

III. *A Letter to the Right Honourable the Earl of Morton, President of the Royal Society. Containing Experiments and Observations on the Agreement between the Specific Gravities of the several Metals, and their Colours when united to Glass, as well as those of their other Proportions: By Edward Delaval, F. R. S. M. A. and Fellow of Pembroke Hall, Cambridge.*

MY LORD,

Read Jan. 24, 1765. **I** TAKE the liberty of laying before your Lordship the following paper, containing a variety of facts and experiments, which I have endeavoured to apply to some Optical inquiries.

Besides the experiments originally contrived and made by myself, I have repeated most of those which I have quoted from others.

Sir Isaac Newton, in his *Optics*, has shewn by a series of experiments, that the several differences of colours, exhibited by thin transparent plates, are occasioned by their several thicknesses; and that therefore the transparent parts of bodies do, according to their different sizes, reflect rays of one colour and transmit those of another; and consequently that the bigness of the component particles of natural bodies may be conjectured from their colours; since the particles of those bodies most probably exhibit the same colours as a plate
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of equal thickness, provided they have the same density. He concludes this whole doctrine in these words: "I have hitherto explained the powers of
 "bodies to reflect and refract, and shewed that
 "thin transparent plates, fibres, and particles, do,
 "according to their several *thicknesses* and *densities*,
 "reflect several sorts of rays, and thereby appear
 "of several *colours*; and by consequence, that no-
 "thing more is requisite, for producing all the
 "*colours* of natural bodies, than the several *sizes*
 "and *densities* of their transparent particles."

Though he has accurately shewn what *colours* arise from the several changes of *thickness*, I do not find that any one has attempted to explain *in what manner* the differences of *density*, in the component particles of bodies, contribute to produce the several differences of *colours*: and therefore I thought, that if instances could be produced of bodies whose several differences of *colour* appear to be proportioned to their several degrees of *density*, it would tend to illustrate this part of Optics.

To this purpose, however, are conducive all those experiments and observations, from which Sir Isaac Newton has inferred that bodies have their *refractive and reflective powers* nearly proportional to their *densities*; and that the *least refrangible* rays require the *greatest* power to reflect them: which is deducible from, hence, 1. that the *red* rays are reflected at the *greatest* obliquity of incidence, and the *violet* at the *least*, 2. that the *violet* is reflected, in like circumstances, at the *least* thickness of any thin plate or bubble, the *red* at the *greatest* thickness, and the intermediate colours at intermediate

thicknesses. 3. The same appears from the table (p. 206.) in which the thicknesses of air, water, and glass, and the colours produced by them are set down.

These experiments are applied by him to transparent bodies and the colours exhibited by them; but they are equally applicable to permanently coloured bodies: and it appears from them, that *denser* substances ought, by their *greater reflective power*, in like circumstances, to reflect the *less refrangible* rays, and that substances of *less density* should reflect rays proportionably *more refrangible*, and thereby appear of several colours in the order of their density.

In confirmation of this reasoning, I shall give instances of natural bodies, which differ from each other in *density*, though circumstanced alike in other respects; and shall shew that they differ in *colour*, in the same order they do in *density*, the *densest* being *red*, the next in *density* *orange*, *yellow*, &c.

In such an inquiry metallic bodies seem to deserve our first and principal attention, as their *specific gravities* have been ascertained by well known and repeated experiments. Without entering into a minute chemical theory of the principles of metals, it is sufficient to observe that they are universally allowed to consist of 1. an inflammable or sulphureous matter, which is of the same kind in all the metals; 2. of a fixed matter or calx, which appears in each of the metals to be specifically different in *weight*, as well as in other properties.

As the sulphureous matter, in the intire metals, acts strongly on the rays of light, it is necessary to calcine, or to divide them into extremely minute particles, in order to examine separately the action of the calx, or fixed matter, on the rays of light.

In order to examine all the metals in like circumstances, by reducing them into the smallest particles, and depriving them of their sulphur as far as was practicable, I exposed each of them, united with a proper quantity of the purest glass, *without any additional ingredient, to the greatest degree of fire* they are capable of bearing, *without having all colour whatever destroyed.*

In this state it appears, from a variety of experiments and facts, that they actually do, without any exception, exhibit colours in the order of their densities, as follows,

Gold	————	Red.
Lead	———	Orange.
Silver	———	Yellow.
Copper	——	Green.
Iron	———	Blue.

GOLD.

G O L D.

GOLD, which is the densest of all the metals, imparts a red colour to *glass*, whenever it is divided into particles so minute, that it can be intimately mixed with the ingredients of which the glass is made; and it seems indifferent in what manner it is reduced to this state. Thus

1. From the powder obtained by rubbing *gold* with a pumice stone, used by the goldsmiths in polishing it, mixed with nitre, borax, and potash, a beautiful *red* glass is produced [*a*].
2. When a small quantity of a solution of *gold* in aqua regia is evaporated on a *glass* plate, with a gentle heat, that part of the *glass* on which it lay thinnest, is tinged *red*, by the entrance of the particles of *gold* into it's surface [*b*].
3. Artificial rubies are made by mixing with *glass*, *gold* dissolved in aqua regia, and afterwards calcined in the furnace [*c*].

