are removed from the first part of the chamber (44. 49. 65), the glass covers also taken off and put into the back part of the chamber (61. 65), the glass quickly examined, to give assurance that all is in good condition, and then the stirring commenced. The stirrer should be put in gently, that no air may be carried down with it, and then drawn through the glass quickly but steadily, so as to mingle effectually, but not to endanger forcing the substance over the edges of the tray or to run the risk of involving air bubbles. The chamber and its contents are cooled by the necessary exposure to the atmosphere, and therefore, when the agitation has been continued until the glass is so much lowered in temperature as to become thick, it should be discontinued, the stirrer carefully removed, the glass covers replaced, the chamber covers restored to their situation, and the temperature allowed to rise for fifteen or twenty minutes, when the operation may be renewed.

77. All the precautions against loose particles, dust, and soot, that were before spoken of (66), should be adopted in this operation. In the act of stirring, the instrument should not be struck carelessly against the bottom or sides of the tray; for the platina in this highly heated state is very soft, and a hole would readily be forced through it; nor should it be brought forcibly against the corners, for the metal is in such a favourable condition for welding, that the least blow upon a doubled part causes adhesion. By merely allowing the stirrer, when ignited, to sink upon the bottom of the tray rather more hastily than usual, it has adhered to the place; and when, for safety, an underlying plate of platina was used (50), it was always found welded to the tray at the places which the stirrer had touched a little more forcibly than the adjacent parts, and could not afterwards be separated without leaving holes in

the metal. This circumstance was the principal occasion of the advantages afforded by the use of the underlying plate being given up.

78. The heat which has to be borne during the operation of stirring, is very considerable, especially upon the hands ; but at such a moment no retreat from the work, because of mere personal inconvenience, can be allowed. But the circumstance renders the use of a cover for the stirring hand very advantageous. I have found a loose linen bag, into which the hand could go freely, more convenient for this purpose than a glove; for being in contact with the skin at distant parts only, the hand is preserved at a much lower temperature. Two small holes in it, one at the front and the other at the top, allow the handle of the stirrer to pass obliquely through, by which arrangement it is easily held with firmness, and the bag itself prevented from slipping towards the glass. It should not be larger than to cover the wrist, or it will embarrass the movements ; and it should be very stiffly starched, and ironed, that no fibrous particles may fly from it to the glass during the stirring.

79. The glass which, adhering to, is brought away with the stirrer, indicates, by its appearance, the general character and state of that in the tray; but during its examination, the experimenter must carefully refrain from touching it; for if the finger, or any other ordinary organic substance, come into contact with it, the next time the instrument is immersed in the ignited glass, the part touched will produce bubbles. It is therefore of importance that the stirrer be preserved perfectly clean from one stirring to another, for which purpose it may be deposited so that the platina shall be received in an evaporating basin, the mouth of which is afterwards covered over.

80. In entering upon the considerations relative to the bubbles, it will be evident, from the nature of the materials and the quantity of elastic matter originally present, that these are at first very numerous. The larger ones soon ascend to the surface, and breaking, are dissipated without inconvenience; but the smaller ones rise with far less readiness, and the smallest have so little power of elevation, that the general currents in the liquid appear sufficient to carry them downwards, or in any other direction, and thus retain them for any period within the mass. A useful idea of the length of time required for very minute bubbles to ascend through a fluid having some tena-

city, may be gained by the person who will take a glassful of clear concentrated white sugar syrup, and beat it up with a little air, until a portion of the latter is in extremely minute bubbles. If these are allowed to remain undisturbed, it will be observed, that though the larger bubbles rise quickly, and the smaller soon after, the smallest will continue for many hours under the surface, destroying the pellucidness of the fluid; and this will be the case although there are none of those descending currents, resulting from difference of temperature, which in the glass assist in retaining the bubbles beneath the surface.

81. From the great length of time which it required to liberate the bubbles even from small pieces of glass, and when no stirring was practised, I was induced to conclude that the evolution of gaseous or vaporous matter had not ceased upon the first fusion of the materials, but that the glass itself when highly heated continued to evolve small portions for some time. It occurred to me also, that in that case its formation might be hastened and the final separation advanced by mixing some extraneous and insoluble substance with the glass, to act as a nucleus, just as pieces of wood, or paper, or grains of sand, operate when introduced into soda water or sparkling champaign; in which cases they cause the gas, which has a tendency to separate from the fluid, to leave it far more quickly and perfectly than if they had not been present.

82. The substance I resorted to for this purpose was platina in the spongy state. It was chosen as being a body solid at high temperatures, uninfluenced by the glass, easily reduced to powder, and likely to retain its finely divided condition during the operation:—its preparation is described in the Appendix. In experiments made expressly to ascertain its action, it was found to assist powerfully in the evolution and separation of the bubbles, and afterwards to sink so completely to the bottom, that not a particle remained suspended in the mass. Even stirring does not render it injurious; for the particles, by that action, are welded to the bottom, and the glass ultimately equally free from mixture with them.

83. The spongy metal should be perfectly pure. It is easily reduced to powder by rubbing it with a clean finger on clean paper. No attrition with a hard substance should be allowed, as that burnishes the metal, and takes away the roughness, which is highly advantageous in assisting the evolu-

tion of the bubbles. When reduced to powder, it should be again heated upon a piece of platina foil in the flame of a spirit lamp.

84. The quantity of powdered platina which I have usually employed has been about 7 or 8 grains for every pound weight of glass. But in order to effect its more general and perfect diffusion, I have usually mixed it with ten or twelve times its bulk of pulverized glass. For this purpose, some of the rough glass, the same in composition with that to be perfected, has been crushed small in a clean agate mortar, and the finer parts separated from the coarser on an inclined and shaken sheet of paper. The former have been then mixed little by little with the platina, and rubbed slightly with the finger, to effect perfect separation of the metal, and then the coarser parts have been added, to increase the bulk. In this state it was ready for use.

