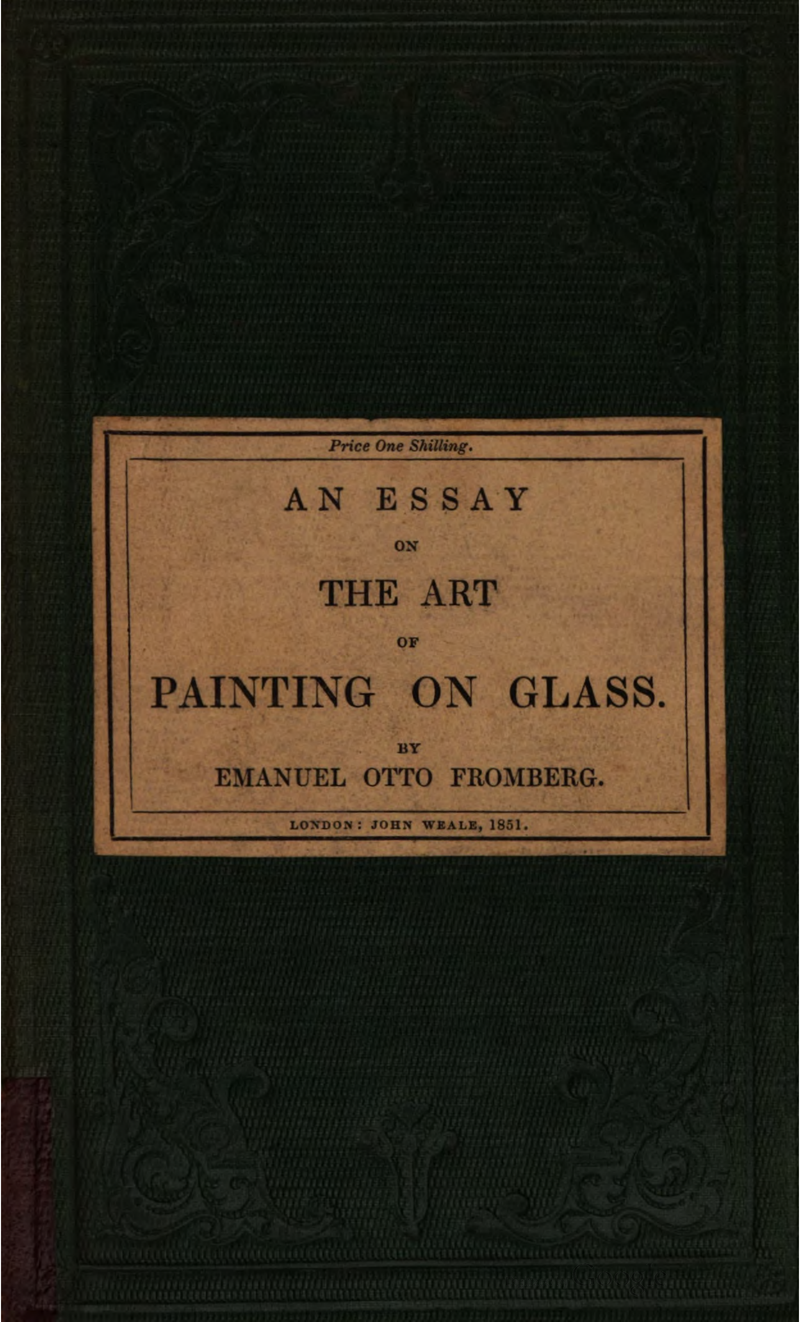

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AN ESSAY
ON
THE ART
OF
PAINTING ON GLASS.

BY
EMANUEL OTTO FROMBERG.

LONDON: JOHN WEALE, 1851.

AN ESSAY

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ON THE ART OF PAINTING ON GLASS.

INTRODUCTION.

Painted windows are allowed to be the richest and most magnificent application of art to the interior decoration of monumental buildings. The brilliancy and liveliness of the colours of which glass is susceptible on account of its transparency will always secure to this kind of painting a distinguished rank among the arts. The dazzling combination of colours, which fills the observer with astonishment on account of their brilliancy, as well as on account of their variety, gives a peculiar character to painted windows which prevents them from falling into oblivion, even should they be neglected for a time. If we go back to the elementary condition of the art, the symmetrical arrangement of pieces of glass of various forms and colours, combined with more or less skill, they are by no means entitled to engage our attention in a higher degree than the lustre of gold, and the most lively colours of the richest decoration. Yet with what magical charm must they not attract our observation and excite our admiration, when painting invests form with these beautiful colours, and breathes life and soul into them!

Painting on glass seems to have made a fresh start within the last few years. The favour with which the productions of this art have been universally received, promises it soon a new and brilliant career. But how has it happened that this species of painting, whose magical effects have been so justly appreciated, has been neglected for so long a time, after having for several centuries exercised the genius of artists, and been cultivated by them to the exclusion of almost every other?

Painting on glass has, in fact, experienced a remarkable fate. In the periods of barbarism, when war and devastation had smothered the taste for the arts, it came into existence, and was never more flourishing than in those centuries of ignorance. At the period of the regeneration of science and the arts, when good taste and the love of what is beautiful and true to nature had begun to spread through Europe, its splendour seemed on the wane, and in process of time it became almost entirely extinct.

What, then, are the causes of so remarkable a decay? In the twelfth century, this art, which had been for a long time still in its infancy, seemed encouraged by the piety of the monks (among whom alone the wrecks of the sciences and of the secret arts were yet to be found) to make a vigorous attempt to release itself from the state of oppression into which it had fallen. But while the spirit was active and ready to soar, the means were wanting, and much time was spent in the choice of the proper mode of carrying it into practice. Many kinds of painting would have to be tried; and, at a time when taste had not yet been refined by long practice, and especially by the study of classical models, the preference would naturally be given to that kind of painting which was most capable of seducing the eye by the brilliancy of its colours. The combination of colours was the sole charm that painting could lay claim to; the merit of a beautiful outline, on the contrary, one which exhibited grace, purity, and correctness of form, was utterly neglected.

Hence the splendour of painted glass, and the almost universal admiration paid to it by those who felt themselves compelled to do so by the guardian genius of the art.

But in the succeeding centuries taste was cultivated. Art had less of the material, and found other facilities and other means of producing effect. She strove after effects of a much higher kind; and as genius endures with impatience the bridle of a difficult execution, the obstacles which the painting on glass presents to the expansion of thought would considerably diminish the favour that it had enjoyed in consequence of the liveliness of its colours. Oil-painting was soon called into existence by Jean de Bruges. This new form of the art, the imitation of nature, gained the victory over the one which had preceded it, and painting on glass was driven from its throne.

The consequent decline of the art was not, however, sudden and precipitate. The revolution which in the sixteenth century took place in the arts, was also not without its influence upon the progress of painting on glass. Its most beautiful works were produced at that time. The most celebrated men did not disdain to support it by their talent, and never at any time was it more deserving of honour. It had, however, attained the summit of its greatness, and was soon to become a spectacle of the most complete decay.

Many causes undoubtedly conspired against its further prosperity. To these, among others, belong the religious disturbances and the wars which followed the reign of Francis I., and the calamities that were brought on by subsequent discords. But, above all, we must take into consideration the very strong prepossession in favour of oil-painting, awakened by the brilliant successes of its productions; and, moreover, the favour with which the art of engraving on copper, as well as all those arts which have drawing for their basis, were received. These arts shared among themselves the consideration that had been formerly given exclusively to painting on glass. Finally, we must bear in mind the singular patronage bestowed on oil-painting by those in power.

The various phases of the art of glass-painting clearly ascertain the mighty influences to which it must have yielded. The study of them offers to the inquirer matter for the most serious consideration. In the twelfth and thirteenth centuries, in the shadow of barbarism, if I may be allowed the expression, we see it making considerable progress. In the fourteenth and fifteenth centuries it bears unlimited sway over the arts. In the sixteenth century it becomes a rival to oil-painting, and, after an obstinate struggle, sinks into oblivion. All the old painted windows have something characteristic of the period to which they belong. The modifications which successively appeared in them offer to the archæologist points of the deepest interest for observation and comparison, while they are at the same time the seals of their respective eras. These distinctive marks exist not merely in the painting, but also in the general conception of the entire work. We have only to cast our eyes upon a window of the twelfth and thirteenth centuries, and we shall discover in a truly remarkable manner the whole spirit of the Gothic monuments of that period. This kind of architecture, so rich in its ever alternating details, yet without any confusion, and regular in its monotony, successively presents that remarkable feature which we recognize alike in the entire structure and in each of its parts; and the reason of this lies in the fact, that the observer, before he can comprehend the numerous details, gradually perceives that they form an essentially harmonious whole. This peculiarity prevails in Gothic church windows to an extraordinary degree. When viewed at a certain distance, they present a magnificent decoration of the most lively colours, distributed in a manner worthy of the most skilful workers in mosaic. It is a rich carpet whose simple but graceful pattern is illuminated in alternate gradations of colours admirably combined. Upon a closer inspection, we obtain a complete view of the forms of the various ornaments which contribute to the general effect, the naïveté of which makes us feel less regret at the imperfection of the execution.

Gothic painting borders on the mosaic, and we may go so far as to say that to this it owes its origin. Like the mosaic, its art was primarily limited almost exclusively to the symmetrical arrangement of pieces of glass of various colours. The art of drawing played here only a subordinate part; but, like the latter, it afterwards borrowed its forms from nature. In proportion as the taste for correct drawing was carried to perfection, the simple arrangement of glass lost its importance, and was finally eclipsed by the art of painting.

In the sixteenth and seventeenth centuries correct delineation completely gained the ascendancy in painted windows, and we find in these neither the effects of symmetry nor of the mosaic. It underwent a change in every particular to an historical kind of painting, of a much higher and more elaborate style, but which was no longer so rich and so brilliant: the sentiments of the soul gained at the expense of the impressions of the senses.

In the intervening centuries a transition took place from the one extreme to the other. At first we see the ground diversified with a thousand brilliant colours, on which, however, larger figures, drawn with greater skill, and after a pattern more or less understood, are occasionally to be met with, and occur as exceptions. In process of time these figures are surrounded with splendid borders or friezes, which are finally obliged to give way to architectural backgrounds and the imitation of the antique. These are the various forms under which the art of painting on glass was cultivated during a period of more than six hundred years. In the eighteenth century it seemed to be completely lost.

But is it destined to lie neglected because the reign of oil-painting will endure? Painting on glass cannot for a moment contend for the approbation of artists as the rival of the latter. The difficulty which attends the practice of it, and the necessity for the co-operation of chemistry in the productions of this kind of painting, leave its resources ever insufficient to enable it to vie with oil-painting, to which, on that account, it must unquestionably yield the pre-eminence. But if the artist who devotes himself to glass-painting is content to avail himself only of the legitimate resources of his art, if he does not strive after effect nor endeavour to pursue the path of oil-painting, we have not the slightest hesitation in asserting that painting on glass, considered as a monumental style of painting, constitutes an art, inimitable in itself, capable of being executed with great spirit, and worthy of engaging the most distinguished talents.

But then the painter on glass must refrain from attempting to imitate oil-painting. On the contrary, he must acquire the conviction that, although these two arts have unquestionably a point of contact, they nevertheless possess sides extremely dissimilar. To these belong, in the first place, the proper modes of practising them respectively; secondly, the different conditions under which their effects are produced. Thus, for example, painting on glass, on account of the distance at which the picture is placed from the spectator, requires to be treated in a perfectly distinct manner. It excludes detail, which, on an opaque surface, is susceptible of great effect, but which, through the transparency of the glass, is lost, even should not a defect in the burning have done injustice to the talent of the painter. But if, after all, the artist be bent upon giving to his performance all the harmony of an oil-painting, he must sacrifice the transparency and the liveliness of the colours, which constitute the most beautiful feature of this kind of painting: besides, the presence of the lead-work and the iron bars, which unite the various portions of a painted window, and which it is in vain to attempt to conceal entirely in the shadows of a picture, must ever prove the stumbling-block on which the claim of the artist to imitate oil-painting is sure to founder.

There is a fact which observation itself has demonstrated to an inexperienced artist, and which must lead us to deliberate upon the method of proceeding in practising the art of painting on glass. It is this, viz. that in the colouring of a very elaborate cartoon the half-tints, which have been diversified in gradations of colours delicately and harmoniously blended together, always run together into one colour, producing the same effect in every part as soon as they are viewed at a distance. It is not our intention to account for this remarkable phenomenon, but we content ourselves with merely calling the attention of the glass-painter to the fact, in order that he may join with us in drawing the following conclusion from it.

A painted window of very elaborate execution, which is designed to adorn a building dedicated to the worship of God, and consequently must be viewed at a certain distance, not only loses the fineness of the details, but is also obscured by the blending of the half-tints, and therefore becomes heavy, dry, and hard.

The art of painting on glass, for the purposes of decoration, is founded solely and entirely upon the observation of the above-mentioned fact. This species of painting, in fact, owes its origin to the necessity which the artist is under of conforming his work to the conditions imposed upon him by the distance at which the spectator must view the painting. What would be said of an artist who thought of treating decorative painting exactly as he would miniature-painting? If we insist strongly upon this truth, it is for the purpose of applying it to painting on glass, which is indisputably a decorative kind of painting, and must be cultivated in this acceptation, except perhaps in the case of small cabinet windows, similar to those which are known under the name of Swiss-painted glass. If these rare exceptions be not taken into account, the painted glass in church-windows is at such a distance from the spectator, that it would be more prejudicial than useless to attempt perfection and elaborateness of detail, as it is practised in the case of an oil-painting. A pure and correct style of drawing, united to a simple and vigorous copying, are the qualities which the painter on glass must, before all things, endeavour to attain.

Unfortunately the assumption of superiority which has impelled mankind in all ages to outdo their predecessors has also misled those who, in modern times, have attempted to revive the art of painting on glass. It is seldom that we avail ourselves of the experience of the former, and we attribute to their impotency that which is in reality the result of mature consideration, which, however, we are utterly incapable of appreciating. Thus, too, it has been taken for granted that the last painters of the sixteenth and seventeenth centuries were not in a condition to make further advances in their art. Their performances were criticized at the same time that they were compared with the contemporaneous productions of oil-painting. The recognition of this principle would, in our opinion, have been more modest as well as more reasonable, viz. that the glass-painters of former times preserved their art free from all imitation; that a long experience taught them to be content with borrowing spirited ideas from oil-painting, and not to aim at producing the same effects by means differing so widely from one another, so that in the end they made painting on glass an isolated art, unlike any other in its effects as well as in its means, and one which is subject to peculiar conditions. But, on the other hand, it has been said that the ancients did not understand the art of painting on glass, and under this impression an attempt was made to execute what *they* had never been able to perform. This kind of emulation is undoubtedly noble and honourable; but it is to be regretted that such praiseworthy exertions have been misdirected, for, instead of continuing the progress begun by the ancients, when it was so easy to do so, artists consume their emulation in impotent attempts, until a personal experience induces them to resume the labours of the ancients at the point where the latter have left off. We must, however, do justice to him who rescued from oblivion an art that had been so long neglected. For this our thanks are due to the learned superintendent of the royal porcelain manufactory at Sèvres, Herr Brongniart, who contributed much to its revival.

We believe we have now satisfactorily defined what we understand by the art of painting on glass. In our opinion there is still a future for this art, if its votaries do but follow the paths marked out for them. With respect to the kind of composition best adapted to it, we shall content ourselves with merely remarking that the good taste of the artist alone must preside over his conceptions. As, however, some have given their opinion in favour of the Gothic style exclusively, others in favour of the style at the period of the revival of the art, according to the several directions which their studies have taken, we cannot forbear expressing our opinion upon this subject. We have no thought of enlisting followers for either party, but without the smallest intention of drawing a comparison in this controversy, we may be permitted merely to hint that the artist should not allow himself to be taken up with these discussions, and that in the conditions of his art alone he has to seek for the spirit that must direct the suggestions of his imagination. He should avail himself of all the resources afforded him by the nature of the things on which he has to exercise his talents. Ought he, for example, to forego the powerful effects which a skilful arrangement of colours enables him to produce? Should he disdain to derive advantage from the lively colouring of the glass because it is the most goodly dowry of the Gothic style of the art? We think not; but we are far from advising him, on the other hand, to sacrifice to such endeavours all the resources of painting which the revival style is capable of affording him, provided that he uses all these means with moderation, and, we repeat it, keeps within the conditions of his art. We submit this opinion to the intelligent artist who does not allow his ardent spirit to be carried away by his ideas; but we have no hope of convincing those who, in the wanderings of their fancy, as well as in the right path, have become the slaves of their imagination.

A very natural question presents itself to the mind, with regard to the erroneous belief which universally prevails, that the secrets of the art which were known to the ancients are lost. Are we capable, if not of surpassing, at least of resuming and continuing, the labours of the ancients? When we compare the glass of the old church-windows, of any period whatever, with the glass of our manufactories, we cannot for a moment doubt that our system of manufacturing it produces far more perfect results, certainly as far as regards its transparency, whiteness, and clearness, and generally with respect to all those qualities which are peculiar to glass. Besides, it is allowed that the methods of working have been considerably improved. And if, on the other hand, we compare fragments of old painted glass with that which we manufacture at the present day, it will appear in the most convincing manner, that our painted glass is not in the slightest degree inferior in point of colour to that of the ancients. There was a time when the manufacture of coloured glass was discontinued, because, in consequence of the decline of the art of painting on glass, this article was of no further use; but none of the secrets of the colouring were lost. Persons who were little aware of these circumstances, and mistook the effect for the cause, maintained that the reason why the art yielded nothing more was, that the painters on glass no longer understood how to produce the ruby of the ancients. But this assertion was very soon shown to be false; for as soon as the determination to restore painted windows manifested itself, the glass-house of Choisy in France, among others, proved by the most successful results, that the art of manufacturing coloured glass was in no way lost, but was only asleep. In fact, we possess a multitude of receipts of the ancients, according to which coloured glass was produced in former times. Moreover, in pigments we are much richer than the ancients; our pigments, too, are much better, more adhesively enamelled, in consequence of the improvements which have been introduced into the system of burning in the colours in modern times.

From what has been premised, we may conclude that our artists are in no respect in want of the material elements; on the contrary, they are far better aided by resources and means which await their disposal than the ancients were; and if their works attain no remarkable superiority, the reason for it must be sought for in the fact, that the best means and modes of execution in the arts are unfruitful when they are not employed with sufficient taste and spirit.

Glass-painting has, in our time, risen into life again, surrounded by the fairest hopes; and what we know of the artists who are already practising it, leaves us not the slightest reason to doubt that it will soon be cultivated with a success worthy of the present age. We would gladly contribute in some degree to draw it forth from the state of oblivion in which it has been for a long time buried. For this purpose we shall now communicate a number of practical observations which lie in the sphere of glass-painting. We believe that we cannot contribute more effectually to the diffusion of the art, than by clearly laying down the methods employed in its practice. We shall advert to those both of the ancients and of the moderns, and compare them with one another, in order to show the improvements that have taken place in our time. At the present day, when artists as well as amateurs are most zealously engaged in glass-painting, we flatter ourselves that this information will not be uninteresting to many. Little has yet been written about it, and the majority of the publications that have appeared on the subject treat more of the history than of the practice of the art.

The art of painting on glass by no means consists in the mere application of the colouring materials to the surface of the glass, by methods similar to those employed in oil-painting. The colours used are of a peculiar kind, and possess the power of vitrifying at a high temperature, and of fixing themselves unchangeably upon the glass: consequently the glass, after the paint has been applied, must be exposed to a certain heat in a furnace adapted to this purpose. Appropriate means must also be employed in the application of vitrifiable colours.

A painting on glass—as, for example, a church-window,—always consists of a great number of pieces of coloured glass, whose various hues illuminate an ornamental pattern or an historical subject. These pieces of glass are either symmetrical or irregular, so as to agree with the sentiment exhibited in the composition itself. After they have been arranged in their proper places, they are encased in lead, and united so as to form one complete piece. These pieces are united by an iron frame-work, called the *arming*.

After the brief explanation we have just given of the conditions to which glass-painting is subject, we have to determine its connection with other arts. In the first place, it is evident that the science of the chemist must be united to the talent of the painter, and that the glazier himself must lend his assistance. We have therefore divided this little work into several sections, in which the various branches of the art will be successively treated of. We have circumstantially discussed the following particulars:

1. The quality of the pigments, their composition, their preparation, and lastly, all the chemical operations which are necessary previous to the painting;—2. The means used in laying on the colours; the various methods employed for this purpose, and everything which has reference to the proper art of glass-painting;—3. The manner in which the vitrifiable colours are burnt in;—and 4. That part of the glazier's art that is concerned in the putting together painted windows in churches. Finally, we have given an account of the various mixtures with which the glass is coloured *en masse*.

Glass-painting, as it is practised at the present day, has scarcely anything in common with that of the ancients, as far as regards the colours. When this art, which had been entirely neglected for a whole century, was rescued from oblivion, the improvements in the manufacture of glass had so materially changed the quality of this substance, that the ancient methods employed in the painting were no longer applicable. Towards the middle of the eighteenth century, glass was still composed almost exclusively of flint and potash or soda. This simple silicate was deficient in fusibility, and preserved an extraordinary tenacity even at the highest temperature; it was difficult to purify, occasioned an enormous expense in fuel, and was not capable of being worked well. In the year 1760, Bosc d'Antic tried a mixture of lime in the form of carbonate of lime, which Kunckel had before proposed. A striking improvement in glass was thus obtained. When combined with silica and with soda or potash, it forms a bisilicate, which is much more fusible than the simple silicates. The proportions of these substances were, however, for a long time badly determined, and it was not till lately that the makers were enabled to impart that fusibility to glass which renders it so easy to work and so cheap to manufacture.

It is obvious that the pigments of the ancients, which were prepared for a hard kind of glass, could not have fusibility enough for the glass which is now manufactured. Other ingredients had to be sought for. But if the ancient methods of painting were no longer in accordance with the quality of the glass, still less were we acquainted with them. Moreover, the knowledge of enamel colours for metals, as well as for various kinds of earthenware, afforded easily applicable principles, according to which a series of properly fusible colours could be composed. The vast conquests of chemistry within the last fifty years, promised besides, to this manufacture, a very certain success. Modern glass-painting is thus almost entirely of late origin; and, with the exception of the process of burning in, has experienced modifications in every particular in a very remarkable manner. If we believe the testimony of the authors as far back as the period at which Levieil wrote, the glass-painters at that time burnt in their colours in iron boxes, in which the glass was arranged in layers with calcined and pulverized lime strewed between the strata of glass. But towards the year 1758, an English artist made known a new method of burning in, which he employed himself, and which, with some trifling modifications, has remained in use since that time. We shall describe this method more particularly in its proper place. The superiority of this new method of burning in the colour over the ancient method, and especially over that of Levieil, is incontestable. According to the method of the latter, the melted pigments were placed in contact with powdered lime: a portion of this powder adhered to the colours, and injured the transparency. If this was not always the case, the reason was, that the pigments, on account of their slight fusibility, merely adhered to the surface of the glass, and then again its transparency was impaired. The painted windows of the Levieil family furnish a proof of this, and in particular that in the chapel at Versailles, the blues of which are so obscured that they appear black; and among others, Pierre Levieil himself, in his work, admits the fact.

What we have said about the process of burning in, as far back as the time of Levieil, is founded upon the testimony of the writers who have left us some very interesting notices of the state of glass-painting at that period. To these, among others, belong Kunckel, Haudicquer de Blancourt, Levieil, &c. We have not, however, received their opinions upon this matter without due reflection. For how could it be supposed, that in the sixteenth century, when both glass-painting and enamel-painting were so generally honoured and cultivated, it should never have occurred to any of the artists, who were frequently skilled in both arts, to subject the process of burning in to those conditions which are indispensable in enamelling,—namely, a contrivance for heating the plates of glass, isolated and entirely removed from contact with any other body which can adhere to the colours when in a state of fusion, soil their surface, and deprive them of their transparency? This fact may easily be explained with regard to the former centuries, in which the Gothic style only was cultivated in glass-painting. Because, as this kind of painting is limited to a mere outline upon a ground of glass, coloured *en masse*, little depended upon the smoothness and brilliancy of the colours which were applied in the painting; on the contrary, a complete opacity was indispensable. But in the age of a Pinaigrier or a Jean Cousin, when the use of pigments for painting almost entirely superseded that of coloured glass, it is hardly to be supposed that the glass-painters were unacquainted with a method of burning in, similar to that which is now employed. And this is the less credible, inasmuch as the works of this period prove that pigments could be prepared of great clearness, free from all impurity, and just as good as the enamel-painters could produce. It may well be supposed that the traditions of the Levieil family have not informed us what the process was before their time. The progenitor of that family lived somewhere about the end of the seventeenth century. Glass-painting, which was gradually declining, was at that time only cultivated by a few artists. The Pinaigriers, and those of their school, had carried all the secrets of their art with them into the grave; and this was the case at that time with all who practised an art which was enveloped in mystery. Even the very writers who furnished the public with information upon the arts, always reserved that which was most useful for themselves. Cassius did so, according to his own confession, and Levieil made it a subject of complaint against Kunckel and Taunai. Before Guillaume Levieil, but one artist, Jacques de Paroi, had written about glass-painting, and from this common source several authors who followed him, as well as the painters who in the most modern times devoted themselves to glass-painting, seem to have drawn. To the former belong Felibien, Florent le Comte, and Haudicquer de Blancourt; and to the latter the Levieils and the brothers Recollet. This is proved by their receipts, which they have transmitted to us, which are for the most part like one another, and are many of them completely identical.

It may be easily supposed that the Levieil family were unacquainted with the method of their ancestors, who kept it a secret, when it is certain that Pierre Levieil himself, in spite of his profound erudition, was ignorant of what was anterior to his time, although it had been made known. Fifteen years after the appearance of the English work already mentioned, and actually at the time when he was writing, he still continued to adhere to the manifestly antiquated traditions of his family. However it may be in other respects, we have certainly, in the present state of our knowledge, no reason to envy the ancient glass-painters in regard to their methods of operation. Consequently, we have nothing to hope for from pretended discoveries of the secrets of the ancient artists, which were at times so pompously announced, because, as we have before stated, the improvements which took place in the arts in consequence of the progress of science, have placed us in an entirely new situation, which makes the methods of operation that were in vogue at a period far distant from the present time appear utterly useless.

CHAPTER I.

OF THE QUALITY AND COMPOSITION OF THE PIGMENTS.

By the pigments necessary for painting on glass are understood vitrified or vitrifiable substances of various colours, which are applied to the surface of the glass, and fixed by being exposed to a temperature which brings them into a state of fusion.

Several qualities are indispensable to the pigments: 1. fusibility at a given temperature; — 2. the power of adhering firmly to the glass and completely uniting with it;—3. a peculiar transparency, or an opacity;—4. a glassy appearance after fusion;—5. a sufficient hardness to resist entirely the friction of solid bodies;—6. insolubility in water;—7. the being unchanged by the action of the air, moisture, and the gases, which are ordinarily diffused through the atmosphere;—lastly, 8. an expansibility equal to that of the pieces of glass that are to be painted with them.

The fusibility of the pigments must always be greater than that of the glass. As the latter becomes soft at a red heat of some intensity, it is necessary that the pigment should be in a state of fusion and become fixed to the glass before it reaches the temperature at which it would be spoilt by bending, from being at the point of fusion.