[*a*] Sol sine veste, cap. 8.

Junker, Conspectus Chem. tab. xxxiii. de Auro, p. 852.

Aurum detritum pumice, seu pulvis auri pumice, quo aurifabri sua opera poliunt et abradunt, commistus, Gold-Schliff, si cum ana nitri, boracis, et cinerum clavellatorum liquido fundatur, præbet *vitrum*, instar optimi opificum encaustici, *rubro colore* pellucidum, subidentibus paucis auri granulis; testante autore Solis sine veste.

Shaw on Boerhaave's Chem. vol. i. p. 79. *Gold* ground with pumice, and afterwards fused with equal parts of nitre, borax, and pot ashes, affords a fine transparent *red glass*.

[*b*] Philos. Trans. N°. 286.

[*c*] Neri's art of Glass, chap. 129.

Calcine *Gold* with aqua regia many times, pouring the water upon it five or six times: then put this powder of Gold in

4. Kunkel

4. Kunkel prepared a powder for the same purpose, by precipitating the *gold* from the solution by an alkaline liquor [*d*].
5. *Gold* precipitated by tin from aqua regia, and melted with *glass* in a proper proportion, tinges it with a beautiful ruby colour: this method was discovered by Cassius [*e*], and farther improved by Kunkel [*f*].
6. The same colour is produced by fusing *gold* with a large proportion of tin, and two thirds of lead, or by mixing it with regulus of antimony, or tin by calcination, and adding to *glass* the powders of *gold* obtained from these processes [*g*].
7. *Gold* amalgamated with mercury, and digested with it for a considerable time, may be reduced to a subtile powder by expelling the mercury: this powder, melted into the *glass*, tinges it of a *beautiful red* [*h*].

earthen pans, to calcine in the furnace, till it becomes a *red* powder; which will be in many days; then this powder, added in sufficient quantity, and by little and little, to *fine crystal glass*, which has been often cast into water, will make the transparent *red of a ruby*, as by experience is found.

[*d*] Lewis's History of Gold, p. 176.

[*e*] Cassius de Auro, p. 105.

[*f*] Junker, Confp. Chem. tab. xxxiii. de Auro, p. 861.

[*g*] Shaw's Notes on Boerhaave's Chem. vol. i. p. 78.

[*h*] Shaw's Abridgement of Boyle, vol. i. p. 459.

An industrious person, having united *Gold* with a particular quicksilver, kept them in digestion for some months; when the fire having been immoderately increased, the sealed glass burst with a frightful noise: though the upper parts were blown off and shattered to pieces, yet the lower escaped tolerably whole; and I took notice, with delight, that it was tinged throughout of a *fine and glorious red*, hardly to be matched by that of *Rubies*.

8. *Gold leaf* melted into the surface of *glass*, by the electric force, imparts a *red colour* to it: this was first observed by Dr. Franklyn, and has been often repeated [*i*].

There are many other ways of communicating this *colour to glass* by *Gold*; and I find no method by which it can be made to produce any other colour. If it be mixed in larger masses, without being minutely divided, it imparts no colour to the glass, but remains in its metallic form.

Grummet attributes this colour to the manganese, used in making some sorts of glass, the colour of which he supposes revived by the nitre used in the preparation of the gold: it is necessary therefore to mention, that I have given a *red* by *gold* to several *glasses*, in the composition of which there was *no manganese*, and often by gold in the preparation of which there was *no nitre*.

Several preparations of *gold* will impart a *fine red* to the fritt or materials of which glass is made, in a small degree of heat; though not minutely enough divided, or in too large quantity, to remain mixed with the glass, when exposed to a degree of heat sufficient to vitrify them perfectly.

[*i*] Franklyn's Letters on Electricity, p. 65.

L E A D.

LEAD, which is the metal whose *density* is next in order to that of gold, affords a glass of the colour of the Hyacinth, a gem whose distinguishing character is, that it is *red* with an admixture of *yellow*, the same colour which by writers in optics is called *orange*.

1. Lead, kept in fusion for a considerable time, in a strong crucible and a very violent heat, is reduced to a glass of the colour of that gem [*k*].
2. Lead reduced to litharge, and melted with one third or fourth part of it's weight of sand, in a covered crucible, in a strong fire for two or three hours, unites with the sand into an *orange-coloured glass* like the former [*l*].
3. *Glass of Lead* is mentioned by several authors, as a composition proper, without the addition of any other ingredient, for imitating the *Hyacinth* [*m*].

[*k*] Flora Saturnizans, chap. II. Henckel de appropriatione, cap. ii. sect. 4.

[*l*] Junker, Conspect. Chem. tab. XIX. p. 434.

Recipe Lithargyrii partes tres, arenæ nitidæ partem unam; mista imponantur forti tigillo; per 3 circiter horas tenuissime fundantur, quo facto massam fluentem in calidum mortarium effunde, et habebis vitrum pellucidum, *Hyacinthini ferme coloris*.

[*m*] Shaw's Lectures, p. 299.

Lead melted into glass with sand is the foundation of imitating all the coloured gems: for this glass itself will resemble the Hyacinth, &c.

Merret's Notes to Neri, chap. 61.

