

I. *Experiments upon Metals, made with the Burning-Glass of the Duke of Orleans. By Monsieur Geoffroy, F. R. S.*

THE Duke of Orleans, out of the desire he has to promote useful Arts and Sciences, having permitted such of the Royal Academy of Sciences as have had most Experience in subjects of this Nature, to make use of his Burning-glass; I took this Opportunity to examine the different Changes that Metals suffer when placed in the Focus of this Glass, whose Heat and Efficacy far surpasses the force of our common Fires.

The Burning glass is three Foot in Diameter; it collects the Rays of the Sun at ten Foot distance, where it forms a Focus of about three Inches over, which is again contracted by means of an other Glass-Lens to an Inch Diameter, and consequently is render'd three times as strong.

I shall only relate here what I have observ'd upon the four Imperfect Metals, *viz.* Iron, Copper, Tin, and Lead: And shall say nothing at present of Gold or Silver; because as their Analysis seems to me much more difficult than that of the other Metals; I shall forbear Inquiries upon them, 'till I have examined as far as possible into the Nature and Composition of the former.

What was a great hindrance to me in making these Experiments in the Focus of the Glass, was the difficulty I had to find any Matter capable of holding the Metals in fusion.

Char.

Charcoal; which is commonly made use of, is indeed a very proper substance; but it is impossible with it to vitrify any one of the Metals: The Particles of the Metal, when held any long time in fusion in the Focus of the Glass, dissipate and fly away in Fume or small Particles; and as long as any part remains, that little that does remain, is always Metallick, until the whole be quite evaporated.

The reason of which I take to be this. Charcoal is a substance deeply impregnated with Oily or Sulphurous Parts (if I may so call them.) The first Effect that Fire has upon Metals is to separate the sulphurous Parts: now, if in proportion as the Sulphur is separated from the Metal, the Body that supports the Metal furnishes it anew with other sulphurous Parts, the other Principles will never separate, and the Metal will always remain Metal. And nothing but the greatest degree of Fire is able to raise and separate the Sulphur, and that but by little and little, and in very small Particles.

I had then recourse to an other Matter, that could not any ways be suspected of containing any Oily Parts. Mr. *Tschirnhaus*, to whom we are obliged for Making of these large Glasses, and the first Experiments that have been made with them, says, he has vitrified Metals by holding them in *China* ware. It is true, this succeeds pretty well, provided the Pieces be very thick, and the Glazing taken off: But the difficulty I had to find a sufficient quantity of thick and proper *China* ware to make all these Experiments, forced me to have recourse to more common subjects, as well as such, if possible, as were less capable of melting.

Of all the different sorts of Matter that I made Tryal of, what seem best were the Common Coppels and Plates of gray Fire-stone. The Coppels hold the Metal a long time in fusion in the Focus of the Glass without melting; excepting Lead, which easily runs thro' them as soon as

it vitrifies, and helps to dissolve them. The Plates of Fire-stone bear the Heat of the Focus much longer than any other Matter ; but great care is to be taken in heating them without breaking, 'till they become red-hot, and when they are hot the least cold Air makes them melt. Nevertheless this is the only substance that I have used with most success, to hold Metals a long time in fusion, tho' with the greatest caution that was possible, to avoid the Inconveniencies aforementioned.

An other thing that has hinder'd me from carrying on these Inquiries upon Metals so far as I could have wished, has been the few clear Days we have had for these two Years past ; for the greatest part of these Experiments require a bright, strong, and constant Sun to keep the Matter a long time in perfect fusion : And I have scarce had, for this last Year, above three or four such days as I could wish for ; the Sky having been almost every day cover'd with Clouds about Noon, which is the only time of the day fit for these Experiments.

I come now to the Particulars of what Experiments I have made ; and shall begin with those on Iron.

Of Iron.

I placed in the Focus of the Burning-glass a piece of forged Iron of about a Drahm weight: It turn'd red-hot, and its surface was cover'd with a black Matter like Pitch or Tar. If one withdraws the Iron out of the Focus in this state, this Matter fixes itself on the surface of the Metal, and there forms a small Skin or very fine blackish Scale, which is commonly very easily separated by striking upon it ; and that part of the Iron that was cover'd with this Scale appears blacker than ordinary. This Scale is some of the sulphurous part of the Iron that rises to and Surface of the Metal when it is ready to melt, the there remains for some time before it exhales.

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It is plainly this sulphurous part that rises upon Iron and polish'd Steel when heated, and gives them all those different Colours, from a Yellow, to a Violet, Water-Colour, or Black.

If one continues to hold this Piece of Iron on the Charcoal, it intirely melts; and at the same time casts forth very bright Sparkes in a great quantity, sometimes to above a foot distance from the Coal.