The pigments are almost always more or less transparent, and only a few must be opaque. In contradistinction to the other enamel-paintings, which convey to the eye merely reflected rays of light, a painting on glass receives its colour from transmitted rays. We can understand, therefore, that transparency is a quality very frequently necessary to the pigments. It is not always indispensable that this transparency should be perfect and possess the clearness of glass; on the contrary, it is often an advantage when the objects which are behind the window cannot be distinguished. A half-transparency is usually sufficient, provided that it admits of a rich and magnificent colouring; but there are cases in which the painting requires perfectly opaque pigments.

The hardness of the pigments varies according to their composition. They must always possess a degree of hardness sufficient to enable them to resist easily the friction of hard bodies; but since the causes which operate mechanically upon painted windows, to the destruction of the pigments that lie on the surface of the glass, are exceedingly rare, the artist need not always exclude those pigments that are even of moderate hardness.

The resistance of the pigments to the chemical action of bodies must be such that they cannot be affected by any of those agents to the influence of which they are ordinarily exposed, *e. g.* the action of the air, water, sulphuretted hydrogen,* and other gases diffused in the atmosphere; but it matters little whether the pigments are capable of being acted upon by bodies with which they only accidentally come in contact, or not.

The unchangeableness of the pigments is as conditional as that of the glass, and is usually in proportion to their hardness.

Expansibility is one of the principal qualities of which the pigments must possess a precise and accurate amount. In the frequent changes of temperature which the painted plates of glass undergo, during and after the burning, the expansibility of the pigment must be in exact proportion to that of the glass. Were it otherwise, the expansion and contraction taking place irregularly in both bodies, would produce movements in the glass in opposite directions, which must occasion numerous fractures. These are in fact the accidents produced by pigments whose expansibility is ill suited to the glass. Pigments of this kind crack and split, and soon peel off the surface of the glass in the form of scales, while the glass itself, which on

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* Or, hydrosulphuric acid.

account of its thickness possesses firmness and a greater power of resistance, remains uninjured.

The pigments are composed:—1. of colouring materials, which in most cases belong to the class of metallic oxides; 2. of fluxes or vehicles for colour, which are vitreous or vitrifiable compounds, through the medium of which the colouring matter is fixed upon the glass. These fluxes are generally silicic, boracic, or borosilicic salts, in which the acids are combined with the bases in certain proportions, and whose state of neutralization varies according to the several indications of which we shall afterwards have occasion to speak.

In order to colour the pigments, the colour which a substance in its uncombined state affords is sometimes employed, sometimes that afforded by its combination with another substance which usually forms a part of the flux. In either case the colouring matter is always mixed with the pigments. This observation admits of a very nice distinction between them, so that we have divided them into two classes.

The first class comprehends those pigments in which the colouring matter is uncombined with the flux, and is in a state of simple mixture, as, *e. g.*, in the case of oil-painting the colour is mixed with the oil. We shall call them *pigments coloured by mixture.*

The second class comprehends those whose colouring matter is in combination with the flux, has become a constituent part of it, and forms with it an entire vitrified mass, possessing all the properties of glass itself. We shall call them *pigments coloured by combination.*

This classification of the pigments has not been invented merely for the purpose of systematical arrangement, but is grounded rather upon practical considerations of the greatest importance.

The composition of the fluxes is not arbitrary. Independently of the peculiar qualities which they must possess in order to be really unchangeable, it is also necessary, since they are the medium through which the union between the vitreous and the colouring matter is effected, that they should be adapted to the nature of the former, to insure their adhesion to it for a long period, and that they should also accord with the qualities of the colouring materials which they have to unite with the glass. The necessity there is for the fluxes being accommodated to all the requirements of the colouring materials, is the principal reason why a much larger quantity of this vehicle must be employed, as we shall show hereafter.

We shall first consider the composition of the fluxes in the several relations they bear to the colouring matter.

In the pigments of the first class it is necessary that the flux be of such a quality that it will preserve the colouring matter in the isolated state upon which the obtaining the requisite colour depends, and that it contain nothing that can effect a change in the properties of the colouring matter. In the fused colours of the second class, on the contrary, it is indispensable that the flux should exhibit a powerful action upon the colouring matter, by which action the combination from which the colour is to be obtained is effected. We shall now make a few observations, from which we shall deduce the principles of the composition of the fluxes, considered in that point of view in which we exhibited them above.

The fixed acids combine with bases in all proportions; but each of these combinations has a certain point of saturation at which, when in a liquid state, it possesses just as little affinity for a greater quantity of base as for a greater quantity of acid. This neutral state takes place in the most easily fusible combination, and the reason is as follows:

If among the combinations of a fixed acid with a base but little or not at all fusible, that be chosen which possesses the greatest fusibility, and an attempt be made to unite with it successively fresh quantities of base, it will be observed that the temperature must be raised in proportion to the increased amount of base brought into combination. This, for example, is the case with the silicates of lime, iron, cobalt, copper, &c. If, on the contrary, we wish to add successively to the combination of a fixed infusible acid with a base fresh quantities of acid, it is a well-known fact that the temperature must likewise be raised in proportion to the quantity of acid which has entered into combination. Therefore it may be asserted that in the combinations which consist of a fixed acid and a base, beginning at the most fusible combination, an increase of base or acid requires a proportionate increase of temperature, provided that the substance which is to be added is not very easily fusible, and its combination in consequence independent of the temperature.

The principle which we have just established is certainly subject to modifications, sometimes in favour of the bases, sometimes in favour of the acids, according as they are more or less fusible. In the silicates of lead the same degree of temperature is not necessary for the combination of a quantity of base, as is requisite for the combination of a larger quantity of acid, because the ready fusibility of the former makes its combination with the silica independent of the temperature. But we have in the borates of iron, cobalt, and copper, an example of the contrary, and here the rule is modified in favour of the bases, because the fusibility of boracic acid renders an increase in the temperature unnecessary. But exceptions like these are not to be found in the combinations we have just been speaking of, if, in the place of the fusible element, an infusible one be substituted in the mixture. This is the case, for instance, when oxide of iron is added to silicate of lead, or silicic acid to borate of lead.

From what has been premised, we infer that when we begin at the neutral state, the temperature which is requisite to unite an oxide with a flux affords a rule for determining the disposition of this flux to become still more saturated. The more it is saturated, the greater difficulty it has in combining with a larger quantity of base, provided that the latter is not fusible. The proportions of the base which have to be brought into combination depend upon the temperature; the amount of base is determined according to a given temperature, the above-mentioned cases of easy fusibility excepted. If, therefore, we were to add a fresh quantity of base under the same conditions, it would not enter into chemical combination. This circumstance has now been taken advantage of in the composition of the fluxes of the pigments of the first class.

When the temperature at which the pigments pass into the liquid state is determined, the proper point of saturation for them is at the same time that which is proper for the flux, because we are assured that the colouring matter which has to be combined with it will remain uninjured. If, then, we take the melting point of the pigments at a cherry-red heat, experience teaches us that the triple silicic and the double sub-boracic salts of lead, soda, and potash, which are then completely fused, can be saturated no further. If, therefore, we wish to colour a pigment with an oxide which shall only remain with its flux in the state of mechanical mixture, we must add to the latter the triple silicic and the double sub-boracic salts, of which we have just been speaking.

But if we wish to obtain a colour by means of an oxide which is to enter into chemical combination with the flux, the degree of saturation at which this combination is effected is fixed with as little precision as that of the temperature. If in this case it is judicious to employ a less saturated flux, this may only be done within the limits in which the pigment preserves its indispensable physical properties. As the temperature lends its aid, the combination of the oxide is always obtained. Hence it follows, that however the composition of the fluxes of the pigments of the first class is subject to certain strict conditions, this is not the case with the pigments of the second class. But even in these, as we shall soon see, directions of great importance must be given.

In the composition of fluxes for pigments of the first class we have taken a moderate red heat as the point of saturation, for the following reasons: first, the glass which is painted is capable of bearing only a slight degree of heat, and the standard is its point of fusion, consequently the temperature must not be raised to this limit. Besides, the degree of saturation which we have recommended is at the same time that at which the flux accommodates itself best to the expansibility of the glass, without our being thereby obliged to sacrifice the other desirable qualities of the pigments.

The saturation of the flux, and the temperature which it has to undergo, are, however, not the only things which must be attended to in the composition of the pigments. There are other secondary conditions, which are likewise of importance, partly to prevent the combination of the oxides with the pigments of the first class, partly to favour their combination with those of the second class. The exact degree of heat is not always easily obtained; and if it should happen to be exceeded in the pigments of the first class, the flux immediately regains its power over the colouring oxide. The change in this substance is in proportion to the quantity of flux. Hence we have a reason for prescribing as little flux as possible in pigments of this kind.

An opposite principle directs us to use as much flux as possible in the pigments of the second class. Besides, it is known that a greater saturation of the oxide is still more favourable to its combination. In order that the pigments of the first class may not be exposed to injurious alternations of temperature, the fluxes are not fused together with the oxides before they are required; while, on the other hand, no use is made of the pigments of the second class until a previous fusion has shown a perfect combination of the colouring matter.

We have already observed that the saturation of the triple silicic and double sub-boracic salts has been selected because it fulfils the requirements of the colouring matter and of the glass, without endangering the intrinsic qualities of the pigment. In fact, we are strictly obliged to confine ourselves to these limits if we wish to avoid the unpleasant results that have been mentioned above.

When a salt of silicic acid and a metallic oxide is combined with a silicic salt, having an alkaline base, by the agency of heat, the one is dissolved in the other. Does this result from an act of combination, or from simple mixture? The learned observations of Dumas upon the fortuitous crystallization of glass have proved that the different kinds of glass are composed of certain definite silicates, and we have reason to believe that they are in a state of combination with one another. But even independently of the quality of these silicates, their various states of saturation produce numerous modifications in the properties of these compositions. The most important fact, however, which has been noticed, is the following: Mr. Faraday has observed, that if only a slight addition be made to the quantity of oxide of lead which the common flint glass contains, this glass, which before was quite proof against moisture, then acquires the property of a hygrometer in a remarkable degree, and in damp air soon loses its transparency. Several others have ascertained the truth of this fact from their own experiments. Flint glass is a silicic compound, of which the acids contain eight of oxygen to one of base. Whenever glass in general contains a greater quantity of base, it is much more easily affected by water. This may be said of window-glass, looking-glasses, &c., especially when they have been polished. All these combinations yield an alkaline silicate, which is soluble in boiling water, and an insoluble silicic earth is precipitated. This takes place at the various degrees of saturation which lie between the octosilicate and the bisilicate. But it is a very remarkable fact, and one which has been especially observed with regard to those glasses which contain lead, that if flint glass, containing a soluble alkali, be reduced to a bisilicate in such a way as to be combined with a greater quantity of lead, this flint glass when pulverized gives up almost all its alkaline silicate in cold water, and that, too, almost immediately.

Hence it is that the combination of a silicic salt of lead with an alkaline silicate, which is very easily decomposed in mass, in proportion as we descend from the octosilicate, possesses no stability at all when we reach the bisilicate; for then the latter has become soluble in cold water, and is immediately dissolved in it. It is, however, probable that this is not the case with all bisilicic compounds; for basic silicates are combined with one another in those kinds of glass which contain lead, whilst in bottle-glass, for example, silicates of any kind are combined with basic silicates, and combinations like these have more stability. But our business here is only with the silicates which contain lead; for the pigments that are usually employed almost always contain lead. The reason of this is, that the silicic salts of lead are extremely useful in modifying the expansibility of the pigments. By increasing or diminishing the quantity of oxide of lead, we almost always succeed in imparting a degree of expansibility to the pigments equal to that of the glass. The same result cannot be obtained from an alkaline silicate. This shows us the reason why potash is avoided in the composition of the pigments. The necessary fusibility and expansibility require that the fluxes should be brought into that state of saturation in which they have very little stability, and are very liable to decomposition. At a high temperature the potash is decomposed, and evaporates; when cold, the pigments are easily affected by moisture. This disagreeable circumstance is avoided by substituting for the potash borate of soda: the latter is much more fusible than the silicate of potash, and consequently enables us to obtain a proper fusibility without lowering too much the degree of saturation. And so less colouring, less liability to change, and greater hardness, are simultaneously obtained.

The whole matter may be shortly summed up thus:

1. In the pigments coloured by mixture, those silicates only may be used whose acids contain at most three times as much oxygen as the bases.
2. In the pigments coloured by combination a greater quantity of oxygen in the acids can only be of advantage when all other conditions have been complied with.
3. No pigment containing lead is to be prepared which contains the silicate of an alkali in a state of saturation beyond that of the trisilicate; that is to say, which contains a smaller portion of acid, or a greater quantity of base.
4. In every case, the indispensable conditions of fusibility, hardness, and expansibility must be satisfied.

In the composition of fluxes, silicic and boracic salts of various metals are usually combined, because the salts formed by these combinations possess greater fusibility, and because among the simple silicates and borates, which might, perhaps, be sufficiently fusible, they would not have the requisite whiteness if they were employed alone. For instance, the silicic and boracic salts, which contain a great quantity of base, would possess sufficient fusibility, but they have a yellow colour, which is more distinct in proportion as they are saturated. It is therefore necessary to combine them with a certain quantity of alkaline silicates or borates, in order to render this colour less conspicuous.

It would be better if the silicic or boracic salts which are used in the pigments were all insoluble, like those of lime, aluminum, lead, &c. But the necessity for obtaining a great degree of fusibility requires the use of alkaline silicates and borates, which, within certain limits, obtain a sufficient stability from their combination.

From the principles which have been laid down above, it might seem that two kinds of fluxes are sufficient for the two classes of pigments. This would certainly be the case if nothing more than the proper colour were attended to in the preparation of the pigments. But these pigments, which are made on purpose to be laid on the glass, must possess the same expansibility as the latter. Now the physical properties of the pigments are modified in a remarkable degree by the various substances employed in colouring, collectively and separately, in different ways. Consequently, it is only by changing the nature of the flux that we are capable of imparting the requisite expansibility to the pigments. Hence, also, arises the necessity for the existence of a great variety among the fluxes. When we come to treat of the pigments particularly, we shall also specify the fluxes proper for each. We shall, however, mention a few here, which may be adduced as an illustration of the rules we have laid down.

FLUXES FOR PIGMENTS OF THE FIRST CLASS.

	No. 1.	No. 2.	No. 3.
Silica	1 pt.	3 pts.	2 pts.
Oxide of lead	3 „	8 „	6 „
Calcined borax	0 „	1 „	1 „

Haudicquer de Blancourt, who has described the preparation of the flux No. 1, in his *Art de la Verrerie*, calls it *rocaille*, and it was formerly used as a glaze for common pottery-ware. This flux, however, whose state of saturation is admirably adapted to the preparation of pigments of the first class, cannot be advantageously employed in every case. It frequently happens that a colouring oxide, when mixed with it, contributes to its decomposition, since it favours the separation of its elements. The pigment then undergoes a change on exposure to the air, the surface loses its brightness, and crumbles to powder. We are, however, unable to specify the nature of the action of the colouring substance. Perhaps it is only mechanical, and proceeds from the great distribution of parts, and from the porosity itself, which a powder in the state of simple mixture imparts to the pigment; perhaps, too, the oxide of lead has less affinity for the silica than the new substance which tries to supplant the first.

The rocaille flux is, after all, only employed with advantage in the pigments of the first class when they have previously to be melted. The more intimate mixture of the flux with the colouring matter then imparts a greater density to the pigment, which defends it against the action of the air. We prefer this explanation. When the pigment does not require to be melted first, it is advisable to substitute No. 2 or No. 3 for No. 1; for they are only a modification of the latter, and possess greater stability.

FLUXES FOR PIGMENTS OF THE SECOND CLASS.

	No. 1.	No. 2.	No. 3.	No. 4.
Silica	3 pts.	1 pt.	3 pts.	3 pts.
Minium	8 „	8 „	6 „	6 „
Borax	3 „	2 „	3 „	2 „
Saltpetre	0 „	0 „	1 „	0 „

Every pigment might be prepared according to the above directions, if nothing but the good quality of these vitreous compounds were had in view. But those pigments chiefly that are to be produced by combination are so changed in regard to their expansibility by certain oxides, *e. g.* those of copper and manganese, that, in order to destroy the effect of the latter, it is necessary to reduce the fluxes to a state of saturation, which cannot be done by the use of alkaline silicates, for they must be employed in such small quantities that they may be enveloped, as it were, by the other silicates, and thus protected from the action of the water.

In this case the fluxes are very much saturated and less fitted to dissolve the oxides. But even then, methods may be employed to facilitate their combinations, which we shall describe when we come to speak of the pigments in particular.

OF THE PREPARATION OF THE PIGMENTS IN GENERAL.

The preparation of the pigments, which embraces a number of particulars with regard to each, may, however, be reduced to two general methods of operation, according as they are coloured by mixture or by combination.

In the first case, as we have already said, a flux in which the base preponderates is chosen; and with this object in view, care is taken, at the same time, that the colouring oxide shall remain as short a time as possible in contact with the liquefied flux: for this purpose they are only mixed together by means of the runner upon the mill-stone,* and the mixture is not heated until it is ready to be laid upon the glass, and exactly as much flux is used as is necessary to give body, smoothness, and brilliancy, after the burning in, to the pigment.

In the second case—1. A pigment must be selected in which the acids predominate as much as possible;—2. It is also necessary to fuse them together in a strong heat, in order to facilitate the reaction;—3. The flux must likewise be present in as large a quantity as possible without injuring the richness of the colouring;—4. The oxide must be perfectly free from combination, which might impede its union with the flux.

These are the most important varieties of the pigments, with regard to their composition and preparation. We subjoin some further considerations concerning the pigments collectively, that is to say, concerning the means of modifying their properties according to circumstances.

With respect to transparency, the pigments coloured by simple mixture are remarkably dissimilar to those which are coloured by chemical combination. It will be readily understood, that an opaque colouring matter diffused through a glass vessel diminishes the transparency of the latter, so that the enamel which is produced by it will be less permeable to light than another which has been coloured by a substance dissolved in a flux. It is also just as evident, that in the former case the opaque colouring matter diminishes the transparency of the flux in proportion to the quantity in which it is added to it. Thus the transparency of the pigments is increased according as the quantity of colouring matter is diminished. But this can only be done at the cost of the colouring, and in such circumstances, where intensity of colour is not required, it will be better even to impair its stability; for the more flux there is, the greater the action known to take place upon the colouring metallic oxides. With regard to the pigments of the second class, their transparency can only be diminished by the mixture of substances which impart opacity to them.

The hardness of the pigments under circumstances in other respects the same, increases in proportion to the quantity of

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* Described under the head 'Mill for grinding the pigments.'

the silica. This is just the case with regard to their resistance to the action of chemical agents. Consequently the opposite effect is produced as soon as the base is made to predominate.

We now come to their *expansibility*. It is of great importance to make this property of the pigments accord with that of the glass: it may, however, be very easily modified in the case of the former. With regard to this, we believe we have observed, that in the borate, silicate, and borosilicate of lead, the base usually produces the opposite effect to that of the acid; but we are unable to state whether the one diminishes or the other increases the expansibility. It is enough for us to know, that if a pigment becomes full of cracks, the proper degree of expansibility may easily be imparted to it either by increasing or diminishing the quantity of oxide of lead. We would recommend here the former method as the proper one in almost all cases.

FUSION OF THE FLUXES.

After the requisite quantities of the various substances that are to be used for a flux have been levigated and accurately weighed, nothing more remains than to fuse them. The powder is first well rubbed and mixed in a mortar. After careful mixture, it is put into a covered crucible, which is placed in the furnace; a gentle heat is first applied, which is gradually increased, until the whole is brought into an undisturbed state of fusion, and all bubbles have ceased to form. The crucible is then taken out of the furnace, and the contents are poured into a vessel of cold water: they are then collected and dried upon paper. The action of the cold water splits the mass into small fragments, which can afterwards be more easily levigated. Without this precaution, the flux would concrete into a vitreous mass, difficult to pulverize. This is exactly the mode of operation when we have to combine a flux with a colouring metallic oxide for a pigment of the second class, as is the case with all vitrifications of fluxes or pigments.

If we would have our colours bright and pure, it is of essential importance that the pigments should be prepared from none but the purest substances. It is consequently necessary that we should be well acquainted with the properties of the substances to be employed. We therefore think it advisable to make a few preliminary remarks concerning some of them, and to give a full account of them afterwards in their proper places.

Silica.—Silica is procured from flints, and white ones, or those of a beautiful black colour, are selected for this purpose. The yellow flints are less pure, and contain a great quantity of iron. For this purpose they are heated red-hot, and then thrown into cold water to quench them. If the action of the cold water fails in cracking them in such a manner as to allow of their being easily crushed by the fingers into a coarse sand, the operation is repeated; they are then reduced to powder, and rubbed through a silken sieve. This powder must then be washed, and the supernatant water poured off, as long as a fine powder continues to float on the surface, which gives the silica a yellow colour. This powder appears to consist of impurities, which originate partly from the furnace, partly from the cast-iron mortar which is employed in levigating the flint: they seem to be united with very fine silica, which could better be spared than retained in company with these foreign bodies. The particles of iron, being very fine, are carried off by the water in which the powder is washed, and separated before the process of heating the silica (of which we shall presently speak), in which those particles of iron would otherwise be further oxidized, and might not be so easily affected by acids.

After the silica has been washed in the manner above described, it is strongly heated and thrown a second time into cold water. The little grains of which it is composed undergo a fresh division, which facilitates the action of the acids with which they come in contact, and also the fusion of the metals. They are now treated with hydrochloric acid, washed and dried. Silica might also be obtained in the same way from white granular quartz; but even the purest granular quartz contains a greater quantity of iron than flint does, on which account the preference is usually given to the latter.

Borax.—The borax which is used in the preparation of the pigments is *fused borax*, which must not be confounded with *calcined borax*. The latter contains still a greater quantity of water. It is indispensably necessary to make use of the fused and perfectly vitrified borax, not only to enable us to calculate the quantities exactly, but also to avoid the swelling which would take place if borax in any other form were employed.

We shall hereafter enlarge more minutely upon the manner in which this operation is performed. When the borax is in a state of fusion, and appears perfectly clear, it is poured upon a smooth stone: it then presents the appearance of a beautiful white and entirely colourless glass. It must now be kept in a bottle well corked.

Minium.—The *orange-coloured* minium, as it is called, is most usually employed: it is the purest, and can be used without requiring a particular preparation. We shall only observe, however, that the minium must part with 2·23 per cent. of oxygen, in order that it may be reduced to the state of protoxide.

Of the other bodies which are used for fluxes we shall have occasion to speak elsewhere. Now that we have finished treating of the pigments in particular, we intend to subjoin a few general reflections, which we recommend to the consideration of the reader.

GENERAL REFLECTIONS CONCERNING THE COLOURING MATERIALS.

The chief colouring substances of the pigments are metallic oxides. Sometimes they are simply mixed with the whole body of the glass; at other times they are combined with the silica, and probably form double salts with the silicates of the fluxes. The analogy which prevails between the pigments and the other kinds of glass supports this hypothesis. It is known that in these compositions such alkaline silicates as are soluble in water when uncombined become almost insoluble as soon as they are combined with other silicates, *e. g.* with silicate of lime, silicate of lead, silicate of aluminum, &c.

Now the combination of these bodies is the sole means by which their properties can be modified.

In the pigments coloured by mixture, the colouring oxides are not always used separately; sometimes several are employed, after they have been previously combined with one another. But the conditions to which they are mutually subject are always independent of the flux.

The oxides which are combined in a pigment of this description do not give it the colour which the mixture of their respective colours would produce, but they give it peculiar shades of colour, which are determined by their state of combination.

Several oxides are frequently employed also in the pigments of the second class, but are not combined with one another, and the colour which is obtained is only the result of the mixture of the colours which each oxide produces of itself.

The combination of the oxides with one another is a valuable auxiliary in the preparation of the pigments. Sometimes these combinations impart to the oxides a greater power of resisting the action of the flux; at other times, on the contrary, they facilitate their solution in the latter. It is evident at once that the former are used for the pigments of the first class; the latter, on the other hand, for those of the second class. In the former case, we should combine oxide of iron, for instance, with oxide of zinc; because the former, by virtue of this combination, which possesses great stability, would prove much more powerful in resisting the action of the flux, and thus the real colour of the oxide could be given to the pigment.

In the second case, on the contrary, we should combine oxide of cobalt with oxide of lead, so that their less stable combination may bring the former of these bodies into a state of fine division favourable to the action of the flux. This direction may be complied with in a very simple manner, if, instead of preparing the flux beforehand in order to combine it with the colouring matter by a second fusion, the colouring oxide be heated when mixed with the ingredients of the flux; for the oxide of lead, which forms one of these ingredients, will dissolve the colouring oxide, and by that means dispose it to combine more easily with the silica. We have therefore no hesitation in prescribing this method universally for the preparation of the pigments of the second class. We know no reason of sufficient importance to oblige us to use fluxes previously vitrified, as is the case with the pigments coloured by mixture.

The combination of two oxides forms a real salt, in which the one appears in the character of the base, and the other in that of the acid. We shall now give a list of these bodies, in which those that act as base and those that act as acid are classed according to the energy they exhibit:

ACID OXIDES.

Antimonic acid.
Antimonious acid.
Stannic acid.

INDIFFERENT OXIDES.

Protoxide of tin.
Oxide of antimony.
Oxide of chromium.
Sesquioxide of manganese.
Oxide of iron.
Oxide of aluminum.
Oxide of zinc.

BASIC OXIDES.

Protoxide of iron.
Protoxide of manganese.
Protoxide of lead.
Oxide of silver.
Oxide of bismuth.
Protoxide of cobalt.
Oxide of copper.

We shall now give a few examples of the above-mentioned compositions, as they are frequently employed:

Antimonite of lead	Yellow.
———— cobalt	Dark green.
———— copper	Pistachio green.
Perantimonite of iron	Bees'-wax yellow.
———— zinc	Yellow.
Zincate of iron	Yellow ochre colour.

It is evident that a great number of combinations similar to those we have mentioned might be formed. A variety of mixed gradations of colour are obtained from these compounds, which in painting are called *broken tints*, and which are of great service to the artist. Among these compounds are:

Ferrate of manganese,
———— chrome,
———— cobalt,
———— copper,
Manganate of cobalt,
———— copper,
———— chrome,
Cuprate of silver, &c.

We shall treat of the preparation of these colouring substances hereafter.

CHAPTER II.

OF THE PIGMENTS IN PARTICULAR.

Red for the flesh-tints.—This pigment is coloured with oxide of iron, as it is obtained by calcining the green vitriol of commerce; but it must first be purified, principally in order to rid it of the sulphate of copper, which it almost always contains, and which, when the pigment is used, turns the red black.

Purification of the vitriol.—Dissolve the vitriol in twice its weight of cold water, and throw into the solution iron turnings, iron filings, or iron cuttings of any kind. The sulphate of copper will be decomposed, and the copper precipitated in the metallic state, in the form of a reddish powder. The solution should be stirred from time to time, and after the precipitation is completely at an end, the liquor poured off and filtered. To know whether all the copper has been precipitated, dip into the solution a bright blade of iron, and see whether it is covered with a surface of red copper.

The filtered solution of sulphate of iron must be put into an iron or leaden vessel, which is placed in a common oven, in order that it may become so concentrated by boiling as to have lost ⅝ths of the water which has been taken into solution. Its specific gravity will then be 40° of Beaumé's areometer, and the solution will begin to grow turbid; it is then left to crystallize in a wooden vessel covered with wax; twelve hours afterwards the mother liquor is poured off, and the crystals are collected, strained, and dried.

Drying of the salt.—In order to dry the salt, and to perform the subsequent operation, two pounds of salt at the most should be treated at a time, for the sake of greater facility in manipulation.