Our author mentions not a *Hyacinth* from *glass of Lead*. Bap. Porta supplies you with it, l. vi. c. 7. in these words: To make

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SILVER.

S I L V E R.

YELLOW is the only colour which *silver*, the metal next to lead in *density*, can by any preparation be made to impart to *glass*.

1. Without insisting upon what some chymists affirm, that *silver*, on being calcined and exposed to a violent fire for a long time, was partly reduced to a *yellow glass* [n],
2. I have often given *that colour*, by moistening the surface of the *glass* with a *solution of Silver*, and afterwards making it red hot.
3. If *Silver* be calcined with sulphur, it readily communicates a *yellow colour* to *glass* [o].

a very *Hyacinth*, and not much differing from the true one, put *lead* into earthen pots that are very hard, in a *glass furnace*, and there let it stand some days, and thus your *lead* is turned into *glass*, and imitates the *colour of the Hyacinth*.

Nichols's History of precious stones, part i. chap. 7. of the *Hyacinth*.

The *Hyacinth* is a stone (as saith Boetius and Rulandus) which is *red* with a certain *yellowness*, or *rufescit in auro*; that is, it is *red in yellow*. Impostors adulterate it with a kind of *glass made of Lead*.

Boetii gemmarum et lapidum historia, l. ii. c. 31. Adulterium *Hyacinthi* vix meretur; in illius locum aliquando substituitur *ex plumbo vitrum*, quod a verâ gemmâ pondere et duritie facile distinguitur; mollius enim et gravius verâ gemmâ.

[n] Merret's Notes on Neri, chap. 82. Claveus saw *Silver* calcined two months in a *glass furnace*; the twelfth part of which became a *citron glass*.

[o] Shaw's Abridg. of Boyle, vol. i. p. 458. To shew more particularly that *glass* is porous, we took *silver* calcined by burning *sulphur* on it in the open air, and laid it upon a piece of *glass*, and placed it with the pigment uppermost, upon a few

4. Having

4. Having carefully purified an ounce of *Silver*, I kept it in fusion some hours, with a small quantity of *glafs*, and found, that the *glafs*, when cold, had formed a beautiful *yellow enamel* on the surface of the *silver*.
5. *Leaf silver* laid on red hot *glafs* tinges it *yellow*.

When we meet with authors, who mention a blue or greenish colour communicated by *silver*, the cause must have been, that the *silver* used in such processes was mixed with *copper*, as it generally is, when it is not carefully purified [p]. I have always found, that *silver* purified by the *test* retained so much *copper*, that, when melted several times with nitre and borax, it imparted a *green tinge* at the first and second melting, though afterwards *no such colour* was obtainable from it.

quick coals to Neal a while; we gave it such a heat as might make and keep it red hot, without fusion; and then suffering it to cool by degrees, we found that the *glafs* had required a *yellow and almost golden colour*.

Shaw's Abridg. of Boyle, vol. ii. p. 98. I learned from one of the chief artificers in painted *glafs*, that those of his trade colour it *yellow* with a preparation of a *calx of Silver*.

Kunkel's Art of *glafs*, part ii. art. 49. Experiment shews that it is from *Silver* the *finest yellow* is obtained. Shaw's Lectures, p. 316. A little *Silver* tinges white *glafs yellow*.

Hook's Micrographia. obs. 10. of Metalline colours. A third argument that the particles of metals are transparent is, that being calcined and melted with *glafs*, they tinge the *glafs* with transparent colours. Thus the *calx of silver* tinges the *glafs* on which it is annealed with a *lovely yellow or gold colour*.

[p] Merret's Notes on Neri, c. 90. Junker, Conspect. Chem. tab. xxxiv. p. 889. 901. Shaw's Abridg. of Boyle, vol. ii. p. 98.

C O P P E R.

GREEN is the only colour which *copper*, the metal next to silver in *density*, communicates to *glass*, when melted with it in a sufficient heat, *without any additional ingredient*: Thus

1. By grinding *crystal glass* in a *copper* mortar, and afterwards melting it, it becomes *green*.
2. *Copper* calcined *per se* in a furnace [*q*].
3. *Copper* calcined with sulphur [*r*], and
4. Scales beaten off from red hot *copper* plates mixed with *glass*, equally impart a *green colour* to it.

It is indifferent in what manner the *copper* is prepared, in order to tinge the *glass* green, provided it be exposed, *without any other ingredient*, to a sufficient degree of heat [*s*]. I have frequently produced a *fine green* from *copper* filings unprepared.

[*q*] Shaw's Abridg. Boyle, vol.iii. p. 98. Though *copper calcined per se* affords but a dark and basely-coloured calx, yet the *glass-men* tinge their *glass* *green* therewith.

Neri, chap. 92. This sort of *purest glass* will be tinged into all colours you desire: for example, into an *emerald* with *brass* thrice calcined, as is done for ordinary *glass*: into a *sea green* with *brass* calcined to redness.

[*r*] Junker, Consp. Chem. tab. xix. p. 433. *Beryllus marinæ viriditatis per cuprum cum sulphure calcinatum*.

