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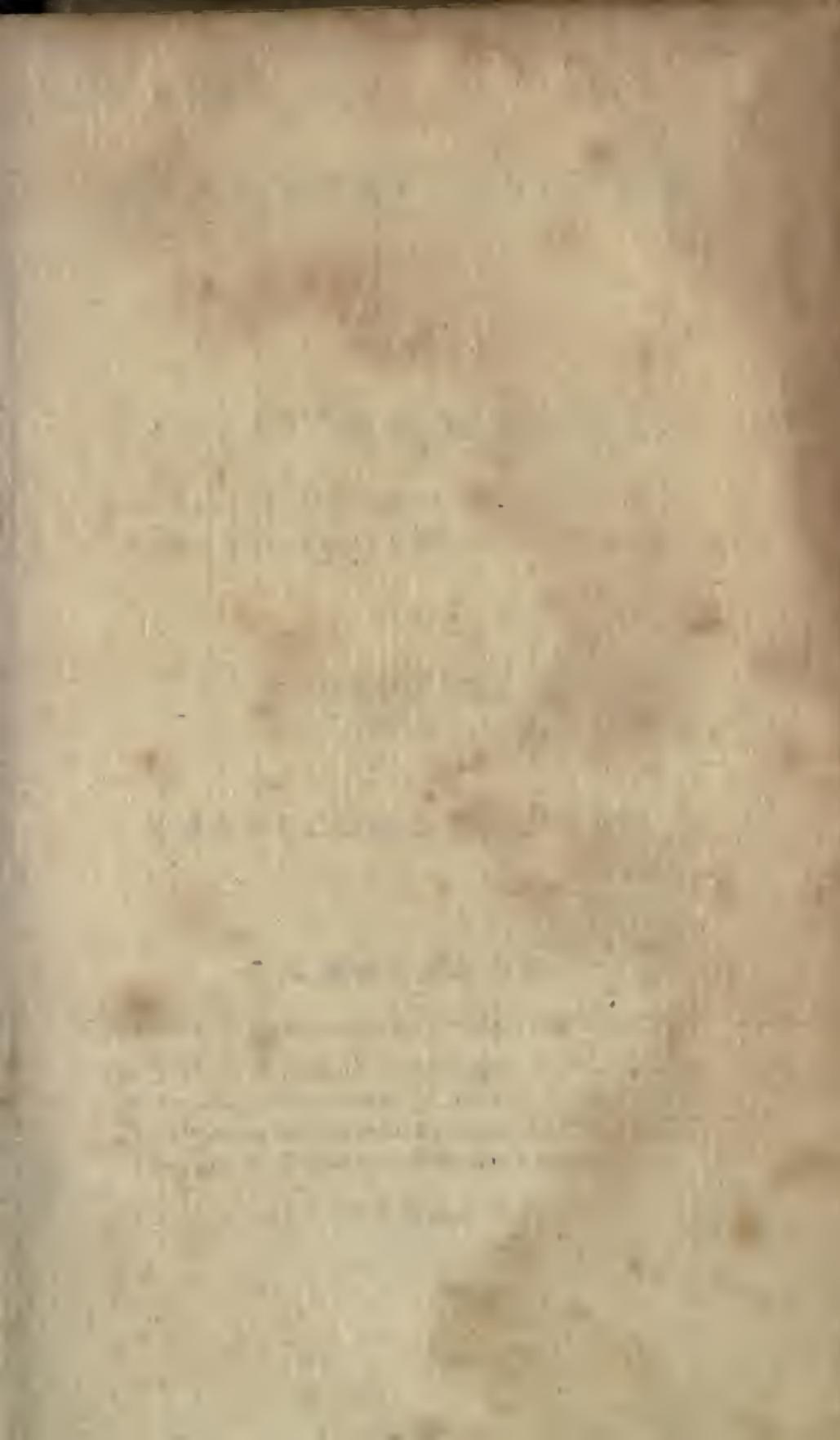


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CHEMICAL ESSAYS.

BY

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AND REGIUS PROFESSOR OF DIVINITY IN
THE UNIVERSITY OF CAMBRIDGE.

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MDCCLXXXVI.

C O N T E N T S.

ESSAY

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PRE.



P R E F A C E.

ABOVE two thousand copies of the former volumes of my Chemical Essays have been sold, in less than five years. I mention not this circumstance out of vanity, or as if I thought it contained any proof of their merit; but I produce it as a solid proof, of the disposition of the Public to become acquainted with chemical Subjects, when they are treated in a popular way. This disposition has been long prevalent in foreign countries; it seems to be gaining ground in our own; and if I

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have endeavoured to contribute a little towards its establishment amongst us, I hope the utility of the design will plead my excuse with those who, in the severity of their judgments, may think, that I have contributed more than, from the nature of my Profession and Situation, I ought to have done.

When I was elected Professor of Divinity in 1771, I determined to abandon for ever the Study of Chemistry; and I did abandon it for several years: but the — *veteris vestigia flammæ* — still continued to delight me, and at length seduced me from my purpose. When I was made a Bishop in 1782, I again determined to quit my favourite pursuit; the volume which I now offer to the Public is a sad proof of the imbecility

P R E F A C E.

tity of my resolution. I have on this day, however, offered a sacrifice to other people's notions, I confess, rather than to my own opinion of *Episcopal Decorum*—I have destroyed all my chemical Manuscripts.—A prospect of returning health might have persuaded me to pursue this delightful science; but I have now certainly done with it for ever, at least I have taken the most effectual step I could to wean myself from an attachment to it, for with the holy zeal of the Idolaters of old, who had been addicted to *curious arts*—*I have burned my books.*—I will have one word more, however, at parting. I have spent the best part of my life in this University; and have not been wholly incurious in observing what, I thought, were either excellencies

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lencies or defects in our mode of Education. I mean not on this occasion to enlarge upon either, but simply to take the liberty of suggesting an hint, which has often engaged my attention. The hint respects — *The Utility of an Academic Institution for instructing young Men of Rank and Fortune in the Elements of Agriculture; in the Principles of Commerce; and in the Knowledge of our Manufactures.*

This kind of study would agreeably solicit, and might probably secure, the Attention of that part of our Youth, which, in being exempted from the discipline of Scholastic Exercises, has abundant leisure for other pursuits; which, in being born to opulence, is (I will say) unhappily deprived of one of the strongest incentives to intellectual Exertion —

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P R E F A C E.

narrowness of fortune; — it would prepare them for becoming, at a proper age, intelligent Legislators of their Country; and it would inspire them with such a taste for Husbandry, as might constitute the chief felicity of their future lives.