Two pounds of the purified crystals are accordingly put into an iron vessel, which is placed in a furnace, and a moderate fire is applied, in order to melt them in their water of crystallization. When this has taken place the liquid mass begins to boil, and soon assumes the consistency of thin paste, and the colour of clay softened by moisture. After it has become concentrated the temperature is lowered, that the melted mass may not boil over. In proportion as the water evaporates and the contents of the vessel are drying they are continually stirred, and during this process the bottom of the vessel especially must be scraped with an iron ladle having a long handle, until the salt is at length converted into a more or less coarse powder. It is now allowed to cool, after which it is pounded in an iron mortar, and finally rubbed through a silken sieve. In this state it is fit for the preparation of the red pigment.

Preparation of the red pigment.—For this operation a very thick cast-iron vessel is required, and it is not a matter of indifference whether merely a common iron vessel of moderate thickness be employed for this purpose or not; for there would be a danger of its being perforated with holes and destroyed before the conclusion of the operation: cast iron is more durable than wrought iron when applied to this use.

An earthen cylindrical furnace must likewise be employed, with a bottom of the same substance, and open at the top. A hole is bored at the bottom, to receive the muzzle of a small smith's bellows. The dimensions of this furnace must be six inches in diameter, and the same in height. In default of such a furnace, a common one might be used, but the temperature can be regulated much better in the one we have just described; for as soon as the operator ceases to blow, the fuel, receiving no air from any quarter, begins to go out. The vessel must be of the same width as the furnace.

These proportions for the furnace and the iron vessel must be adapted to the quantity of the salt that can be used at once, in order to perform the operation with due precaution.

The sulphate of iron, prepared according to the above directions, is heated until it assumes a dark red colour. Meanwhile it is continually stirred with an iron scraping instrument until the operation is finished, in order that fresh surfaces may be continually exposed and the whole may be uniformly heated. The powder at first becomes yellow, then brown, and at last assumes a greenish brown appearance, which after cooling changes to red. An acid and pungent gas is now disengaged. The operation is continued until the powder is reduced to about two-thirds of its volume. It is now taken from the fire and allowed to cool.

After a little practice, we may know by the colour of the substance when the operation must be brought to a conclusion. Should the operator, however, want experience, let him take portions of the substance at different periods of the operation, and he will thus be sure of obtaining the requisite tint. In every case the operation must be concluded before the gas has ceased to be given off; for if it were prolonged to this point, it would be all to no purpose, and the result could only then be used as a dark brown or iron violet colour.

The red which has been obtained is put into a vessel, and boiling water poured upon it to dissolve the sulphate of iron that has not yet been decomposed. It is frequently stirred, allowed to subside, and the supernatant water is poured off. The red pigment is then cleansed from a few impurities remaining in it by being stirred in a vessel of fresh water, which is quickly poured off as soon as these impurities have subsided. If this operation be repeated as often as is necessary, the impurities will be completely removed. They are generally of a greenish grey colour. The powder of oxide of iron is now washed in a filter with cold water until the latter exudes from the filter perfectly tasteless. The result, when dried, is now ready to be mixed with the flux.

Theory.—What takes place in this operation? In the first place a portion of the acid of the salt is decomposed into sulphurous acid which is given off, and oxygen, which converts the rest of the salt into persulphate of iron, which is mixed with the oxide of iron that has been liberated. This sulphate is now decomposed again; sulphuric acid is disengaged, and oxide of iron, mixed with undecomposed persulphate, remains.

It is well known that the red oxide of iron changes its colour in proportion as the temperature to which it is exposed is increased. At first it possesses a yellowish red colour, which afterwards passes into a darker red, and finally into violet. If, therefore, it is required to produce a delicate red for the flesh-tints by calcining sulphate of iron, the latter must be acted upon by a heat sufficient to decompose it, but still not so great as to deepen the red which has already formed. Hence is evident the importance of always keeping it at a dull red heat, and of stirring it incessantly, so that the parts which lie at the bottom may not be too much heated. With respect to this circumstance we subjoin the following practical remark, viz. that in order to keep the powder at a dull red heat, while it is stirred, the bottom of the vessel must be at a cherry-red heat.

The operation must be concluded before the sulphate is all decomposed (and this is of the greatest importance), so that the red which is formed may be mixed with a certain quantity of this salt. When the latter has been dissolved by the water in which it is washed, the oxide that remains is in a state of finer division, and possesses a lively red colour.

If the operation be continued too long, it seems to be prejudicial to the beauty of the red, even if the temperature be not very high. We may infer from this, that the oxide condenses not only in consequence of the high temperature to which it has been exposed, but also on account of the length of time during which it has been heated. And this is the reason why only a small quantity of the salt should be operated upon at a time.

Red of a beautiful tone from iron may be obtained with much greater certainty by a method which is based upon the theory we have just explained. A mixture of sulphate of iron and sulphate of potash is calcined, as in the foregoing operation, these salts having been previously combined in the state of solution, and then evaporated and dried by heat. The mixture may be heated merely in a crucible, provided that care is taken to increase the temperature slowly up to the dull red heat, and to keep it so until the operation is finished. But this latter method is less certain. In every case the undecomposed sulphate of iron, as well as the sulphate of potash, is separated by repeated washings with hot water.

There is still another method which furnishes a red of great richness of colour, particularly for the flesh-tints. It consists in grinding sienna in a solution of sulphate of potash, drying it by heat in an iron vessel or even in a crucible merely, and calcining it the proper length of time at an incipient red heat, in order to develope the colour of the oxide of iron. The product is then washed with boiling water, to separate the sulphate of potash.

A similar result is obtained by calcining a mixture of equal parts of green vitriol and alum, previously united in solution, and proceeding in other respects according to the method we have just described for obtaining the red from sulphate of iron and sulphate of potash.

The preparation of the red from iron requires much more delicate manipulation than would be supposed. Whatever method be employed, the calcining must be performed with the greatest care, and we would particularly caution the reader against imagining that the details we have given are superfluous. It is difficult to determine which method of preparation deserves the preference, because, on a comparison of the various methods, we cannot always be sure of being subject to the same conditions, and we often lay to the charge of the method that which ought properly to be attributed to the manipulation. If we were to recommend one method more than another, it would be the second, that which we have most frequently employed.

It now remains for us to explain why sulphate of potash is used in the preparation of the red obtained from iron. This salt is unchangeable at a red heat, and at this temperature has no chemical action upon the component parts of the sulphate of iron. Its action here is entirely mechanical. It supports, as it were, the complete decomposition of the sulphate of iron. But, although it remains undecomposed itself, its presence is by no means a matter of indifference. When the sulphate of iron is dried in contact with the sulphate of potash, it is kept by the latter salt in a state of fine division, analogous to that which it possesses in the state of solution; for every minute particle of iron is surrounded by numerous minute particles of sulphate of potash, so that, when the oxide of iron is separated, it must preserve the extremely fine division of the salt by which the oxide of iron was produced. It thus escapes that condensation and conglomeration which oxide of iron always undergoes when it is heated by itself. The unchangeableness of sulphate of potash at a red heat is the only reason why this salt has been selected for the operation in question. It is likewise employed for the same purpose in similar cases, where, as in the present instance, the object is to obtain oxides free from water in a state of the most minute division. There are various methods of applying it to this purpose.

1. Sulphate of potash is calcined at a red heat, together with the metallic sulphate whose oxide is to be obtained, provided that this sulphate is decomposable. The process is the same as has been described in the case of the red obtained from iron.

2. If the salt is not decomposable, the oxide in question is precipitated with potash; the solution is then evaporated to dryness, and the product is submitted to a red heat in a crucible. The sulphate of potash is next removed by boiling water.

3. If the oxide of another salt, not a sulphate, is to be obtained, we proceed as follows: after the oxide has been precipitated with potash, and the precipitate washed, it is mixed with a saturated solution of sulphate of potash, next evaporated, and the rest of the process is the same as we have described above.

M. de Montami treated certain oxides, probably with the same object, with chloride of sodium in a similar manner, but his efforts were misdirected. He triturated red oxide of iron and chloride of sodium dry in a mortar together, and calcined the mixture in a bright red heat. In this way he calcined oxides, free from water and already condensed by the action of the fire, with the chloride. The oxides could not penetrate so deeply into the latter combination, which was applied in a solid state, as if it had been in the state of a red-hot liquid; and besides, they had undergone a very great change from the heat before it was introduced.

The red pigment is composed of

Red oxide of iron	1 part.
Flux No. 1, or No. 3, of the 1st class	3 parts.

The flux must be pulverized before it is weighed, because a certain quantity is always lost by pulverizing it in an iron mortar. It is then mixed with the oxide of iron, and the mixture levigated; at the same time a sufficient quantity of water is added to obtain a liquid paste, which is afterwards dried on plates.

This pigment must contain as much flux as will give it brilliancy when it is exposed to a cherry-red heat; a larger quantity of flux must, however, be avoided, because the flux would re-act upon the colouring oxide, and contribute to the production of a green silicate of iron which would be prejudicial to the purity of the red. We shall afterwards explain how this pigment is to be prepared for use, and under what conditions it must be heated after it has been laid on the glass.

If a greater degree of freshness and brilliancy is required in the red pigment which is used for the flesh-tints, a certain quantity of chloride of silver must be added. The yellow tint which this combination produces imparts a greater liveliness to the red colour of the iron. The taste of the artist can alone determine the proportion of the substance to be added. The chloride of silver must previously be fused with the flux. The oxide of iron is added afterwards.

Purple (*purple-red*) *pigment.*—The preparation of the purple is a very delicate operation, the success of which is extremely uncertain. The reason of this is, that the method which is employed in the majority of cases for the preparation of a solution of tin furnishes an exceedingly variable compound, although the process is on every occasion the same. The precipitate which by this method is apparently obtained under exactly the same conditions, frequently varies from a more or less lively purple to a violet more or less dark, and even of a blackish colour; and even the purple of the most beautiful tone is not always proof against the drying, and is turned black by the separation of the gold.

The method employed in most cases is as follows: Take aqua regia of 8 parts nitric acid and 1 part sal-ammoniac, diluted with twice its weight of distilled water. Set the apparatus in a cold place, and introduce small pieces of tin one after another in proportion as they are dissolved. The action of the acid must be slow, and without a considerable quantity of heat being evolved. When the liquor has assumed a yellow colour, not very intense, it is fit for use. On the other hand, dissolve pure gold in aqua regia containing 1 part nitric acid to 2 parts hydrochloric acid. The gold has now to be precipitated by means of a solution of tin. For this purpose, a few drops of the solution of gold are poured into a glass, and at least a thousand times their volume of water is added. Into this liquid some of the solution of tin is introduced, a drop at a time, until the water is coloured red. This liquor is kept in a vessel by itself, and the same process is repeated until at length the requisite quantity of purple is obtained. In a few moments the purple collects in red flakes, which sink to the bottom. As soon as all the purple is precipitated the supernatant liquor is poured away. It is then washed several times with distilled water, which is likewise poured away. Next it is filtered, and whilst it is still moist it is triturated with its flux.

The success of the operation depends upon the manner in which the salt of tin is prepared. In order that the purple may be of the proper quality, the action of the acid upon the tin must be neither too strong nor too weak; if it is too weak, too much protochloride of tin is obtained, and if it is too strong, nothing but perchloride of tin is produced. It is necessary to know how to keep the acid in exact equilibrium, so as to obtain a mixture of the two salts combined in as nearly as possible the proper proportions. The difficulties which accompany the regulating the effect of the acid in such a way as to obtain every time the same result, although the operation is not performed under the same conditions of temperature, are obvious to every one. Sometimes the protochloride, at other times the perchloride, is in excess: this explains the different appearances which this composition exhibits when used.

If the products of the operation are uncertain, variable in their colour, and disposed to decomposition during the process of drying, there is every reason to believe that the salt of tin is of a bad quality. The difficulty of imparting the requisite properties to this composition induced M. Reboulleau, among others, to seek for a simple and easy method of procuring with certainty a solution of tin adapted to the preparation of the purple. It is composed in a way that Dumas also considers the best, viz. of one atom of protochloride and one atom of perchloride of tin.

The method employed by M. Reboulleau for this purpose is as follows: Protochloride of tin is first prepared by introducing grains of pure tin into a leaden vessel which can be closed by a lid of the same metal. A small quantity of concentrated hydrochloric acid is then poured upon the grains. The apparatus is gently warmed in a sand-bath, and small quantities of acid are gradually introduced until the tin is dissolved. The liquor is evaporated to 40° of Beaumé's areometer, and allowed to crystallize. We have then merely to convert a definite portion of the protochloride of tin into perchloride. The crystallized protochloride is dissolved in a sufficient quantity of water; the solution is divided into two parts, one of which is set apart, while chlorine gas is infused into the other until the protochloride is completely changed into perchloride, which is removed for fear it should precipitate gold. This solution is added to the one which was set apart, and thus a solution of tin is obtained, in which the two chlorides are present in accurately determined proportions. The success which this method insures in the preparation of the purple is so perfectly certain, that it may be safely recommended to glass-painters and other artists.

The solution of tin serves only for precipitation from chloride of gold which is prepared by dissolving gold in aqua regia composed of 1 part nitric acid and 4 parts hydrochloric acid, evaporating it until it is dry, in order to drive off the excess of acid, and adding a quantity of distilled water sufficient to dissolve the salt which has been obtained.

The precipitation of the purple is a part of its preparation that requires very delicate manipulation. The manner in which the mixture of the two salts is effected is not a matter of indifference. Two methods may be employed: the solution of gold may be poured into the solution of tin, or *vice versâ;* but these two methods do not promise equal success. The following remarks will show why one method is to be preferred to the other.

When the precipitation of the purple is effected by the mixture of the salts of tin and gold, one of these three things will take place: viz., either the salts will be in proper proportions, or the salt of tin will predominate, or the salt of gold will be in excess.

If the salts are in proper proportions, the purple precipitate follows, accompanied by certain indications with which it is necessary to be acquainted. The liquor assumes an intensely red colour, similar to that of wine. The precipitate does not follow immediately, but the purple remains a longer or shorter time, as the case may be, in the solution, and frequently it is several hours before the separation is complete. When the precipitation takes place too quickly, it is always a proof that the purple is of a bad quality and contains an excess of gold.

If the salt of gold is in excess, a precipitate is formed which varies from a pale rose colour to a more or less lively red, and the separation takes place immediately. In this case also the purple is imperfect.

If, on the contrary, the salt of tin predominates, no formation of purple takes place; the liquor assumes a yellowish or rose-coloured appearance, without affording any precipitate.

From what we have just stated, any one would be inclined to think that if the quantities of the two salts are previously determined, it would be sufficient to pour the solution of the one into that of the other, and to stir them together. But this expectation is not easily realized; and it is thought more advisable to obtain a proper mixture by adding successive drops of the solution as long as it shall be found necessary;

nor even then is it immaterial whether the solution of tin be poured into the solution of gold, or the solution of gold into the solution of tin.

Is the solution of tin to be poured into the solution of gold? As the addition is made by drops, the gold remains in excess in the liquid until the whole of the solution of tin has been introduced. Consequently an imperfect precipitate may be formed if the proper quantity of the solution of tin be not introduced with tolerable rapidity; and this is very frequently the result. If, on the contrary, too much solution of tin be added, no precipitation takes place, and it becomes necessary to reverse the operation, and to add the solution of gold. This method is therefore very uncertain.

Is the solution of the salt of gold to be poured into that of the salt of tin? So long as the salt of tin is in excess no precipitation takes place; but if we continue to add gold the purple soon makes its appearance, and we can always stop at the right time, because we are not obliged to hurry ourselves in the least degree. Only an inexpert operator runs the risk of introducing too much solution of gold. In such a case, a precipitate of bad quality would be produced, and the experiment would entirely fail.

It is evident that, of these two methods, that according to which the solution of gold is poured into the solution of tin has the best prospect of success, and is the least liable to accidents. It may be asserted that it is the only one which affords invariable results: it admits, too, of the treatment of any quantity we please, while the other method is only applicable when the solution has to be treated with a few *decagrammes*[*] at a time.

But whatever method be pursued, the solution of tin must at all events be diluted with a thousand times its weight of water, in order that the precipitate may be so much the more finely divided and more gelatinous. After the precipitation of the purple powder has subsided, it is put into a filter and washed with distilled water: it is advisable then to dissolve it in ammonia, and keep it in a well-stopped bottle: the capability of being dissolved in ammonia is the test of its good quality;—if this property is wanting, we may be certain that it is of no use, for it will not possess durability.

In order to unite the purple with its flux, the latter is pul-

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[*] The *decagramme* is equivalent to 154·42 English grains avoirdupois (the *gramme* being 15·442 grains), according to the new metrical system of weights and measures.

verized, moistened with the ammoniacal solution of the purple powder, and the mixture is effected by levigating them together upon a plate of glass. The relative quantities of the purple and the flux depend upon the richness of the colour which is intended to be given to the pigment. One-tenth of the purple in a dry state gives an intense colour. If we know the composition of the purple, the quantity of gold that is used, the quantity of ammonia in which the purple has been dissolved, it is an easy problem to determine the proportions of this solution, which must be added to the flux, in order to have used the equivalent of one-tenth of dry purple.

The purple colour which is produced in fused pigments by the above-mentioned composition proceeds from metallic gold in a state of exceedingly fine division. The same colour is likewise obtained from pure chloride of gold, sulphuret of gold, and fulminating gold, in similar circumstances, and these combinations play the same part as the purple powder. When the latter is mixed with its flux, and strongly heated, the tin is separated from the gold; but the latter, reduced to the metallic state, remains in a state of the most minute division, because the flux, being melted, is present in a liquid form. But as soon as the gold can collect together in particles of a larger size, there is a transition from red to violet and blue. This phenomenon is produced by several circumstances, which arise from the following causes:

The flux for the purple must contain not much lead, but, on the contrary, a great quantity of acid, and must at the same time possess great fusibility. Stannic acid has in fact a great affinity for oxide of lead. When it is combined with gold in the form of the purple powder, and is brought into contact with a flux containing a large amount of base, and at the same time lead, it leaves the gold in order to combine with the lead before the pigment is completely melted. This premature separation of the tin from the gold facilitates the agglomeration of the particles of the latter, which then assume the violet or blue colour we have been speaking of.

A large proportion of acid gives more stability to the silicate and borate of lead, so that it is more capable of resisting the action of the stannic acid.

The colour of the purple is, on the other hand, destroyed when the flux with which it is mixed wants fusibility. The temperature necessary to fuse the mixture produces at the same time the decomposition of the purple before it can be brought into its incipient state of division. So also a purple pigment mixed with its flux, if too strongly heated, would undergo the same change from a contrary action, because the too great fusibility of the flux is favourable to the condensation of the gold. Consequently it is necessary that the purple, at the moment when it is being decomposed, should be held in solution in a dense mass of liquid glass, in which every one of its particles may, as it were, remain isolated, in the same way as an oleaginous body is suspended in a slimy fluid.

The flux which seems best adapted to the purple is the following:

Calcined borax	7 parts.
Silica	3 ,,
Minium	1 part.

This flux possesses sufficient fusibility, and at the same time great stability.

Another still more fusible flux:*

Calcined borax	7 parts.
Silica	3 ,,
Minium	1 part.

These substances are fused together.

Another still more fusible flux:

Calcined borax	7 parts.
Silica	1 part.
Minium	1 ,,

These substances are likewise fused together.

For the purpose of obtaining a still more fusible flux, it is not unusual to increase the quantity of borax very considerably, without employing the other substances in larger quantities. Thus, for example, the following flux is used:

Calcined borax	12 parts.
Sand	1 part.
Minium	1 ,,

A flux like this is, indeed, far more fusible than the foregoing, and more conveniently used for glass-painting, because only a moderate heat is required for it; but such a composition is liable to imperfections, and is not only more easily affected by moisture, but is also in the habit of coming off in scales. The purple colours generally possess these imperfections. It is owing to the great quantity of acid which they contain that their expansibility does not accord with that of

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* There is evidently some mistake in the original, this and the foregoing flux being perfectly identical.

certain kinds of glass. When this kind of painting is looked at with a magnifying glass, after the burning in, several cracks and fissures may be observed; and after a certain time, especially when the painting has been exposed to moisture and a variable temperature, it scales off, so that at last the glass becomes perfectly bare. It is of importance to examine in every case whether the pigments agree well with the glass in regard to expansibility, and it is frequently necessary either to vary the composition of the flux or to choose another kind of glass.

A carmine tint is given to the purple by adding to it a small quantity of chloride of silver, previously fused with ten times its weight of the flux which is used for the purple.

As the purple from gold is prepared in different manufactories in a great variety of ways, and the preparation is attended with various results, we shall conclude by stating several methods, for which we are indebted to men whose reputation is great in the scientific world.

According to Bastenaire Daudenart, the purple is prepared in the following manner: Nitric acid and gold are taken in the proportion of 8 parts, by weight, of the former to 1 of the latter. In order, however, that the operation may be performed with greater certainty, it is better, in case the acid should be more concentrated at one time than at another, and in order that similar results may be always obtained, to introduce gold into a retort until the acid is completely saturated. Especial care must be taken that the solution of gold is in a perfectly neutral state.

The nitro-muriatic acid,* for the solution of gold, is composed of

Nitric acid	4 parts.
Muriatic acid	1 part.

The former acid is poured into a retort, which is placed in a heated sand-bath, the muriatic acid is then introduced, and the liquid is at the same time stirred; a few minutes after, the gold is thrown into it, a small piece at a time. Gold riband should be preferred, which may be bought at the goldbeater's, or else the gold, if it is at all thick, should be beaten very thin. When the acid is observed to be incapable of dissolving any more gold, the retort is taken out of the sand-bath and placed upon a layer of rushes of a concave form, to receive the globular part of the retort. The liquid is left for some hours

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* This is erroneously called 'Salpetersäure,' nitric acid, in the original.

by itself, after which it assumes a beautiful dark yellow appearance.

The solution of tin is likewise made with nitro-muriatic acid, but instead of 4 parts of nitric acid 6 are used, and the following compound is obtained:

Nitric acid	6 parts.
Muriatic acid	1 part.
Distilled water	4 parts.

The solution of the tin requires infinitely greater care than that of the gold; it must take place without any effervescence, and very slowly. Tin leaf, such as is used for covering mirrors, is selected for this operation. The solution takes place without heat, and only a very small quantity at a time is introduced into the acid which has been diluted with water; *e.g.* pieces of tin leaf eighteen *millimetres** square, one after another, for the space of twelve hours, until the acid is completely saturated. When both the solutions have been prepared in this way, the one is precipitated with the other; and this is the moment when it is the most difficult to obtain a beautiful purple. Many persons have been quite discouraged, and have given up even attempting to prepare this colour, because they have undertaken the operation too carelessly, when, in fact, it requires great nicety, or because they have not clearly understood the theory of the phenomena which take place in the mutual decomposition of the two soluble salts. Care must first be taken that both the solutions are very considerably diluted with water, for without this precaution gold is precipitated by the tin in a metallic state, which causes such a cohesion of the minute particles of the metal, that the desired results cannot be obtained in the precipitate. To avoid this disagreeable occurrence, which renders the whole operation fruitless, a large glass vessel, three parts full of distilled or at all events very pure water, must be taken, and into this a certain number of drops of the solution of gold must be poured. The number of drops must be in proportion to the size of the vessel. Suppose the vessel is capable of containing one *litre*† of water, as much as eighteen drops of the solution of gold may be dropped into it. This done, the liquid is stirred with a piece of the tube of a barometer, and it must then be of a pale yellow colour, but very clear; eight, ten, or twelve drops of the solution of tin are then dropped

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* The *metre* is 39·37079 English inches; the *millimetre*, being the 1000th part of the *metre*, is therefore equivalent to ·03937079 inches.

† The *litre*, or cubic decimetre, is ·22009687 of an imperial gallon.

into the vessel, and care is taken to stir the mixture well, just while the solution is being dropped. As soon as the liquid is observed to have assumed a colour like that of red wine, no more solution of tin is added, (we should suppose that this would take place at the sixth drop,) because if the process be continued after the beautiful red colour has appeared, only a purple is obtained, which approaches too near to violet.

There must be a large vessel of porcelain, or well-glazed Delf ware, ready to receive all the red liquid which is transferred from the glass vessel into which the solution of tin was dropped. Accordingly, when the liquid in the latter vessel is well saturated with the purple colour, it is introduced into the large vessel of Delf ware, and a fresh quantity of water is poured into the glass vessel, and then eighteen drops of the solution of gold. Whilst the solution of tin is being dropped, the liquid is stirred with a glass rod: the drops of the solution of tin must never amount to more than two-thirds of those of the solution of gold, especially if the purple is to be of a beautiful rose colour.

When as much gold and tin as is considered necessary has been precipitated, all the water which has been coloured red is poured together, and then left undisturbed. In the course of twenty-four hours a reddish brown precipitate settles at the bottom of the Delf ware vessel. To hasten this subsiding, one or two pinches of kitchen salt may be thrown into the red liquor. Some writers have also recommended the addition of a certain quantity of fresh urine; but some solution of phosphorus may be more advantageously substituted for the latter. In other respects, it is far better that the subsiding at the bottom of the vessel should take place slowly and of itself, and in that case the supernatant liquor must be perfectly clear. This is poured off, and the remainder edulcorated several times with plenty of water: the precipitate is collected upon a piece of white paper, and dried in the shade. In the course of a few days it is easily removed from the paper, whereupon it is put away in a wide-mouthed bottle with a greased stopper, and kept from the light.

The formation of the purple proceeds:—1. from the elective affinity of gold and tin; 2. from the high state of oxidation of the tin; and 3. from the circumstance that the solutions are diluted with a great quantity of water, to weaken the affinity of the acid for the oxides as bases; for so long as the metals (gold and tin) are intimately combined with the acids in which they are dissolved, there is no chance of obtaining a purple of a beautiful colour.

Moreover, all the precipitates which are obtained by means of gold and tin differ from one another in a variety of circumstances. The quantity of water poured into the first vessel, namely, in that into which the solution of tin is dropped to mix with the solution of gold; the number of drops of the solution of tin in proportion to the number of those of the solution of gold; the purity of the water in which the precipitation is effected: all these circumstances might produce a great variety of tints. However, in general the purple is the more disposed to assume a violet colour when the precipitate contains a greater quantity of tin in proportion to the gold; on the other hand, the purple is more beautiful or more rose-coloured, the more solution of gold the precipitate contains. It is therefore quite at the option of the experimenter to prepare a more or less beautiful purple, if he only act upon this intimation with proper care. Proust and Oberkampf* have analyzed several red and violet-purple precipitates: they found in a beautiful rose-purple—20·58 oxide of tin, and 79·42 gold; and in a violet-purple precipitate, 60·18 oxide of tin, and 39·82 gold.

According to Berzelius, the purple contained—28·35 oxide of gold,—65·00 oxide of tin,—7·65 water.

According to Buisson, the purple precipitate contains—28·50 gold,—65·00 oxide of tin,—5·20 chlorine.

Cassola, Professor of Chemistry at Naples, gives the following receipt for the preparation of the purple: Hydrochlorate of gold is prepared in the usual way: at the same time, tin filings are digested in vinegar for two or three days, and the solution is filtered. The solution of gold is then diluted with four or five times its weight of water, and the solution of protacetate of tin is generally poured into it until the red precipitate has formed; it is then washed and bottled up.

Cassola asserts that he obtained the same results by using a solution of protonitrate of tin, procured from tin filings, dissolved in concentrated nitric acid which had been diluted with fifteen parts of water. According to what he says, this solution of protonitrate of tin must not be used until it has been for two days in contact with the tin. Both solutions—that of the tin and that of the gold—must be mixed cold, in which case a purple precipitate, without a tinge of black, is immediately produced. Cassola, however, prefers the process with

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* Annales de Chimie, t. lxxx. et lxxxvii.—(*Note of the Author.*)

acetate of tin. He also employed protosulphate of tin, diluted largely with water, for the precipitation from the solution of gold, and obtained the same favourable results. The same phenomenon, however, with regard to the colour of the precipitate, takes place in precipitating with sulphate of tin, if it is used in excess, as if muriate of tin is employed in too great a quantity.