[*s*] Kunkel's Notes on Neri, chap. 32. Though with *copper* alone one may produce *green*, it is nevertheless *crocus martis* differently prepared that makes a variety in it. I have not found that the different manners of preparing *copper* have produced different colours. I have experienced that by calcining *copper per se*, without any addition, I could produce all the effects that the author teaches us to bring about by different preparations of that metal.

If a quantity of *salts* be added in the preparation, they will, by attenuating the mixture, and consequently *lessening* its *specific gravity*, make the glass incline to blue, the colour next in order [*t*]; but this happens only when the fire is moderate; for in a greater degree of heat, the redundant salts, even those of the most fixed nature, are expelled [*u*].

It is true, that copper is mentioned by some writers, as an ingredient in *red* glass and enamel: but the *red*, which is the colour of the metal not dissolved or mixed with the glass, remains only while the composition is exposed to such a degree of heat as is too small to melt and incorporate it; for, if it be suffered to remain in the furnace *a few minutes after the copper* is added, the mass will turn out *green* instead of *red* [*w*]: in effect, the preparation of *copper* recommended on this occasion, is exactly the same as that used in tinging *glass green*.

[*t*] Flora Saturnizans, chap. xi. art. 6. When a green colour is to be given to glass, care must be taken *not* to use *too much salt* in the composition of the glass; otherwise the colour will be *blueish*, and bordering on the colour of the aigue marine.

Neri, chap. 32. An emerald colour in glass.

In making green you must observe that the metal have *not much salt*; with metal that hath much salt, as crystal and rochetta have, you cannot make a fair green, but only a sea green; for the salt consumes the green, and always inclines the colour to a blue; wherefore, when you would make *a fair green*, put *common metal*.

Shaw's Lectures, p. 29. Copper precipitated with common salt out of aqua fortis gives the torquois colour to white glass, when melted therewith.

[*u*] Kunkel's Remarks on Merret's Notes, p. 299.

[*w*] Neri, chap. 127. This chapter describes the method of making red glass, in the composition of which copper is used; and

I R O N.

IRON, being of all metals the most imperfect, is subject by various means, to be calcined or reduced to a ruddy crocus, similar to the rust that arises from it's being corroded by the acid in the air. In this state, it requires a considerable degree of heat to dissolve and incorporate it with glass: till that heat is applied, it retains it's ruddy colour; by increasing the heat, it passes through the intermediate colours, till it arrives at it's *permanent* one, which is *blue*: this being effected in the same degree of heat in which we have examined the other metals, that is, *the greatest that the glass will bear without losing all colour whatever.*

The green, with which the glass used for bottles and chemical vessels is tinged, is occasioned by the iron contained in the vegetable ashes and sand, of which that glass is composed. When the pots, in which the matter has been kept in fusion, are

Kunkel makes the following remark on it: " This composition " is very difficult to make ; it is necessary to seize the moment " at which the matter is well tinged *red*, to take it immediately " from the fire ; for half a quarter of an hour too much is sufficient to *change it's colour.*" In the next chapter, speaking of a *red enamel*, into the composition of which *copper* enters among other ingredients, Kunkel makes this remark : " This composition is very fine, and less troublesome than the preceding one : " but, after having added the *copper*, the matter must not be left " on the fire : if this is not attended to, *it becomes green*, and the " *red colour* that it had taken at first *does not last.*"

Gellert, Chem. Metallur. problem 97. *Copper* gives a blood-red to glass; but if it is left too long on the fire, *it becomes green.*
nearly

nearly emptied, the glass remaining at the bottom is always *blue*; this is caused by it's continuing longest exposed to the fire, and in so small a quantity that the fire has a greater effect on it. The whole mass acquires the *same colour*, if too much sand be added in proportion to the ashes; for, in that case, the materials being more difficult of fusion, the workmen are obliged to apply a greater heat, and to continue it longer.

It is known, from the experiments of Lemery and others, that the vegetable ashes contain iron [x]. To examine whether that metal be also contained in the sand used in making this glass, and how far the colour of the glass depends upon it, I made the following experiments :

Exp. 1. Having procured some of the sand used in making green glass, I melted two parts of it with one part of borax, and one part of nitre, and found that it produced a glass similar in colour to that which is made with the same sand fluxed with pot ashes. From hence it appears, that the colouring matter was contained in the sand.

Exp. 2. I mixed three parts of this sand with one of powder'd charcoal, and exposed it for some

[x] Becher, *Phyf. Subterr.* p. 67.

Hæc prima terra (vegetabilis) cum mineralibus vitris, quæ ex arena et silicibus parantur, conveniens est, ut nulla re, nisi colore, inde discerni queat, qui *viridis* est, vel *subcæruleus*, indelebilem regni sui asteriscum servans, nempe *vegetabilem viriditatem* exprimens.

Flora Sat. cap. 8. Note

As that *blue* or *green* colour is owing to the *iron* which is found in the ashes of all vegetables, it must not be looked on as a mark capable of characterising a vegetable earth.

hours

hours to a red heat. When this mixture was cold, I separated from it, by a magnet, small grains of *iron*, weighing about one twentieth part of the sand.

Exp. 3. I melted sand thus *deprived of it's iron*, with half its weight of borax and the same quantity of nitre, and found that it produced a perfectly *colourless* and transparent glass.