When the Treaty with *Ireland* was agitated last year in Parliament, the utility of a comprehensive knowledge of our commerce and manufactures was perfectly understood, both by those who possessed it, and by those who lamented their want of it. The commerce of Wool, Corn, Cotton, Hemp, Flax, Silk, Beer, Wine, Spirits, Salts, Sugar, Tar, Glass, Earthen Ware, Iron, Copper, Lead, Tin, &c. &c. are subjects of great importance to this Country, and it is humbly apprehended, that they are subjects also

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on which there are but few persons in either house of Parliament, who have had an opportunity of being properly instructed, during the course of their Education.

Davenant, Child, Postlethwayte, Anderson, and a great many other eminent writers on Trade and Commerce, would supply ample Materials for a System of Lectures, equally useful and entertaining. But as the attention of young men to abstract speculations is apt to flag, unless the subject be enlivened by a reference to the Senses, together with the commercial Account, I should think there might properly be given, both the Natural History, and the Chemical Analysis of the various objects which may fall within the comprehension of such a plan.

My

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My own notion, indeed, of National Improvement, Security, and Happiness, tends not so much to the extending of our commerce, or the increasing the number of our manufacturers; as to the increasing of an hardy and, comparatively speaking, innocent Race of Peasants, by making Corn to grow on Millions of Acres of Land, where none has ever grown before. Let us but once have as many Britons in the Kingdom, as the well cultivated Lands of Great Britain are able to sustain, and we shall have little to regret in the loss of *America*; nothing to apprehend from the *partitioning* policy of all the continental Despots in Europe. I enter not into the question concerning the population of the country; whether the Inhabitants of the Kingdom

P R E F A C E.

are more or fewer now than they were a century ago, cannot be conjectured with any great probability from the surveys of particular districts, but the real number may be known with little difficulty, whenever the Legislature shall be desirous of obtaining information on the Subject: for the Kingdom being divided into Counties, and the Counties into Parishes, &c. an actual Enumeration of the Inhabitants might be made every ten years, by the Ministers and Churchwardens of the several Parishes, with as much certainty as the nature of the subject, considered in a political light, would require. But whatever may be the present number of the Inhabitants of Great Britain, there is no one who has thought upon the subject, but must admit, that were
our

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our Lands brought to their proper State of Cultivation, they would afford maintenance to twice as many as at present exist in the Country. In thus fixing the Basis of National Strength, in the improved Cultivation of our Lands, I am far from insinuating, that Manufactures and Agriculture cannot subsist in an eminent degree of perfection together: on the contrary, I consider them as mutually subservient to each other, and am quite aware, that in the present state of the Finance of this Kingdom, our Commerce ought to be cherished with singular Indulgence. Nor shall we sufficiently avail ourselves of the inestimable Advantage of an Insular Situation, if we do not consider our Glory and our Safety as closely connected with the Number
of

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of our Seamen; and every child in Politics must know, that the number of our Seamen will ever be proportioned to the extent of our foreign, and domestic Commerce.

Of all the Amusements or Employments in which Country Gentlemen are engaged, that of superintending with intelligence the cultivation of a Farm is one of the most useful to the Community, as well as to the Individual who applies himself to it. Great Improvements have been made in Agriculture within the last fifty years: there is a chaos of printed Information on the Subject, which wants to be digested into form, in order to be made generally useful. The several Agricultural Societies, which have been established by Gentlemen in different parts of the Kingdom,

dom,

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dom, have done great Service; we owe to their endeavours and to the patriotic Exertions of one deserving Citizen *, the present flourishing condition of our Husbandry; but far more Gentlemen would, probably, have been induced to turn their thoughts that way, and all of them with better prospects of succeeding in their inquiries, had they, in their youth, been carefully instructed in the *Principles of Vegetation*, in the *Chemical Qualities of Soils*, and in the *Natures and Uses of different Manures*. — But I mean only to give a hint concerning an Institution, which I have no manner of expectation of seeing established, though I am fully persuaded it would be both a public benefit, and highly useful to that

Class

* Arthur Young, Esq;

P R E F A C E.

Class of Persons of whose Education I have been speaking.

Young Men of Fortune feel not the want of personal Merit during the short time which they spend at the Universities: they see Consequence and Respect, it is true, annexed in those Seminaries to Learning and Talents, but in the world they see little respected but Wealth; and possessing that, or expecting to possess it from their Ancestors, they are easily allured by the Indolence which is natural to the Human Species, and by the Improvidence which is incident to their time of life, to shrink from the task of acquiring accomplishments really honourable, really useful, and really their own. When they are called to the Legislation of their Country, or when they be-

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become Masters of families, or are in any way settled, as it is called, in the world, then they begin to be sensible of the deficiencies of their personal Acquirements; they cease not to lament through life their own want of foresight, in neglecting the Opportunities of Improvement which were offered to them in the Universities, or the Supineness of those who had the care of their Education, in not having stimulated them to the pursuit of useful studies. This is only the general account, for there are some to whom it is not applicable; and though it may not be in our power to counteract the indolent propensities of Nature, or to stem the torrent of fashionable levities, to which young Men, by a too early introduction into the world, are fatally

ex-

P R E F A C E.

exposed; yet it is our Duty to endeavour to augment the number of those, who, at so green an Age, have learned to make a proper estimate of their future intellectual wants; and I know no method better adapted to effectuate this desirable End, than to propose to them entertaining Objects of Study, of which they may clearly perceive the immediate utility, in the application of the knowledge they attain, to the important purposes of Legislative Policy and Rural Œconomics.