A beautiful purple may also be obtained by the following method: One part thin gold leaf is dissolved in aqua regia, the solution is poured into a glass, and diluted with 15 parts rain water; a solution of 1½ part clean tin filings in muriatic acid, which has been allowed to cool, is added, and at the same time the mixture is continually stirred. After it has remained a quarter of an hour undisturbed, one-half part clean urine is poured into it, and the whole is well stirred. About two hours afterwards the liquor is poured away from the purple, which has now subsided, and the latter is completely edulcorated.

According to Stegers, a very beautiful purple is prepared in the following manner: Fine gold is dissolved in aqua regia. If the gold has been alloyed with silver, the solution is poured away from the precipitated chloride of silver; the latter is washed with distilled water and added to the solution, which, without being filtered, is evaporated with a moderate heat until a thick incrustation of crystals is formed, and only a little of the red solution bubbles up from under the incrusted surface when the vessel is inclined on its side. The whole is now left to cool, whereby it gradually solidifies throughout, and is dissolved without delay in ten times its weight of water; to avoid the attraction of moisture, the solution is filtered, and a small quantity of metallic gold is left behind. In order to wash out the filter, a portion is reserved out of the water, which has been accurately weighed, and this is afterwards added to the solution. The crystallized salt of tin of commerce is quite good enough for the purpose; if it is moist it should be dried between printing-paper. One part of this salt is dissolved in four parts of distilled water; the solution is filtered and used immediately, because in time it becomes turbid, owing to its attracting oxygen from the air, and submuriate of tin is deposited in the form of a white powder. Next, 1 part of gum-arabic is dissolved in 3 parts of hot distilled water, and the solution is filtered through gray blotting-paper, because printing-paper, on account of its greater closeness, impedes the passage of the glutinous fluid. When the three liquids have been prepared in the foregoing manner, 20 grains of the solution of gum are mixed with 3 ounces of distilled water, and, after careful stirring, 14 grains of the solution of tin are introduced. The vessel in which the latter was weighed out is rinsed with a little water, the whole is then mixed with 23 grains of the solution of gold, and the vessel which contained it is likewise rinsed, not with water, but with the mixture itself. The colour which arises from the above-mentioned proportions of these ingredients is a fiery reddish brown; it is only in the fire, when this preparation is used for glass-painting, that it developes a purple unequalled in beauty. The colour may be slightly affected by the action of the acid which has been disengaged by the formation of the purple in the liquid; but this is obviated by diluting the solution with twice its weight of water, dissolving 10 grains of bicarbonate of potash in it, and mixing with it, according to the above direction, some of the solution of tin containing gum.

To separate the purple, whose precipitation is at present retarded by the gum, alcohol is added to the mixture until it grows very turbid; for this purpose about twice its weight of 75 per cent. spirit is required, that is to say, if bicarbonate of potash has been used, otherwise three times is necessary. In the course of an hour, if the solution has been occasionally stirred during this time, the purple is precipitated in reddish brown flakes, and the supernatant liquor remains clear, with only a slight tinge of colour. This is decanted, and the precipitate is then washed with some more spirits of wine; it is strained through a filter of printing-paper, gradually deprived of its moisture by being squeezed with the latter through blotting-paper, removed to a rubbing saucer, and then ground with weak 50 per cent. spirits of wine to a thin paste, which is boiled for three minutes in a vessel proper for the purpose, and then poured into a cylindrical glass. As soon as it has subsided in this vessel, the liquor is poured away, and is replaced by twice as much water. This operation is repeated, by which means the gum is removed, all except a slight residue, which can do no harm. Should the purple subside very slowly from the last liquor, and form a dense, almost transparent, red stratum over the sediment (a fact which proves a disposition to be dissolved), the water must be poured away, and a small portion of strong alcohol must again be added to the remainder, in order that the purple may coagulate rather more densely, and the last addition of liquid may be filtered. In either case, the precipitate from which the liquor has been strained is pressed, as before, with the filter, between blotting-paper, and, while moist, is scraped off with a blunt knife, and dried in a porcelain saucer, whereby it diminishes considerably in bulk, and becomes of a perfectly dingy colour.

According to Buisson, the purple is prepared with the greatest certainty in the following manner: 1 *gramme* of the purest tin is dissolved in a sufficient quantity of muriatic acid. The solution must be neutral. Further, 2 *grammes* of tin are mixed with aqua regia, composed of 3 parts of nitric acid and 1 part of muriatic acid, so that the solution contains no protochloride of tin. Lastly, 7 *grammes* of fine gold are dissolved in a mixture of 1 part of nitric acid and 6 parts of muriatic acid, and this solution must likewise be neutral. The latter is diluted with 5½ *litres* of water, the solution of perchloride of tin is added to it, and that of the protochloride is introduced a drop at a time, until the precipitate that is being formed possesses the requisite colour. This precipitate is edulcorated as quickly as possible.

It is of importance to know that the perchloride and the protochloride must not be produced separately, but both the chlorides at the same time, to enable us to obtain the purple from chloride of gold; and that it is further requisite that the three chlorides should be prepared for use perfectly free from acid.

Herr G. Creuzburg,* a practical chemist, particularly recommends, in the preparation of the purple, the use of a solution of tin chemically pure; he therefore advises that the broken tin ore should be first treated with nitric acid, which dissolves all other foreign metals, and converts the tin into an oxide. After the blue solution which contains the foreign metals, and among others copper, has been poured away from the oxide, which is in the form of a white powder, and the latter has been washed, dissolved in muriatic acid, and inspissated, chloride of tin, chemically pure and free from acid, is obtained. It now only remains to observe, that perchloride of tin, digested with metallic tin, gives protochloride of tin. When the two solutions of tin have been prepared in this manner, the remainder of the operation is performed according to Buisson's method. After a few slight preliminary experiments have shown about the maximum of perchloride of tin that the solution of gold will bear, in order to give the purple with the protochloride, the requisite quantity of perchloride is

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poured all at once into the very dilute solution of gold, which is not thereby rendered turbid, and a slow precipitation is produced by the introduction of the protochloride, very much diluted, until the purple tint appears.

It was now a still more difficult task to find a suitable flux and other ingredients, in order to obtain a beautiful enamel colour. At last it was discovered that antimony and white enamel were the substances which, when mixed with the flux, were capable of lightening the tint of fine purple, so that the rose colour was particularly beautiful. The addition of metallic silver and chloride of silver, by which the purple colour used formerly to be brought out more strongly, was not applicable to this purple, and gave a useless colour, mingled with a horny-looking yellow, even on the addition of a very minute quantity of these substances.

Porcelain, of different kinds of glazing, gave various tints with one and the same purple. Herr Creuzburg observes, that antimony not only brings out the purple tint more finely than any thing else, but also gives considerably more body to the colour, so that it bears more flux, and consequently a given quantity goes further.

Persons who were experienced in the preparation of a beautiful purple, and with whom he was personally acquainted, assured him that they never used the precipitate of Cassius in the preparation of their finest purple, unless they had obtained it accidentally. According to their assertion, the precipitate, which is of a grey colour approaching to violet, should give the most beautiful purple; the dirtier the colour of the precipitate, the more brilliant the purple which it gives when fused. This dirty precipitate should contain more gold, and urine should be employed in its preparation.

Frick, the privy-counsellor of the mines, gives the following process for the preparation of the purple: Tin is dissolved in very dilute aqua regia, without the application of heat, until the liquid begins to assume slightly the appearance of opal; the tin is then taken out and weighed, the liquid is diluted with a very great quantity of water, and some dilute solution of gold and dilute sulphuric acid, in certain given weights, are simultaneously poured into it whilst the mixture is being stirred. The quantity of the solution of gold to be poured into the solution of tin must be such that the weight of the gold will be to that of the tin as 36 to 10.

We are indebted to Professor Fuchs, of Munich, for a remarkably simple method of preparing the purple. A solution of permuriate of iron is added to a solution of protochloride of tin until the former loses its colour and assumes a greenish tinge. The mixture is then diluted with water, and some of it is poured into the solution of gold which has been properly diluted. The most beautiful purple is immediately produced, while the protoxide of iron remains in the solution without having any injurious effect. The precipitate becomes lighter-coloured in drying, and appears as a dirty brown powder.

Herr C. F. Capaun considers the method of Professor Fuchs the best, judging from his own experience, but recommends the following process in the preparation of the purple powder: Let a solution of perchloride of iron be diluted with three parts of water, to which let a solution of protochloride of tin, prepared from one part of protochloride of tin dissolved in six parts of distilled water by means of a few drops of muriatic acid, be added, until the mixture has assumed a greenish colour. Let this mixture be further diluted with six parts of distilled water, and kept ready for use. If both the solutions were to be diluted at once with the whole quantity of water, the transition of the brown into the greenish colour would not be so clearly perceived. In the mean time, let pure muriatic acid be poured upon so much gold as is required for the operation: let the whole be heated to boiling, and pure nitric acid be introduced, in small quantities at a time, until all the gold is dissolved: an excess of acid, especially nitric acid, should be avoided. To this solution let a portion of distilled water (360 times that of the gold to be used) be added, and some of the solution of iron and tin be poured into the mixture, whilst it is being stirred, as long as precipitation takes place. The precipitate will be of a beautiful purple, when dry will appear browner, but will dissolve in ammonia and fused pigments with an intense purple colour.

Dr. Bolley, however, could not always obtain exactly the same preparation according to the above method; he therefore attempted to procure a solution of the sesquioxide of tin in another way. The combination of chloride of tin and chloride of ammonium (*pinksalt*, as it is called, a salt consisting of an equal number of atoms of chloride of tin and chloride of ammonium) seemed very well adapted to this purpose. This salt is anhydrous, and not affected by the air, so that when exposed to dry it undergoes no changes which would be likely to induce an unscientific chemist to adopt wrong methods of proceeding. It contains an accurately balanced quantity of chloride of tin not liable to change, and this very circumstance renders it adapted to the preparation of the oxidized matter which lies half-way between the protoxide and the peroxide.

Dr. Bolley does not recommend the production of this sesqui-salt of tin by the use of a prescribed weight of protochloride of tin dissolved in water containing muriatic acid, because any directions for doing this would be uncertain on account of the various quantities of water which the salt of tin contains, and partly on account of the increased oxidation of the latter: experience alone teaches us that perchloride of tin boiled with tin can be converted into the protochloride, and consequently, if the right quantity of tin be used, into the sesquichloride. According to Dr. Bolley's experiment, perchloride of tin combined with sal-ammoniac is the same in this respect as perchloride by itself. The pinksalt contains 70·8 per cent. perchloride, of which 32·3 per cent. is tin: if this amount of tin be increased by one-third, the quantity of chlorine remaining the same, sesquichloride will be produced from the perchloride. Consequently 100 pinksalt requires 10·7 metallic tin. Dr. Bolley subjected pinksalt and tin in the proportion we have specified, together with water, to the action of heat until the tin was dissolved: he then used the solution for the precipitation of the purple.

We now proceed to give a more detailed account of the experiment: 1·34 grammes of gold were dissolved in nitro-muriatic acid, an excess of acid being carefully avoided, and the solution was diluted with 480 grammes of water, the proportion specified by Capaun. To 10 grammes of dry pinksalt he added 1·07 of tin filings; 180 grammes of water were weighed out, and of these about 40 grammes were immediately brought in contact with the tin and pinksalt, and heat was applied until the tin was dissolved. The solution was now mixed with the remaining 140 grammes of water, and some of it was gradually introduced into the slightly warmed solution of gold until all precipitation ceased: the precipitate soon subsided, was taken out of the filter, washed and dried at the temperature of 100° C.: it weighed 4·92 grammes, and had become dark brown. The strained liquor was yet only of a pale red colour. The precipitate dissolved when digested in strong ammonia. The gold which it contained (calculating from the quantity of gold consumed) amounted to 21·4 per cent., a result which is most in accordance with Fuchs' analysis of the purple: he found in it 19 per cent. of gold. In either case, every one who is engaged in the preparation of the purple for the purpose of applying it to the arts, will find in what we have stated an infallible means of obtaining the most efficacious proportions of the peroxide and the protoxide of tin that have yet been discovered.

Of the Blue.—The blue pigment receives its colour from oxide of cobalt, and belongs to the class of fused pigments which are coloured by chemical combination. The oxide of cobalt combined with silica and boracic acid acts as base. This pigment is also one of those which require to be fused before they are employed. As the peroxide is the most easily prepared of all the oxides of cobalt, it is usually mixed with the flux, for we know that it passes into protoxide at a high temperature. This change takes place much more rapidly and more effectually when assisted by the action of a fixed acid. The presence of the flux satisfies the latter condition. The peroxide of cobalt is reduced in contact with silica and boracic acid, and readily unites with them in the state of protoxide. The ease with which the reduction and combination take place is naturally in proportion to the abundance of silica or boracic acid in the flux. But if, on the contrary, the flux contains too great a quantity of base, the cobalt, upon which the action of the acids is now less powerful, is reduced with difficulty to the state of protoxide, and requires an intense heat to effect a perfect combination; and even then the colour is seldom pure, and a blackish blue tint is usually obtained. Another circumstance, viz. impurity, contributes to impede the solution of the cobalt in the flux. There are even anterior combinations of cobalt with certain oxides, which, whenever they happen, render it extremely insusceptible of the action of the flux. In this case it very frequently assumes a greenish tint. It is therefore evident that everything which contributes to resist the conversion of the peroxide into the protoxide opposes the combination of cobalt with the acids of the flux. The whole resistance lies in this; for if the protoxide is for a moment produced, it is rapidly absorbed again, as will appear from the following remarks.

Certain necessary conditions of expansion frequently require that the vitrification of the cobalt, contrary to the directions we have given, should be effected in very saturated fluxes. In such a case its combination is assisted in a remarkable manner by the following process. If a certain quantity of oxide of antimony be added to the peroxide of cobalt at the moment of its mixture with the flux, by virtue of its great affinity for the oxygen, it rapidly and completely effects the reduction of the peroxide of cobalt. The antimonious acid which is thereupon produced does not injure the purity of the colour in the slightest degree, and does not perceptibly impair the transparency, provided that too much oxide of antimony is not used. It is extremely probable that the protoxide of tin produces the same effect.

A mixture of oxide of zinc and peroxide of cobalt produces the same effect in another way. The remarkable endeavour of the oxide of zinc to enter into various combinations with the protoxide of cobalt affects the peroxide in the same way as the silica itself.

Phosphoric and arsenic acid likewise favour the solution of protoxide of cobalt in the fused pigment, whether they are added in an isolated state or in combination with the cobalt itself, that is to say, in the state of phosphates and arseniates. In the former case, they act by increasing the quantity of the acids; in the latter, because they contain cobalt in the state of protoxide. It is then only necessary to mix them with the flux.

We have said that the peroxide of cobalt is generally employed in order to obtain silicate of cobalt, which colours the fused pigment blue. The principal reason why this is chosen is, that if protoxide were used, it would be converted into peroxide before the combination is effected, because it burns at a red heat. The carbonate would furnish the same result. But a combination of oxide of cobalt with oxide of zinc, which resists the action of heat better, may be employed with advantage. This combination is obtained by dissolving one part of sulphate of cobalt and two parts of sulphate of zinc in a sufficient quantity of water. Into this liquid a solution of carbonate of potash is poured until no more precipitate is produced. This precipitate is placed in the filter, washed, and dried, and is then the composition which was required.

Not only does the oxide of cobalt produce the richest colour of all the oxides, but also a very small quantity only is necessary to impart a very deep colour to the fused pigment. The blue pigment is composed as follows: Peroxide of cobalt 1 part, or zincate of cobalt 3 parts, flux from 6 to 9 parts.

The flux which is used for the blue pigment is one of the three which we have specified among the fluxes for pigments of the second class. The flux and the oxide are levigated together, the mixture is put into a crucible, which is kept at a red heat until the contents are perfectly fused and all ebullition has ceased; the pigment is then poured into cold water, dried, and levigated.

The oxide of cobalt is employed in various proportions according to the strength or weakness of the colouring. The taste of the artist is easily satisfied in this respect.

As far as regards the blue pigments of the ancients, they are the best of all their compositions. The receipts of Felibien and Haudicquer de Blancourt, which we possess, afford a very excellent coloured glass. The blue pigments that Levieil and the brothers Recollet used to employ seem to have been drawn from the same source, although the imitation is not very correct. This pigment was composed in the following manner:

Minium	1 part.
Oxide of cobalt	1 „
Silica	4 parts.
Nitrate of potash	3 „

It is a quadrisilicate, and reminds us of M. Guinant's composition of flint glass. For 2 atoms of oxide of lead, 2 atoms of protoxide of cobalt are substituted here.

This enamel, like the majority of the ancient ones, is not capable of being used as a pigment, on account of its slight fusibility. However well it might have been adapted to the window-glass of the ancients, it is certainly unfit for the glass of the present day, which is much more fusible.

The saturating point of this pigment was applied by the ancients to other colours, particularly to green, on account of which we have dwelt longer upon it than we should otherwise have done.

Of the Yellow.—The fused pigments may be coloured yellow by a great number of substances.

A lively and brilliant colour is obtained by means of metallic silver. The oxide of uranium by itself, when dissolved in a flux, furnishes also a beautiful yellow; but, in most cases, those oxides which are used as colouring materials are combined with one another by twos, and often in greater numbers. Thus, *e.g.* we combine protoxide of lead with antimonic acid; protoxide of lead with oxide of iron; oxide of zinc with oxide of iron; oxide of iron with antimonic acid. Other compounds likewise furnish useful yellow pigments. Among these are chloride of silver, chromate of lead, &c.

Each of these colouring substances produces the colour which belongs to it.

Silver gives a yellow varying from siskin yellow to purple.

The oxides of lead and antimony also furnish a siskin yellow, but it is opaque.

The oxides of zinc and iron give an ochre-coloured yellow.

Chromate of lead, too, yields a very lively yellow tint, &c.

Among all these colouring substances, the chloride of silver, zincate of iron, and antimoniate of lead, are considered the best. The three tints which are produced by these colouring materials satisfy all the requirements of glass-painting.

Yellow from silver.—This colour is obtained without the intervention of a flux. The process consists in covering those parts of the glass that are to be stained with a paste composed of chloride of silver and calcined yellow ochre, both levigated together with water. After the glass has been heated to a red heat in the muffle, the layer of ochre which adheres to the surface is removed by means of a spatula, and the glass is found to be stained. The yellow obtained in this way varies from siskin yellow to purplish yellow. It is not always, however, at the option of the artist to obtain any of these tints whatsoever, for some kinds of glass are stained by this process only bright light yellow, while others are capable of receiving a deep orange colour. The orange colour is frequently only to be obtained by repeating the process once or twice.

That kind of glass which, when plastered over with clay, is most disposed to lose its glaze, and which partly or entirely gives up the potash which it contains, seems to receive the best colour.

Dumas is of opinion that the white kinds of glass, those which contain a great quantity of aluminum, are the best for staining with silver, and they are the very kinds which, according to this chemist, can be the most easily deprived of their glaze. In the act of parting with their glaze, which is effected by the assistance of a paste or cement, a formation of certain silicates which crystallize, and a separation of a part of the bases, take place. Those of them which are volatile, *e.g.* the alkalies, are disengaged, and the fixed oxides, *e.g.* those of iron and manganese, pass into the state of sesquioxide.

This is the case with regard to the separation of a portion of soda or potash, upon which the colouring of the glass by means of silver depends. When the glass is covered with the paste of clay with which chloride of silver is mixed, and exposed to a red heat, the chloride is volatilized, its vapour saturates the glass, and as soon as it comes in contact with the potash which has been liberated, the silver is reduced to the metallic state; chloride of soda or chloride of potash is produced and volatilizes, while the metallic silver is fixed upon the surface, and often even penetrates a considerable depth into the body of the glass. If the quantity of reduced silver is small, the colour is siskin yellow. If it is more considerable, the yellow becomes deeper, and passes over into a more or less intense red.

The latter colour may be obtained in less time, and with greater certainty, by using glass with which a certain quantity of chloride of silver has been mixed at the moment of its manufacture. For this purpose the glass must be well refined, and contain no excess of uncombined alkali by which the chloride of silver would be reduced too soon. The colouring is then effected in the manner we have already described.

That it is the reduced metallic silver which produces the colour in the glass has been demonstrated by very decisive experiments.

If we take glass with which $\frac{1}{200}$th of its weight of chloride of silver has been mixed, heat it red-hot, and in this state cause a stream of hydrogen gas to pass over its surface, the glass immediately receives an intensely red colour, which result is likewise obtained by covering the glass with pure clay. In the former case, the action of the hydrogen gas upon the chloride of silver is manifestly the principle upon which the colouring of the glass depends. Now the action of this gas consists in reducing the silver to the metallic state; for if the quantity of chloride of silver be increased, the surface, when acted upon by the hydrogen gas, is covered with a stratum of silver possessing a metallic lustre.

The same colour is also produced, as we have stated, by the surface being in contact with a layer of clay, and we believe that the nature of the process by which it is produced is exactly the same. It does not appear, however, as if the clay effected this by an immediate action, that is to say, by the reduction of the chloride of silver. We attribute this action to one of the phenomena which accompany the depriving the glass of its glaze, namely, to the volatilization of the potash.

Even up to the present day, the staining the glass yellow has been attributed to the oxide of silver; but experience incontrovertibly proves that this effect is produced by metallic silver. In this there is a striking analogy between the manner of colouring of the latter and that of gold. The yellow or red colour proceeds from the silver in a state of extremely fine division, and the purple from gold in the same condition.

When the silver is in such a state of division as to be capable of colouring the glass, it only continues so under certain conditions. Accordingly, as soon as the yellow is produced, care must be taken not to let the glass pass into the state of fusion, for in the disturbance produced by the motion of the liquid mass the particles of silver assemble in larger groups, from whence arises a new colour in place of the former. The silver in this state of less minute division assumes a very intense blue colour. Hence we arrive at this practical conclusion, viz. that silver is only capable of colouring glass at that moment of its formation at which it has been brought to the proper density, and that for the colouring of fused pigments it can only be used within certain limitations of fusibility at a heat which the glass shall be able to bear.

We have one or two more words to say upon the preparation of the paste for the yellow. Ferruginous clay is used, commonly known by the name of *yellow ochre*. This clay must be calcined, otherwise the paste which is laid on the glass would be full of cracks, in consequence of the diminution in bulk which clay undergoes when exposed to a strong heat. Those parts of the glass which correspond to these cracks would then receive no colour. Consequently, the yellow ochre must be raised to at least as high a temperature as the glass in the muffle.

The relative quantities of chloride of silver and burnt ochre are as follows:

Chloride of silver	1 part.
Ochre	from 6 to 12 parts.

A greater proportion of chloride of silver would cause the paste to adhere too strongly to the glass. The chloride of silver and the clay are carefully rubbed upon a glass plate with a sufficient quantity of water to form a paste, which is applied in a thick layer to the surface of the glass by means of a paint-brush.

This yellow is frequently employed to give brilliancy and liveliness to the red obtained from iron. In this case it is applied to the side opposite to the painting.

Chloride of silver, by itself, is also capable of staining the fused pigments yellow; but then it imparts to them a colour of its own, if it mixes with them without being decomposed. Here metallic silver is not the cause of the colour. The chloride of silver must be fused with its flux in the proportions of from 1 to 2 parts of the former to 10 of the latter. When united to one of the fluxes for pigments of the first class, it is used as a mixture to the flesh-red to give it brilliancy. With the purple it produces a carmine tint, and only a very small quantity requires to be mixed with it.

The yellow pigment which chloride of silver furnishes can also be employed in an isolated state.

Orange colour from silver.—This orange colour is only a shade of the yellow from silver which we have been speaking of, and is likewise prepared in the same way, except that for chloride sulphuret of silver in the same proportions is substituted. Similar phenomena may be observed during the process, and metallic silver is always the element of the colour. Orange yellow is obtained with much greater certainty from sulphuret of silver, while on the other hand chloride of silver answers much better for a light yellow, although it is not always in our power to produce any given colour.

Red from silver.—A red colour is also infallibly obtained by using sulphuret of silver. In this case the preparation which was employed for the orange yellow is slightly modified by adding a few drops of sulphuric acid at the moment when it is being used. If no red be obtained at the first laying on of the pigment, it must be laid on a second time.

The sulphuret gives an intense colour with much greater certainty than the chloride of silver, for at a red heat it decomposes of itself, and can therefore produce its effect without the aid of the unglazing. The latter, however, is not prejudicial to it, and is only to facilitate the saturation of the glass by metallic vapours. The mixture of sulphuric acid has, in our opinion, no other object than this. Some sulphate or other is undoubtedly formed by the agency of this acid, which is decomposed in the red heat by the silica of the clay and occasions the internal motion of the glass, whilst it affects its surface. This is what actually takes place in the unglazing of the glass, which unglazing we are convinced is effected by means of a mixture of sand and sulphate of lime.

The unglazing which is capable of facilitating the colouring of the glass by silver is not so great a change in the glass as to deprive it of all its transparency, but merely a slight modification by which its properties are uninjured. It is worth observing, however, that a piece of glass stained red in this manner does not possess the purity of colour which belongs to one coloured by copper. When the tone of colour is the same for both, that which was coloured by silver appears the darker.

Sulphuret of silver is prepared in the following manner: Pure silver is melted in a crucible, half its weight of sulphur is then introduced. The sulphuret of silver which is generally used is prepared by heating together 2 parts of silver and 1 of sulphuret of antimony.

Ochre Yellow.—The ochre yellow pigment is one of those fused pigments which are coloured by mixture. It receives its colour from the mixture of oxide of zinc and oxide of iron. This fused colour is a zincate of iron in which each atom of the one oxide is combined with an atom of the other oxide. This salt is obtained from sulphate of iron and sulphate of zinc precipitated with potash, soda, or their carbonates.

The persulphate of iron is prepared by dissolving 96 parts of protosulphate of iron in 100 parts of water, and adding half as much sulphuric acid as the salt already contains. The solution is heated to boiling, when small portions of nitric acid are introduced, until all nitrous acid has ceased to be disengaged. This operation may be explained in the following way:

The protoxide of iron contains

1 atom of iron	339·21
1 „ „ oxygen	100·
1 „ „ acid	501·16
1 „ „ protosulphate of iron	940·37

The persulphate of iron consists of

2 atoms of iron	678·43
3 „ „ oxygen	300·
3 „ „ acid	1503·48
1 „ „ persulphate of iron	2481·91

It is therefore necessary for the obtaining 1 atom of persulphate of iron to add to 2 atoms of protosulphate of iron 1 atom of sulphuric acid, that is to say, half as much as the salt already contains, and 1 atom of oxygen besides, which is supplied by the nitric acid.

The protosulphate of iron, when crystallized, contains 44 to 45 per cent. water, and the sulphuric acid of commerce contains only 81·68 per cent. pure acid. Consequently 18 parts of the sulphuric acid of commerce must be added to 100 of crystallized protosulphate of iron.

In order to form zincate of iron, so that each atom of the one oxide shall be combined with an atom of the other oxide, a solution of persulphate of iron and another of sulphate of zinc, both having the same weight on the areometer, must be prepared separately, and so much in volume must be taken from each, that the salt of zinc may be to that of iron as 2 to 5; or a solution of the salt of zinc, weighing 10° B., and another of the salt of iron, weighing 25° B., may be mixed together in equal quantities. The precipitate which is then obtained by means of potash, or its carbonates, will contain in its composition the proper proportion; for sulphate of zinc consists of

1 atom of oxide of zinc	503·32
1 „ „ acid	501·16
1 „ „ sulphate of zinc	1004·48

The quantities of the sulphate of zinc and the sulphate of iron, each of which contains 1 atom of oxide, are in the proportion of 2 to 5.