Exp. 4. To two parts of the white sand used in making crystal glass, and one of borax and *nitre*, I added a twentieth part in weight, of the *grains of iron*, which I had extracted from the sand by Exp. 2. and having vitrified this composition, I found that it was become exactly similar in *colour*, to that commonly used in making green glass.

Exp. 5. I exposed several pieces of *green bottle glass*, made at different glass-houses, under a muffle, to a strong fire, for the space of half an hour, and found that they were all become *blue*.

If the crocus of iron is added in too great a proportion, it continues to adhere together, and remains unmixed, or at least imperfectly mixed, with the glass, retaining for that reason the colour natural to it when undissolved; or if it be in a smaller quantity, though yet in too great a proportion to be dissolved, it will make some intermediate colour between the *ruddy* and the *blue*, which last it always imparts, when in a sufficient degree of fire and a proper proportion. The necessity of a due proportion of metal to the glass has been already instanced in gold, which if in too large a proportion to be dissolved by the glass, in-

stead

stead of imparting a red colour to it, runs together in it's metallic form.

Henckel has given us a method of making a *beautiful blue glass* by this means. It consists merely in mixing *iron* with the matter of which the *purest glass* is composed, and exposing it to a *violent fire*. Gellert observed also, that *iron* imparts to *glass* this colour [y]. Mr. Lehman obtained the same colour from emery, which is a kind of *iron ore*, or *ferruginous stone*, by mixing it with a vitrifiable earth; which colour he attributes to the *iron* contained in it [z]. Neri mentions a *sky colour*

[y] Henckel, Defert. 6. On a *blue* obtained from *iron*.

I coloured glass with *iron*, and gave it a *very fine blue*. I had calcined, in a pot, filings of Styrian *steel*, which I kept about a quarter of an hour in the fire, without stirring them, till they had taken a purple colour, bordering on violet; I mixed about half a grain, which I had ground well in a glass mortar, with fifteen grains of very white flint and a very fine alkali; I put the whole into a crucible, covered it with care, and exposed it to the *most violent fire*. The furnace being cooled, I found a *glass* of the colour of a *sapphire*; it was impossible to see a finer *blue*, either for colour or transparence.

Gellert. Chem. Metallurg. vol. ii. prob. 97. Cobalt calcined gives to glass a very fine blue; but if too much cobalt, for example an eighth part, is used, the glass will become black. The calx of *iron* produces the *same effect*; and sometimes it happens that one side of a thin piece of glass is of the colour of *rust*, while the other side is *blue*.

[z] Lehman, Treatise on the formation of metals, p. 37.

As to the earth of cobalt, or bismuth, which is the basis of the blue colour, Henckel considered it as a *martial earth* in his Opusc. miner. p. 573. Some experiments which I have made render that opinion very probable. I have obtained a *very fine blue colour* from a *ferruginous Spanish emery*: having once pulverised half a pound thereof and mixed it with an equal part of black flux, I melted this mixture in a well-covered crucible in a pretty

imparted to glass by Bohemian granates, which he constantly practised at a manufactory in Flanders [a]. It is well known that *iron* is the metal contained in those stones; that they obey the loadstone [b]; and that, being calcined with a proper heat, they yield a considerable quantity of iron [c].

I exposed in a crucible to a glass-house fire, for the space of thirty hours, part of a flint glass retort, in which a native *green vitriol of iron* had been distilled, and which had been corroded and tinged by it: by this means it became coloured of a *fine*

violent fire: when the matter was melted, I flung in an inflammable substance: when that had intirely ceased burning, I emptied the crucible, and obtained a mass of a *most beautiful sapphirine blue*; but which, as one may imagine, soon attracted the moisture of the air: I repeated the experiment again without putting any black flux, and the colour became still finer; but it was *remarkably beautiful* when the mixture was melted with a *vitriifiable earth*. I can attribute *this colour* only to the parts of *iron* contained in the emery.

[a] Neri, chap. 90. A curious person and practical chemist may extract a wonderful red from gold, from silver a *sky colour*, and a much fairer from *granates* of Bohemia, which are low priced; for, being small, you may draw a tincture from them, as I have often done in Flanders.

[b] Boyle of gems, Shaw's Abridg. vol. iii. p. 107. Suspecting, for several reasons, that some *granates* contain, besides other metal-line substances, many corpuscles of a *ferruginous nature*, I made choice of some small ones, which, by their deep and almost dark colour, I guessed to participate largely of *iron or steel*, and applied them to a vigorous loadstone, which, as I expected, took them up: and hereto they constantly adhered till they were forcibly separated therefrom—ibid. vol. iii. p. 120. A *chalybeate* tincture obtained from granates.

[c] Junker, tab. x. p. 273. *Multi granati minus pellucunt; atque ex his vulgares præduri, atque alioquin igne indomiti, per ignem solarem grandibus vitris causticis collectum, denique in fluorem redacti sunt, ac merum ferrum præbuere.*

transparent

transparent blue, not distinguishable from that which cobalt imparts to glass.

Iron vitrified *per se* is converted into a blue glass [d].

In short, it is indubitable that *iron is the only metal*, which will, *without any addition*, impart to the matter of glass a *blue colour*; for *copper* will not communicate that colour, *without the* addition of a considerable quantity of *salts*, or some other matter that attenuates it; and the other metals *cannot by any means* be made to produce it at all.