I shall be told, that there is not time for this; that even Classics, Ethics, Mathematics, and, God forbid I should omit what is of infinitely more value than all the rest, the Institutes of Christianity, can be but superficially attended to during the
few

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few Months which these young Men reside in the Universities. I will not attempt to obviate this Objection by making an invidious comparison between the Utility of Classics, Ethics, or Mathematics, and the branches of Study here hinted at; I admit the force of it in its full extent. But I beg leave to ask, whose fault is it that young Men of Fortune stay not more years with us, and reside not amongst us more months in every year? Why must they, as soon as they have huddled through six or eight Terms, be hurried abroad as if it were from an Apprehension, that they have Learned as much as an English University can teach them? Foreign Travel is of great use, when it is undertaken by Men who have learned to bring their passions under the control

P R E F A C E.

trol of Reason and Religion; who have had some Experience in Life; acquired some Knowledge of the Manufactures, Policy, Revenues, and Resources of their own country; the acquaintance of such Men will be sought after by persons of Character and Learning in every country they pass through, they will be in a condition to receive, because they will possess the Ability of communicating Knowledge. But the present mode of sending our young Men into *France* and *Italy* tends only to fill *Great Britain* with dabblers in Virtù, pretenders in Taste, sciolists in Literature, and infidels in Religion.

But I perceive myself insensibly falling into what I mean to avoid — A discussion of the excellencies and defects of our System of Education. —

Our

P R E F A C E.

Our Excellencies are greater, perhaps, than those who know us not are apt to suppose; and our defects are not so much defects in our Institution (though I have never scrupled to profess an humble Opinion that it might be amended) as in our Discipline; and the defects in our discipline, are not so properly our defects, as the defects of the Manners of the Age. If a young Man at seventeen be accustomed at home to have horses always at his command; to follow country diversions without restraint; to mix in long convivial familiarity with persons of advanced age; to drink as much as he pleases at his father's table; to hear improper connexions with the Sex spoken of in all companies as venial levities, and not to hear them seriously censured in any

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as Offences against Christian Morality; and if to all this he be supplied, through a destructive indulgence, with sums of money excessive for his age, and far superior to his wants, can it be a matter of wonder, that it is not in the power of an University to rectify the disorders of such a domestic Education? I have no intention to mislead the Opinion of the world concerning us, nor to exculpate ourselves by criminating others: If we yield to the corruption of the Age, we yield as slowly as we can; and it is not, perhaps, possible for us, wholly to escape the Malignity of its Influence.

Cambridge,
Feb. 9, 1786.

P R E F A C E.

Three of the following tracts have been published, the other three were only printed and given away: they would make a fifth volume, but I think it would not be acceptable to many readers.

Institutionum Chemicarum in Prælectionibus Academicis explicatarum, pars Metallurgica. Cantabrigiæ, 1768.

Experiments and Observations on various Phenomena attending the Solution of Salts. Published in the Philosophical Transf. 1770.

An Essay on the Subjects of Chemistry and their general Division. Printed at Camb. 1771.

A Plan of a Course of Chemical Lectures. Printed at Camb. 1771.

Some Remarks on the Effects of the great Cold in February, 1771. Published in the Phil. Transf. 1771.

Account of an Experiment made with a Thermometer, the Bulb of which was painted black, and exposed to the direct Rays of the Sun. Published in the Phil. Transf. 1773.

E S S A Y

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1. The first part of the book is devoted to a general survey of the subject.

2. The second part contains a detailed account of the various methods of investigation.

3. The third part is devoted to a discussion of the results of the experiments.

4. The fourth part contains a list of the names of the persons who have assisted in the work.

5. The fifth part is a list of the names of the persons who have assisted in the work.

6. The sixth part is a list of the names of the persons who have assisted in the work.

7. The seventh part is a list of the names of the persons who have assisted in the work.

8. The eighth part is a list of the names of the persons who have assisted in the work.



ESSAY I.

*Of Lapis Calaminaris — Blende —
Zinc — Brass.*

THE two principal ores of zinc are *calamine* and *blende*. The Arabic word *climia*, or, as it is pronounced by some, *calimia*, denotes the same substance which we call *lapis calaminaris*, *calamine*, or *calamy*; and hence *Salmasius* is of opinion, that they judge very preposterously who would derive *calamine* from *calaem*, an

Indian word signifying, according to him, a species of metal resembling tin, which is dug near *Malacca* *. With due deference to his authority, I would observe, that Indian *calaem* is not like tin. Many years ago the Dutch took a Portuguese vessel which was laden with *calaem* †, and from all the experiments which were made upon that substance, it appeared to be *zinc*, or that metallic substance, which we in Europe have very lately

* *Cadmia Arabibus dicitur climia, quod quidam pronuntiarunt calimia, unde Græcis recentioribus κελιμια interdum scribitur, unde nostris Gallis calamina et lapis calaminaris: quam vocem quidam præpostere deducunt ab Indico calaem, quod metalli genus est stanno simile haud longe ex Malacca erui solitum. Salm. de Homony. Hy. Iat. C. CXXII.*

† *Savotus de Num. Ant. P. II. C. XIV.*

lately learned the method of extracting from calamine. Both *calamine* and *zinc* have the property of changing copper to a *yellow* colour; and this is the most distinguishing property of them both; it is that for which they are both sought after in commerce, and as *climia* and *calaem* have the same radical letters, and denote in the Arabic and Indian languages, two substances which agree in one of their most characteristic properties, I leave it to others to determine whether they are not the same word, and in which of the two languages that word was originally formed. — The other ore of zinc is called by the Germans *blende*; from its blinding, or misleading appearance; it looking like an ore of lead, but yielding (as was formerly thought)

no metallic substance of any kind *. A particular sort of lead ore has been called by *Pliny*, *galena*, from a Greek word signifying to shine, because it is composed of shining particles; our potters ore and the Derbyshire lead ore is of this sort; blende much resembles galena, but yielding no lead, it has been called false or *pseudo-galena*, or *mock-lead*; our English miners have called it *black jack*, and that is the

* *Pseudo-galena* nomen suum exinde acquisivit, quod faciem quasi mineræ plumbeæ præ se ferat, sed mentiatur, cum id revera non contineat, quod externo aspectu pollicetur. Germanis appellatur *blende* a *blenden*, quia, cum falso speciem mineræ saturninæ præ se fert, exinde oculos fascinet, vel iis imponat. Pott de *Pseudo-galena*, p. 106.—They have in Staffordshire a sort of iron, which they call *blende-metal*, of which they make nails, hammers, &c. Plot's Staf.

the name by which it is known to the makers of brass. Black jack resembles lead ore so much, that the miners sometimes succeed in selling, to inexperienced smelters, black jack instead of lead ore; I have heard of the fraud being carried to so great an extent in Derbyshire, that from a ton of ore there was not obtained above a few ounces of lead; though a ton of unadulterated lead ore yields in Derbyshire, at an average, 14 or 15 hundred weight of lead.