85. The time of introducing this prepared platina is, like the times of stirring, as yet under investigation. It has usually been sprinkled from the platina ladle (28) over the surface of the well-fused and highly-heated glass, at the period of the first stirring. This method has the advantage of bringing the assisting substance into contact with the glass when the latter is highly disposed to throw off its adhering gaseous matter, and also allows of thorough mixture; but it also causes the addition of fresh glass after the concoction of the materials has been proceeding for many hours; and it likewise occasions the introduction of many bubbles formed by the air in the interstices of the powder.

86. On other occasions the prepared mixture of platina and glass has been introduced into the tray at the period when it was charged with the due quantity of rough glass, and before the application of fire. Particular attention was then paid to its general diffusion throughout the charge, and on these occasions its action commenced the moment the glass in contact with it was fluid. I am inclined to believe the latter will ultimately prove the better method of proceeding, both for the greater length of time during which the platina can act, and for the facility and convenience of its introduction.

87. In either mode of appliance the platina has been found highly serviceable; and in every case since its use, where stirring has not been necessary, the resulting glass has proved to be perfectly free from bubbles.

88. As already mentioned, the best periods for stirring and repose have not

been finally determined. Stirring introduces bubbles, and therefore should, if possible, be avoided towards the conclusion of the experiment. Rest, or at least that condition in which there is no other motion than what is due to the currents produced by slight differences of temperature, causes striæ even after very careful mixture (71. 72), and is therefore equally to be feared; and whatever other variations may have been adopted, I have always found it important to apply a careful concluding stirring. The following may be considered as the order of an experiment. If the spongy platina has not been introduced into the tray with the rough glass, then about the sixth hour after lighting the fire it is added in the manner already directed (85), and the glass well stirred (76). At about the twelfth hour the stirrings are recommenced, for the purpose of making the mixture perfect, and are repeated every 20 or 30 minutes, according to the fusibility of the glass and the state of the heat (60), for 8 or 9 times. The glass is then allowed to remain at rest for 6 or 8 hours, that bubbles may ascend and be dissipated, after which it is well stirred twice or thrice more with particular attention, that if possible no air may be introduced, and is finally mixed for the last time.

89. This concluding stirring is peculiar, in that it has to be continued until the glass is so cold and thick that no ascending and descending currents can be formed in it; after which its temperature is not again to be allowed to rise: hence the operation requires certain preliminary arrangements. The first point necessary is to clear out a considerable quantity of slag from the flue furnace, or that part beneath the chamber (47). This slag results from the fused ashes of all the coke which has been consumed there, with other portions that have passed on from the coal fire. It is to be drawn on to the bars of the furnace by a fire-rake which will pass into the passages beneath the chamber. If not taken out in its fused state, it would be impossible afterwards to remove it without risk of great injury to the furnace. At the same time that the slag is removed, all the coke is likewise to be withdrawn. All the fuel in the fire bars is also to be brought out of the furnace; and if the bars are embarrassed with clinkers, they are to be loosened. These things being done quickly and quietly, and the furnace apertures closed, a few moments are to be allowed for the little dust that may have been agitated to settle, and then the chamber

is to be opened and the glass stirred. The heat will have fallen very little by the preceding operations, and the glass may be well mixed, but with this precaution, that when once the stirrer is beneath the surface, it should not again be taken out until the conclusion. By opening the feed-hole, or the ash-pit, air may now be allowed freely to enter the furnace, and will rapidly lower its temperature, especially at such parts as the bottom of the pan, which are thin and at this moment exposed to the atmosphere on both surfaces. The temperature of the glass will fall in a corresponding degree, and the stirring being all this while continued, though more slowly if convenient, the substance will gradually thicken, until at last motion will endanger its being pushed out of the tray, and then the stirrer is to be carefully withdrawn. No currents in the glass need be feared, for the temperature cannot now rise higher. But a single cover being put over the tray, and the outer orifice of the air-tube closed by a good cork, the whole may be left a few minutes to cool still further for perfect security, until, the glass being supposed to have arrived at the state of a thick paste, the annealing should commence. Then the ash-pit, the fire-place, and all the other apertures to the furnace are to be closed; the second glass-cover put into its place; the chamber shut up by its iron and tile covers; a layer of bricks arranged close together over the whole upper surface of the chamber and furnace; the damper of the flue closed to prevent air passing through the fire-place, and the whole left to cool gradually for several days.

90. The interval between the common temperature and that at which the glass begins to lose solidity and acquire softness, is so much less with this variety than with flint glass, that it is probable a much shorter period of time is required for its perfect annealing than for the latter. That no failure might occur in this point, however, four days and nights have been allowed for the annealing of the large plates. If every thing were left as just described, the contents of the chamber would be warm on the sixth or even the seventh day, so gradually do the arrangements allow it to cool; but on the morning or the evening of the third day, according to circumstances, the damper in the flue is withdrawn a very little to allow the passage of a small quantity of air, and by this means the cooling facilitated and regulated.

91. When the furnace and its contents are cold, the chamber is opened: if

the experiment has been well conducted, every thing will be found loose, and unaltered in disposition from what they were when first arranged. The earthenware supports are to be removed, and the tray taken out. After examining the glass itself, the exterior of the tray should be carefully observed, whether there be any appearance of leakages either through imperceptible holes or at the corners, and such places as can be rectified by a patch should be noted in reference to the future use of the platina.

92. An operation which, to be successful, requires much care, is then to be performed; namely, the stripping off the platina from the glass. The tray should be placed on clean smooth paper upon a cloth. The corners are one by one to be opened by a blunt smooth knife, or some softer instrument, from the side towards which they were folded; and being then carefully pulled outwards by their extremities, will usually open, so that the platina becomes single again. Then proceeding from corner to corner, the platina will peel or strip easily from the sides of the glass, and will remain adhering by the bottom only. From time to time as fragments of glass are formed, they should be blown away or otherwise removed, that they may not cut the metal. If now the glass be placed a little over the edge of the table and firmly held, the platina may gradually be separated from the bottom in the same manner as from the sides, and the glass and the metal finally divided from each other without any injury to the former, and very little to the latter.