Having shewn that the *metals* exhibit colours, invariably in the order of their *densities*, when melted with *glass* in a proper proportion, *without any other ingredient*, and *exposed to a sufficient heat*; I shall proceed to shew that the other preparations of the metals, viz. their solutions, precipitates, crystals, &c. do for the most part exhibit the same *colours*, in the order of their *densities*, though not so invariably as their glasses; some small variation of colour happening in the more imperfect metals, probably from a change of density in their different preparations.

[d] Lewis's Course of Chem. p. 49. The specific gravity of iron is to that of gold as 7,645 to 19,640. This metal requires a great degree of heat to melt it, when it throws out sparkles, loses considerably of its weight, and is at length converted into a *dark blue glass*.

G O L D.

G O L D precipitated from aqua regia, and washed with hot water or boiled in a solution of alkaline salt, becomes *red* on being exposed to a slight heat. Lewis, History of gold, p. 108.

2. The same *colour* is produced when this precipitate of *gold* is ground with oil of vitriol, or spirit of sulphur; or if it be mixed with sulphur, and the sulphur burnt away. Junker, tab. xxxiii. p. 859.
3. The smoaking spirit of Libavius, mixed with *gold* and afterwards drawn off from it by distillation, changes it's colour to a *blood red*.—Sol fine veste, exp. 19. Junker, tab. xxxiii. p. 861.
4. *Gold* is reduced into a *red powder*, by amalgamation with mercury, and exposing it for a considerable time to a slow heat.—Boyle's Abridg. vol. ii. p. 77. Junker, tab. xxxix. p. 987.
5. If six parts of antimony are fused with one of *gold*, and the antimony driven off by the blast, a *red powder* of *gold* is left behind.—Cassius de Auro, cap. 10.
6. If *gold leaf* be cemented and ground with decrepitated salt, hartshorn, pumice, or chalk, and exposed to a proper heat, *the metal becomes red*, and may be precipitated from a solution of those substances in a *red powder*.—Junker, tab. xxxiii. p. 854. Lewis's History of gold, p. 74. Sol fine veste, cap. 6.

7. A *red* tincture may be prepared from *gold* by several methods mentioned by Libavius, Alchem. lib. ii. p. 130. Junker, tab. xxxiii. p. 868.
8. A solution of *gold* in aqua regia prepared from sal ammoniac may be sublimed of a *blood red* colour. The same is effected by dissolving the calx, or crocus of *gold*, in other menstrua. Lewis's History of gold, p. 100. Junker, tab. xxxiii. p. 857.
9. A solution of *gold* in aqua regia, evaporated properly, affords crystals of a *bright red* colour.—Cassius de Auro, p. 109. Junker, tab. xxxiii. p. 862. 868. Lewis's History of gold, p. 99.
10. *Aurum fulminans* moistened with water, has been found to tinge gems deeply of a *fine red*. Phil. Transf. N°. 179.
11. A solution of gold tinges ivory, cotton, the skin, and other substances *red*.

Rubies being frequently found in *gold mines*, it is very probable that they receive their colour from that metal; and from this circumstance, before the experiment had been made, Libavius rightly conjectured that a solution of *gold* would communicate a *ruby* colour to *glafs*. Libavii Alch. p. 88.

It does not appear that, excepting the colour natural to *gold* in its intire state, any other than *red* can be obtained from preparations of this metal: it is from this colour, which *gold* assumes whenever its metallic brightness is destroyed, that writers in chemistry call it *leo ruber* [e].

[e] Libavius de natura metallorum, lib. i. cap. 4. de auro. In suo manifesto citinum est, in occulto summam continet *rube-*

L E A D.

THE only coloured preparation of *lead*, is that produced by calcination in the furnace. The first of the primary colours produced by this process is yellow, the calx passing from that colour through *orange* into red.

It is remarkable, that, though in the calcination previous to the reverberatory heat in which these colours are produced, the lead is *diminished in weight*; yet in the reverberatory fire it *gains* considerably, and in proportion to that *increase of gravity*, it passes from the *more refrangible* to the *less refrangible* colours; so that while the calx remains of a *less weight* than that of the *lead originally*, it's colour is *yellow*; with the *next increase of weight* it passes to *orange*, which is the colour of

dinem; unde et non tantum tinctum ipsum est, sed et tincturam *rubedinis* confert abundantem.

Dum *citrinum* dicitur, externus vultus qualis est post excocti-
onem respicitur: illa tamen citrinitas igne cæmenti et in opere
philosophico summa *rubedine* permutatur. Itaque hinc est philo-
sophorum axioma, quod in *citrinitate* lateat *rubedo* excellentissima,
qualis est *rubedini* gemmæ.

Voces occultum, manifestum, non ita pueriliter sunt accipiendæ,
quasi in superficie sit flavum, in centro *rubrum*: sed progressiones
colorum in perfectione artificiali notantur, quod naturali pro-
clivitate et dispositione post citrinitatem abolitam, assumat
rubedinem.