Calamine is found in most parts of Europe; we have great plenty of it in *Somersetshire*, *Flintshire*, *Derbyshire*, and in many other parts of England. It is scarcely to be distinguished by its appearance from some sorts of limestone; for it has none of the metallic lustre usually appertaining to ores; it

differs, however, by its weight from every sort of stone, it being, bulk for bulk, near twice as heavy as either flint, or limestone. Before the reign of Elizabeth, this mineral was held in very little estimation in Great Britain; and even at so late a period as towards the end of the last century, it was commonly carried out of the kingdom as ballast, by the ships which traded to foreign parts, especially to Holland *. Its use is now as perfectly understood in England, as in any part of the world; and as we have greater plenty of calamine, and that of a better sort, than most other nations have, there is no fear of our losing the advantages in this article

* Essay on Metal : Words by Sir J. Pettus,
— and Phil. Transf. for 1694.

ticle of trade, which we are now possessed of.

Great quantities of calamine have of late years been dug in Derbyshire, on a spot called *Bonsale Moor*, in the neighbourhood of *Matlock*. A bed of iron stone, about four feet in thickness, lies over the calamine; and the calamine is much mixed not only with this iron stone, but with cawk, lead ore, and limestone. The calamine miners never wish to meet with lead ore; they say, that it eats up the calamine; and the lead miners in return never wish to meet with calamine in a rich vein of lead ore, since they are persuaded that it injures the quality of the ore. It would be too much to infer from these observations of the miners, that one of these substances arises from the na-

tural decomposition of the other. Juxtaposition of substances in the bowels of the earth is no certain proof of their being derived from each other; for no one will contend that *chert* is derived from the limestone in which it is bedded; or flint and pyrites from the chalk in which they are found; yet when a great variety of substances are found mixed together in the same little lump, the mind cannot help conjecturing, that a more improved state of mineralogy will shew some connexion in their origin. I have often seen *calamine*, and *black jack*, and *lead ore* — and *cawk*, *black jack*, and *lead ore* bedded together in the same piece of spar.

The calamine annually raised in Derbyshire, amounts to about fifteen hundred tons. Sixty years ago,

(as

(as I was informed by an intelligent dealer in calamine, whose father was one of the first who dug it in that county,) they did not raise forty tons in a year. The *Derbyshire* calamine does not bear so good a price as that which is gotten about Mendip in *Somersetshire*; the former being sold for about forty shillings, and the latter for sixty five or seventy shillings a ton before *dressing*: when thoroughly dressed, the *Derbyshire* calamine may be bought for about six guineas, and the other for eight pounds a ton. This dressing of the calamine consists, principally, in picking out all the pieces of lead ore, limestone, iron stone, cawk, and other heterogeneous substances which are mixed with it, when it is first dug from the mine; this

picked

picked calamine is then calcined in proper furnaces, and by calcination it loses between a third and a fourth part of its weight.

The substance which is lost during the calcination of the calamine is not either sulphur or arsenic, or any thing which can be collected by the sides of an horizontal chimney, as is the case in some sorts of copper and lead ores; hence it would be quite unserviceable to roast calamine in a furnace with such a chimney. The truth of this remark will appear from the following experiment.

I took 120 grains of the best *Derbyshire* calamine, and dissolved them in a diluted vitriolic acid; the solution was made in a Florence flask, and the weight of the acid and flask was taken before the solution commenced.

About

About twenty hours after the solution had been finished, I weighed the flask and its contents, and found that there had been a loss of 40 grains, or one third the weight of the calamine; about a grain of earth remained at the bottom undissolved. If the same quantity of the purest limestone had been dissolved in the same way, there would have been a loss of weight equal to 54 grains; the substance which is separated from calamine by calcination, or by solution in an acid, is of the same nature with that which is separable from limestone by the same processes — *fixed air*. This air having the property of changing the blue colour of vegetables to a red, as well as many other properties of an acid, and being contained in great abundance in the atmosphere, has been called by some

some — *aerial acid* — and by others from its constituting nine parts in twenty of chalk and other calcareous earths — *chalky acid* — and from its being destructive of flame and animal life, some have denominated it — *mephitic air*. The weight which was thus lost by dissolving the Derbyshire calamine in an acid, corresponds sufficiently with that which the workmen observe to be lost during the calcination of that mineral; so that these processes, as was observed in a former Essay concerning similar ones when applied to calcareous earths, mutually confirm each other.

Bergman observes, that 100 grains of *Flintshire* calamine lost by calcination 34 grains *; now this quantity corresponds, as much as can be expected,

* Vol. II. p. 327.

pected, in things of this sort, with the loss which I observed during the solution of 120 grains of the *Derbyshire* calamine; for if I had dissolved only 100 grains, the loss would have been $33\frac{1}{3}$. The same author, however, remarks that 100 grains of *Flintshire* calamine, when dissolved in an acid, gave only 28 grains of air; and he thinks that 6 grains of water are contained in every 100 grains of that sort of calamine; for he takes the difference which he observed, between the weight of air obtained by solution, and the loss of weight sustained during the calcination of 100 grains of calamine, to be owing to the water which is dispersed during the process of calcination*. *Fontana* obtained 190 grains of

* Bergman has used the same method of
analyz-

of fixed air from 576 grains of *Somersetshire* calamine; according to the same proportion, had he used only

100

analyzing other substances, containing fixed air, particularly calcareous earths. He found that 100 grains of transparent calcareous spar gave, by solution in an acid, 34 grains of fixed air, and lost by calcination 45 grains; the difference, 11 grains, he says is water, which, though expelled by the fire, remains mixed with the acid, and hence 100 grains of such spar contain 55 grains of lime, 34 grains of fixed air, and 11 grains of water. I have a little difficulty in admitting this mode of *inferring* the quantity of water contained in these bodies; I do not absolutely deny the justice of it, but I hesitate concerning it; because from experiments which I made with all the care I could, and which are mentioned in the Essay on calcareous earths, I found that fine transparent spar, very white marble, &c. lost, as nearly as could be estimated, the same weight, whether they were dissolved in an acid, or calcined in a strong fire.