93. Immediately upon the separation of the platina, and before it can receive any mechanical injury beyond what it was impossible to avoid, it is to be put into a pickle consisting of nitric acid and water, and left there for several days. The dilute acid acts upon the adhering glass, dissolving and loosening it, and the plate is thus rendered fit for future operations (41). The stirrers also, when no longer required in an experiment, should be taken from their iron handles and put into the same pickling liquor. In this way the platina is perfectly cleaned, and being afterwards washed carefully in pure water and ignited, is again ready for use.

94. Such is the nature of the process as practised at present, by which plates of heavy optical glass seven inches square and eight pounds in weight have been prepared. I am encouraged to believe that it will admit of improvement, perhaps even to the full extent of our desires; but it will require time and patience

to effect it. As I have before said, we are in the course of our experiments only; and up to the last have seen reason to vary the arrangements, and still intend to make alterations. Every thing agrees to convince me that the size of the plate is not a circumstance involving any additional difficulty; but that, on the contrary, it will probably be safer to make a large than a small experiment. We can at pleasure obtain a glass perfectly free from striæ, unexceptionable in hardness, and with less colour than crown glass; but it is the simultaneous absence of all striæ and bubbles, with at the same time that degree of hardness and colour which will render the glass fit for optical purposes, that I am aiming at, and that I trust shortly to obtain.

95. As soon as the plates of glass are removed from the platina and briefly examined, they are sent to Mr. Dollond, who then enters upon the discharge of his particular duties in the Committee, by cutting, examining, and even working them into telescopes. It is not, however, my place to detail this gentleman's exertions (as a member of the Glass Subcommittee) in the cause of science. They will, I trust, appear in due season; and I hope that the want of perfect success on my part will not long be a cause of delay.

### § 2. *General qualities of the heavy Optical Glasses.*

96. A great variety of glasses have been formed by the use of different proportions of ingredients. They vary importantly from each other, though by no means to the extent of the difference existing between any of them and flint glass. The *specific gravity* rises very high in borate of lead, consisting of single proportions, i. e. nearly 24 by weight of boracic acid and 112 of oxide of lead; it is often as high as 6.39 or 6.4, being double that of some specimens of flint glass. In silicated borate of lead, which, in addition to the former quantities, contains 16 parts, or a proportional of silica, it is about 5.44. As the proportion of oxide of lead diminishes, so also does the specific gravity lessen, and it is in some of the specimens as low as 4.2; still permitting by the proportions present such fusibility and other qualities as consist with the process described. The specific gravity of Guinand's heavy flint glass is about 3.616; that of a specimen of ordinary flint glass 3.290; that of plate glass 2.5257; and that of crown glass 2.5448.

97. The *refractive* and *dispersive* powers of the glasses increase with their

specific gravity, as was to be expected. The powers of two of them, namely borate of lead, and silicated borate of lead, consisting always, if not otherwise expressed, of single proportionals, have been ascertained by Mr. HERSCHEL, and are as follows:—

| | Bor. Lead. | Sil. Bor. Lead. |
|---|---|---|
| Angle of glass prism | 29° 6′ | 30° 26′ |
| Refractive index for extreme red rays . . . $\mu$ = | 2.0430 | 1.8521 |
| ——— maximum yellow . . . — = | 2.0652 | 1.8735 |
| ——— extreme violet : : . . . — = | 2.1223 | 1.9135 |
| Dispersive index $= \frac{\delta \mu}{\mu - 1} =$ | 0.0740 | 0.0703 |

These intense powers upon light are not accompanied by any circumstance rendering the glass optically unfit for the compensation of the dispersive powers of crown or plate glass. Three object-glasses have been constructed for the express purpose of ascertaining this point; and all of them tend to demonstrate that the compensation or correction may be effected with equal if not greater facility than with flint glass.

98. One important circumstance connected with the application of these glasses to the purposes for which they are designed, is their *colour*. The great power they have of developing strong tints from metallic impurities, has been already described and illustrated (22. 23), and creates a difficulty in the way of obtaining them unobjectionably free from colour. The usual colour is more or less of yellow, and is perhaps almost altogether, if not quite, dependent upon the presence of a little iron. Like many of those dependent upon mineral substances, it is very much heightened by elevation, and lessened by diminution of temperature. It is rapidly and permanently diminished by increasing the proportions either of the silica or the boracic acid. The silicated borate of lead has latterly been obtained of such faint tint by the precautions relative to impurities, already described, that, when 9 inches in thickness, white paper looked at through it in open daylight resembled in appearance and depth of tint the surface of a lemon. Glass consisting of 1 proportional = 112 oxide of lead, 1 proportional = 16 silica, and $1\frac{1}{2}$ proportional = 36 boracic acid, when 7 inches in thickness and examined in the same manner, did not give a colour surpassing that of pale roll sulphur. The tri-borate of lead glass is almost as colourless as good flint glass, but might perhaps be found objectionable on other accounts.

99. As there is a certain quantity of light intercepted by glass which is altogether dependent upon and in proportion to its colour, it is evident that this property of the heavy glasses must be considered in relation to their use in telescopes; but there appears no reason for supposing they will ultimately prove inapplicable on this account. The colour of the glass already obtained is far less in depth than that of the crown glass constantly used in the construction of telescopes, which yet intercepts by its colour no important quantity of light; and if two plates 8 or 10 inches long, one of the yellow heavy glass and the other of crown glass, be looked through edgeways, it will be seen in a moment that the crown glass intercepts by far the most light. The colour of the glass is of no consequence, otherwise than as causing a loss of light from interception; for the tinge which is cast over objects looked at through a telescope constructed with it is scarcely perceptible to the most acute eye, and quite unimportant. When to these circumstances is added the reasonable expectation entertained of removing a large proportion of the little remaining colour by the use of purified silica (21), it will not be anticipated that experience will prove the glass faulty in this respect.