If one saves what flies off during this sparkling, by holding a Sheet of Paper under the Coal; we find that they are so many very small Globules of Iron, and the greatest part of them hollow.

All the Iron that is held in fusion upon the Coal, flies away in sparkles after this manner, 'till none remains. Sometimes the Metal leaves off sparkling, when the Coal is in part consumed, and cover'd with a Bed of Cinders, upon which lies the melted Iron. For as the sparkling of the Iron seems to me to proceed from nothing but the oily parts of the Coal acting upon those of the Metal, the Cinders hinder this Oil from passing from the Coal to the Iron, so that it remains quietly in fusion. But if thro' any shake, or the like accident, the Cinders are so removed that the Iron comes to touch immediately the Coal, it will begin to sparkle afresh. Sometimes the Heat that keeps in fusion the Metal, vitrifies also the Cinders; and this vitrified Matter mixing with the Metal makes a considerable Ebullition. If one at this instant withdraws the Metal out of the Focus, it appears half vitrified, or reduced to a blackish friable Mass. Othertimes this vitrified Matter swims on the surface of the Metal, and there forms it self into Drops, that are sometimes clear and transparent, and other times opake, according as it is more or less mixed with the Metal.

Furthermore, if after having let the melted Iron cool upon the Coal, one exposes it again to the *Focus* of the Glass upon the Stone, it sparkles afresh till it is all consumed; which common Iron will not do, that has not been exposed to the heat of the *Focus* upon Charcoal. This Sparkling probably proceeds from the sudden Rarification of the Oily parts of the Coal, with which the Pores of the Iron are so plentifully saturated; or perhaps it may be caused by the Salts of the Iron acting on the Oil of the Coal.

I exposed to the *Focus*, upon a Stone-slate, Iron and Steel: they grew red hot, and melted without crackling or casting off any Sparkes: they smok'd very considerably, and the melted Metal turn'd by little and little like an Oil. After having withdrawn this melted Matter out of the *Focus*, it fix'd in a Regulus-like, friable Mass, and appear'd sometimes lightly striated, or shot into sharp Points like Needles. Tho' this matter does not appear at all transparent, yet we may look on it as the beginning of Vitrification, or a middle state between Metal and Glass; for it would vitrify in the end like other Metals, if one could hold it a sufficient time in the *Focus* without melting or mixing with what sustains it: But continuing it long in the *Focus*, the extream Heat of the Sun, that is necessary to keep it in perfect fusion, melts likewise the Stone or Coppel that contains it, the result of which mixture is a brown or greyish sort of Enamel.

We may then take this Regulus Mass to be a half vitrified Iron, by reason it is deprived of great part of its Sulphur. If one adds to this Mass a Sulphur like that which was taken from it, from being friable it turns very hard and malleable; and the dulness it had before, changes to the brightness of a Metal. This is what I have experienc'd in exposing again this Matter to the *Focus* upon Charcoal: it melts, and so continues a considerable time
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in fusion without sparkling, but at last it sparkles with the same briskness as Iron itself; and when withdrawn from the Focus, appears nothing different from melted Iron.

It appears from these Experiments, that Iron contains a sulphur or oily Substance, that renders it bright, malleable, and easy to melt.

That this Sulphur is raised by the Fire of the Sun, when the Metal is for some time held in fusion in the Focus of the Glass.

That this same Sulphur may be raised by the Flame of common Fire, which tho' not strong enough to melt the Iron, yet is able to reduce it to an Eschar or sort of Rust.

That Iron deprived of this sulphurous part, melts into a Regulus, or brittle and friable Mass, in colour much like Antimony.

That if one can hold a sufficient quantity of this Matter long enough in the Focus by itself, without melting or mixing with the Body that contains it, it perfectly vitrifies.

That this Glass or metallick Regulus, with the help of a little Oil, returns to its former state of a Metal.

That it reassumes this metallick Form upon Charcoal, by drawing thence this oily Substance.

That, in short, this oily part contain'd in the Coal, is little different from the Sulphur of Iron. Nevertheless we must imagine it to differ in some particulars, in that melted Iron that has been saturated with it, crackles and sparkles very much when melted again upon the Stone or Coppel.

Iron being the only Metal in which I have observed this sparkling, I take it to be a Property peculiar only to Iron and not to any other Metal. Perhaps we may attribute it to the vitriolick Salt that this Metal so plentifully abounds with, which is very greedy of Sulphurs.

To this same greediness also, with which the vitriolick Salt of Iron absorbs the oily part of the Coal, we may attribute the easiness with which Iron consumes the Coal; for there is no other Metal that so soon waists the Coal in the Focus of the Glass, as Iron does.

An other Observation upon Iron is, that it is the only one of the four imperfect Metals, on which vitrified Drops arise while it is in fusion upon the Coal: The reason of which I have not yet been able to discover.

Of Copper.