100 grains, he would have had 33 grains of fixed air, instead of the 28 which Bergman got from the Flintshire calamine; I say instead of the 28, for I am inclined to think, that the Derbyshire, Flintshire, and Somersetshire calamines do not differ much from each other in the quantity of air which they contain; but that the apparent difference, in the analyses of them here mentioned, proceeds rather from the mode of operating, than from the substances themselves. But though future experience should prove, that very pure pieces of the calamines we are speaking of do exactly agree, as to the quantity of air contained in them, it will not follow, that the calamines, as prepared for sale by the miners or burners, will be similar to each other in all their

their properties; since they may be mixed with different quantities and with different sorts of heterogeneous substances; from which it may be impossible wholly to free them.

The reader must not conclude, from what has been said, that all sorts of calamine lose one third of their weight by calcination, or afford fixed air by solution in acids. Bergman analyzed some calamine from Hungary, and he found 100 grains of it to consist of 84 grains of the earth of zinc, 3 of the earth of iron, 1 of clay, and 12 of silicious earth; no mention is made of water in this analysis*.

In the great works, where calamine is prepared for the brass-makers, after it has been properly calcined, by which

* Berg. Chem. Ess. Vol. II. p. 325.

which process, as has been observed, it loses between a third and a fourth part of its weight, it is again carefully picked, the heterogeneous parts having been rendered more discernible by the action of the fire; it is then ground to a fine powder, afterwards it is washed in a gentle rill of water, in order to free it, as much as possible, from the earthy particles with which it may be mixed; for these, being twice as light as the particles of the calamine, are carried off from it by the water; it is then made up for sale. A ton of the crude Derbyshire calamine, as dug from the mine, is reduced, by the various processes it undergoes before it becomes saleable, to about twelve hundred weight; and hence it has lost 8 parts in 20. Of the 8 hun-

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hundred weight thus lost in a ton, $6\frac{2}{3}$ may
 be esteemed fixed air, the remaining
 part, amounting to $1\frac{1}{3}$, consists of
 some impurities which have been
 picked out or washed away, and of
 some portion of the metallic part of
 the calamine, which is inflamed and
 driven off during the calcination;
 for I cannot agree with *Wallerius* *
 in supposing that the ores of zinc lose
 no part of their substance during the
 ordinary process of calcination; the
 blue flame which is visible in the fur-
 nace where the calamine is calcined,
 and the injury which the calamine
 sustains from being calcined with too
 strong a fire, are proofs to the con-
 trary. It would be possible to use
 calamine for the purpose of making
 brass without calcining it, for the

* Metallur.

fixed air would be dissipated by the heat applied in making the brass. But as, in using a ton of uncalcined calamine, there would be between six and seven hundred weight put into the brass pots, which would be of no manner of use in the operation, it is a wiser method to get rid of so large a quantity of unserviceable matter; especially as the carriage of six or seven hundred weight to the distance to which the prepared calamine is sent for the making of brass, would cost more than the calcination of a ton of it amounts to.

There are many sorts of *blende* or *black jack*, which differ from each other not only in their external appearance, but in their internal constitution. In general they contain zinc and sulphur, united together by the

intervention of iron, or of calcareous earth: and they must be previously freed from their sulphur by calcination, before they can be applied to the making of brass. Some sorts of blackjack lose one fourth, other about one sixth of their weight by calcination; what is thus dispersed consists principally of sulphur with a little water; what remains consists of a large portion of zinc earth, mixed with one or more of the following substances, viz. iron, lead, copper, clay and flint. Black jack is found in *North Wales*, in *Cornwall*, and in *Derbyshire*; and probably it may be met with in many other parts of Great Britain. It has for many years been used, as well as calamine, for the making of brass at Bristol, and, I believe, it was first used there under

der

der a patent; but so little was this application of it known in other parts of the kingdom, that in the year 1777, they begged me in Derbyshire (where they had a little before that time begun to save it) not to divulge the purpose to which it might be applied.

It has not been long well understood, that either calamine or black jack contained any metallic substance.

Matthiolus, Agricola, Caneparius, and other expert and more ancient metallurgists, esteemed calamine to be a mineral, in which there was no metallic substance*. Their mistake on this subject was very excuseable; for the metallic substance contained in calamine, being of a volatile and combustible nature, it is consumed or dissipated by the ordinary processes in which

* *Canep. de Atram. p. 12—21.*

which metals are extracted from their ores. Most ores require to be fluxed in contact with charcoal, or some other substance containing phlogiston, before they will yield their metals; and when they are thus fluxed, the metal, instead of being dispersed in vapour, is collected into a mass at the bottom of the vessel, or furnace, in which the operation is performed. Calamine, in like manner, must be united to phlogiston, before its metallic part, which is called zinc, will be properly formed; but as soon as it is formed, it flies off in vapour, and taking fire burns with a vivid flame. This phenomenon is easily made apparent, by mixing calamine in powder and charcoal dust together, and exposing the mixture to a melting heat, for a flame will issue from it

very

very different from what charcoal alone would yield; no mass of any metallic substance will be found at the bottom of the vessel; but in the place where the experiment is made, there will be seen many white flocks floating in the air; these flocks are the ashes of the metallic substance of the calamine, they are called *flowers of zinc*, *lana philosophorum*, *nihil album*, and by other fanciful names. The metallic vapour which rises from a mixture of calamine and charcoal, when exposed to a proper degree of heat, and the firing of which causes the flame which may be observed, cannot burn without air; and it was on this principle that Marggraf proceeded, when he extracted zinc from calamine by distillation in close vessels in 1746. He put 8

B. 4 ,

parts

parts of powdered calamine, and 1 of powdered charcoal well mixed together, into an earthen retort; and having fitted a receiver, with a little water in it, to the neck of the retort, in such a manner as to exclude the air, he exposed the mixture to a strong heat; there rose into the neck of the retort, where it was condensed, the metallic vapour of the calamine. By this method he ascertained the quantity of zinc contained in different sorts of calamine.