100. There is one very important action of the glass upon light, however, which may perhaps interfere more with its application, in telescopes at least, than any other, i. e. its *reflective power*. This is very strong in all the heavy glasses, far stronger than in flint, and exceedingly surpassing the similar power of crown glass. It is in proportion, as might have been expected, to the refractive power and the density of the glasses, all these properties increasing with the oxide of lead. The loss of light occasioned by the reflection from the two surfaces of a plate through which a ray is passed, appears to me to be greater than from the united action of both colour and bubbles in a piece of glass 7 inches thick.

I endeavoured to ascertain the comparative quantities of light reflected by these heavy and other glasses, in some photometrical experiments made upon the principle of similar shadows, measuring only the reflexion from the first surface of the different glasses, that from the second surface being destroyed. The ray was made incident in all the cases at an angle of 45°. It was obtained from a small single-wicked lamp *a*; and when reflected, its intensity was measured by the distance of a similar lamp *b*, whose direct light cast the comparative shadow. The uniformity of the two lights, or at least of their relation to each other, was established by trials before and after the experiments with the reflecting surfaces, and each surface was tried two or three times, at intervals, and in a mixed manner; so that no anticipation of the result could in any case bias the mind. The following Table shows the results, small decimals being neglected:

| | | Inches. | | |
|---|---|---|---|---|
| Light *a* direct | | 10.70 | 1 | 1 |
| ——— reflected by glass | 5 | 36.75 | 11.80 | $\frac{1}{11.8}$ |
| | 1 | 40.69 | 14.46 | $\frac{1}{14.4}$ |
| | 4 | 43.46 | 16.50 | $\frac{1}{16.5}$ |
| | 9 | 47.31 | 19.56 | $\frac{1}{19.5}$ |
| | 6 | 50.31 | 22.12 | $\frac{1}{22.1}$ |
| | 7 | 51.63 | 23.29 | $\frac{1}{23.3}$ |
| | 3 | 52.69 | 24.26 | $\frac{1}{24.2}$ |
| | 8 | 54.33 | 25.80 | $\frac{1}{25.8}$ |
| | 2 | 54.56 | 26.02 | $\frac{1}{26.}$ |

The first column refers to the glasses below; the second gives the distance of the measuring flame *b*; the third, the preceding numbers squared and reduced to the direct light as unity; and the fourth, consequently, the proportion of the light *a* reflected by the first surface of each glass. No. 5 was glass consisting of 1 proportional of oxide of lead, $\frac{1}{2}$ a proportional of silica, and $1\frac{1}{2}$ proportional boracic acid. No. 1 was composed of 1 oxide of lead, 1 silica, and $1\frac{1}{2}$ boracic acid. No. 4, of 1 oxide of lead, $1\frac{1}{2}$ silica, and $1\frac{1}{2}$ boracic acid. No. 9 was flint glass; No. 6, 7 and 3, different pieces of crown glass; and No. 8 and 2, different pieces of plate glass. 1, 3, 5, 6 and 7, were natural surfaces; 2, 4, 8 and 9, polished surfaces.

The deficiency of light resulting from the increased reflecting power, though considerable, may easily be compensated for by slightly increasing the area of the plate; and the power of obtaining plates of any size is professed to be given by the general process: but whether that expedient involves any other objections, it will be for the optician to determine.

101. In *hardness*, these glasses differ from each other as much as in any other

quality, and indeed more. The borate of lead is very soft; the bi-borate of lead is harder, and the tri-borate equal to flint glass in hardness. The silicated borate of lead is softer than flint glass; but the glass consisting of 1 proportional oxide of lead, 1 of silica, and $1\frac{1}{2}$ proportional of boracic acid, is as hard as ordinary flint glass, at the same time that it has that degree of fusibility, colour, and other properties, which makes it a very promising variety.

102. The hardness increases with the diminution of the oxide of lead; but the *fusibility* diminishes in the same proportion; and this is a property which it is essential to preserve to a certain degree for the removal of striæ and bubbles. The borate of lead is so fusible as to soften and lose its form under the surface of boiling oil. The silicated borate, and the glass consisting of the proportions above mentioned, are quite fusible enough to allow of the processes necessary for the removal of striæ and bubbles.

103. The fusibility of these glasses, and of glass generally, must not be confounded with their relative tendency to soften by elevation of temperature. It is not that glass which softens first, that becomes most fluid at a certain given high temperature; for glasses, like other substances, vary in their readiness to pass into the fluid state. Hence it has often occurred amongst the variety of compositions tried for glasses, that when the resulting substances have been placed side by side on platina foil, and heated, that which first softened did not when heated highly become so fluid as some other specimens that longer resisted the first impression of heat. It has however always been found that those glasses which when subjected to a rising temperature, most slowly passed from the solid to the fluid state, were also those which when subjected to long annealing processes, were least liable to assume a crystalline structure; and thus very useful indications of the probable qualities of compounds under investigation were often obtained.

104. A most important consideration relative to the application of these glasses to the construction of telescopes, is their liability to change and injury by the action of substances usually occurring in an ordinary atmosphere. When the value of a good object-glass is considered, frequently amounting to many hundred pounds, this point will be thought of no little consequence; and when it is known that even flint and plate glass are frequently injured in this way,

a little anxiety for the capability of resistance in the heavy glasses may readily be allowed, since they contain so much less of the substance (silica) which confers the power of resistance, and so much more of that (oxide of lead) which is considered as the vulnerable part, than does either of the former kinds.

105. The superficial changes of glass which interfere with its optical uses are of two kinds. The one is shown by a tarnish upon the surface, which when strong is iridescent. It is quickly produced by the intentional presence of sulphuretted hydrogen, which acting upon the oxide of lead present, reduces it, and forms a sulphuret of lead. It takes place only with flint glass, and is in every case produced either by sulphuretted hydrogen or other sulphuretted vapours. In plate glass the change is of another kind, and is shown by the appearance of minute vegetations or crystallizations, which spread, obstructing the light wherever they occur. Mr. Dollond, who has shown me cases of both kinds of injury in flint and plate glass, is inclined to believe that the latter has, during his long experience, proved most injurious.