When the oxides are precipitated by means of a fixed alkali any excess of the precipitating substance must be avoided, to prevent the oxide of zinc from being dissolved again. Just so much, however, is added as will produce a complete precipitation. The product is filtered, washed, and dried. Lastly, it is submitted to a red heat, in order to drive off the water which it contains. If the solutions of zinc and iron, after they have been poured together, are treated with an alkaline carbonate, the precipitate must in this case be heated to drive off the carbonic acid. The calcining is intended moreover to give stability to the combination of the two oxides. If it is required to colour a fused pigment by chemical combination or simple mixture, the object must be to obtain the colouring oxide in a state of the finest possible division. By this means, in the former case the combination takes place more easily, and in the latter the mixture is more intimate. Now calcining is always opposed to the direction we have given, for oxides condense by being calcined. This is also the case with the kind of pigments we have just been speaking of. On this account it answers to use the means which we recommended for obtaining the flesh-red; for they not only admit of compliance with the conditions which require calcining, but of the production of the colouring matter in a state of the finest division. We will now speak of the mixture of sulphate of potash.

The precipitate from the two oxides contained in the carbonates of zinc and iron is mixed with a concentrated solution of this salt; the liquor is evaporated, and the precipitate, when dry, is calcined at a dull red heat. It is then softened with water, placed in a filter which separates the zincate of iron from the solution of sulphate of potash: this precipitate is carefully washed and then dried.

This we consider to be the best process for the preparation of zincate of iron. The colouring matter which is obtained must now be united with the flux which serves as a vehicle for it. The best kind of flux for ochre yellow is No. 3 of the first class. They are mixed in the following proportions:

Zincate of iron	1 part.
Flux	4 parts.

As this fused pigment belongs to that class which is coloured by mixture, it ought not to be melted before it is used; we have, however, found it useful to frit it, *i. e.* to keep it at a dull red heat for some time; it is then levigated for use. In this way the colour becomes more beautiful and more transparent. This method should be employed principally in that kind of painting which the French glass-painters call *peinture par enlevage.*

Yellow from antimonite of lead.—The fused pigment which is coloured with antimonite of lead belongs to the foregoing class, inasmuch as it contains the colouring matter in a state of simple mixture. It is prepared by fusing in a crucible 1 part of antimonic acid and 3 parts of minium, levigating the product and mixing with it twice its weight of rocaille-flux, and then fusing the mixture again. This pigment has the fault of not being transparent. Therefore, although it is one of those which are coloured by mixture, it is advisable to melt it, in order to impart to it the greatest possible transparency. The quantity of flux must also be very small, for the oxide of lead being attracted by the flux is easily liberated from the antimonious acid, and the latter then gives only a feeble, opaque, white colour to the glass. The rocaille-flux is therefore preferred in this case also, because it is the most saturated, and consequently the least disposed to act upon the colouring matter.

The tint produced by antimonite of lead may be modified by adding some oxide of zincate of iron.

In order that it may be better understood what takes place in the process by which this colour is prepared, we may mention that at a red heat the antimonates are converted into antimonites.

Yellow from antimonite of iron.—The yellow obtained from this compound belongs to the same class as the two preceding. Like them it wants transparency, but it possesses a very rich colour, so that it can be used in many cases for mixed tints, and for the shading of green and brown. It is also of great use when employed alone.

Antimonite of iron is obtained through double decomposition, that is to say, by precipitating persulphate of iron with antimonate of potash. The product is washed, dried and calcined. Antimonite of iron is likewise prepared by direct mixture of antimonic acid with oxide of iron in the proportion of 4 to 1. This latter method admits of the relative quantities of the two compounds being varied at pleasure. The antimonite of iron, like the foregoing, is used with the rocaille-flux or with some flux of the first class. In the former case the mixture must be brought into a state of fusion, according to the treatment of the rocaille-flux in all other circumstances. In the latter case it is only levigated: 3 parts of flux to 1 of colouring matter are required.

We think it superfluous to speak of the pigments that can be prepared with the aid of the other yellow colouring materials which have been mentioned; they are little studied, and moreover are not in general used. It may be briefly stated, however, that in modern times the metal uranium has been used in Germany for the preparation of a yellow pigment. The process is as follows: Uranium ore is broken in pieces and roasted, dissolved in nitric acid, the solution filtered and the lead which is present in it precipitated by the addition of some drops of sulphuric acid. The clear green solution is then evaporated to dryness, and the salt is heated until it is converted into a yellow mass: 1 part of the substance so obtained is ground with 3 parts of a flux composed of 4 parts of minium and 1 part of powdered silica, fused together and levigated.

Of the Green.—The green pigment generally receives its colour from oxide of copper, oxide of chromium, and protoxide of iron, either separately, or by the combination of two or more with one another. The ingredients of this pigment are in combination with the flux. It is difficult to make its expansibility the same as that of the glass on which it is laid. The oxide of copper, even in a very slight quantity, alters this property in a great degree, and disposes the pigment to shell off the surface of the glass. The oxide of chromium does not partake of this quality in so remarkable a manner, but it requires a very fusible flux to dissolve it. Now this fusibility can only be obtained by mixing with the flux substances which modify its expansibility in the same way as oxide of copper does, and borate of soda in particular is one of these substances. The colour which protoxide of iron gives by itself is not rich enough, consequently this protoxide can never be employed alone. In most cases it is used in combination with oxide of copper.

To colour a fused pigment green, the oxide of copper must be in combination with one or more acids of the flux, that is to say, it must be in the state of borate, silicate, or borosilicate. One of the fluxes which we have specified for the pigments of the second class seems best able to effect its solution, but these fluxes receive a degree of expansibility from the copper, which ill accords with that of the glass. Those fluxes therefore must be avoided which contain an abundance of acid, and those should be preferred which contain a large amount of base, especially of oxide of lead, although they possess less capability of being dissolved. Flint glass * (*fondant rocaille*) seems best adapted for this purpose, and yet no large proportion of oxide of copper can be mixed with it without producing the unpleasant result just stated. The green pigment is therefore best obtained from the following composition:

Minium	12	parts.
Silica	4	"
Oxide of copper	1	"
Red oxide of iron	⅛	part.

This pigment may be prepared in two ways:

1. The colouring oxides are melted in a crucible with the flux which has been previously prepared and ground together with them.

2. The oxides are fused together with the substances proper for the composition of the flux, after which the whole is well mixed and ground together.

It is not immaterial which of the two methods is employed; we have always preferred the latter. In this method, when the mixture begins to be red-hot, the oxide of lead begins to melt, and dissolves the oxide of copper, while at the same time the latter is acted upon by the silica. This previous union of the two oxides is intended to separate the particles of the copper so as to dispose it to combine with the silica as soon as ever it is acted upon by it. In the former case, on the contrary, the oxide of copper is merely acted upon by the silica of the flux.

The foregoing receipt for the green pigments affords a colour of no great intensity, and we cannot expect to obtain a richer green by merely increasing the quantity of copper, for this, as

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* Bleiglas, lit. lead glass. This flint glass, the composition of which is given under the head No. 1 of the fluxes for pigments of the first class, will be found to contain more oxide of lead than the English flint glass.

we have just shown, could not be done with safety. Accordingly, in order to increase the respective proportions of the colouring oxides without risk, the composition of the flux must be modified at the same time by an addition to the quantity of oxide of lead.

Darker Green.

Silica	1 part.
Minium	4—7 parts.
Oxide of copper	1 part.

In these receipts we have no intention of laying down absolute proportions, for we well know that there are certain kinds of glass which will bear a greater quantity of oxide of copper without the colour shelling off. But we have endeavoured to impart such qualities to our pigments as will insure continual success, and consequently we have perhaps carried our caution to an extreme, rather than render the success doubtful.

Oxide of chromium does not answer so well for the green of the fused pigments as oxide of copper; for it seldom obt so pure and bright a colour as the latter. Even if it is combined with very fusible fluxes it generally wants transparency, and yet the quantity of the substances which impart greater fusibility to the flux cannot be safely increased.

Oxide of chromium is mixed with one of the fluxes for pigments produced by combination, in the proportion of 1 part of oxide to 9 parts of flux, the same proportion that we specified for oxide of copper; and we are of opinion that it is better to heat the oxide of chromium with the elements of the flux than with the flux itself.

Notwithstanding what we have said concerning the properties of protoxide of chromium, it should not be neglected in the preparation of the pigments. As glass-painting frequently bears a certain degree of opacity very well, oxide of chromium may be employed with advantage, especially if it is only used for the colouring of a pigment by mixture. The green colour peculiar to it, which it possesses before it is united with a flux, makes it very well suited to this purpose, and the only problem now is to preserve it in a state of sufficiently fine division.

There are other substances which may be used for green pigments, but they give an opaque colour. Among these are zincate of cobalt, Rinmann's green, and antimonite of cobalt. Of course these compounds are not acted upon by the flux, and merely form pigments of the first class.

With respect to this matter we will describe a method which, in our opinion, seems to promise manifold advantages. When it is required to mix oxide of chromium with a fused pigment containing lead, the neutral chromate of lead may be used, which furnishes at the same time oxide of chromium and oxide of lead, or at least a part of the latter. When this salt is submitted to a red heat it parts with oxygen and leaves behind a combination of the two oxides in the following proportions:

1 atom of oxide of lead	1394·6
1 „ „ chromic acid	650·7
1 „ „ neutral chromate	2045·3

And this gives after calcining,

1 atom of oxide of lead	1394·6
½ „ „ „ chromium	502·
1 „ „ plumbate of chromium	1896·6

It is evident that the oxide of chromium, which is thus held in combination with oxide of lead, must be in a state of most minute division, whereby its union with the silicates or borosilicates of the flux is facilitated to a remarkable degree. This pigment may be composed in the following way:

Silica	2 parts.
Minium	5½ „
Calcined borax	3 „
Calcined chromate of lead	2 „

These ingredients are melted and poured out.

The old glass-painters frequently availed themselves of the combined effects of yellow and blue, in order to obtain a green. Thus, for example, they gave to glass which had been coloured blue in the melting pot a yellow stain with the help of sulphuret of silver and the paste. This method is not in general use at the present day.

Of the Violet.—There are two modes of preparing violet pigments. The first consists in employing a colouring substance which is capable of producing a violet of itself; according to the second, the requisite violet is obtained by mixing a blue with a red pigment. The substances which are capable of bringing out a violet without the assistance of another colour are the purple precipitate of Cassius and oxide of manganese.

We have already explained, in speaking of the red pigment, under what circumstances stannate of gold affords a violet colour, and have observed, that the purple of Cassius, whenever it is decomposed before the fused pigment can dissolve its particles, produces a violet and even a blue, according as the change which takes place in it is more or less complete; and this happens in the case we are now speaking of. If 1 part of the purple of Cassius be mixed with 9 parts of one of the fluxes coloured by combination, without fusion, a violet pigment is obtained. This product is the effect of two causes which operate simultaneously, that is to say, the want of fusibility in the pigment, and the too great abundance of oxide of lead. Should the violet which is obtained in the manner we have just specified be not brought out with sufficient clearness, it may be still better developed by adding to the fluxes of the first section a little of flux No. 1.

Oxide of manganese gives an exceedingly deep violet colour, but, as we have elsewhere observed, it imparts to the pigments an extraordinary disposition to crack and shell off. This unfortunate property is easily overcome, however, by adding a large quantity of minium to its composition.

The composition should be as follows:

Silica	1 part.
Minium	6—8 parts.
Peroxide of manganese	½ part.

When this oxide of manganese is heated in contact with oxide of lead, it rapidly gives up oxygen, and is converted into sesquioxide.

This pigment is distinguished from the rest by this remarkable peculiarity, namely, that it can only be employed on condition that it is not painted on with any liquid, which, after the burning in, leaves a carbonaceous substance in its mass. This will be more apparent, when we remember that peroxide of manganese is used for whitening glass, on account of its property of extracting the carbon, which would impair its clearness. Here the carbon acts upon the manganese, deprives it of a portion of its oxygen, and converts it into a colourless protoxide, while it is liberated itself in the state of carbonic acid.

Now this would be the case if the pigment, at the moment of its liquefaction, contained carbon which was produced by the vehicle with which it was laid on the glass before the burning in. We would therefore recommend for this purpose a solution of borate of soda, instead of the gum or sugar water, and the thickened essence of turpentine, which are generally used.

The violet, which is obtained by a mixture of blue and red, is prepared with common smalt and the purple of Cassius, the proportions varying at the discretion of the artist.

There is another violet, which is produced by the red oxide of iron, which is exposed to a white heat for some time; but it is almost entirely opaque, and produces on the glass only a kind of opaque and dull violet-grey. The pigment which is thus obtained is, nevertheless, of great use in glass-painting, and is prepared in the following way:

Violet oxide of iron	1 part.
Flux	3 parts.

No. 3 of the pigments of the first class is used for the flux.

Of the Brown.—The brown is an undefined colour, which may be prepared in a variety of ways, according to the requirements of the art, and the taste of the artist. We will describe the principal browns.

Zincate of iron, which contains one atom of zinc, and two of iron, gives a *yellowish brown,* which is frequently used. It is prepared in the same way as ochre yellow, except that the quantity of the salt of iron is doubled. For the composition we are now speaking of, the salt of zinc must be to the salt of iron as 2 to 10. The flux proper for this is the same as that which is used for the ochre yellow, and is also employed in the same proportions.

Zincate of iron, ochre yellow, as it is called, when mixed with either red oxide of iron or burnt sienna, gives a *reddish brown,* whose shade of colour varies with the proportions.

The same zincate of iron (ochre yellow) forms, with burnt umbre, a much *darker brown* than the preceding, and one which has no affinity to red.

Oxide of iron alone, when properly prepared, affords a *brown* of considerable utility. It is prepared in the moist way as follows: A solution of persulphate of iron is treated with an alkaline or carbonized oxide (with potash, soda, ammonia, or their carbonates); the precipitate which is obtained is either an hydrated oxide or a carbonate. It is placed in a filter, washed and dried, and then subjected to a red heat, in order to drive off the water or the carbonic acid. After this preparation the oxide of iron presents a brown colour, whose shade may be varied by heating it more or less. This oxide of iron bears no resemblance to that which is obtained in the dry way, although the calcining develops in it a more or less distinct red tone.

Burnt umber, when mixed with a flux, also affords a brown pigment.

A mixture of peroxide of manganese and oxide of iron likewise serves as a brown pigment of some utility. In order to prepare all these pigments, it is merely necessary to know that each of the colouring substances we have mentioned must be mixed with thrice its weight of flux No. 3 of the pigments of the first class.

No previous fusion is required. The colouring materials are merely brought into a state of the most intimate mixture by levigation together. The brown pigments are all pigments of the first class, and possess great opacity, but by virtue of this property they are exactly adapted to the use to which they are applied.

Of the Black.—The completely opaque pigments, whatever their proper colours may be, when laid upon glass, appear black in a transmitted light. The reason of it is this, viz. that a substance which allows no transmitted ray to reach the eye must cause a shadow, and consequently produce a black colour. Therefore either a black or an opaque colour may be used for the black lines of a drawing upon glass, or the parts that are in shadow. There is, however, a difference between the effect produced by a really black colour and that of any other colour not transparent.

When we look at a large transparent surface, *e.g.* a church window, besides the refracted rays transmitted through the glass, the eye receives also a few reflected rays, especially if the external light is not particularly intense. In this way the pigments, which only produce a black colour by virtue of their opacity, are slightly tinged with the colour which properly belongs to them. The black which proceeds from them thus loses its hardness, and falls more agreeably upon the eye. On this account pigments of *broken tones*, as they are called, are used for the black lines and shadows of a picture, and of these the brown pigments exhibit a great variety.

A pigment which shall appear black in a reflected as well as in a refracted light, may be prepared in two ways:

1. Opaque substances of a black colour may be mixed with a flux, *e.g.* oxide of iron, peroxide of manganese, peroxide of cobalt, and oxide of copper, in such considerable quantities as to prevent their vitrification taking place during the time of the burning in. A black pigment, by mixture, is thus obtained, which is composed of—

Oxide of copper	1 part.
Peroxide of manganese	1 „
Peroxide of cobalt	1 „
Oxide of iron	1 „
Flint glass	8—12 parts.

2. A black pigment by combination may also be prepared, and, after fusion, a certain quantity of oxide may be united with it, merely in the state of mixture, in order to render its opacity complete, as well as to impart to it the property of not splitting off in scales. This is therefore a combination of the two kinds of pigments. For the preparation of this compound, the following ingredients are melted in a crucible, in the following proportions:

Oxide of iron	2 parts.
Oxide of copper	2 „
Peroxide of manganese	1 part.
Flint glass	5 parts.
Fused borax	½ part.

As soon as the whole is melted, the contents of the crucible are poured out and levigated with

Peroxide of manganese	1 part.
Oxide of copper	2 parts.

The theory of the composition of this pigment may be explained in the following way: By fusing together oxide of iron, oxide of copper, and oxide of manganese, with the flux of flint glass and the borax, borosilicates are formed. The two former are green, and the latter are violet-red. Now green and violet-red, in proper proportions, give a black. The oxides which are afterwards added, as we have already stated, only render the opacity complete, and give the pigment a proper expansibility. The advantage of this latter circumstance is evident, when the effect of the oxides of copper and manganese upon expansibility is considered. If, on the other hand, it is required to prepare a pigment which shall only appear black in a reflected light, let the following ingredients be mixed together without being fused:

Black oxide of iron	1 part,

or even

Red or bright violet oxide of iron	1 part.
Flint glass or flux	2—3 parts.

When this colour is used, it appears black by a transmitted light, but by reflected light it assumes a reddish tint approaching to violet, less hard and more agreeable than black.

Of the White.—The white pigment is almost useless in glass-painting. We shall, however, treat of it more fully than we should otherwise have done, in order to complete the series of the pigments of which we have here given a short account.

The white pigment has been used in modern times for ornamenting panes of glass with a kind of drawing whose whole effect depends upon the combination of the dull and opaque white of the pigment with the transparent glass, without the aid of any other colour. This branch of art, which borders a little upon the one we are treating of, seems, however, to have received no particular cultivation. The white pigment is a vitreous compound of more or less opacity, and this opacity is owing to the presence of zincic or antimonic acid. This pigment is prepared according to the following process: An alloy is first made of 20 parts of tin to 80 parts of lead. The metal is melted in an iron ladle or a vessel of a similar kind, and the oxide which covers its surface is removed as fast as it is formed. When the entire mass has been converted into oxide, the calcining is continued a little while longer, while the oxide is stirred incessantly until it assumes a perfectly homogeneous appearance. It is then poured into a vessel full of water and well stirred, in order to effect the separation of the unoxidized grains of the alloy, which are mixed with the mass. These grains collect at the bottom of the vessel. The oxide is now dried and is fit for use. When this substance is mixed with potash, silica, and borax, in the proportions which we are about to specify, and then vitrified at a high temperature, a white pigment is obtained.

The white pigment of commerce that is used in enamel-painting may also be employed for the purposes of glass-painting, although it is rather deficient in fusibility. It is usually composed of the following ingredients:

Potash	1 part.
Oxide of lead	8 parts.
Silica	6 ,,
Stannic acid	2 ,,
Calcined borax	2 ,,

This enamel is also prepared by fusing together in a crucible the following ingredients:

Carbonate of potash	2 parts.
The oxides of tin and lead calcined	5 ,,
Silica	3 ,,
Borax	1 part.

As soon as the enamel has ceased to bubble, and appears in the state of a clear liquid, it is poured out. It must be melted several times after being levigated, or at least pounded in a mortar. It is thus freed from the excess of potash which it contains, and at the same time rendered whiter.

The enamel of M. Clouet, as a specimen of an enamel coloured by antimonious acid, may be contrasted with the above. It is prepared from

White glass	12 parts.
Uncalcined borax	4 "
Saltpetre	1 part.
Purified *antimonium diaphoreticum*	4 parts.

This is a quadruple borosilicate of lime, potash, soda, and alumina.

It is less adapted to painting on glass than the one we have mentioned before, and more disposed to scale off, since it is deficient in oxide of lead.

We recommend the following enamel, which seems to contain the qualities requisite for painting on glass. Its composition is as follows:

Silica	3 parts.
Calcine[*]	7½ "
Calcined borax	2 "

The ingredients are melted, and then poured out.

The old glass-painters frequently used white pigments similar in composition to those which we call pigments of the first class. Levieil prepared a white pigment by mixing sulphate of lime (gypsum) with rocaille-flux (flint glass). Felibien, Haudicquer de Blancourt, and the Abbot of Marsy propose the same substance, but with a different enamel. Flint, pulverized rock-crystal, and the powder of calcined bones, have also been used for this purpose; a better result would have been obtained with stannic acid employed in the same way.

Calculation of the atomic weights of the pigments.—Now that we have shown that the various kinds of glass are composed of several silicates in definite proportions, probably in combination with one another, the study of their atomic weights must on this account be the more interesting. Moreover, if we would employ ourselves in making satisfactory inquiries into the art of composing the pigments, this cannot be done with any success unless we are acquainted with the calculation of the atomic weights which are made use of in these compositions. We will therefore communicate an easy method of determining

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[*] By *calcine* is meant the calcined oxide of an alloy of 20 parts of tin and 80 of lead.—(*Author's note.*)

the composition of a pigment, or any other kind of vitreous substance, according to the atomic weights, as follows:

Silicic acid	192·6	Sesquioxide of manganese	1011·5
Boracic acid	435·98	Peroxide of manganese	555·7
Oxide of aluminum	643·33	Stannic acid	935·29
Oxide of calcium	356·03	Antimonious acid	1006·4
Oxide of potassium	587·91	Oxide of zinc	503·32
Nitrate of potash	1264·93	Oxide of cobalt	469·
Oxide of sodium	390·92	Peroxide of cobalt	1038·
Subcarbonate of soda	666·25	Oxide of chromium	1003·
Borate of soda	1262·88	Oxide of copper	495·6
Oxide of manganese	1467·	Protoxide of lead	1394·5
Oxide of iron	978·		

When it is required to determine the number of atoms of each of the bodies which are used for a pigment whose composition is known, each of the expressions of the formula must be multiplied by one and the same number, *e.g.* 100, 1000, or 10,000, just as it may happen to be necessary, in order to enable us to divide all these expressions by the atomic weight of the substance which they represent.

Let a pigment, for example, be composed of

Silica	45 parts.
Potash	6 „
Oxide of lead	70 „

If only the two first expressions of the formula were considered, it would be sufficient to multiply them by 100; for the products would be divisible by the atomic weight of the silica (192·6) and that of the potash (587·9). But it is evident, that they must be multiplied by 1000 in this case on account of the third expression. Accordingly we get

Silica	45,000	divisible by	192·6
Potash	6,000	„ „	587·9
Protoxide of lead	70,000	„ „	1394·5

If the division is performed, the following result is obtained:

Silica	240	atoms or	24
Potash	10	„ „	1
Protoxide of lead	50	„ „	5

Consequently, if every atom of these bodies contains 100 parts of oxygen, the quantities of this gas will be to one another as the atoms themselves, namely:

Silica	2,400	or	24
Potash	100	„	1
Protoxide of lead	500	„	5

The oxygen of the acid is four times as much as that of the bases. A double quater-silicate thus appears. The oxygen of the potash is moreover to that of the oxide of lead as 1 to 5, and consequently we have 1 atom of the quater-silicate of potash and 5 atoms of the quater-silicate of lead.

To compose an enamel, then, which shall contain 5 atoms of silicate of lead and 1 atom of silicate of potash, we must take

5 atoms of oxide of lead = 1394 × 5 = 6970
1 atom of potash = 587 × 1 = 587

Further, if it be required that these bases should form with the silica quater-silicates, we must take as many atoms of silica as are necessary, in order that the latter may contain four times as much oxygen as the bases. Now if the oxygen of the bases amounts to 6, we get for the silica $4 \times 6 = 24$.

24 atoms of silica = 192 × 24 = 4608.

By simplifying the expressions we obtain at length

Protoxide of lead	70	parts.
Potash	6	„
Silica	45	„

In order to obviate the necessity of making calculations, we have drawn up Tables, by the assistance of which the reader may discover at the first glance the quantity of any body which corresponds to a given number of atoms.

Silicic Acid.

Atoms.	Parts.
5	1
10	2
15	3
20	4
25	5
30	6
35	7
40	8
45	9
50	10

Boracic Acid.

Atoms.	Parts.
1	0·4
2	0·9
3	1·3
4	1·7
5	2·2
6	2·6
7	3·0
8	3·5
9	3·9
10	4·0

Oxide of Potassium.

Atoms.	Parts.
1	0·6
2	1·2
3	1·8
4	2·3
5	2·9
6	3·5
7	4·1
8	4·7
9	5·3
10	5·9

Subcarbonate of Potash.

Atoms of Potash.	Parts of the subcarbonate.
1	0·9
2	1·7
3	2·6
4	3·4
5	4·3
6	5·2
7	6·
8	6·9
9	7·8
10	8·6

Nitrate of Potash.

Atoms of Potash.	Parts of the Nitrate.
1	1·3
2	2·5
3	3·8
4	5·
5	6·3
6	7·6
7	8·8
8	10·1
9	11·4
10	12·6

Oxide of Sodium.

Atoms.	Parts.
1	0·4
2	0·8
3	1·2
4	1·6
5	1·9
6	2·3
7	2·7
8	3·1
9	3·5
10	3·9

Borate of Soda.

Atoms of Boracic Acid.	Atoms of Soda.	Parts of the Borate.
2	1	1·3
4	2	2·5
6	3	3·8
8	4	5·
10	5	6·3
12	6	7·6
14	7	8·8
16	8	10·
18	9	11·3
20	10	12·6

Subcarbonate of Soda.

Atoms.	Parts.
1	0·7
2	1·3
3	2·
4	2·7
5	3·3
6	4·
7	4·7
8	5·3
9	6·
10	6·7

Oxide of Calcium.

Atoms.	Parts.
1	0·3
2	0·7
3	1·1
4	1·4
5	1·8
6	2·1
7	2·5
8	2·8
9	3·2
10	3·6

Oxide of Aluminum.

Atoms.	Parts.
1	0·6
2	1·3
3	1·9
4	2·6
5	3·2
6	3·8
7	4·5
8	5·1
9	5·8
10	6·4

Protoxide of Lead.

Atoms.	Parts.
1	1·4
2	2·8
3	4·3
4	5·6
5	7·
6	8·4
7	9·7
8	11·1
9	12·5
10	14·

Minium.

Atoms of Protoxide.	Parts of Minium.
1	1·4
2	2·8
3	4·3
4	5·7
5	7·1
6	8·5
7	10·
8	11·4
9	12·8
10	14·3

The difference between minium

and protoxide of lead is so considerable, that it may be perceived at once in any given number of atoms, as will appear from a comparison of the two Tables.

Protoxide of Manganese.

Atoms.	Parts.
1	1
2	2
3	3
4	4
5	5
6	6·1
7	7·1
8	8·1
9	9·1
10	10·1

Deutoxide of Manganese.

Atoms.	Parts.
1	1·5
2	2·9
3	4·4
4	5·9
5	7·3
6	8·8
7	10·3
8	11·7
9	13·2
10	14·7

Peroxide of Manganese.