	Parts.	Parts.	
Calamine from near Cracow	} 16	gave	$2\frac{1}{2}$ of zinc.
———— from England			
———— from Breslaw	16	—	$4\frac{1}{2}$ ———
———— from Hungary	16	—	$2\frac{1}{3}$ ———
———— from Holy-well in Flintshire	} 16	—	7 ———
———— from Holy-well in Flintshire			

He tried some stones from *Aix-la-Chapelle*, which had been given him
for

For calamine, in the same way, but obtained no zinc from them, and thence he concludes, that they were not calamine stones; for every stone, says he, which being mixed with charcoal, and exposed in close vessels to the action of a violent fire, does not yield zinc; or which in an open fire does not with copper and charcoal produce brass, ought not to be considered as a calamine stone*: Henckel had long before given a similar definition of zinc, when he observed that it was the only substance in nature which had the quality of giving copper a yellow colour †.

Pott wrote a dissertation on zinc in 1741, in which he enters into the history of the discovery of this semi-metal;

* *Opus. de Marg.* Vol. II. p. 94.

† *Pyrito.* French Transf. p. 248.

metal; *Bergman* has availed himself of all that *Pott* knew on the subject, and has added several things of his own; I cannot compress the matter into a less compass than he has done. “The semi-metal, which at present is called zinc, was not known so much as by name to the ancient Greeks and Arabians. The name which it bears at present first occurs in *Theophrastus Paracelsus**, but no one as yet has been able to discover the origin of this appellation. *A. G. Agricola* calls it *contrefeyn* †; *Boyle*, *speltrum* ‡: by others it is denominated *spiauter*, and *Indian tin* ||. *Albertus Magnus*, more properly called:

* In *Operibus*. passim.

† De *Re metallica*.

‡ *Ponderab. flammæ*.

|| *Tæda Trifida Chymica*.

called Bōlstadt, who died in 1280*, is the first who makes express mention of this semi-metal. He calls it golden marcasite, asserts that it approaches to a metallic nature, and relates that it is inflammable. However as zinc is white, the name of golden marcasite is not very proper; it would therefore appear probable, that it derives that name from the golden colour which it communicates to copper, had not Albertus expressly said, that copper united with golden marcasite becomes white; but he has probably either misunderstood or misrepresented what he had heard related by others. It may also happen, that zinc was formerly thought to contain gold. J. Matthesius † in 1562, mentioned a white and a red zinc;

* In Libro mineralium. † Sarepta.

zinc; but the yellowness and redness are only to be understood of the ores. Hollandus, Basil Valentine, Aldrovandus, Cæsius, Cæsalpinus, Fallopius and Schroeder, observe a profound silence on that head*. The eastern Indians have long since been in possession of the method of extracting pure zinc from the ore; at least in the course of the last century this metal was brought from thence to Europe. Jungius mentions the importation of zinc from India, in 1647 †; a metal of this kind, under the name of tutenag, is still brought from thence, which must be carefully distinguished from the compound metal of that name. G. E. Van Lohneis tells us, in 1617, that a long

* Pott on Zinc.

† De Mineralibus.

long time before zinc had been collected by fusion at Goslar *. It has been long usual to form orichalcum from the ores of zinc by the addition of copper; but it does not yet appear at what time this art was invented. Pliny makes mention of the orichalcum, as also of three species of Corinthian vases, one of which is yellow, and of the nature of gold †. Erasmus Ebner, of Noremberg, in the year 1550, was the first who used the cadmia of Goslar for this purpose. In the year 1721, Henckel indeed mentioned that zinc might be obtained from lapis calaminaris by means of phlogiston, but he conceals the method ‡. The celebrated Anton.

* Bericht Von Bergvercken.

† Hist. Nat. XXX. C. II.

‡ Pyritologia — Henckel's words deserve
to

ton. Van Swab, in 1742, extracted it from the ores by distillation, at Westerwick in Dalecarlia *. It was determined to found a work for the purpose of extracting larger quantities of this semi-metal: but afterwards, for various reasons, this project

to be quoted, I take them from the French translation of the Pyritologia, p. 295. — On fait, par exemple, avec la calamine, non-seulement du fer, il est vrai en petite quantité, mais encore *une tres-grande quantité de zinc*, que l'on obtient non-seulement en lui présentant le corps avec lequel il peut s'incorporer, c'est-a-dire le cuivre qui est son aimant, mais encore ce demi-metal se montre simplement par l'addition d'une *matiere grasse qui metallise*; il faut seulement pour eviter que ce phénix ne se reduise en cendre, *empêcher qu'il ne se brûle*, et observer le tems et les circonstances.

* Elogium magni hujus Metallurgi coram R. Acad. Stock. recitatum.

ject was laid aside; therefore the illustrious Marggraf, not knowing what had been done by the Swedish mineralogists, in the year 1746, published a method of performing this operation, which he had discovered himself*. It is not known how zinc is extracted in China. A certain Englishman, who several years ago took a voyage to that country for the purpose of learning the art, returned safely home, indeed, and appears to have been sufficiently instructed in the secret, but he carefully concealed it. We find afterwards that a manufactory had been established at Bristol, where zinc is said to be obtained by distillation per descensum. We have already seen that it had been before obtained in Sweden

* Mem. de l'Acad. de Berlin.

Sweden by distillation per ascensum; which afterwards was effected in larger quantity by Mess. Cronstedt and Riman, two very celebrated mineralogists and metallurgists. The difficulties occasioned by the volatile and combustible nature of this metal for a long time retarded the knowledge of the ores containing it; nor is that wonderful, as being of a metallic form, it has even to our times been considered as composed of two or three ingredients. Albertus Magnus thinks iron an ingredient; Paracelsus called it a spurious son of copper; Lemery holds it to be a species of bismuth; Glauber, and many alchemists, consider it merely as an immature solar sulphur; Homberg, as a mixture of tin and iron; Kunckel, as a coagulated mercury; Schluter,

Schluter, as tin made brittle by sulphur, &c.—The celebrated Brandt, in 1735, shewed that blende contained zinc *; and soon after D. Swab actually extracted it from the Bolognian Pseudo-galena, which possesses a metallic splendor. The Baron Funch, in 1744, determined the presence of zinc in pseudo-galena from the flame and the flowers †; and in 1746, Mr. Marggraf set the matter out of doubt.”