106. From the commencement of the experiments it was expected that these heavy optical glasses would tarnish more than flint glass; but as specimens of borate of lead and other dense compounds of that metal had been retained in an ordinary atmosphere, without any particular precautions, for long periods of time, yet without tarnishing, there was encouragement to continue the investigations: and though when specimens were put into atmospheres purposely contaminated with sulphuretted hydrogen, they tarnished quickly, and much more than any flint glass, yet it did not follow that they should of necessity tarnish in the telescope; especially as, being from the construction of the achromatic object-glass inclosed by the tube and the crown or plate glass lens, they would be considerably protected, and at the same time would admit of the intentional application of extraneous chemical protectors.

107. The kind of protection which occurs to the mind is the application of such substances to the interior of the tube as, having a strong attraction for sulphuretted vapours, should continually retain the atmosphere within free from their presence. Carbonate of lead, precipitated borate of lead or finely-ground litharge, mixed with the pigment which is usually applied to blacken the inside of the telescope that all extraneous light may be absorbed, will probably effect this purpose completely.

108. A very curious and important influence of alkali in facilitating the tarnish of glasses containing oxide of lead, was discovered during the course of these investigations; and when the quantity of lead in flint glass is increased but a little beyond the ordinary proportions, its effect is powerfully manifested. Ordinary flint glass consists of 33.28 oxide of lead, 51.93 silica, and 13.77 potassa; the rest of the substances present, being in very small quantity, may be disregarded. Here the oxide of lead is 33.28 hundredths of the whole; and if it be only a little increased, for the purpose of giving greater dispersive power, the glass is liable to tarnish in an ordinary town atmosphere. Such is the case with a specimen of GUINAND's glass, which I have analysed, and which contains 43.05 oxide of lead, 44.3 silica, and 11.75 potassa. But provided the alkali be away, the quantity of oxide of lead may be enormously increased; and a glass containing 64 per cent of oxide of lead, in combination with 36 per cent of silica, has not tarnished by an exposure for 18 months on the same shelves with flint glasses that have tarnished. The following case will point out the effect still more strongly: A combination of equal weights of silica and oxide of lead was formed, and the compound has shown no tendency to tarnish in an ordinary atmosphere since February 1828. Eight parts of this was fused with as much pearlash as was equivalent to 1 part of potassa, and a glass was formed which has since become much tarnished. But other 8 parts being fused with 3 parts more of oxide of lead, so as almost to double the proportion of the latter, gave a glass without alkali, which does not yet exhibit the slightest trace of tarnish.

109. Hence the reason why the absence of alkali has been earnestly insisted upon in the preparation of the ingredients for the heavy optical glasses (18. 24). Hence the reason also why heavy flint glass, as already mentioned, has tarnished equally with some of the heavier glasses, though containing so much less lead, and of such inferior specific gravity. This influence of alkali is associated with, and perhaps directly referrible to, another circumstance affecting the liability of change in the glass; I mean the action of water or of aërial moisture, which is frequently considerable, and appears to be dependent upon the alkali present.

110. If a small quantity of flint glass be very finely pulverized in an agate mortar, then placed upon a piece of turmeric paper, and moistened with a drop

of pure water, strong indications of free alkali will be obtained. The same effect is produced by using plate glass; and if the pulverization be very perfect, the alkali can be detected in glasses containing far smaller quantities of that substance than either of those mentioned. This experiment, due to Mr. Griffiths, shows that in whatever state of combination the alkali may be, it can still act upon, and is subject to, the action of moisture; and that flint glass is by no means a compound resulting from very strong chemical affinities, is also shown by an experiment which I made many years ago; namely, that if flint glass be pulverised exceedingly fine, the powder will indicate the presence of sulphuretted hydrogen in air by becoming blackened, almost as readily as carbonate of lead. Glass may be considered rather as a solution of different substances one in another, than as a strong chemical compound; and it owes its power of resisting agents generally to its perfectly compact state, and the existence of an insoluble and unchangeable film of silica or highly silicated matter upon its surface.

111. The half-combined and hygrometric state of the alkali appears to be the cause of the deposited film of moisture which is well known to adhere to ordinary glass when exposed to the atmosphere at common temperatures. This film is highly calculated to condense any portion of sulphuretted vapours which may be floating in the atmosphere, and thus bring them into contact with the oxide of lead under the most favourable conditions for the production of that action which is the direct cause of tarnish. Now from this cause of action the heavy glass is free; and hence a satisfactory reason to me why the heavy glasses have suffered so little when left with common care in an usual atmosphere.

112. An extraordinary difference exists between the electrical relations of this glass and other glasses, due principally to the same absence of alkali. Ordinary glasses, either flint, plate or crown, will, from the hygrometric film of moisture upon the surface, freely conduct electricity under common circumstances. Thus if a gold-leaf electrometer be diverged, and then touched with them in their ordinary state, the electricity is instantly discharged, even though the hand be two or three feet from the part touching the instrument. If a similar experiment be made with these heavy glasses, they have no sensible power of discharging the electricity, but insulate as perfectly as sealing-wax

or gum lac. If one of these plates of glass, without any previous warming and drying, be lightly brushed or wiped with flannel or silk, it instantly becomes strongly electrical, and retains its electricity for a long time; but it would be almost impossible to develop electricity by such slight means with flint or plate or even crown glass in a similar state. Hence the glass makes as good an electrophorus as lac or resin, and may probably be found hereafter to answer many useful electrical purposes. But the great point at present in view, is the proof which such electrical properties give of the absence of that film of moisture which is so constant upon other glasses.

113. All these circumstances are favourable to the opinion that the heavy glass will not be found objectionable in the construction of telescopes, because of any undue tendency to tarnish, and especially when precautions are taken to protect it from sulphuretted vapours in the manner before described (107). No difficulty can be anticipated in preserving the air within a limited and inclosed space free from such a contamination: to preserve it dry, if that had been necessary, under the different circumstances of varying temperature and the inevitable change of the air more or less frequently, would have been a far more difficult task.