Atoms of Protoxide.	Parts of Peroxide.
1	1·1
2	2·2
3	3·3
4	4·4
5	5·5
6	6·7
7	7·8
8	8·9
9	10
10	11·1

Peroxide of Manganese.

Atoms of Deutoxide.	Parts of Peroxide.
1	1·7
2	2·3
3	5
4	6·7
5	8·3
6	10
7	11·7
8	13·3
9	15
10	16·7

These two latter Tables show the quantities of peroxide of manganese which are necessary to produce by their decomposition a given number of atoms of protoxide or deutoxide.

Oxide of Zinc.

Atoms.	Parts.
1	0·5
2	1
3	1·5
4	2·0
5	2·5
6	3
7	3·5
8	4
9	4·5
10	5

Oxide of Iron.

Atoms.	Parts.
1	1
2	1·9
3	2·9
4	3·9
5	5
6	5·9
7	6·9
8	7·8
9	8·8
10	9·8

Protoxide of Cobalt.

Atoms.	Parts.
1	0·5
2	1·3
3	1·4
4	1·9
5	2·3
6	2·8
7	3·3
8	3·7
9	4·2
10	4·7

Peroxide of Cobalt.

Atoms of Protoxide.	Parts of Peroxide.
1	0·5
2	1
3	1·5
4	2·1
5	2·6
6	3·1
7	3·6
8	4·1
9	4·7
10	5·2

The Table of the peroxide of cobalt has been composed on the same principle as that of the peroxide of manganese.

Oxide of Chromium.

Atoms.	Parts.
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
10	10

Oxide of Copper.

Atoms.	Parts.
1	0·5
2	1
3	1·5
4	2
5	2·5
6	3
7	3·5
8	4
9	4·5
10	5

Antimonious Acid.

Atoms.	Parts.
1	1
2	2

Antimonic Acid.

Atoms of Antimonious Acid.	Parts of Antimonic Acid.
1	1
2	2·1
3	3·2
4	4·1
5	5·3
6	6·3
7	7·4
8	8·4
9	9·5
10	10·5

Stannic Acid.

Atoms.	Parts.
1	0·9
2	1·9
3	2·8
4	3·7
5	4·7
6	5·6
7	6·5
8	7·5
9	8·4
10	9·3

In order that we may make no mistake in laying down the proportions of the oxygen of the base to that of the acids, we must remember that these compositions contain different quantities of oxygen to one atom, namely:

	Parts.
1. Boracic acid	300
2. Alumina	300
3. Sesquioxide of manganese	400
4. Protoxide of manganese	300
5. Peroxide of manganese	200
6. Oxide of iron	300
7. Stannic acid	200
8. Antimonic acid	500
9. Antimonious acid	200
10. Oxide of chromium	300
11. The other bodies	100

Before we conclude the chemical part of our subject, we wish to direct the attention of those who are engaged in the preparation of pigments for glass-painting to a series of compositions which are capable of being used with very great advantage in the art. We wish to speak of certain combinations of the colouring oxides with one another, about which we have at present said very little. Further back, where we were speaking of the colouring substances in general, we expressed our opinion concerning these kinds of compositions, which we likewise admitted into the class of salts. We have already had occasion to consider a certain number of these combinations which are very much used in the manufacture of the pigments, and we now intend to impart what information it is in our power to give upon a few other matters less known, but which seem capable of affording valuable resources to the art of painting on glass; and lastly, we intend to point out those particulars which, in our opinion, deserve to be studied. We wish to open to fresh observers a fruitful field, full of objects both useful and interesting, and we only regret that it was not our lot to explore it ourselves.

The most stable amongst the combinations which the indifferent oxides are capable of entering into with the basic oxides, are the following:

Protoxide of manganese and oxide of iron;
Protoxide of manganese and peroxide of cobalt;
Protoxide of manganese and oxide of copper;
Protoxide of manganese and oxide of chromium;
Protoxide of manganese and oxide of zinc;
Oxide of iron and peroxide of cobalt;
Oxide of iron and oxide of copper;
Oxide of iron and oxide of chromium.

Amongst all the other possible combinations of the colouring metallic oxides with one another, there are a few more of great stability, although certain of the oxides out of which they are formed are remarkably deficient in this stability. Thus, among other combinations, there are a cuprate and a plumbate of silver, of which the oxide of silver is reducible at less than a red heat, and further, a manganate of silver, which appears to possess the same property.

Protoxide of manganese and oxide of iron combined in equal atoms.—First process: Two solutions, both of equal weight, according to Beaumé's areometer, one of protosulphate of iron, and the other of protosulphate of manganese, are mixed together; they are then raised to the boiling point, and treated with an excess of carbonate of soda. The precipitate, after it has been washed and dried, is moistened with nitric acid, and exposed to a red heat in a crucible, until it is perfectly decomposed. This operation explains itself, and we need merely remark, that these sulphates contain equal quantities of protoxide, and that both the protoxides are converted into sesquioxides, and give an equal number of atoms.

Protosulphate of Iron.		*Protosulphate of Manganese.*	
2 at. protoxide	878·42	2 at. protoxide	911·4
2 at. acid	1002·32	2 at. acid	1002·32
2 at. protosulph. iron	1880·74	2 at. protosulph. mang.	1913·72

Sesquioxide or Peroxide of Iron.		*Sesquioxide of Manganese.*	
2 at. protoxide	878·42	2 at. protoxide	911·4
1 at. oxygen	100·00	1 at. oxygen	100·00
1 at. peroxide	978·42	1 at. sesquioxide	1011·4

Second process: A stream of chlorine gas is caused to pass through water with which carbonate of manganese, or the oxide obtained by precipitating sulphate of manganese with potash, has been mixed. The oxide which is obtained in the state of hydrate is mixed in proper proportions with hydrated oxide of iron, and exposed to a red heat.

Hydrated Peroxide of Iron.		*Hydrated Peroxide of Manganese.*	
2 at. iron	678·45	2 at. manganese	711·5
3 at. oxygen	300	4 at. oxygen	400
Water	168·70	Water	150
1 at. peroxide	1147·15	1 at. peroxide	1261·5

The following result is obtained by heating the mixture:

Anhydrous Peroxide of Iron.		*Anhydrous Sequioxide of Manganese.*	
2 at. iron	678·45	2 at. manganese	711·5
3 at. oxygen	300	3 at. oxygen	300
	978·45		1011·5

These hydrates, it is evident, must be mixed together in equal parts.

Protoxide of manganese and peroxide of cobalt.—This combination is obtained by precipitating with an alkali, as in the case of iron, from a solution of sulphate of manganese and sulphate of cobalt, in equal quantities and of equal density, and calcining the precipitate merely at a red heat. The atoms of the acids are here likewise combined in equal proportions. We have assumed these proportions for all analogous combinations.

Protoxide of manganese and oxide of copper.—The composition is prepared in the same way as the foregoing; but it is better to effect the precipitation from the sulphate of copper and sulphate of manganese with an alkaline carbonate, because the oxide of copper is very likely to be re-dissolved if an alkali is used. Moreover, the proportions of the solutions must be equal. We may proceed in the same way in the calcining; it is as well, however, to add a little nitric acid to the mixture, to render the oxidation of the manganese complete.

Protoxide of manganese and oxide of chromium.—This combination arises from pouring chromate of potash into a solution of sulphate of manganese. The protoxide of manganese is oxidized at the expense of the chromic acid, which is thus transformed into oxide of chromium.

Protoxide of manganese and oxide of silver.—This combination arises from heating a mixture of peroxide of manganese and metallic silver, which has been precipitated with copper from a solution of nitrate of silver.

Oxide of iron and peroxide of cobalt.—This is obtained from a mixture of solutions of sulphate of iron and sulphate of cobalt, which are treated with an alkaline subcarbonate, in order that the precipitate which is thus obtained may be calcined.

Oxide of iron and oxide of copper.—The same process as before.

Oxide of iron and protoxide of copper.—A mixture of oxide of copper and finely triturated iron filings is subjected to a red heat. The copper returns into the state of protoxide, and gives up its oxygen for the iron to form an oxide with it. Probably it would be necessary, in using this compound as colouring matter, to keep it carefully from the air as soon as it passes into a liquid state. We may avail ourselves of this composition for colouring glass red, but it is probable that in this case there is no combination between the two oxides.

Oxide of iron and oxide of chromium.—This combination takes place when a solution of protosulphate of iron is treated with chromate of potash. The protoxide of iron is brought into a higher state of oxidation by means of the oxygen which the chromic acid gives up, and the chromic acid is thereby reduced to the state of oxide of chromium.

Protoxide of copper and oxide of silver.—This combination is obtained by heating in a crucible oxide of copper with metallic silver in the form of powder. The same phenomena may be observed here as in the case of iron and copper.

Plumbates.—We have already mentioned the fact, that oxide of lead to a great degree possesses the property of combining with the other metallic oxides. The combinations into which it enters with them are particularly valuable, although for an entirely different reason from that for which the similar compounds of which we were just now speaking are valuable: they are valuable, because the oxide of lead imparts a very slight stability to them. But while it combines with the oxides, it dissolves them, separates their particles, and facilitates in a remarkable manner the vitrification of those pigments which are coloured by combination.

The most important of the plumbates are those of cobalt, copper, and manganese, which are prepared by subjecting minium with the oxides of one or other of these metals to a red heat.

CHAPTER III.

THE MECHANICAL PART OF GLASS-PAINTING.

Preparation of the colours for use.—We shall now distinguish the colouring materials, when combined with their fluxes, by the epithet *colour*.

The colours must first be reduced to an extremely fine powder, by long-continued levigation upon porphyry, or in a mill of porcelain biscuit, constructed expressly for this purpose, which we shall describe hereafter. In order to do this it is necessary to mix with it a sufficient quantity of pure water; it is then dried and put away in well-stopped bottles.

The levigated colours, at the time when they are used, are mixed with liquids of various kinds, but all for the purpose,—1. of giving them sufficient stickiness and consistency, so that they may not run on the surface of the glass;—2. of causing them to adhere sufficiently, when dry, until the time when they are fixed by the firing;—3. of adapting them to the various kinds of paint-brushes which are generally used in glass-painting.

These liquids are usually—water, oil of turpentine, and oil of lavender, somewhat thickened by the substances which are to fix the colours, after they are dry, upon the glass. Thus, for example, sugar-candy or borax are generally mixed with water; thickened oil of turpentine and oil of lavender to the oils of turpentine and lavender. This inspissation is produced by a longer action of the air upon these essential oils or essences. Among the preparations which are brought under the name of thickened essence of turpentine, &c., we must distinguish between those which have been really thickened by the action of the air, and those which are nothing more than the residue after the distillation of the ordinary essences of turpentine and lavender. A residue like this will never answer our purpose well, and we might just as well use turpentine, or even varnish. But it will be explained hereafter why liquids of this kind must be rejected.

The *fat*, or thickened essence, as it is called, is obtained by exposing to the air and light one of the above-mentioned essential oils in a glass vessel with a wide mouth, which must be covered with a woven texture that will allow the air to pass through without difficulty. The contents are stirred from time to time, and the essential oil has attained to the proper degree of inspissation when it is of the consistency of a thick syrup.

The water colours and the essential oil colours may both be advantageously employed, and they are frequently used alternately in one and the same painting.

The implements with which the colours are laid on glass are various sorts of paint-brushes; viz.

1. *Marten's-hair pencils*, brushes which run to a fine point, and are generally used for water-colour painting.
2. *Fitch pencils.*—These are not finely pointed, but cut off abruptly at the lower part, so that they present a flat surface perpendicularly to their length.
3. *Broad badger's-hair pencils.*—These are broad and flat brushes for softening the colours.
4. *Stockfish-tails*, of soft hog's bristles, of the same form as the foregoing.
5. *Hard pencils*, of the same form as the fitch pencils, only prepared from hog's bristles.
6. *Hog's-bristle pencils*, such as are used for oil-painting.

Use of these pencils.—In order to lay an uniform coating of colour upon the glass, a marten's-hair pencil must be used when the space which has to be covered is small; if, on the contrary, it is large, either a stockfish-tail, or a cut badger's-hair pencil, must be used. By the help of these implements, the colour is laid on the glass and spread over its surface by being rubbed in one direction, and then in the opposite, until the whole coating is uniform. Painting of this kind has generally furrows or channels which are caused by the hairs of the pencil, but these may be removed when it is considered necessary, by means of a fitch pencil, or, still better, by means of a cut badger's-hair pencil.

The fitch pencil, as we have stated, is terminated by a flat surface, and it is used for touching the glass with the ends of its hairs, but not for drawing over the surface, as is the case with the other pencils. If this is done skilfully, and continued for a sufficient length of time, not only will the streaks thereby disappear, but the colour will also be diffused uniformly over the whole of the surface which is to be covered. The pencil must, however, be used until the colour is almost dry, and a very short time before this takes place the colour will be distributed with perfect uniformity.

The fitch pencil answers very well for laying on thin coatings of very liquid colour, when they are required. A little colour is taken with the pencil from the palette, and lightly dabbed on those parts which are to be covered with the colour.

The marten's-hair pencil, on the contrary, is used for laying on those colours which are required to be fused, for marking the lines, &c.

The hard pencil, of the same form as the fitch pencil, is used for removing certain water-colours which were previously laid on the glass, in order to execute in this way a species of painting of which we shall presently speak more fully.

For mixing up the colours properly, certain precautionary measures are necessary. When a colour is to be mixed with an essential oil, for example, a little of this colour, which, as we have before stated, must have been previously well levigated and dried, is put upon a palette and mixed, by means of a spatula, with a sufficient quantity of thickened essence to allow of its being worked to a stiff paste. It is then diluted with more or less essential oil of turpentine, according as the colour which is to be laid on is intended to be of a more or less rich tone; it is then ground a little more in the mill, and used in the manner above described. These precautions are especially important towards insuring a successful use of the fitch pencil.

The process is the same with regard to the water-colours, except that instead of a thickened essence a thick syrup is used, and instead of essential oil of turpentine, water. The object of this method of operation is to determine the proportion of sugar or thickened essence without difficulty. For the borax colours, and even for those in which pure essence of turpentine is used, we are limited to the employment of as much liquid as will yield a thick paste. As a general rule, the enamel colours should not be much moistened.

It is not immaterial whether a water-colour or an oil-colour, and whether essence of turpentine or essence of lavender, be used. The water-colours are, generally speaking, more liquid than the oil-colours, under circumstances in other respects the same. They have less consistency, and consequently do not admit of being softened so well with the paint-brush. On a large surface of paint, the oil-colours are much better adapted to forming an uniform layer of colour, and the streaks and furrows which the stockfish-tail leaves behind may be more easily removed by means of the cut badger's-hair pencil. The use of the fitch pencil also insures a far more satisfactory result with oil-colours, and consequently these colours are preferred in all cases which are analogous to the above.

In comparing the essence of lavender with the essence of turpentine, we find that the latter dries much sooner than the former; the former, therefore, is employed whenever a liquid which is long in drying is required. It is not used alone in the preparation of the colours, but as much of the essence of turpentine is mixed with it as is necessary to cause it to dry at the proper rate. These means are employed when the fitch pencil is to be used for softening, which always requires time. In the water-colours we cannot advantageously substitute for sugar other viscid substances, *e. g.* gum, &c.; for the former has the advantage of being much softer, and at the same time is not so liable to peel off.

Two styles of execution essentially different from each other are adopted in glass-painting. That which in former times was chiefly employed, namely, the Gothic, consisted in using no enamel for colouring the glass, but in merely marking the outlines and shadows with a brown opaque pigment upon glass which had been coloured in the melting-pot. This style of painting, or rather of drawing, notwithstanding its simplicity, is susceptible of the most beautiful effects which the decoration of panes of glass is capable of producing. To it we are indebted for the beautiful Gothic windows which adorn our old churches. This style of glass-painting is moreover the easiest of execution, for the artist need only be a skilful draughtsman, and has occasion for nothing else, except one single pigment, which is easily prepared, and not at all difficult to use.

The second style belongs to the period of the revival of glass-painting; it supposes likewise the use of coloured glass, but at the same time requires the use of numerous pigments, by means of which the artist executes a real painting on the glass, which, in regard to its effects, may be compared with oil-painting. The artist is therefore under the necessity of having a palette covered with vitrifiable colours, which is of the same use to him as a palette supplied with oil-colours is to the oil-painter. The execution of this style is difficult, and requires a particular study.

Glass-painting, taking it altogether, presents numerous and considerable difficulties, which proceed from the nature of the colours and of the glass itself, either in relation to the mechanical application of the pigments, or in relation to the realization of the results which the artist endeavours to obtain. We will mention the kinds of manipulation which are necessary in the various cases.

The smooth and polished surface of glass is not very favourable to the laying on the colours. When we are laying any colour on the glass, a second stroke of the brush frequently takes off what the first had deposited; and thence arises the impossibility of hesitating in this work. This difficulty has disposed some artists to paint only on glass whose smooth surface has been removed by sandstone or emery.

But the greatest obstacle to the painter arises from the nature of the vehicle, which does not easily admit of the several coatings of colour being laid one over the other, which, on account of the substances that are used, do not even adhere after the first coating is thoroughly dry. As the vehicle for fixing on the first coating retains its solubility, it is capable of being softened and removed from the surface by the succeeding coatings. To meet this difficulty it was happily suggested that the vehicle should be changed in every coating of colour which was laid on over another. Thus, for example, we paint with water-colour upon an oil-colour, and *vice versâ*, with oil-colour upon a water-colour. The fixing substances of the one colour being insoluble in the liquid of the other, there is no danger of removing, by a second application of the colour, that which has been produced by a first.

The inconvenience, however, which accompanies the employment of colours prepared in different ways, gave rise to the discovery of a method by which we may paint with the same vehicle. This discovery was arrived at by observing the following fact. An oil-colour, rendered viscid with thickened essential oil of turpentine, or Venice turpentine, retains its solubility in this liquid, if it has been dried by exposure to the air; but if the painted pieces of glass have been submitted to a moderate temperature in a drying-oven, the colour loses its easy solubility, bears the friction of the pencil very well, and the fresh coatings may be laid on without difficulty.

In proceeding according to the method which we have just described, the painter will sometimes have occasion to interrupt his work, in order to dry the painted pieces of glass in the oven; and this circumstance was so disagreeable to many artists, that they considered how they might avoid the necessity of doing so, and at length they succeeded in painting on glass with water or oil colour, as is the practice in painting on canvas, without being obliged to dry the first painting. We must observe, however, that this is to be attributed more to their skill and dexterity, than to the method itself to which they ascribe this invaluable superiority in practising their art. In order to explain their method of proceeding, we will consider a painting with water-colours. The artist first of all makes up his colour, and mixes with it no more sugar than is necessary to cause it to adhere. This colour laid on, he paints upon the first coating with colours which contain more dissolved sugar, without being thereby of a thicker consistency. The increasing solidification of the vehicle prevents its solvent action upon the colour which was originally laid on.

If this is dexterously performed, it admits of the painting being *impasté*, to use a technical expression. Nothing but long experience and perfect dexterity will—we repeat it—enable us to employ this method with advantage.

For the execution of paintings on glass, particularly Gothic, a method as simple as it is ingenious is frequently had recourse to, which enables the artist to work with the greatest certainty of success. This mode of painting is designated by the French term *peinture par enlevage*, and consists in drawing the outlines with an oil-colour, and painting over the whole with a water-colour, which, after it is perfectly dry, is to be removed with a hard paint-brush. By a dexterous use of this paint-brush, portions of colour of different degrees of thickness are removed, according as shadows, half-tints, or lights are required. Wherever the glass is left bare by a complete removal of the colour, we get the lights; the places which the brush has spared give the shadows, and the half-tints are produced by an imperfect removal of the colour. In this way the process of laying on the ground-colour of the picture is performed, and after the latter has undergone the firing, it is again painted over, and retouched with a colour which has been made up with sugar or thickened essence.

The colour proper for the *peinture par enlevage* is an enamel colour, with which a little borax is mixed, and which is then levigated with enough water to give a thick paste. The colour is laid on by means of a stockfish-tail, and softened uniformly with a cut badger's-hair pencil, with the assistance of which the colour is easily spread over the glass. The small quantity of borax which has been mixed with the colour causes a sufficient adhesion of the latter to the glass, so that the hard pencil may be fearlessly applied to the removal of the water-colour.

The majority of the pigments of the second class are well adapted to the employment of this method. There are, however, among the pigments of the first class, some whose colouring matter is acted upon by borax, so that a combination arises which imparts to the colour which has been laid on too much adhesiveness to admit of its being removed with the hard pencil. Among these colours are ochre yellow and all those pigments which contain oxide of zinc.

This unpleasant circumstance may, however, be certainly obviated by fritting these pigments before they are levigated for mixing with borax.

To *frit* a pigment is to heat it to that point at which it coagulates, and, by reason of an incipient fusion, forms a mass of the consistency of dough.

Pigments of the second class are seldom used for the *peinture par enlevage*. As this kind of painting only has in view a simple sketch upon a previously coloured ground, it requires in most cases merely an opaque pigment coloured by mixture. That which is best adapted to this purpose consists of a flux of flint glass and of brown or violet oxide of iron in the usual proportions, with a mixture of calcined borax, whose weight is equal to the eighth part of that of the flux. The proportions of the borax and the flux are calculated for the preparation of flux No. 3 of the pigments of the first class.

The method which we have just described is capable of an important modification with respect to the preparation of the colour proper for *peinture par enlevage*. Instead of dissolved borax, merely the oil of turpentine of commerce is used. In this case, the drawing is first sketched with a pen in water-colour, and a coating of oil-colour is laid on over it. This modification is based upon the property which essence of turpentine possesses of giving sufficient firmness for the *enlevage* pencil to be used. The essence of turpentine owes this property to a small quantity of resin which it contains, but which is not to be found in it after it has been rectified by a new distillation. Hence it follows that this method is the opposite to the former. Certain precautionary measures, however, ought not to be neglected, to obtain a successful result. The water-colour must accordingly be properly mixed with sugar, so that the oil-colour may be incapable of softening it. Moreover, after the oil-colour is laid on, it must be submitted in the drying-oven to a temperature sufficient to produce the requisite firmness. It is also necessary to avoid adding essence of turpentine frequently to the same colour, because the proportion of resin is likely to be increased by that means, and the consequence would be too strong an adhesion of the pigment to the glass, so that it could not then be easily removed with the *enlevage* pencil.

Circumstances arise in which this method is rather complicated, and this is the case when it is required to paint upon glass which has not been coloured. In order to paint a head, for example, a light tint is laid on for the colouring of the lights, and upon this a coating of colour suited to the *enlevage*, in order to form the shadows and half-tints. Thus, upon a drawing prepared with water-colour, the first coating must be laid on with a colour mixed with thickened essential oil, and the second with a colour mixed with borax; but if the drawing has been executed in colour mixed with thickened essential oil, the first coating of paint must be laid on with colour mixed with sugar-water, and the second with colour moistened with pure essential oil, in conformity with the directions we have given above.

The *peinture par enlevage* is not only simple, but is also executed in a very short time. It is peculiarly adapted to decoration, especially to the execution of such designs as stand out in light colours from a dark ground, and to the representation of the embroidered parts of drapery. In this case the *enlevages* are executed in a different way. To make the drawing clean and correct, wooden scrapers of various forms must be substituted for the hard pencils. The colour which is here operated upon is of no particular kind, but may be any pigment whatever that has been levigated with thickened essential oil.

Finally, glass-painting justifies every possible artifice the object of which is to lessen difficulties, or to enable us to obtain results which are not to be obtained in any other way. Thus, for example, it is not uncommon to paint both sides of the glass, in order to obviate the unpleasant results of laying on one colour over the other. The same method is adopted in the case of yellow from silver, because the substances by which it is produced ought not to be brought into immediate contact with the colouring enamels. In this way a green is obtained, that is to say, by giving a yellow stain to the back of a piece of glass which has been painted blue.

The same method is also followed in order to impart brilliancy and a remarkable freshness to the brownish red colours from iron; that is to say, a yellow is applied to the opposite side of the brown.

Whatever method be adopted, the employment of the colours is always, however, subject to certain restrictions. Care must be taken to use as few mixtures as possible. The colours are by means of the latter mutually destroyed at the temperature at which they are burnt in, while at the same time new combinations take place. By avoiding a mixture of the pigments we obtain purer, less perishable, and much more certain colours. It is better to lay one colour over the other, instead of mixing them. In order, therefore, to produce an effect similar to that which may be obtained with ochre yellow and red from iron, the yellow is first laid on and then tempered with red.

It is also of consequence to lay on the pigments as thin as possible, and there are several reasons for so doing. Thus if the colours are laid on too thick, the adhesive substances that are in them form a mass which possesses too little softness and flexibility. The motions caused by expansion, which the glass undergoes in the changes of temperature, unless they are shared by the painting, at length overcome the adhesion of the colours and loosen them from the surface of the glass. This always takes place when water-colours and oil-colours are laid on in alternate coatings, for the heterogeneous qualities of the substances by which those colours are fixed are still more conducive to this result. The mere drying of itself is often sufficient to produce this unpleasant result in consequence of the unequal contraction of these substances.

On the other hand the water-colours certainly part with the water they contain, in drying on the glass, but then they retain the sugar which was mixed with them; the oil-colours give up the volatile part of their vehicle, whilst the thickened essence which is in the latter has lost the power of being converted into vapour, and consequently remains upon the glass. Hence it follows, that these substances must be consumed in the firing, and leave a certain quantity of carbon lying between the particles of the pigment. The body re-acts upon certain combinations, *e. g.* the oxides of iron and lead, which it turns black by robbing them of their oxygen, which it does so much the more, as the carbon being protected by a thick coating of colour resists combustion the longer. This circumstance is at least of importance with regard to the flesh-colouring. This *contretemps* which we have just pointed out would not take place if a firm substance, and one perfectly volatile at a certain temperature, were invariably used as a means of fixing on the colour, as, for example, camphor, or borax, which contains no carbon at all. But the former substance is yet to be tried, and the latter could not always be conveniently used. Nevertheless, it follows from what we have already stated, that, of the substances which are adapted to fixing the painting upon the glass, the preference should be given to those whose combustion leaves the least carbon behind, and which at the same time preserve a certain ductility, as a security against cracking and splitting. Perhaps wax would answer very well with regard to these two particulars, for a portion of it volatilizes when it is exposed to heat, and it possesses moreover great ductility. For this purpose we have only to dissolve it in essential oil of turpentine.

It would be a waste of time to describe the various manipulations used here, which are purely artistical; and we would rather therefore confine ourselves to some few particular cases. Painting on glass is always done by copying oil-paintings, or original designs expressly prepared, which are called *cartoons*. The original design is traced by means of transparent paper, and this is used for transferring the drawing to the glass. For this purpose the piece of glass is laid upon the tracing, which has been first spread out upon a table. The transparency of the glass makes it easy to follow the outlines and shadows of the tracing; but if the glass is very much coloured and destitute of transparency, it becomes necessary to use a perforated pattern for finding out the drawing through the glass. This is a kind of tracing, the outlines of which are drawn through numerous contiguous punctures of the size of a needle's point. The paper which lies on the glass is then struck with a bag of powdered charcoal, and the outlines appear marked with sufficient distinctness. It is best to begin by drawing in Indian ink the object to be painted, when it is in our power to correct and modify the sketch, just as we think proper, and then the painting may be executed according to it with the greatest certainty. If corrections are made after the pigments have been laid on, a want of uniformity and completeness will always be observed in the work. Besides, correcting is then much more difficult. In other respects the same rules and precautions are applicable to glass-painting as to painting on canvas. The easel and the *maulstick* are used equally in both. The easel is constructed in a particular manner, which we shall describe hereafter. The pieces of glass that are placed upon it must be fastened with a soft adhesive wax prepared solely for this purpose. In order to take advantage of the transparency of the glass, the painter places his picture between himself and the light, and can at once judge of the effect of his work, as he proceeds.