Copper expos'd to the Focus of the Burning-glass, at first turns white on its surface, and afterwards grows black, and is covered with a kind of Skin, or black, furrow'd, and uneven Scales, till at last it quite melts.

I have withdrawn this Metal out of the Focus as soon as this white colour has appear'd, and after it has been cold, found nothing extraordinary on its surface, which has again by little and little recover'd very near the same Colour as it had before.

I have not been able to discover from whence this white Colour proceeds; unless we may attribute it to some Volatile Arsenical Salt contain'd in the Copper, and driven by extremity of Heat to the surface of the Metal; or whether it purely proceeds from the alteration that is made in the grosser parts of the surface of the Metal when it begins to melt. The black colour that Copper afterwards takes, seems to be caus'd by the sulphurous Matter that melts first in this Metal as well as Iron, and is rais'd to its surface by the extream Heat.

I plac'd a piece of Copper in the Focus upon Charcoal: It melted, and emitted a very thin Fume, and by little and little diminish'd till it was all evaporated.

I put a piece of red Copper on a Coppel into the Focus of the Glafs: it melted, and sent forth some thin Fumes; and after it had been some time in fusion, it turn'd liquid like an Oil. I withdrew this melted matter, and as it grew cold, it fix'd into a Regulus of a reddish brown colour, which was hard, brittle, and not ductile under the Hammer. If one breaks it, it turns into a red Powder like Cinabar of Antimony; and when view'd with a Microscope, appears so many little, red, transparent Grains like small Rubies; in so much that one would readily take this Regulus to be a deep colour'd red Glafs.

I endeavoured to make this vitrified Copper spread abroad in melting, by mixing it with common white Glafs; for which end I powder'd some of this vitrified Copper and common Glafs, and mixing them melted them together; but the Mixture when in fusion took at first a beautiful green Colour, and continuing it longer in the Focus, it turn'd blewish. I believe we may attribute this change of Colour to the Alkali Salts of the Glafs acting on the Particles of Copper; for those Salts usually draw a green or blewish Tincture from this Metal.

To preserve therefore this red Colour of the vitrified Copper, when mix'd with common Glafs, I made use of this Expedient. I melted in the Focus upon a Coppel a piece of Copper, and as soon as it began to vitrify I cast upon it some common Glafs; as soon as the Glafs was melted I took them together out of the Focus without confusing them; and as soon as they were cold, separated the Regulus from the Glafs as well as possible; and pick'd out of it some pieces of the Glafs, loaded with some very small red transparent Particles of the Regulus.

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This vitrified Copper is then nothing but Copper deprived, by means of heat, of the sulphurous part, that gave it the form of a Metal. A proof that this metallick form proceeds from nothing else but this Sulphur, is, that if one exposes this vitrified Copper to the Focus upon Charcoal, it reassumes in a little time the Colour and Consistence of melted Copper; and as it grows cold, fixes into a good red malleable Copper, as fine and hard as it was before it was vitrified.

It follows from these Experiments, that the Basis of Copper is a red Earth susceptible of Vitrification.

That this Earth receives its metallick Form from a sulphurous substance, in appearance no ways different from the Oil of Vegetables or Animals.

That one may deprive Copper of this Oil, by holding it long enough in the Focus, or by calcining it in the Flame of common Fire.

That Charcoal restores again this oily Part to Copper, and at the same time its metallick Form.

It appears further, that the Oil of the Coal has not so considerable an effect upon Copper, as it has upon Iron.

Copper exposed a long time to the Focus upon a Stone or Coppel, fumes very much, and diminishes in weight very considerably. I don't think that this fume is only the sulphurous part of the Metal, the Evaporation of which must be insensible; but I believe that with this Oil there is mixed a great deal of the earthy, vitrifiable part of the Metal, which the heat of the Sun sublimes and raises in Flowers.

Of Tin.

Tin exposed upon Coal to the Focus of the Burning-glass, melts, and emits a gross, white, thick Fume, until it is all consumed in Vapours.

If one melts Tin upon a Coppel in the Focus of the Glass, it fumes very much, and its surface is cover'd with a white rarified Calx; on which by little and little arises a tuft, or heap of sharp, needle-like, transparent, cristalline Particles, consisting of an infinite number of small Points.

If one continues to hold this Mass in the Focus upon the Stone, these Cristals at length leave off fuming, and remain fixt, while the Stone melts and vitrifies.

I took Calx of Tin, which is Tin reduced to a grey Powder by means of Fire, that has taken away by Calcination great part of its oily Substance, and exposed it on a Coppel to the Focus, where it fumed again very much, and was reduced into sharp cristalline Particles consisting of other small Points.

In re-exposing these chrystalline Particles to the Focus upon Charcoal, they melted very easily, and took again the Form of Tin; the Coal having furnished them with the sulphurous part that the Fire had before taken away. Every body knows, that if one adds any Fat, or the like inflammable Matter, to the Calx of Tin when red-hot in the Crucible, it reassumes immediately the form of Tin.