Leo ruber non solet vocari, ante quam ab arte eleboratum, et
astrale, ut aiunt, factum. Potentia tamen etiam simplex et natu-
rale aurum ita vocare non est absurdum, cujus *tinctura* appella-
tur ejus sanguis, quo vocabulo et *fermentum rubeum* denotatur.

glafs of lead; and when the calx is increased more in weight, so that it's gravity is become *greater* than that of the *lead originally*, it passes into *red*, the next colour in order.

These three colours succeeding each other in proportion as the gravity of the metal increases, seem to prove that, in this case, the *greater* density produces the *less refrangible* colours: and as *orange* is the colour of this calx, when in a *middle degree of weight*, between that which is lighter and that which is heavier than the original metal, it appears that *orange* is the colour natural to *lead* when it's weight is neither much increased nor diminished.

S I L V E R.

THE only preparation of *silver*, which is of any primary colour (except the yellow it imparts to glafs, and other vitreous substances, as earths or salts) is luna cornea, which Mr. Boyle says is of a *fair yellow*, Shaw's Boyle, vol. i. p. 255. Physical Essays, Edinburgh, 1754, vol. i. p. 310 [*f*].

[*f*] Art. 10. Remarks on chemical solutions and precipitations, by A. Plummet, M. D.

When either a muria of sea salt, a solution of salt ammoniac, or spirit of sea salt (for these three have nearly the same effects) is put into a *solution of silver*; it becomes milky, and, as it were, crudled, and at length a white powder subsides to the bottom: this powder, being washed with warm water and dried, is soft and impalpable; it's weight exceeds that of the silver dissolved by

COPPER

C O P P E R and I R O N.

IT appears then that all the preparations of *gold, lead, and silver*, invariably retain the *colours* peculiar to the *order* of their *densities*, and that they are the *same with those which they communicate to glafs.*

The two most imperfect metals, copper and iron, being very easily acted on by almost all menstrua, the colours of their solutions, &c. viz. green and blue, are apt to change into each other's order; the copper in some solvents becoming blue and the iron green, and in other solvents vice versa; this probably depending on the increase or diminution of their densities.

The solutions of copper, in the acids of nitre and sea salt, and in the vegetable acids, are green. But if copper be attenuated, by solution in volatile alcalies, it becomes blue. Theophrastus and others have observed, that *emeralds* are frequently found in *copper mines*; and it is probable that they obtain their tinge from that metal.

I melted some *emeralds* with twice their weight of salts, and found that they had formed a fine *geren glafs*, such as would have been produced from the same quantity of a *vitriifiable earth*, and about a hundredth part of its weight of *copper*.

more the one sixth part. This powder comes much sooner to fusion than silver, but does not recover the appearance or properties of that metal; for it looks like a piece of *yellowish glafs*, semiopaque and brittle, yet bending or yielding a little, whence it gets the name of *luna cornea*.

Iron

Iron dissolved by the vitriolic acid is green ; but if further attenuated by a chemical process, it produces that beautiful colour called *Prussian blue*. Phil. Transf. N^o. 38. Henckel, Dissert. 6.

A similar *blue* may be obtained from the *iron* contained in the ashes of all plants. Henckel, Flor. sat. chap. 8. parag. 55.

Having exposed a pound of wood ashes in a luted crucible, to a pretty strong fire, for thirty hours, the greatest part of them became tinged *blue* by the *iron* contained in them.

A *blue* may be also extracted from a *martial vitriol*, by spirit of wine. Henckel, de appropriatione, chap. 2. parag. 257.

An instance of a mineral substance changing it's colour from *green* to *blue* on it's *specific gravity* being *diminished*, appears in a stone described by Dr. Grew in the Museum of the Royal Society : this gem is a kind of *emerald*, which, when *expanded* by heat, becomes *blue*, and remains of that colour till *cold*, in which state it returns to it's usual colour, which is *green*.

Tin is not capable of being vitrified, or imparting any colour to glass ; nor are any preparations of it of any primary colour.

M E R C U R Y.

THERE is no body of an intermediate *weight* between *gold* and *mercury*; and it is probable that a great part of the difference between their specific gravities depends on the *fluidity* of the one and the *solidity* of the other.

Mercury is not capable of communicating any colour to *glass*, being so volatile that it will not bear the degree of heat necessary to incorporate it with the glass in fusion.

But it is well known that it's *calx*, either prepared *per se*, or by dissolving it in an acid and evaporating the menstruum, is *red*.

2. A solution of mercury tinges the skin, &c. *red*, as *gold* does.

P L A T I N A.

THE *specific gravity* of *platina* being nearly equal to that of *gold*, it seems necessary to examine whether the colour of it's preparations correspond with those of gold.

On looking into a dissertation written by Dr. Lewis on that metal, in the *Philos. Transf.* I find that the *precipitates* and *crystals* obtained from solutions of *platina* are *red*: and that a solution of that metal in aqua regia to perfect saturation is of a *dark red*, though, when diluted, *yellow*; in the same manner that “a *red liquor* (as Sir Isaac Newton “observes) in a *conical glass*, looks of a pale and
“ dilute

“ dilute *yellow*, at the bottom, where it is thin ;
 “ and a little higher, where it is thicker, *orange* ;
 “ where it is thicker still, it becomes *red* ; and
 “ where it is thickest, the liquor is *deepest and dark-*
 “ *est*.” Newton’s Opt. p. 160.