114. The other kind of superficial change, i. e. the corrosion or crystallization which takes place principally on plate glass, is doubtless also due to the alkali present. Sometimes, indeed, specimens of glass may be found where the alkali being too abundant, a similar but more extensive action has taken place over the whole of the surface, and the glass falls off in scales. Whether the alteration be due to the action of the alkali on the water only, or on the carbonic acid and other substances it finds in the air, or to its united action on all together, is of little consequence at present, as the substance on which it depends is altogether absent from the glass under consideration.

115. Among the great number of glasses made, there are several of different composition, which have been selected, because of their general characters and properties, for more extensive trial and investigation when time will permit. Of these it would be useless to speak at present, as what might be stated of them now would probably require correction from future experiments. Up to this period the attention has been devoted, as it still must be for a while, to the establishment of a process which, competent to produce with certainty a

Fig. 1.

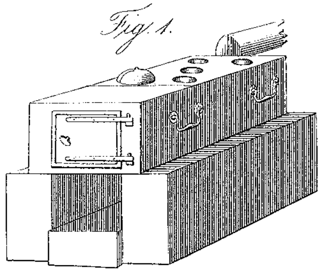


Fig. 5.

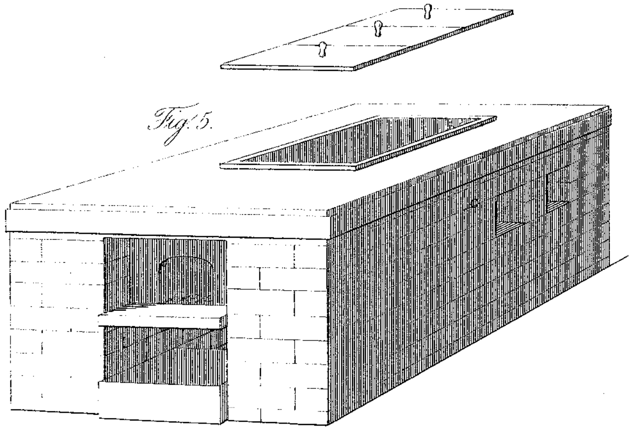


Fig. 7.

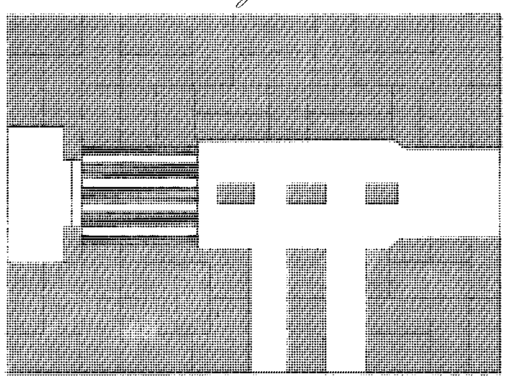


Fig. 2.

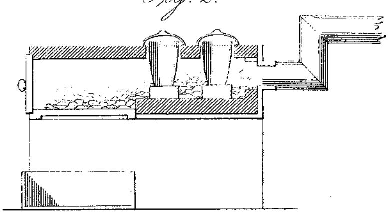


Fig. 3.

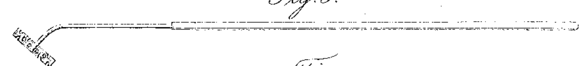


Fig. 4.

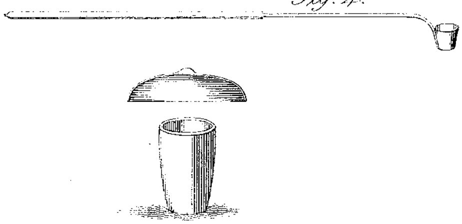
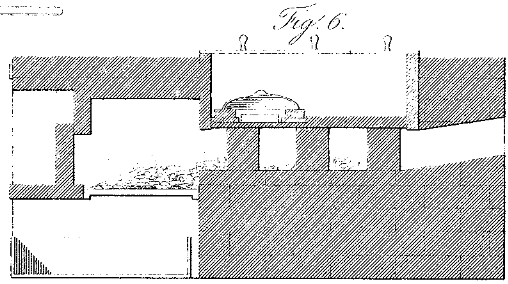


Fig. 6.



Scale.

Fig. 1. 2. 5. 6. 7. half an inch to a Foot.
3. 4. one inch to a Foot.

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glass fitted for optical purposes, may have the philosophy and practice of every part so fully ascertained, as to be capable of description in a manner sufficiently clear to enable any other person, with moderate care, to obtain the same results without the labour of long and tedious investigation.

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## Appendix.

### *Rough glass furnace.*

The only furnace for making rough glass which has been constructed, answers its purpose exceedingly well; and though if a second were to be made, it should be upon a larger scale, yet I think it better to describe the tried one accurately, than to direct alterations which have not been experimentally approved of; especially as there seems to be nothing which, in principle, need differ in a larger furnace. An iron box (see fig. 1. & 2.) 30 inches long, 14 inches wide, and $8\frac{1}{2}$ inches deep, forms the principal part of the exterior: it is open entirely at the top, and at the bottom also, in the fore part, where a fire-grate is to be placed. It has a common iron furnace door in front, the aperture of which is 8 inches wide by 6 inches high; and at the opposite end, or back of the furnace, a flanched aperture $6\frac{1}{2}$ inches by $4\frac{1}{2}$ for a piece of funnel pipe to connect the furnace with a powerful flue. The sides of this box, and such part of the bottom as is not appropriated for the fire-grate, are lined with fire-stone $1\frac{1}{2}$ inch in thickness, except in the fire-place, where it is $2\frac{5}{8}$. The grate is 12 inches long by 8 wide; and the part above it is closed by a fire-tile 2 inches thick and 12 inches square, which, resting on the edges of the lining, finishes the portion intended for the coal fire, leaving it $5\frac{1}{2}$ inches in depth from the covering tile to the grate. The other part is covered by an iron plate $17\frac{1}{2}$ inches long, 13 inches wide, and $\frac{5}{8}$ths of an inch thick, which, resting upon the edges of the lining, incloses a space of 16 inches long, 10 inches wide, and 5 inches deep, for the reception of crucibles. This plate is formed with circular holes about 3 inches, or rather more, in diameter, arranged as in the engraving, that the crucibles inserted through them may leave plenty of room for the intervention of coke and flame. As many round crucible covers belong to the plate as there are holes, serving to close such of them as are not occupied by crucibles.