Bergman in this history of the discovery of the method of extracting zinc from calamine, wholly omits the mention of *Dr. Isaac Lawson*; of whom Pott, in his *Essay on Zinc*, speaks very respectfully, acquainting us that he really obtained some grains of that semi-metal from calamine.

* Act. Upsal.

† Act. Stock.

mine. So that though *Henckel* was the *first*, *Lawson* was, probably, the *second* person in Europe who procured zinc from calamine; whether he was the Englishman who, according to *Bergman*, went to China to discover the method of doing it, is what I have not been able to learn with certainty. Our English writers, who have touched on this subject, speak in high terms of *Lawson*, I suppose from their personal knowledge of him, for they do not refer to any written account*. Thus *Dr. Pryce*, says,

* *Pott* gives us several quotations from a dissertation of *Dr. Lawson's De Nihil*, which I have never met with, and amongst others the following one, *Quamvis lapis calaminaris nec sublimatione, nec cum fluxu nigro det zincum, tamen similes flores, similis in igne color, similis tinctura cupri, et augmentum*

says, “ * the late Dr. I. Lawson observing that the flowers of lapis calaminaris were the same as those of zinc, and that its effects on copper were also the same with that semi-metal, never remitted his endeavours till he found the method of separating pure zinc from that ore.” And Dr. Campbell, in his Survey of Britain, is still more particular: “ † the credit if not the value of calamine is very much raised since an ingenious countryman of ours discovered that it was the true mine of zinc; this countryman was Dr. I. Lawson, who died before he had made any advantage-

mentum ponderis probabilissimum præbent argumentum lapidem calaminarem esse mineram zinci. Pott De Zinco, p. 9.

* Mineral. Cornub. p. 46.

† Polit. Surv. of Brit. Vol. II. p. 35.

tage of his discovery." The authors of the Supplement to Chambers' Dictionary, published in 1753, expressly affirm, that " * Dr. Lawfon was the first person who shewed that calamine contained zinc; we have now on foot at home a work established by the discoverer of this ore, which will probably make it very unnecessary to bring any zinc into England." — To all this I shall only add one testimony more, from which it may appear that the English knew how to extract zinc from calamine, before Mr. Van Swab taught the Swedes the method of doing it; though this gentleman, unless I have been misinformed, instructed the late Mr. *Champion* of Bristol, either in the use of black jack for the same purpose

Artic. Calam. & Zinc.

pose as calamine, or taught him some improvements in the method of obtaining zinc from its ores. The testimony occurs in a dissertation of Henckel's on zinc, published in 1737, he is there speaking of the great hopes which some persons had entertained of the possibility of obtaining zinc from calamine; hopes, he says, which had been realized in England, Ce qu'un Anglois arrivé depuis peu de Bristol, dit avoir vu réussir dans son pays*.

The manufactory, however, of zinc was not established at Bristol till about the year 1743, when Mr. *Champion* ob-

* This observation was first published in the 4th vol. of the *Acta Physico-Medica Acad. Nat. Cur.* 1737, but I have made the quotation from the Ed. of Henckel's Works, published at Paris, 1760, Vol. II. p. 494.

obtained a patent for the making of it. About 200 tons of zinc are annually made at the place where the manufactory was first set up; and about seven years ago, zinc began to be made at Henham near Bristol, by *James Emerson*, who had been many years manager of that branch under Mr. Champion, and his successor in the business.

Near twenty years ago I saw the operation of procuring zinc from calamine performed at Mr. Champion's copper works near Bristol; it was then a great secret, and though it be now better known, yet I am not certain whether there are any works of the kind yet established in any other part of either England or Europe, except that before mentioned at *Henham*. In a circular kind of oven, like a glass
house

house furnace, there were placed six pots of about four feet each in height, much resembling large oil jars in shape; into the bottom of each pot was inserted an iron tube, which passed through the floor of the furnace into a vessel of water. The pots were filled with a mixture of calamine and charcoal, and the mouth of each was then close stopped with clay. The fire being properly applied, the metallic vapour of the calamine issued through the iron tube, there being no other place through which it could escape, and the air being excluded, it did not take fire, but was condensed in small particles in the water, and being remelted was formed into ingots, and sent to Birmingham under the name

of zinc or spelter *. The reader will understand that this zinc will be more or less pure, according as the calamine is free from or mixed with iron, lead, copper, or other metallic substances. At *Goslar* in *Germany* they smelt an ore which contains lead, and silver, and copper, and iron, and zinc in the same mass; the ore is smelted for the purpose of procuring the lead and silver, and by a particular contrivance in the furnace, which is well described by Cramer †, they obtain a portion of zinc in substance; another portion of it is inflamed, and the

* There is another substance which is denominated spelter or spelter solder by the braziers, it is composed of two parts of zinc and of one of brass.

† *Ars Docim.* Vol. I. p. 236.

the ashes of the zinc which is thus consumed, and which it has been observed before are called philosophic wool, &c. stick to the top and sides of the furnace, and are denominated by the smelters *cadmia fornacum*, or *furnace fragment*: these ashes are used as calamine is for the making of brass. We know nothing of the method of fluxing the zinc which is brought from India. According to Musschenbroeck, a cubic foot of Indian zinc weighs 7240 ounces; the same bulk of Goslar zinc, taking the medium of three specimens, gave 7210 ounces*; the Goslar zinc, which I examined, gave only 6953 ounces to a cubic foot; a cubic foot of English zinc, from Bristol, weighs 7028, and hence if the lightness of zinc

* Introd. ad Phil. Nat. Vol. II.

zinc be a criterion of its purity, our English zinc is preferable to the Indian and nearly equal to the German zinc.