A paint-brush or a goose-quill is used for drawing on glass with a pigment. A water-colour is best adapted to the goose-quill. Oil-colours, which are preferred for painting upon a flat surface, because they admit of being diffused more uniformly with the pencil, are not suited so well to the quill and do not adhere so well to the glass; nevertheless they are frequently used. A large quantity of sugar facilitates the drawing; still it is necessary to define the amount which should be mixed with the colour. Six grains of sugar to one drachm of colour produce a sufficiently strong adhesion, but for the quill at least seven grains of sugar must be mixed with the colour. A mixture of twelve grains would cause the colour to peel off. It is a very good precaution, when it is intended to paint with a quill, to wash the glass beforehand with essential oil of turpentine. Drawing in Indian ink is likewise more easily executed if this plan be adopted.

Should it devolve upon a glass-painter to paint a church window of large dimensions, he must begin by dividing it into more or fewer compartments which are surrounded by iron bars properly disposed and firmly united, so that all parts may be equally firm. He first determines the direction which is to be given to the iron bars and lead casing which are intended to unite the different parts of the picture. In doing this he must study to make these parts follow the outlines as much as possible, and to hide them in the shadows in such a way that they may not injure the effect of the picture. He ought not to be afraid of giving them a proper thickness, and increasing their number when necessary for the sake of greater firmness; this is of the greatest importance for the duration and preservation of a work of art which is always exposed to the violence of the winds. It is a necessary condition which fetters the author of the original design himself in his composition. He must always take care that the execution of the painting will not require pieces of glass which are too large to admit of being durably fixed by means of iron bars and leading.

If the artists of the present day understand not only how to insure firmness to a painting on glass, but also at the same time how to satisfy the demands of the art as far as is necessary,—this, whatever may be said of it, is an improvement which we owe to the modern style of painting, and to which the manufactory at Sèvres has greatly contributed. As for the rest, both these conditions may be satisfied at once without much difficulty. The presence of the iron bars and of the leading does not disturb the harmony of the painting nearly so much as would be supposed. Can this be a magical result of this kind of human creation? The human mind has the power of dismissing these obstructions, and the largest of them always appear like objects which are outside the picture. Now, whether the ancients sacrificed everything to solidity, or were deficient in mechanical skill, their church windows afford frequent instances in which the painting is far from harmonizing with the materials which support it. Thick iron bars are frequently carried across the figures or abruptly cut the masses in the finest centre of light. Every one, therefore, will certainly coincide in our opinion, namely, that this is granting too much to the demand of solidity and too little to the effect of the painting. But did not a very simple principle of economy frequently predominate in this matter? This hypothesis seems at least reasonable, the construction of the *arming* being one of the most expensive parts of the construction of painted church windows. When we come to work the iron bars into complicated forms, this, as every one must see, can only be done at a great expense. It is a consideration of some importance, why the ancients thought themselves obliged to restrict the claims of the art to limits marked out by economy.

After we have explained the various manipulations of the proper art of glass-painting, we must not omit to speak of a branch of industry which has something in common with the art with which we are at present engaged. We mean the manufacture of the *mousseline* glass, which consists in covering panes of ordinary window-glass with a coating of opaque white enamel, upon which a transparent sketch is drawn by *enlevage*, which seems to be executed upon a faintly-polished ground.

To obtain this result, a fitch pencil must be used, whose form we have already described. This is dipped into thickened oil of lavender, and the surface of the glass is touched perpendicularly with it until the whole is covered with an uniform coating. As soon as this layer has acquired a proper consistency, a powder composed of one part of oxide of tin and three parts of a flux of the second class is sifted over it. The thickened essence retains a proper quantity of this enamel. This coating is then dried for six or eight hours, and after it has become sufficiently hard, the excess of enamel powder is removed by means of a badger's-hair pencil.

Now, in order to draw upon a plate of glass like this lines which shall possess the polish and transparency of glass, we lay under the glass a pattern whose lines are sufficiently conspicuous even through the layer of powder. The pattern having been previously well secured, the artist removes by means of an etching-tool the colour from those places which are indicated by the drawing. This painting is now exposed to a proper degree of heat, that it may adhere or become burnt in. There is little in this operation that admits of the application of the proper art of glass-painting, the use of the wooden etching-tool alone being accidentally borrowed from this art. It is an exceedingly convenient tool for executing transparent drawings in imitation of embroidery; it is also much better adapted to *enlevages* than the steel scraper. The method which is employed in producing white enamel is preferred on account of its succeeding in a very short time, but is better adapted to white enamel than to the other colours. Laying on by means of the fitch pencil insures greater uniformity, and enables us to obtain the requisite tone of colour with certainty.

The burning in of the painting.—The glass, after it has been painted, must be exposed to a temperature at which the pigments liquefy, and are thereby united to the glass. For this purpose the pieces of glass are arranged in a kind of box of fire-clay, called the *muffle*, which is placed in a furnace and there heated until the colours which have been laid on are liquefied.

Description of the furnace.—The furnace consists of four walls formed by bricks standing on their ends; these bricks enclose a space which is again subdivided into three parts. The upper compartment contains the muffle, which is open in front for the purpose of putting the glass in and taking it out. This aperture must be walled up, after the muffle has been filled. The intermediate space contains the fire-place; the lower space contains the ash-pit. A cast-iron grate separates the fire-pot from the ash-pit; it is composed of single cast bars, in order that it may be more easily repaired. These bars are merely laid by the side of one another. Two or three arches span the fire-pot transversely, and are placed at equal distances from each other; they serve for the support of the muffle. An arch of burnt clay is perforated with several holes to allow the escape of the flame and the products of combustion. The muffle has a wide aperture in front for the purpose of putting in and taking out the glass, and another one of a small size under the arch for the escape of the gases which are evolved in the interior of the muffle. The door which closes the large aperture is usually provided with a sort of pipe in the middle, through which the experimental pieces of glass or the pyrometer are introduced into the muffle. By means of the latter we are enabled to observe the temperature. It is better, however, to have two apertures of the same kind, as we shall presently see on a closer examination.

Management of the painted pieces of glass in the muffle.—As the colours which have been laid on are to be melted, the plates of glass should not be placed in immediate contact with one another, or they would necessarily bake into one mass. They are therefore laid apart from one another by means of fire-proof earthenware shelves, (in France, by means of slabs of lava from Auvergne,) or plates of cast iron, which are ranged horizontally in parallel layers, so that a small space is always left between them. These shelves are kept apart by the insertion of small parallelopipeda of baked clay in the four corners. The shelves are also laid upon cross-bars of iron, of which two are used for every shelf, and are inserted at both ends of the muffle into notched bars; the former method, however, is preferred. Before the glass is put into the muffle, the shelves must be covered with a stratum of Spanish chalk mixed up with water, so that the glass, if it should happen to become soft when heated, may not adhere to the surface of the shelves. This coating of the shelves must be carefully dried, and then the pieces of glass must be laid side by side, but without touching one another; moreover, a clear space must be left at each corner of the shelves for the little supports which we have already mentioned. After the muffle has been filled, the aperture is hermetically sealed by being plastered over with clay which is proof against fire, and the front of the furnace is walled up with bricks. Thus shut up, the glass may be heated without the colours being exposed either to the action of the flames or the vapours which arise from the fire-pot.

According to Dr. M. A. Gessert, to whom we are indebted for an excellent history of glass-painting, the introduction of the painted pieces of glass into the muffle is effected in the following way in Germany:—Well-calcined lime is first of all slaked with water, and when it has crumbled to powder, is properly dried over the fire. The bottom of the muffle, to the thickness of an inch, is covered with this powder, as it falls through a coarse hair sieve; this substratum is carefully levelled, otherwise the pieces of glass might become distorted in the firing; these pieces of glass are then laid side by side, but in such a manner that they may not be in contact either with one another or with the sides of the muffle. A thin layer of lime is then sifted over them, other painted pieces of glass are disposed in a second series, and the process is continued, until we reach the centre of the muffle, at least the aperture for drawing out the tests, which consist of strips of glass from 6 to 7 inches in length and 1 inch in breadth, painted over with patterns of the colours which are to be burnt in. These, like the painted pieces of glass, are laid upon a stratum of lime, and sprinkled over with a coating of the same, but are so arranged that one end of them reaches to the centre of the muffle, while the other projects half an inch out of the test aperture, to admit of their being taken hold of and drawn out by the pincers. The artist then continues introducing the other pieces of glass, and strewing lime, until all have been arranged in their places in the manner above described, or the muffle is full. If only *one* has to undergo the burning in, the muffle is filled with ordinary pieces of glass instead of painted glass, and the only piece which is to be fused is introduced into one of the interior layers of the muffle. The latter is then covered up.

The furnace must be heated with wood, inasmuch as no other kind of fuel will answer the purpose, at least for the species of furnace of which we are now speaking, because the heating of the muffle is effected less by radiation from the fire-pot than by contact with the flames. Consequently that kind of wood should be selected which gives a long and bright flame, *e.g.* the wood of the aspen, birch, or poplar, which must previously be seasoned as thoroughly as possible. The fire must be made to burn up slowly, in order that the muffle may acquire the same degree of temperature in all its parts. The ignited matter must therefore have time to propagate itself. Were we to proceed otherwise, the glass which lay next to the sides of the muffle would have already endured a degree of heat which would not only affect the pigments but would even bring the glass itself into a state of fusion, whilst the plates of glass which were situated in the centre of the muffle had only obtained the proper degree of temperature. The better to escape so unpleasant an occurrence, we must proceed in the following manner:

The fire must be constantly kept at a moderate temperature, until the muffle has attained a lively red heat, when the temperature must be lowered. The heat penetrates into the interior, and the muffle at last becomes of a dull red heat; the fire is now stirred, and as soon as the muffle is again at a lively red heat, is lowered a second time. This is continued until the centre of the muffle is at the requisite temperature. According to this method it can never happen that the exterior of the muffle has already attained a high temperature before the interior is properly heated.

The temperature which it is intended to arrive at is generally a moderate cherry-red heat; this is determined by looking into the various apertures of the muffle. But these observations are very liable to error, because we are not always in the same condition with regard to light. Suppose, for instance, that the room in which the furnace stands is very well lighted, then the red-hot muffle is not nearly of so bright a colour. In a more subdued light, the red appears much more intense; so that one day's experience is frequently fallacious. It is therefore necessary to hang curtains before the windows, in order to obtain a tolerably uniform light for this examination.

The temperature is also determined by painted pieces of glass for testing, which are laid in the apertures of the muffle; but such tests as these are not conclusive, inasmuch as they only indicate a local temperature. An experiment made in one part of the muffle affords no clue towards determining the state of the other parts. But if after all the artist should be disposed to use this test, he must endeavour to keep always below the requisite temperature, and to lower the fire before the test-glass has actually arrived at the proper degree of fusion; for he may be sure that the temperature will increase towards the centre. Carmine is generally employed in experiments of this kind. The changes of colour which it undergoes in mass, when it is raised to a higher temperature, render it peculiarly adapted to this purpose. When not much heated it has a dirty violet colour, it then passes over into pure carmine; and when at length it is heated too much, it appears yellow in reflected light, and violet in refracted light, that is to say, upon an opaque body, *e.g.* a piece of porcelain, it will appear yellow; upon a piece of glass, on the contrary, in transmitted light, it will appear violet.

Finally, the temperature may be determined by means of particular instruments contrived on purpose to measure the heat of the furnace. Among these are the *pyrometers* of Wedgewood and Brogniart. The former is constructed on the principle that clay contracts in proportion to the heat to which it is exposed. It consists of a plate of copper, on which two or three rulers, likewise of copper, are fixed. Between these is inserted a cylinder of clay baked in the fire, which has been exposed to the degree of heat which is to be determined. The more it diminished in bulk, the greater was the degree of heat which was applied. The instrument is divided into 240 parts. The zero answers to 580°·55 Centigrade; every degree is equal to 72°·22 Centigrade. This pyrometer is therefore adapted to the measurement of very high temperatures, but does not answer well in the case before us, in which the other is preferable. This latter is constructed on the principle of the expansibility of the metals by heat, and consists of an apparatus of baked clay, along which a groove runs longitudinally, but stops short of one of the ends. A bar of metal and another of baked clay lie in this groove in such a way that their ends touch one another. The other end is furnished with a dial-plate, in the centre of which a finger moves, one end of which is in contact with the earthenware bar in the groove.

That part of the instrument which contains the bar of metal is introduced into the muffle in such a way that the bar shall be completely in the muffle. As it expands by the heat, it must necessarily, since it lies at the end of the groove, push forward the earthenware bar; the latter again communicates the impulse to the finger, which then indicates upon the dial-plate the expansion which has taken place. The metallic bar must be made of a metal whose point of fusion is far beyond the temperature necessary for burning in the painting; it must not even become too soft at this degree of heat. Iron and silver may be employed for this purpose, but silver is generally preferred, because it becomes less oxidized. If a metal still more difficult of fusion were required, a bar of platinum might be used.

In order that we may use this instrument effectually, the following conditions must be complied with: the door of the muffle must be furnished with two apertures, one of which must be made in the lower part, and the other in the middle, or rather about the upper third of its height. A pyrometer is prepared for each aperture. When the lower one indicates a dull red heat, the fire is not allowed to increase, but is stirred in proportion as the heat has been reduced below that temperature. The artist proceeds generally according to the directions above given, until the upper pyrometer indicates a proper temperature.

In beginning to light the fire, it is important to cause a feeble current of air to pass through the muffle, in order to allow the gases, which are formed in the latter by the combination of the substances which are used for fixing the painting with those which come out of the fire-pot, and penetrate through the sides of the muffle, to escape with rapidity. For this purpose one of the apertures in front, as well as that of the upper part, is left half-open. Upon the latter is also placed a stove chimney, a few decimetres in length, which when heated draws the air out of the interior of the muffle, and accelerates its upward motion. It is only when the muffle is being first heated that the most injurious of the external gases penetrate in larger quantities. After it has arrived at a red heat, they become more completely dissipated on the exterior. These gases always exercise a pernicious influence upon the painting, which it is necessary to guard against.

The creating the current of air of which we have just been speaking is not less useful as a means of obviating an unpleasant occurrence, which, without this precaution, frequently takes place, viz. the *cracking* of the painting. This may be explained as follows: When the muffle is being first heated, a large quantity of smoke often penetrates through the hole at the top. The glass is still cold, whilst the sides of the muffle are hot; consequently the aqueous vapour of the smoke condenses in small drops upon its surface. As soon as the glass begins to grow hot, the water which lies upon it begins to boil before it is converted into steam, and at last affects the painting with which it is in contact. The consequence of this is, that a peculiar kind of cracking takes place, similar to that which varnish undergoes when it is laid on an oil-painting just finished. The possibility of this accident is diminished by creating a draught of air at the commencement of the heating; but this draught should not be so strong as to chill, and consequently to crack, the objects with which it comes in contact. If this be avoided, it seems to be attended with no other prejudicial results.

There is also another source of moisture, viz. in the clay with which the door of the muffle is plastered over. It is customary, therefore, to heat for a short time the muffle, with its contents, before plastering on the clay, and to close the furnace. The muffle being already hot at the time the clay is laid on, its contents are not so likely to condense the vapour.

That kind of glass-painting which is executed with coloured fused pigments is not finished after the first firing. The fusion of the colours gives in general too feeble a tone of colour. The pigments of the first class especially lose some of the intensity of their colour when they are exposed to too high a temperature. It becomes necessary after the first firing to give expression to those parts which are deficient in this particular, and generally to impart the requisite harmony to the whole. It is even sometimes useful to re-touch the work after the second burning in, and in this case a third burning in becomes necessary; but the painting is not capable of bearing more than this, for a large portion of the pigments would be considerably damaged and even entirely destroyed by the repeated action of heat. When a painting is to be burnt in a second time, and it becomes necessary to restore harmony to the various parts of which it consists, the artist generally lays them together in the position which they are afterwards intended to occupy, in order that he may be enabled to judge of their combined effect. For this purpose he fixes them in their respective places upon the glass plate of the easel, or upon a plate of glass of a proper size, which is placed in a frame.

There are two ways of holding the pieces of glass together. They may be fastened upon the glass plate with wax, which is spread out between the fingers and rolled upon a flat surface. The wax takes the place of the leading, and fills up all interstices. The pieces of glass may also be encased in lead. Fastening with wax has the advantage of being materially cheaper than leading, only it is deficient in solidity. When it is warm, the wax becomes so soft that the pieces do not hold together well, and numerous accidents are the result. A work which has occupied much time may be ruined in a single moment. It is also difficult to free the glass entirely from the wax which adheres to it without a considerable loss of time, and if any wax remains behind it is injurious to the painting. Besides, the idea that leading is more expensive is merely illusory, when it is the painter himself who fastens the pieces with wax; for the cost of the leading is more than compensated for by the value of his time, because the former is done by a glazier, who only solders together the ends of the strips of lead. Fastening with wax is only practised at Sèvres; at Munich leading is preferred.

OF ENGRAVING UPON GLASS WITH HYDROFLUORIC ACID.

This style of decoration, which has nothing in common with the proper art of glass-painting, is nevertheless frequently and advantageously employed as an assistant to this art. It is generally used for *overlaid* glass, as it is called (white glass, upon which a coating of coloured glass is fixed in the blowing). It consists of a kind of white drawing upon a coloured ground, and it is obtained by removing the coating of coloured glass in all those places where it is intended to lay bare the white stratum, according to the form of the drawing. The process of engraving is as follows: The glass is first covered with a coating of oily copal varnish, or, what is better, with merely linseed oil which has been boiled with litharge, in order to preserve from the action of the acid the parts which are not to be etched. This layer is dried in the drying-oven, and the varnish is then removed by means of a graver or needle, and a scraping instrument, from those parts where the glass is to be acted upon by the acid. As soon as this operation is finished, the plate of glass is laid horizontally upon a table, and a raised border of wax is carried round the edge which is capable of containing the acid, which is then poured upon the glass. The acid is allowed to remain upon the glass as long as is necessary to destroy the coloured stratum wherever it is exposed. After this, the piece of glass is washed and freed from the border of wax and the wax ground. The engraving is clean and fine in proportion to the thinness of the coating of glass, and the diluted state of the acid. If the acid is very much concentrated, its action extends over the etching ground, and the lines seem undermined. This kind of drawing is frequently employed for exhibiting silver embroideries upon coloured dresses. It is white at first, but may be coloured yellow, so as thus to imitate gold ornaments.

Glass may be etched by means of hydrofluoric acid, because the latter has the property of dissolving silica. But on account of the exceedingly pernicious effect of this acid upon the health of those who employ it, it has been hitherto almost impossible to use it. In order, therefore, to apply the art of etching on glass to the arts and sciences, it became necessary to find out another means of etching, perfectly harmless, and a suitable etching ground. Dr. Bromeis, of Hanau, a clever young chemist, and after him the celebrated professor, Dr. Böttger, of Frankfort-on-the-Maine, each however by himself, and without being acquainted with the researches of the other, have now discovered such a method of etching, and by means of it have etched plates of glass of any thickness, and have prepared them for giving impressions in the presses which have been hitherto generally employed.

Professor Böttger gave a full account of this invention, which is called *hyalography* by the inventors, in a lecture delivered at a meeting of the *Physical Society* of Frankfort. At the same time he pointed out the advantages which were associated with this discovery, of which we shall only particularize the following:

1. The substance used for etching is *perfectly harmless*, and no vapours or gases are evolved, which, as is the case in copper-plate engraving, are in the habit of producing an injurious effect even upon the plate; moreover, it does not lose its strength, the same quantity can be used for etching several hundreds of lines in glass.

2. Glass admits of an exceedingly delicate treatment, and the lines are more perfectly developed than in engravings on steel or copper.

3. All kinds of porcelain and flint-glass may be very easily supplied with colouring and glittering ornaments, by rubbing in the drawings that are etched upon them with vitreous porcelain colour, which is not difficult of fusion, and then burning it in the muffle.

The inventors intend to make known their method, which, independently of *hyalotypy*, promises to be of great interest, for a very moderate remuneration, as soon as at least fifty persons in the district of the Zollverein will combine to purchase it.

The easel proper for glass-painting.—The easel consists of an oblong wooden frame, whose greatest dimension is its height. Its interior edge is furnished with grooves for the reception of a plate of glass. This frame is placed in a larger frame, and may be raised or lowered in grooves at pleasure. We have an exact representation of it in the old sash-windows. The exterior frame has a series of holes in the direction of its height, on both sides, and the interior frame can thus be supported at any given height by means of pegs which are inserted into these holes on either side. This apparatus is placed obliquely on a table, and supported in this position by two props at the back, which are joined to the upper part of the large frame by means of two hinges. These two pieces are joined together by a cross-bar, and held at a proper distance from the frame by means of moveable iron hooks; a contrivance precisely similar to what we find in step-ladders, for, like them, when it is not wanted to be used, it can be shut up, so as to occupy less room.

Mill for grinding the pigments.—The mill is a circular vessel of porcelain, which receives the runner and the substances to be ground. The bottom of it, towards the centre, rises in the form of a conical or rounded projection, which forms with the lower part of the side a wide groove, in which the runner moves. The runner consists of a thick crown of porcelain, formed out of the segment of a cylinder. It is placed perpendicularly in the vessel, projecting above it. Its lower edge is situated in the groove. As it is supported by the bottom of the vessel, it is capable of revolving on its axis in a horizontal direction. The levigation of the pigments is therefore effected by the rubbing of the lower edge of the runner upon the surface of the groove. This groove is intended to retain the runner in its position, and to cause the substances which are to be ground to collect at the points where the grinding takes place. The upper edge of the runner is level. It has two holes situated opposite to one another, and bored perpendicularly from the surface: they serve to fasten on the piece which is destined to communicate motion to the runner.

A tin plate, of the width of the runner, closes the opening at the top. It has two pegs, which are inserted into the above-mentioned holes. By this contrivance the runner is made to follow every motion which is communicated to the plate.

There are two ways of causing the motive power to act by the help of the plate of metal. We may act upon a point in the circumference by means of a revolving handle, which is let into a wooden plate that serves as a cover. This is the simplest method: but as in this case the runner moves at liberty in its receptacle, as soon as it meets with any check in its circular motion it suddenly quits its path, and the moving it then becomes very troublesome. This might be entirely obviated by means of a pin passing through the centre of the runner and of the outer vessel; but it is better to produce motion by means of a crooked handle, which is made to work in the following manner: The upper surface of the metallic plate has in its centre a circular iron bar, well secured. This bar or spindle serves as an axis, and turns in a hole which is bored in a horizontal cross-piece, or rather in the centre of the lid of a box which covers the runner. The handle is fastened on just where the axis projects out of the box. By this means the centre of the runner is always retained in the same place. It assists the action of the handle, which thus distributes the impulse it receives to all parts at the same time; consequently the runner cannot suffer any concussion, as in the foregoing case.

When the pigments are being ground, it is often advisable to increase the weight of the runner at the commencement of the operation. This is done by placing upon the tin plate another plate of lead of the same diameter, whose weight may be determined at pleasure. It is moveable, and can be easily laid on the plate, and at the same time as easily removed, for which purpose it is merely necessary to take the handle off.

The drying-oven.—The drying-oven is constructed of baked bricks, and at the bottom of it is a cast-iron plate. This cast-iron plate lies over the fire, from which the necessary temperature is conveyed to the interior of the oven. The interior is provided with wire sieves, fixed in frames lying horizontally at short distances one above the other, which admit of a free circulation of air. In front of the oven there is a door, which is closed as soon as the pieces to be dried have been laid in their places. The heating apparatus is similar to that of a common oven which is heated with charcoal or coal.

Furnace.—The furnace consists of a wall of baked bricks,—a fire-pot, the interior of which is lined with fire-bricks, as well as with a coating of clay which is proof against fire,—the grating,—the ash-pit,—a pipe through which the air is conveyed from a pair of bellows into the ash-pit; and grating perforated with several holes, in order to distribute the wind of the bellows uniformly throughout the interior. A good smith's bellows should be used for this furnace.

This kind of furnace is preferred to the common draught-furnace for the preparation of the pigments, because it is capable of producing a very high temperature, and by that means shortening the operation.

Wax for fastening the plates of glass upon the easel.—This wax is similar to modelling-wax, and consists of bees'-wax, 4 parts,—Burgundy-pitch, 1 part.

It owes its ductility to the Burgundy-pitch, and its adhesive property principally to the greasy matter which the bees'-wax of commerce almost always contains. If this is found to be wanting, the deficiency should be supplied by mixing with it tallow in small quantities.

CHAPTER IV.

THE WORK OF THE GLAZIER.

THE work of the glazier consists—1. in cutting out the various pieces of glass which are to be painted, and in giving them exactly the form which the drawing requires;—2. in encasing the glass in lead when the painting is finished, and forming it into the panels of which the whole picture is composed;—3. lastly, in arranging it permanently in the *arming*.

In the two first operations the glazier is guided by a cartoon prepared expressly for this purpose. Upon this the outlines of the pieces of glass are indicated by a mere line, which at the same time determines the arrangement of the strips of lead. The irons by which the glass is fixed in the window are likewise drawn here in their natural dimensions.

Of the cutting the glass.—The cartoon having been placed on a table, the glazier lays upon the drawing a plate of glass whose colour has been determined to a nicety by the painter. He draws the outline of the piece with a brush containing white paint, and then cuts it with the diamond, after which he brings it to the exact form by means of the *riesel-iron*. Among other things he takes care to leave a space between each piece of glass, which is determined by the thickness of the interior of the strip of lead by whose edges the pieces of glass are afterwards to be united. The colour with which the glazier draws the outline of the pieces which are to be cut out is composed merely of Spanish white and weak gum-water; the paint-brush which he employs for this purpose consists of long, flexible hairs attached to a thin cylindrical stick. The painter on porcelain also uses this pencil, and it has the advantage of yielding a line of uniform width.

Although the diamond and its use are well known, we shall, however, mention a few interesting particulars in relation to the properties of this instrument. The diamond which cuts with its natural edge is preferable to that which comes from the hands of the lapidary; for such a diamond only cuts by means of an angle artificially produced. The latter may be very easily seen, when looked at with a magnifying-glass, to possess level sides, and to form a rectilineal edge where these planes intersect. That of the natural diamond is not perfectly rectilineal, but always convex; and this is just the form which is best adapted to cutting glass. When the diamond acts upon the glass by means of one of its edges, it either cuts or furrows it. But in this there is an essential difference, for a piece of glass which has been merely furrowed can never be so well divided. The diamond leaves a scarcely visible trace upon well-cut glass; on furrowed glass, on the contrary, a very distinctly fringed groove may be observed. When the diamond is cutting well, a low, monotonous sound may be heard; if it is furrowing, the sound which it produces is very perceptible to the ear and even to the hand of the glazier. When a line has been drawn with the diamond, and the endeavour which is made to break off the piece of glass is fruitless, the attempt must not be obstinately continued, for it is only necessary to strike gently with the handle of the diamond or some other hard body upon the side opposite to the cut, in order to cause it to begin to separate; only a little more trouble is then required to carry on the separation along its whole length. In this way we avoid breaking the glass. When it is necessary to cut a piece of glass of such a form that it would be difficult to cut it with the diamond, and the attempt would probably fail, recourse may be had to the action of fire.

After the outline of the piece which is to be cut off has been drawn, a little incision is made with the diamond in any part of the line, the glass is then heated with a hot coal at those points through which the separation is to be continued, the heating beginning at the point where the diamond has commenced the separation. If the coal is carried in this way slowly over the glass, in proportion as the separation takes place, the whole piece is at last disengaged. The glazier would do well, however, to draw the piece rather larger than it ought properly to be, for fear that any deviations which might take place as the crack is being continued should spoil the whole piece. The *riesel-iron* is used as a finishing tool to give the requisite form to the glass.