As the plate becomes very hot when in use, it is necessary to have a second above it, which may be formed of sheet-iron with corresponding holes, and when put into its place, separated from the first, a little space, by pieces of tobacco pipe, or other convenient substance, to include a layer of air. But it is much better for the retention of heat, and also for its superior cleanliness, that this second plate should consist of pieces of earthenware fitted to each other, so as to cover the surface of the iron plate, from which it should also be separated by a short interval.

The crucibles used are 5 inches high outside, $3\frac{1}{4}$ inches diameter at the top, and 2 inches diameter at the bottom. They are of pure porcelain biscuit, perfectly white and clean. They should be made as thin as possible, of the finest and most refractory kind of ware, and baked at a high temperature. We have some crucibles made about thirty years ago for Mr. HATCHETT, which, though not of the size required, are precisely the right kind of ware. They have been used many times in succession without cracking or being importantly acted upon by the glass, and no sensible degree of impurity was given to it from them.

When these crucibles are arranged in the furnace, they should be supported by little stands of earthenware, formed out of brick or Cornish tile, so that their edges shall rise about the $\frac{1}{2}$ or $\frac{1}{3}$rd of an inch above the surface of the upper covering plate, that no impurity may enter them. The holes in the plate should be of such dimensions that, when hot, the crucibles may fit loosely, that they may be uninjured, and also that there may be room between for the vapours that are evolved from the mixture to pass away.

The covers to the crucibles are evaporating basins about $4\frac{1}{2}$ inches in diameter. They are slung with their edges downwards by a piece of platina wire sufficiently strong for the purpose, which being first bent at the middle into an angle, is then stretched across the outside of the basin, and has its ends bent round the opposite edges of the latter. The bent extremity of an iron rod passed under the loop thus formed over the middle of the bottom, serves to raise and remove the cover from place to place. When a crucible is in use, the cover should be arranged over it in such a manner as not to touch the vessel, but rest by its edges on the earthenware plate around.

The platina stirrers in use with this furnace have been before described (28. 75) fig. 3. The platina ladle consists of a small crucible of that metal riveted to a platina wire, and that made fast by a screw to an iron rod. (fig. 4.)

The use and manner of working this furnace will be well understood from the above description, and what has before been said (26, &c.). The crucible should never be suddenly heated or cooled. The coke may be fed and arranged at such of the crucible holes as are out of use at the time. From the very valuable effects of a trough of water under the fire bars (45) experienced in the larger furnace, one is constantly used in that just described.

*Finishing furnace.*

This furnace on the outside is a parallelopiped, principally of brickwork, built against a wall, 64 inches in length from the fire front to the beginning of the flue, against which it is built, 45 inches wide, and 28 inches high. (fig. 5. 6. & 7.) It is the only one that has yet been built, and, for the reasons before given, shall be described exactly as it is. The fire-place is at one end, and the course of the flame and smoke is directly from that to the other end, and then immediately into the upright flue. The fire-place is 15 inches from back to front, 13 inches wide, and $11\frac{1}{2}$ inches from the arched roof to the bars. Its outward side, or that from the wall, is $18\frac{1}{2}$ inches in thickness of brickwork, which is intended to give stability to the structure. The mouth of the fire-place is an aperture 8 inches by 6 inches, made in a piece of fire-stone 7 inches inwards from the front of the brickwork: its lower edge is level with a fire-stone sill, which, extending forwards from the fire-place to the outer surface of the brickwork, forms a shelf, on which two bricks stand, that serve in place of a door to close the mouth of the furnace. The ash-pit is 25 inches long, 12 inches wide under the fire, and 10 inches high to the bars. A trough made of rolled iron, riveted together, and $5\frac{1}{2}$ inches high on the sides, occupies its lower part. This being preserved full of water, is sustained at the boiling temperature by the radiation of heat and the hot ashes which fall into it.

From the back part of the fire-place, and 2 inches above the level of the fire-bars, the brickwork is carried on horizontally until close to the stack. The sides of this part are perpendicular, and 12 inches apart: they are continued upwards to the top of the brickwork 14 inches unbroken, except that at 5 inches from the bottom they are thrown back $\frac{1}{3}$rd of an inch so as to form a ledge there. This ledge is for the purpose of receiving the edges of certain fire-tiles, which, when put in, form the top of the flue and at the same time the bottom of the glass chamber; but the whole is so constructed, that the tiles can be put in and taken out at pleasure without disturbing the rest of the work. The side or rather end of the chamber nearest the fire is constructed of a fire-tile, which terminates and faces the brick arch over the fire-place, and extends from the surface of the brickwork downwards 9 inches to the side ledges before described: the further end of the chamber is finished in a similar way, and beyond that the flue is carried in the most convenient and direct manner, but without any unnecessary contraction, into the stack or chimney. The length of this upper aperture, afterwards constituting the chamber, is 25 inches, its breadth $12\frac{3}{4}$ inches. When the bottom tiles are in their places, they leave a depth of 5 inches for that part of the furnace or flue beneath the chamber, which is also 38 inches from the fire to the end, and, with the exception of certain supports in it, is 12 inches wide.

These supports are built in with the bottom of the flue. They are essential to the permanency and regularity of the bottom of the glass chamber, and require considerable nicety in their arrangement. They consist of fire-bricks placed up on end, so that their narrowest surfaces are towards the ends of the furnace, their sides or broadest exposed surfaces parallel with the sides of the furnace itself. They rise to the same height above the bottom of the flue as the ledges on the sides of the brickwork, or 5 inches, and with them, form the support for the bottom tiles. There are three of them in our furnace, placed in a line equidistant from the two sides of the flue; and being $2\frac{1}{2}$ inches thick, they leave spaces for the passage of flame and the reception of coke, which are $4\frac{3}{4}$ inches in width. The first of these is two inches from the back edge of the fire, and in that direction extends 4 inches; the second is 4 inches from the first; and 6 inches beyond that one is the third.