HAVING gone through these experiments and facts, which seem to shew that the *metals* invariably exhibit *colours* in the order of their *densities*, when melted with *glafs*, under the circumstances above mentioned ; and that the *other preparations* of the same metals, for the most part, assume the *same colours* ; it seemed probable that the cause, on which the colour of natural bodies depend, may sometimes be conjectured from the chemical analysis of such substances. This I have attempted with regard to the colour of plants.

It is known from the experiments of Lemery and others, that all earth is impregnated with *iron* ; that the *ferruginous* matter is received into the roots of plants in their growth, and makes part of their substance, and is universally diffeminated through them ; and that *iron* may be separated by a magnet from the *ashes of all vegetables* [g].

It has been already observed, that the *green* colour of the *glafs* used in making bottles, is caused by the *iron* contained in the materials of which it is made ; and I have cited Becher’s opinion, that the *green* or *blue* colour in glafs is an indelible mark of it’s *vegetable* origin.

[g] Lemery’s Mem. de l’Academ. anno 1706.

Memoirs of the Acad. of Upsal and Stockholm, of the earth found in vegetables, by J. G. Wallerius, 1760.

This observation of the constancy of that *colour* in glafs made of *vegetable ashes*, and it's being caused by *iron*, led me to conjecture, that the *colour* of the *intire vegetables* arises also from the iron, so universally diffused throughout their substance in their growth.

Green is the colour which *iron* assumes constantly, when dissolved by the *acid in the air*; that metal thus dissolved being a true green vitriol of iron [b]: and as this ferruginous or vitriolic matter is universally disseminated through the leaves and branches of plants, those parts of it which are at the surface will, by their contact with the air, assume the colour peculiar to its salt or vitriol.

Most vegetables, when they grow in such a manner as to be defended from the contact of the air, are prevented from becoming green.

This happens to the roots of trees, and as much of their stem as is covered with earth: grass growing under stones, or other bodies, that accidentally lie on it, is white; not having the least green, but as the air has access to it: and it is a method commonly used by gardeners, to cover with earth those parts of plants which they would preserve white: by that means hindering them from being tinged green by the contact of the air, as the parts

[b] Shaw's Notes to Boerhaave's Chemistry, vol. i. p. 94. *Iron* is easily dissolved in salts, dew, air, &c. By the action of any of these it contracts a rust, which is nothing but the flowers of iron, or iron dissolved, and forsaken by it's dissolvent: for *iron* examined with a microscope when it first becomes rusty, shews it's surface covered with a number of pellucid *vitriolic lamellæ*, or glebes, which, being afterwards dried by the fluid menstruum's evaporating, become a ruddy calx.

exposed

exposed to it are: though it appears from experiment that the presence of light, as well as of air, is necessary to the production of the colour of plants.

Besides the *iron* dissolved at the *surface* of plants by the air, that which is contained in the *inside* of them, may be kept in a state of solution, when it meets with a proper quantity of *acid*; and it is remarkable that the inside of most fruits and other parts of plants remain *green* no longer than they continue in an *acid* state.

The quantity of *iron* contained in plants will not appear too small to produce their colour, when it is known that one grain of vitriol, of which only a small part is iron, the rest being acid and water, is able sensibly to communicate a *green colour* to ten thousand grains of water. Lemery mentions this great divisibility of iron as an argument of it's being able to pass into the smallest parts of plants. Mem. Acad. anno 1706.

A circumstance which strongly confirms that the *colouring matter of vegetables*, and a *ferruginous vitriolic substance*, are of one and the same kind, is, that the *vitriol of iron*, which is *green*, passes through the same colours, while it's moisture is evaporating, which *vegetables* do, when by withering they undergo the same sort of change: the *vitriol* deprived of it's water by calcination grows first *yellow* and then *red* [i]; and Sir Isaac Newton

[i] Boerhaave's Chem. vol. ii. process 164. If this second calx (that is, *green vitriol* reduced to powder by a moderate heat) be calcined in a crucible, in an open strong fire, it grows *yellow*, *red*, and at length becomes a deep purple powder.

has observed that, “ when *vegetables wither*, some
 “ of them turn to a *greenish yellow*, and others to
 “ a more perfect *yellow* or *orange*, or perhaps to *red*,
 “ passing first through the aforesaid intermediate
 “ colours: which changes seem to be effected by
 “ the exhaling of the moisture, which may leave
 “ the tinging corpuscles *more dense* and something
 “ augmented by the accretion of the oily and earthy
 “ parts of that moisture.” Newton’s Optics, lib. ii.
 prop. 7.

This is the only passage in Newton, in which he
 instances any *permanent colour* of a natural body as
 arising from a *change of density*: and though he
 has not any where at large delivered his opinion
 on this subject; it appears that, in this case, he
 considered the *less refrangible colours* in withered
 vegetables as arising from their *increase of density*;
 which is what I endeavoured in the beginning
 of this paper to prove deducible from his doc-
 trines.

I am,

MY LORD,

Your Lordship’s

most obedient

and most humble servant,

Old Palace Yard,
 Jan. 17, 1765.

Edward Delaval.

IV. *An*