To prevent the necessity of blowing incessantly upon the coal, in order to keep it burning and sufficiently hot, pieces of white wood saturated with subacetate of lead are used, which possess the property of continuing to burn without further assistance, as soon as it has once been ignited at one of its ends. These pieces of wood are generally cut from the willow or poplar, and are then steeped for several days in a solution of the above-mentioned salt, after which they are dried. They are very convenient for hot coals.

The glazier must be supplied with rectilineal and also with curvilinear rulers of various kinds, for cutting the glass. Suppose he has to cut a piece of glass of complicated form—he removes, first of all, from the plate of glass by a rectilineal cut, the glass which lies outside the proper outline, and then, by several cuts in succession, he penetrates into the corners, so that at last it is only necessary to use the *riesel-iron*.

The riesel-iron.—This tool consists of a blade of soft steel 1½ *line* * in thickness, and about 5 inches 5 *lines* in length. At each end is a shallow notch in the direction of its thickness; and by means of these notches a number of small fragments are chipped off the glass one after another, so that those parts which are outside the outline are removed with tolerable rapidity. The glass to be operated upon is held in one hand, and the *riesel-iron* in the other; the edge of the glass is then inserted without any difficulty into a notch of the *riesel-iron,* and by gentle pressure downwards and upwards, the part which lies in the notch is broken off. This action is rapidly and continually repeated, but the use of this instrument requires some skill. The *riesel-iron* must be made of soft steel, and thus possess sufficient flexibility to hold fast the corner of the glass, and at the same time must be hard enough to last a long time for this continuous work. Iron would be too soft.

A *riesel-iron* of a somewhat different construction is also used, which is suited to glass of any strength, and which can be easily repaired. It consists of two perfectly level rulers, 5 inches 5 *lines* in length, at one end of each of which there is a rectangular projection a little more than a *line* in length. These rulers fit one upon the other in such a way that that end of the one which is without a projection is received by the angle of the other, so as to form the notch of the *riesel-iron.* The two rulers slide upon one another, and are joined together by a band, by the binding screw of which they can be fixed in any position. By means of this apparatus, the proper width may be given to the notch, and the instrument may be easily repaired by being taken to pieces.

Of the leading.—After the various parts of a painting on glass have been burnt in, the parts themselves must be united,

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* The line is $\frac{1}{12}$ of an inch, according to French measure.

so as to form a whole. This operation is performed by means of strips of lead in the following manner:

These strips of lead consist of two narrow ribbons joined together lengthwise, by one narrow slip of the same metal running along the centre of both. The arrangement of these three pieces produces a groove in each side of the strip of lead, for the purpose of receiving the edges of the two pieces of glass, which border on one another, and which are thus separated by the middle slip, and covered by the overlapping parts of the leading. The length of the strips of lead is determined at pleasure, and the breadth should be from two to six *lines*, so that the overlapping part may be from two to four *lines* in breadth. We shall afterwards explain how the strips of lead receive their proper form.

The cartoon, according to which the pieces of glass have been cut out, is also used for putting them together and leading them. The glazier begins as nearly as possible in the centre of any of the panels which are to be made up. As soon as the first piece which is to be fixed has been laid in its proper place, it is fastened in several places by pegs which are driven into the table. These pegs or nails without heads accomplish this purpose by the help of small pieces of milled lead, which are laid between the pegs and the glass. One of the sides of the piece of glass is then enclosed in a piece of lead. After this piece has followed the whole outline of the piece of glass, during which pressure has been applied by means of the *lead-jack*, the superfluous breadth is cut off with the lead-knife. A second piece of glass is then fitted on, which, like the first, is fixed with pegs, until a strip of lead has been fastened on. The edges of the lead are pressed down with the *lead-jack*, and the operation is continued until the panel is finished.

The glazier then proceeds to the soldering, which consists in applying the solder to the joinings, thus uniting the various pieces of lead and imparting a greater firmness to the net which they form.

The solder is an alloy of lead and tin, less flexible than the pieces of lead themselves,—consequently it imparts to them a greater power of resistance. In this alloy the tin and the lead are united in equal quantities. Before the solder is used, it must be previously prepared in such a way that it may be conveniently applied. Lead is melted in an iron basin or pot, and as soon as it has become liquid, an equal quantity of tin is added. This done, it is kept at a moderate temperature, and a small quantity of resin or grease is thrown into it, which deoxidizes the metal, and thus restores it to a perfectly liquid state. The oxide and the foreign bodies which float upon the surface are then removed, and the metal is poured out. It is best to cast it in thin ribbon, which on account of its form and its pliability can be much more easily handled. This ribbon may be obtained by pouring a small quantity of solder upon a grooved plate, and inclining the latter a little in the act of pouring. The inclination of this mould must be such that the ribbons or strips which are thus obtained shall be sufficiently pliable without being too thin. As soon as the glazier has provided himself with a sufficient quantity of solder, he sets to work. The solder is applied by means of the soldering-iron: this implement consists of a piece of copper in the form of a cone, the base of which is prolonged and serves as a handle: the latter is held in the hand by means of two concave and moveable pieces of wood which completely surround the hand in their junction. The soldering-iron might also be made of iron, and then it would probably be more durable; but iron does not seem so well adapted to receive the solder as copper. The soldering-iron must be previously tinned at its point. For this purpose, it is necessary to have a tin plate rather concave in form. After the soldering-iron has been heated in a proper furnace, it is rubbed over a piece of sal-ammoniac, in order to clean it, and then over the before-mentioned tin plate, upon which a little resin has been sprinkled for the purpose of deoxidizing the tin. The soldering-iron then receives a portion of tin from the tin plate, and becomes thereby tinned. It is advisable to clean the tinned end of it, whenever it is taken from the fire, by passing it over the tin plate, the metal of which must be renewed as soon as it becomes necessary.

The soldering-iron having been properly heated and tinned, is brought near to the lead, upon which a small quantity of resin has been previously sprinkled. In this position, the solder, which is applied with the other hand, is melted: it is then diffused uniformly and regularly, by the point of the soldering-iron being made to pass over the whole surface of the lead. The soldering-iron must be heated to the proper temperature; if it is too hot, it will melt the lead; if it is too cold, it gives the soldering a wrinkled appearance, which proceeds from the imperfect fusion of the alloy. The lead is soldered on one or both sides, according to the degree of strength which is to be given to the leading. As soon as the soldering is finished, the lead is cleansed from the resin that remains by being rubbed with a piece of linen which has been dipped in oil of turpentine.

The furnace for heating the soldering-iron is nothing more than a circular tin box, with neither grate nor draught. This box is generally placed on three feet, sufficiently high to allow of its being conveniently used. The coals are made to burn up merely by a pair of hand-bellows.

Preparation of the glazier's lead.—The bars of lead are cast in a mould, and when in a rough state bear some resemblance in shape to the strips we have already described, for the production of which these bars are used. The mould is a sort of frame consisting of two parts, each of which is from 1 inch 6 *lines* to 1 inch 10 *lines* in breadth, from 5 to 7 *lines* in thickness, and from 1 foot to 1 foot 6 inches in length. These two pieces have each three longitudinal grooves, which, when they are joined with those of the opposite side, form the cavities in which the bars are cast. The parts of the mould are united at one end by a hinge which admits of the grooves of the frame being shut and opened at pleasure. At the other end of one of these parts is a bifurcated handle which moves on a hinge, and which is capable of clasping the opposite piece with its fork and holding it fast. The grooves of the frame are terminated by a transverse groove near the handle, into which the metal is poured. The frame being shut, is held perpendicularly by the handle with one hand, while the melted lead is poured in with the other. As soon as the lead has solidified, it is taken out of the frame, in order to make room for other castings.

After the casting is finished, the bars are smoothed, that they may be subjected to the milling machine, whereby they are converted into what is called 'glazier's lead.'

The milling machine.—The milling machine consists, first, of two vertical cheeks, which are parallel to one another, and are held together by strong cross-pieces, by means of screws and burrs. Each cheek is furnished with two wide holes between the cross-pieces, in which there are as many revolving cylinders, which we shall presently describe more fully. The corresponding holes in each cheek are at the same height from the bottom of the machine. At the bottom of each of the cheeks also there are two horizontal projections chamfered off, and furnished with holes to receive the iron bolts with which they are fastened to a bench. Two iron cylinders pass horizontally through the intermediate space between the cheeks, and their ends are let into the above-mentioned corresponding holes at each side. The upper cylinder projects beyond the hinder cheek, and at the end of it is a tooth-wheel of 12 teeth, which is held in its place by a burr. The other end of the cylinder only extends to the outer surface of the cheek. The lower cylinder projects beyond the cheeks at both ends. At one end there is a tooth-wheel similar to the one we have already mentioned, into which it fits; the other end is squared to receive a handle. On each of the cylinders, at an equal distance from either of the cheeks, there is a wheel, or disk, which is capable of being disengaged from or fastened to the cylinder. These two disks are thus situated opposite to one another, without, however, coming in contact. The bar of lead which is to be drawn out by the revolving motion of the disks in opposite directions, when the cylinders are set in motion by means of the handle, must pass between these two disks. Their thickness determines the breadth of the groove, and the distance at which they are apart the thickness of the interior strip. On the circumference of these disks there are a few lines engraved, like the scratches of a file, and these are for the purpose of holding the lead more securely.

To each of the cheeks between the cylinders there is attached a heavy piece, of complicated form, which is called the *die*. The die, which is let into a mortised hole in its corresponding cheek, presents an angular surface on its opposite side, which is bounded at the top and the bottom by a rectilineal part called the *nageleinsatz*.

The two planes of the angular surface bear the name of *engorgeures* in French, the broader one being the *engorgeur d'entrée*, the other the *engorgeur de sortie*. At the top and at the bottom of each die there is a semicircular groove corresponding to the adjacent cylinder. It is now evident that the dies, in their mutual relations to one another, in conjunction with the disks, complete the mill which is to give the proper shape to the lead. They serve to form the outer surfaces and the sides of the lead, just as the disks form the core and the grooves. In order to draw the lead, the end of the bar is placed between the two disks in the intermediate space between the dies; the handle being now turned, the bar must pass through the rolling-press, and receive the form and dimensions of the latter. In this operation the lead is considerably lengthened: a bar one foot long will give a strip of lead of more than four feet in length. It is impossible to obtain milled lead of various dimensions without having several pairs of wheels and dies of proper sizes; consequently, if the disks are fixed to the cylinders, it is necessary to have just as many cylinders as disks.

The bench of the machine consists of a simple piece of wood, the ends of which are supported by three legs fixed in the ground.

Before the lead is placed in the machine, it must be smoothed and then *condensed*. The latter operation is performed in the following manner: One end of a bar of lead is bent into the form of a right angle, which is placed under the foot, while the other end is wound upon a piece of wood, by which means the lead is forcibly drawn out: it is thus considerably lengthened, and becomes more rigid. When it is to be used, the lead-jack is passed between the overlapping edges to separate them from one another, so that the glass may be more easily pressed into the groove.

Of the arming.—The chief object of the *arming* is to impart sufficient firmness and power of resisting external violence to church windows. The net of lead which holds the pieces of glass together is by no means capable of doing so for any length of time, unless it is of very small dimensions or supported at certain distances by iron bars. But this iron-work contributes sometimes even to the decoration of the window: Gothic church windows afford an example of this, which consist of numerous panels containing forms of various kinds artistically disposed, so that the whole presents a very pleasing appearance. Here the *arming* pays its tribute to the art by affording the requisite strength to the window: it isolates the panels, and renders their agreeable outlines conspicuous, while at the same time by its complicated pattern it forms a drawing so much the more powerful and effective, as it appears black upon a transparent ground. In those windows, on the contrary, where the *arming* is evidently of no use to the painting, but is merely for the sake of rendering the glass secure, its presence cannot be otherwise than prejudicial to the effect; therefore, in that case, it must be our object to conceal it as much as possible in the shadows, unless we prefer presenting it to the eye as a piece of trellis-work, independent of the picture, just as is generally the case in church windows. The ancients did this very frequently, from a principle of economy.

There are several other methods of constructing the iron *armings;* sometimes, for example, as in the case of Gothic windows, simple iron bars, which have been bent into the form of the outline of the panels, are used, and the latter are fastened to the bars by means of pins disposed at equal distances throughout the whole extent of the former; sometimes there are iron bars which in certain modern church windows receive the panels in grooves in which they are fixed by nails running transversely through them. Sometimes there are merely thin iron bars disposed at the back of the painting, which, by means of bands of the same metal laid on the lead on one side, carried round it and twisted together on the other, render the leading compact.

Armings which are furnished with grooves are difficult of construction: the bars are composed of two plates, which are connected longitudinally at right angles, one in the centre of the other, by means of clenched rivets; or they may be made of a single strip of tin bent at right angles, and then bent back again, so as to form two right angles, which constitute the groove. This kind of *arming* is exceedingly expensive, and will always increase the cost of those church windows to which it is applied. The Gothic *arming,* although simpler, is nevertheless always expensive, on account of the great strength of the iron and the splints which belong to this kind of *arming.* The *arming* which is constructed with thin bars and with ribbons of lead is much more easily prepared, but is less durable, and presents no pleasing appearance.

After the glazier has arranged the panels in the *arming* with splints, nails, or ribbons of lead, he cements all the places through which the rain is capable of penetrating, and thus finishes his work.

CHAPTER V.

ON THE INGREDIENTS FOR COLOURED GLASSES.

The preparation of the glass which is coloured in mass is, strictly speaking, no part of glass *painting,* but belongs properly to the art of *making* glass. Since, however, such kinds of glass are frequently used by glass-painters, we shall here briefly state the ingredients proper for the various kinds of coloured glass.

If we mix with glass, at the time of its manufacture, certain metallic compounds, we impart various colours to it, the shades of which we are capable of varying to any extent by following the general rule, viz. that according as it is required to increase or diminish the intensity of the colour, a small quantity of the colouring metallic oxide must be either added to or taken from the mixture. The colour thus imparted is not superficial, as in the case of porcelain and enamel painting, but is diffused throughout the whole mass, the colouring matter having become a real constituent part of it. In other respects, the same substances are applied to this purpose as are used for the colouring of the pigments in general.

Of the purple glass.—Gold is employed to give a purple colour to glass, similar to that of ruby, for such glass is the most perfect imitation of the ruby in colour, and resembles it almost in brilliancy and liveliness. There is no other substance which is capable of imparting a red of so beautiful a tone to the pot-metal; but extremely delicate manipulation is required in the management of the gold, and a variety of precautionary measures are necessary to insure success. The precipitate of Cassius is the preparation of gold which is most frequently employed for colouring glass purple. We have already described the methods of obtaining it, and we shall now state the reason why it is generally preferred to the rest.

The precipitate of Cassius is one of those combinations containing gold which possesses the greatest stability. It resists a high temperature, and if the reduction of the gold, as we believe it to be, takes place after it has united with the glass, this will only happen at the moment when it can be held by the whole mass in the state of division in which it exists when united with the tin. This combination is less disposed than any other preparation of gold to pass over into violet or blue. The purple of Cassius absolutely requires, in order to be used, to be levigated in a gelatinous state with pulverized glass, borax, or any other substance which is capable of entering into combination with glass, and this with a view to prevent a conglomeration of the particles of the gold. Its power of colouring is such, that one part of the purple of Cassius is capable of colouring 1000 parts of glass. In using this purple it is customary to mix with it the sixth part of its weight of the white oxide of antimony, in order to give the glass a faint tinge of yellow, which reduces the red that slightly approximates to violet to a lively purple. In other respects, all that we have said about the pigments coloured by means of the purple of Cassius applies just as well to the colouring of glass in the melting-pot.

Fulminating gold is also used for colouring glass purple. It is one of those combinations which are obtained by precipitation with ammonia from chloride of gold. Its property of exploding at a very low temperature renders it unsafe to use. In order to deprive it of this property, it is customary to mix it with silica, lime, &c. The same result is obtained with a fixed alkali, the mixture being exposed to a gentle heat. It is also sufficient for the purpose to levigate the mixture with essential oil of turpentine. But the precautionary measures which we are under the necessity of adopting, in order to prevent an explosion, are at the same time indispensable to success in colouring, and that too on the same principle which guides us in the preparation of the purple of Cassius. I mean that the fulminating gold, while moist, must be mixed with a substance which will deprive it of its explosive property, and at the same time hold it in a state of the most minute division.

The purple colour of glass may also be produced by using chloride of gold, sulphuret of gold, and even from aurates, if the operator proceeds according to the method which prevails in the other preparations of gold.

Of the red glass.—The red glass receives its colour from copper, if not in the metallic state, at least at the degree of strongest oxidation. To make red glass, a mixture of sulphuret of copper and oxide of iron is added to the melted mass of glass; or, after a green has been first produced in the mass by means of oxide of copper, the metal is deoxidized by the mixture of a substance containing carbon, and the colour is thus made to pass over into red; this deoxidizing substance is usually bitartrate of potash. It has been found that any other combination which contains carbon would produce the same effect.

Carmine is obtained from copper only; a darker red, from a mixture of iron and copper, in which the former is to the latter as three to one. The quantity of iron is diminished, if it is intended that the tone of the colour shall approach nearer to that of carmine. The glass must be worked as soon as the proper red colour makes its appearance, otherwise it would speedily disappear.

The red which is obtained from copper is so intense that it is necessary to conduct the operation with the greatest care, in order that the glass may not lose its transparency, for it is often in danger of becoming perfectly opaque. Our object must therefore be, to find out a method by which this risk may be obviated. Now this method consists in overlaying the white glass with an extremely thin coating of red glass (*flashed glass*); it is only in this way that transparency can be combined with a beautiful colour.

The ancients only mixed crude tartar, soot, or other deoxidizing bodies, with the mass which had been coloured by copper, for the sake of obtaining the red. But it is best to use protoxide of tin, in order to obtain copper in the state of protoxide. The action of protoxide of tin is not so transient as that of the vegetable substances, whose action naturally terminates with their combustion, and in using which we are liable to a double disappointment; for if they are not sufficiently consumed, the glass will not be so clear, nor the colour so bright, and as soon as the colour has come out properly we must proceed to work up the glass as quickly as possible, because the colour is exceedingly liable to disappear. But all this is avoided by using protoxide of tin. According to Dr. Engelhardt's experiments, the red continued equally fine throughout the whole process, and he never found himself obliged to add deoxidizing bodies. He also met with oxide of tin in all the ancient kinds of glass which he examined, and this oxide was for the most part present in greater quantities than the protoxide of copper itself.

Now, since the colour imparted by protoxide of copper is too intense to admit of its being worked up alone, and the plate which has been coloured throughout would be opaque and appear dark brown, and since it would be necessary to blow it exceedingly thin, in order that the red may become transparent, we can only obtain manageable red plates of glass by flashing a white plate with a very thin coating of red glass. There is, moreover, this advantage in flashed glass, viz. that the red coating may be ground off in different places; thus we obtain white sketches, or, by melting other colours on the surface, sketches of various colours.

That this was the method employed by the ancients is apparent from all the painted windows of the middle ages.

In order to make flashed glass two crucibles are necessary, one containing the red and the other the white glass; the workman first dips his pipe into the red mass and brings up a small globule at the end of it; he then covers this with a proper quantity of white glass. The cylinder which is produced by blowing will exhibit a flashed glass of a beautiful red colour. It is necessary for the purpose of thoroughly uniting the red coating to the plate of white glass, and preventing it from peeling off in the cooling, as happened in Dr. Engelhardt's first attempts, that the composition of white glass should be similar to, if not the same as, that of the red glass; but it is best to make the red glass a little more fusible than the white.

Moreover, the ingredients of the red glass must contain no oxidizing substances. Dr. Engelhardt, who has satisfied himself upon this subject at the glass-houses, proceeds as follows: He places between the large crucibles for the red glass a small crucible, and into this he introduces 4 oz. of protoxide of copper and 4 oz. of protoxide of tin, in addition to the usual ingredients, for every 5 ℔s. of the latter, if they happened to contain minium. But if they do not contain minium, he takes 3 oz. of protoxide of copper, and 3 oz. of protoxide of tin for every 2 ℔s. of salt which the ingredients contained. If the protoxide of copper is not immediately added to the frit, but is introduced into it afterwards, when the latter is beginning to become clear, a much smaller quantity must be added. For scarlet he uses for every 25 ℔s. of frit ½ ℔. of protoxide of tin and 1½ oz. of finely levigated protoxide of iron: these are added just at the beginning of the operation.

As soon as the glass has become clear, he mixes with it 1½ oz. of protoxide of copper, and the whole is well stirred up together. Especial care must be taken to avoid bubbles, which are extremely liable to be formed, and specks of sand, as also that the white and the red mass be ready at the same time to admit of their being worked up together.

It is clear from what we have just stated, that to succeed in obtaining a beautiful plate depends very much upon the workman, for the overlaid glass always remains thicker at the mouth of the tube than at the opposite end of the bulb of glass; the plate is therefore always darker on one side than on the other, and only the middle is uniform; indeed the flashing is sometimes so thin at one end, that the colour disappears and passes over into white. Dr. Engelhardt has in his possession several ancient pieces of glass in which this transition from dark to light has been made of the greatest use in producing certain effects; among others, in the satin drapery of a Judith. However, the workman may with some practice acquire the knack of making tolerably uniform plates of glass, and Dr. Engelhardt hopes soon to obtain this result in a glass-house with which he has become connected for this particular purpose.

A frit containing lead seems more likely to preserve the red than any other frit; Herr Engelhardt, however, says that his experiments are not decisive upon this point.

Of the yellow glass.—There are several compounds with which glass may be coloured yellow, if they are mixed with it at the time of its manufacture. Among these are sulphuret of antimony, antimonite of lead, and chloride of silver. The method of colouring with the latter has, in this case, nothing in common with the production of the silver yellow. The employment of chloride of silver, however, requires a very well-refined glass which does not contain an excess of alkali. Without this precaution the chloride would be decomposed, the silver which is in the melted mass of glass, being now reduced to the metallic state, would suffer a rapid agglomeration of its minute particles, and the colour would in consequence disappear. Chloride of silver is not used on account of its being very expensive. Sulphuret of antimony and antimonite of lead are the only colouring materials in general use. But as the yellow which is burnt in gives a fresher and clearer colour, yellow pot-metal is not much manufactured. We merely wish to mention one other yellow here, which is obtained by an admixture of a carboniferous substance with the pot-metal. This imperfect method, which gives a glass of a disagreeable shade of colour and full of small bubbles, has now fallen entirely into disuse.

In order to colour the glass *blue*, black oxide of cobalt is employed, which causes the formation of the protosilicate.

Violet glass is obtained by means of peroxide of manganese with or without an admixture of oxide of cobalt.

A *green* is imparted to glass with oxide of copper, oxide of chromium, or a mixture of antimonite of lead and oxide of cobalt. Oxide of chromium gives a less transparent colour than oxide of copper.

Black glass is prepared from oxide of manganese, oxide of iron, oxide of copper, and oxide of cobalt, in combination with one another. This colour depends upon the mixture of the three colours which are produced by these oxides; that is to say, the mixture of green, blue, and violet, which in proper proportions will give a black.

Finally, glass is made *white* and *opaque* with stannic acid or phosphate of lime, obtained by calcining bones.

Phosphate of lime, or calcined bones, is also used in the manufacture of *opalescent* glass. The exact receipt for the mixture will be given below. Opalescent glass is employed with advantage in every case where the direct rays, or even the reflected light of the sun, is prejudicial to workmen. This, for instance, is the case in the workshops of goldsmiths, jewellers, &c., in government offices, banking-houses, &c., which are situated on the ground floor, where it is often necessary to use ground glass. So also this glass is of great service for all kinds of lamp-glasses, since the grinding of concave or convex surfaces is attended with difficulty, and makes such glass expensive.

We will now give several receipts for the ingredients of coloured glasses:

Mixture for Rose-coloured Glass.

	Parts.
White sand	100
Potash	48
Slaked lime	8
Purple of Cassius	6
Peroxide of manganese	4

Or,

White sand	100
Minium	78
Caustic potash	35
Nitrate of potash	7
Purple of Cassius	8
Peroxide of manganese	4
Sulphuret of antimony	4

Red Glass.

White sand	100
Minium	60
Caustic potash	30
Nitrate of potash	5
Purple of Cassius	12
Peroxide of manganese	6
Sulphuret of antimony	6

Yellow Glass.

White sand	100
Potash	50
Slaked lime	8
Antimony-yellow, coloured with oxide of lead	6

Or,

White sand	100
Potash	40
Lime	10
Antimony-yellow, coloured with oxide of lead	10

Or,

White sand	100
Minium	80
Caustic potash	36
Crystallized nitrate of potash	12
Antimony-yellow, coloured with oxide of lead	8

Blue Glass.

	Parts.
White sand	100
Minium	150
Caustic potash	35
Calcined borax	10
Oxide of cobalt	4

Or,

White sand	100
Potash	50
Slaked lime	6
Oxide of cobalt	1

Or,

White sand	100
Minium	80
Caustic potash	40
Nitrate of potash	8
Oxide of cobalt	1

Green Glass.

White sand	100
Refined pearlash	50
Slaked lime	8
Green oxide of chromium	2

Or,

White sand	100
Refined pearlash	50
Slaked lime	9
Yellow oxide of antimony	4
Oxide of cobalt, or zaffre	2

Or,

White sand	100
Minium	75
Calcined potash	38
Nitrate of potash	4
Green oxide of chromium	2

Or,

White sand	100
Minium	60
White pearlash	40
Oxide of arsenic	6
Glass of antimony	9
Oxide of cobalt	5

Or,

	Parts.
Whitewashed sand	100
Minium	85
Calcined potash	38
Nitrate of potash	8
Yellow oxide of antimony	4
Oxide of cobalt	2

Violet Glass.

White sand	100
Pearlash	48
Slaked lime	7½
Oxide of manganese	4-10

Or,

Whitewashed sand	100
Minium	78
Calcined potash	35
Crystallized nitrate of potash	8
Peroxide of manganese	1-2

Black Glass.

White sand	100
White pearlash	66
Slaked lime	8
White glass, pulverized	70
Oxide of arsenic	6
Oxide of cobalt	10
Peroxide of manganese	10
Acetate of iron, or even iron in the highest state of oxidation	5

Or,

White sand	100
Pearlash	48
Lime	6
Oxide of cobalt	4
Peroxide of manganese	3
Oxide of copper	3
Black oxide of iron	4

Or,

	Parts.
White sand	100
Minium	82
Calcined potash	38
Nitrate of potash	8
Oxide of cobalt	8
Peroxide of manganese	8
Black oxide of iron	12
Oxide of copper	12

Opalescent Glass.

White sand	100
Refined pearlash	50
Slaked lime	16
Oxide of silver	3-6
Phosphate of lime, or calcined bones	6

Or,

White sand	100
Purified soda	450
Slaked lime	160
Calcine,* or white broken glass	500
Hydrochlorate of silver	10
Phosphate of lime from mutton bones	60
Oxide of arsenic	30

White opaque Glass.

White sand	100
White pearlash	66
Slaked lime	8
White glass, pulverized	50
Oxide of lead	100
Oxide of arsenic	3

Or,

White sand	100
Calcined potash	50
Slaked lime	16
Oxide of tin	60

Or,

White sand	100
Minium	78
Calcined potash	30
Nitrate of potash, in crystals	8
White oxide of tin	62

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* A calcined mixture of oxide of lead and oxide of tin in the proportion of 4 of the former to 1 of the latter.—(*Author's Note.*)

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