During the action of the furnace, coke is supplied to this part, and arranged through two holes level with this space, and wrought in the side of the furnace by leaving out a brick. They are made to occur nearly opposite the spaces between the supports seen when looking across the course of the flame, and are stopped by the insertion of loose bricks, and a piece of paper put before the place, which adheres from the pressure inwards of the atmosphere. These holes, being in the thickness of the walls of the furnace, are 17 inches long.

The tiles which form the bottom of the chamber and top of the flue, are of Cornish ware (52. 53), or at least the one which constitutes the half nearest the fire is of that material; but the other, which is not so highly heated, and never has to be moved, may be some other ware, and $2\frac{1}{4}$ inches in thickness. The tile nearest the fire has to transmit heat to the glass, and if of Cornish ware, and supported as described, is abundantly strong when $\frac{3}{4}$ths of an inch in thickness. It should be nicely adjusted by grinding (53), and when fitted in, the edges should be made close by a little fire lute.

There is a part of the furnace not yet mentioned, which must be arranged as the structure is raised. This is the air tube (55). It is of glazed porcelain, and passes horizontally through the side of the furnace, so that its inner aperture is 2 inches from the end of the glass chamber, and its lower edge level with the upper surface of the Cornish tile constituting the bottom, whilst the outer end is flush with the outside surface of the brickwork. Its length is 17 inches, its internal diameter $\frac{7}{8}$ths of an inch. The short pieces of adjusting tube (55) are 6, 7, and 8 inches in length, and $\frac{7}{16}$ths of an inch internal diameter: their ends are usually finished obliquely.

All those parts of the furnace which are in contact with or near the fire, are of the best fire-bricks laid in loam; but the sides of that part of the cavity already described, which form the glass chamber, are fire-tiles, and they rise about an inch above the neighbouring brickwork, forming a raised edge all round, which, at the same time that it better excludes dirt than if level with the rest of the work, also allows the covers of the glass chamber to apply more closely. These covers are three wrought-iron plates, each $\frac{1}{4}$th of an inch in thickness and 16 inches long; but their widths vary, and are 7, 10, and 12 inches. These put side by side cover the mouth of the chamber, but varied in juxta-position, allow of more or less of the chamber being opened at once, according to whatever the experiment may require; each has a short solid handle fixed to the middle of the upper surface.

Besides the iron covers, there are a set of earthenware covers, consisting of 6 square tiles each $1\frac{3}{8}$ inch thick(62). These are notched to receive the handles of the iron covers, and being put together over them, constitute a covering of earthenware, which very importantly assists in retaining the heat.

The tiles and brick used in the annealing process (89) are the ordinary dry varieties, with some pieces of various sizes, to allow of the close adjustment of the whole.

The earthenware supporting blocks (57) required for the arrangement and support of the platina tray should be formed out of some kind of flat unglazed ware containing as little iron as possible, and should be of various thicknesses, sizes, and forms, although parallelopipeds are the most usual. They should not be of such substance as is liable to fly or send off anything when heated; and when any portion of glass adheres to them, it should either be cleared off or the piece thrown away. The Cornish tile before described (52. 53) is excellent for this use, and may be sawn, rasped or ground into any shape required.

The glass covers (60, &c.) that have yet been used were merely inverted evaporating basins. They answer the required purpose exceedingly well, except that, when large, they are too strong, too heavy, and too deep. Some covers for the purpose are therefore in progress, and as they only have to support their own weight and hold together, they are to be thin. The covers should be of very refractory and highly baked ware; it may be desirable to have them very slightly glazed, to keep them clean, and prevent the absorption of any substance which might send off vapours injurious to the glass.

The fire tools required for this furnace will suggest themselves. Amongst the rest should be a pair of tongs which will readily lay hold either of the earthenware tile or the iron covers; a slag and coke rake (89); and a stoking iron, with its extremity bent, for the purpose of breaking the clinkers off the bars from beneath upwards.

*Preparation of spongy platina.*

The platina used for this preparation should be pure, and may be the refuse pieces resulting from such plate and foil as has been in use for trays in former experiments. This, after being taken out of the pickle (93), and condemned as useless for other purposes in the glass-house, should be trimmed from all alloyed parts, if any such are adhering to it, and then digested in a Florence flask, with a mixture of five measures of strong muriatic, one measure of strong nitric acid, and three measures of water. But little heat should be applied at first until the action diminishes. According to Dr. WOLLASTON, one ounce of platina will be dissolved by about four ounce measures of such acid, and it is advantageous to have a considerable excess of platina present. The solution obtained is to be precipitated by a strong solution of muriate of ammonia; a bright yellow pulverulent substance will fall, and a mother liquid having more or less colour remain. The precipitate being allowed to subside, the liquor is to be poured off, and the former then washed with two or three portions of water. The washing liquors and the mother water may afterwards be concentrated together; but it is better not to prepare spongy platina for this particular use from these fluids, but only from the precipitate which falls on adding the muriate of ammonia.

The yellow precipitate, when washed, is to be dried on a filter, or in a basin, and then decomposed by the application of a dull red heat. This may be done in a clean white earthenware crucible. The heat should be continued until vapours cease to arise; but this will be found a long operation, in consequence of the low temperature which is to be applied, and the exceeding bad conducting power of platina for heat when in this spongy state. The reduction may also be performed by putting the precipitate upon a piece of platina foil in a layer about $\frac{1}{6}$th of an inch in thickness, and covering it with another piece of foil; a spirit lamp will then suffice to reduce the metal, but the foil and powder must be turned occasionally, that both sides may be exposed to the flame. The platina will appear as a dull grey spongy metallic mass. It should be broken up, mingled, and then again heated to insure the dissipation of all volatile matter.

After this is done, the platina should be rubbed to powder by the clean finger, or clean paper (83), heated slightly a third time, and then preserved in a clean and well stoppered bottle.