These Experiments show, that Tin contains a Sulphur that is very easily separated, since common Fire can do it so readily; and that this Metal calcined, or deprived of its Sulphur, is easily saturated again with it from the oily part of any inflammable Matter whatsoever.

It proves also, that the metallick Earth which is the Basis of Tin, is a Cristalline Earth, very difficult to be melted; since common Fire cannot vitrify this Metal by it self, and that the heat of the Sun, in the Focus of this large Burning-Glass of the Palace-Royal, cannot perfectly melt the Calx into which this Metal is reduced. We may presume that the Cristallisation, or reducing of this Metal into sharp-pointed Particles, proceeds from the force

the Sun's breaking and melting together into a Sodder (if I may so speak) some of these small Crystals, by degrees as the sulphurous part leaves them; it not being strong enough to melt them all down together in one intire Mass.

Of Lead.

I took Lead, and held it in fusion upon Charcoal in the Focus of the Glass: it all wasted away in abundance of Fumes.

I exposed the like quantity of Lead upon a Stone to the Focus, where it cast forth great quantities of fumes, and by little and little changed into a fluid Liquor like Oil or melted Rosin. This Liquor, as it grew cold, fix'd into Glass; which has this peculiar to it self, that it is disposed into Plates like *Venetian Talk*, and that it is flabby, soft to the touch, transparent, and in some parts of a greenish or reddish Yellow.

In continuing this matter in the Focus, it spread upon the Stone like Varnish; and at last penetrating it, help'd to melt it.

I placed this talky Earth in the Focus upon Charcoal: It melted, and in a little time after reassumed the form of melted Lead. I withdrew it from the Focus, and having let it cool, found it nothing different from Lead.

These Experiments show, that there is in Lead, as well as the other imperfect Metals, a sulphurous part, that is easily separated by common Fire or the heat of the Sun; and that this Metal has for its Basis a foliated or talky Earth

Of Quicksilver.

I shall add here some Experiments that I have made upon Quicksilver; tho' I can't yet draw any positive Conclusions from them, not having prosecuted them so far as is necessary for that purpose.

I placed Quicksilver in the Focus of the Burning-glass upon Charcoal, upon the Coppel, and upon the Stone: It all immediately dispersed, and exhaled in a very thick Fume.

I exposed upon the Stone to the Focus some *Mercury precipitate per se*, in a degree of heat equal to that of digestion: It seem'd to melt, but presently dispersed in Vapours: only there remained a small quantity of a very rarified Dust, like a Froath or Scum; but continuing it in the Focus, it melted, and gathered into a yellowish Glass, in which one might distinguish some Particles of Metal like Silver.

I exposed some *Mercury Precipitate per se* upon Charcoal: It fumed very much; and as it melted one might see little Globules of Mercury unite and form themselves together upon the Coal, but they dispersed again presently in Vapours.

These Experiments seem to prove, that there is in Quicksilver a Sulphur that may be seperated by a very gentle heat, such as that of Digestion.

That as soon as this Sulphur is taken away, it loses its Fluidity and Brightness.

That the Basis of Mercury is a Calx, or red Earth.

That this Calx does not melt into Glass as the Calx of other Metals, because it is too Volatile, and as soon as it melts is evaporated by the heat.

That if one restores to this Calx a Sulphur, by exposing it again to the Focus upon Charcoal, it reassumes immediately its metallick Brightness and Fluidity, and becomes Quicksilver.

I cannot tell whether this light Earth, that remains upon the Stone after the evaporation of the Calx of the Mercury, be a part of the Earth of the Mercury more exactly deprived of its Oil, and consequently more fixt and proper for Vitrification; or whether it may not be some Matter foreign to the Mercury, that fixes it self, and remains behind at its Evaporation. But this I shall examine more particularly hereafter.

The Result of all these Experiments is, that these four Metals which we call imperfect, *viz.* Iron, Copper, Tin, and Lead, are composed of a sulphur or oily Substance, and of a metallick Earth capable of Vitrification.

That from this Sulphur proceeds the Opacity, Brightness, and Malleability of a Metal.

That this metallick Sulphur does not appear at all different from the Oil of Vegetables or Animals.

That it is the same in Mercury as in the four imperfect Metals.

That these four Metals have for their Basis an Earth susceptible of Vitrification.

That this Earth is different in every one of these four Metals; in that it vitrifies differently in each of them.

And that on this difference in Vitrifying depends the difference of Metals.

It remains that I should examine more particularly the Nature of these Earths or metallick Vitrifications; so know if any other Principles or Substances may be separated from them: But this I shall endeavour to do hereafter, in prosecuting the Analysis of these Metals as far as possible.