If the reader has never seen a piece of zinc, it will give him some idea of it to be told, that in colour it is not unlike lead; that it is hard and sonorous, and malleable in a small degree; that it does not melt so easily as either tin or lead, but more easily than silver or copper; that in a degree of heat just sufficient to melt it, it burns away into a kind of gray ashes without being inflamed; that in a stronger heat it burns with a yellowish blue or green flame, resolving itself into a white earth, which is either driven off by the violence of the fire during the combustion, or remains surrounding the burning zinc

zinc like a piece of cotton wool. This combustion of zinc is as striking an experiment as any in chemistry, and it is in the power of any person to make it, by sprinkling filings of zinc on a pan of burning charcoal, or on a poker or other piece of iron heated to a white heat: it is this property which renders fine filings of zinc of great use in fire-works. Zinc is a very singular metallic substance, it not only burns when sufficiently heated with a vivid flame, but it yields an inflammable air by solution in the acids of vitriol and of sea salt, and even in some of its ores it manifests a phosphoric quality; I have seen a piece of black jack from Freiberg, which being scratched in the dark with the nail of a finger emitted a strong white light. The Chinese
zinc

zinc is said to contain about half a pound of lead in an hundred, and the German zinc somewhat more*, and our English zinc is thought by some to make the copper with which it is melted harsher and less malleable, than when either of the other sorts of zinc is used; though this opinion I suspect is rather founded in prejudice than in truth. There is an easy method, when pure zinc is required, of obtaining it: nothing more is requisite than to melt it with sulphur and some fat substance to prevent its calcination, for the sulphur will unite itself to the lead, the copper, or the iron contained in the zinc, and reduce them to a kind of scoria which may be separated from the melted zinc, but

* Berg. Ess. Vol. II. p. 318, note.

it has no action on the zinc itself*.

The zinc made by Mr. Emerson is whiter and brighter than any other either English or foreign zinc, but I do not know that it owes these qualities to its being purified by sulphur. Zinc and copper, when melted together in different proportions, constitute what are called pinchbecks, &c. of different yellow colours. Marggraf melted pure zinc and pure copper together, in a great variety of proportions, and he found that eleven, or even twelve parts of copper being mixed with one part of zinc, (by putting the zinc into the copper when

* I am aware that Mr. Morveau has found out a method of combining zinc with sulphur; but in this general view, I purposely pass over many things which are deservedly esteemed of great importance by persons deeply skilled in chemistry.

when melted) gave a most beautiful and very malleable tombac or pinch-beek *. Mr. Baumé gives the following process for making a metal, which he says is called *Or de Manheim*, and which is used for imitating gold in a variety of toys, and also on lace. — Melt an ounce and an half of copper, add to it three drams of zinc, cover instantly the mixture with charcoal dust to prevent the calcination of the zinc †; this covering of the melted mass with charcoal is certainly serviceable in the way the author mentions; and it is on a similar principle, that when they melt steel at Sheffield they keep the surface of it covered with charcoal; but I think it probable also, that the charcoal contributes to exalt the golden colour.

* Mem. of Berlin, 1774.

† Chy. par M. Baumé, Vol. II. p. 662.

lour of the pinchbeck. These yellow metals are seldom so malleable as brass, on account of the zinc which is used in making them not being in so pure a state, as that is which is combined with copper when brass is made; yet it appears from the experiments of Marggraf and Baumé before mentioned, that when pure zinc and pure copper are used in proper proportions, very malleable brass may be made thereby. Mr. Emerson has a patent for making brass with zinc and copper, as I have been informed, and his brass is said to be more malleable, more beautiful, and of a colour more resembling gold than ordinary brass is. It is quite free from knots or hard places, arising from iron, to which other brass is subject, and this quality, as it re-

spects

spects the magnetic needle, renders it of great importance in making compasses: the method of making ordinary brass I will now describe.

Copper in thin plates, or, which is better, copper reduced (by being poured, when melted, into water) into grains of the size of large shot is mixed with calamine and charcoal, both in powder, and exposed in a melting pot for several hours to a fire not quite strong enough to melt the copper, but sufficient for uniting the metallic earth of the calamine to the phlogiston of the coal; this union forms a metallic substance, which penetrates the copper contiguous to it, changing its colour from red to yellow, and augmenting its weight in a great proportion. The greater the surface of a definite weight of copper,

the

the more space has the metallic vapour of the calamine to attach itself to, and this is the reason that the copper is granulated, and that it is kept from melting and running into a mass at the bottom of the vessel, till near the end of the operation, when the heat is increased for that purpose.

The German brass-makers, in the time of *Erckern*, used to mix 64 pounds of small pieces of copper with 46 pounds of calamine and charcoal, and from this mixture they generally obtained 90 pounds of brass*. *Cramer* recommends 3 parts of powdered calamine to be mixed with an equal weight of charcoal dust and 2 parts of copper, and says, that the brass

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* *Fleta Minor*. by Sir J. Pettus, p. 286. Newman gives the same proportions, p. 65.

obtained by the process exceeds the weight of the copper by a fourth, or even a third part of its weight *. At most of our English brass-works they use 45 pounds of copper to 60 pounds of calamine for making ingot brass, and they seldom obtain less than 60 or more than 70 pounds of brass; at Holywell they reckon the medium product to be 68: and hence a ton of copper, by this operation, becomes rather more than a ton and an half of brass. This is a larger increase of weight in the copper, than is observed in any of the foreign manufactories that I have ever read of, and it may be attributed to two causes, to the superior excellence of our calamine, and to our using *granulated* copper. Postlethwayte,

* Cram. Ars Doc. Vol. II. p. 246.

thwayte, in his Commercial Dictionary, attributes the difference in the increase of weight acquired by the brass to the different natures of the coppers which are used, "there is an increase of 48 or 50 pounds in an hundred, if copper of Hungary or Sweden be used; that of Norway yields but 38, and that of Italy but 20." When they make brass which is to be cast into plates, from which pans and kettles are to be made, and wire is to be drawn, they use calamine of the finest sort, and in a greater proportion than when common brass is made, generally 56 pounds of calamine to 34 of copper. Old brass which has been frequently exposed to the action of fire, when mixed with the copper and calamine in the making of brass, renders the brass far

more ductile and fitter for the making of fine wire than it would be without it; but the German brass, particularly that made at *Nuremberg*, is, when drawn into wire, said to be preferable to any made in England for musical instruments. If this preference be real, it will cease to exist as soon as any ingenious man shall undertake to examine the subject, for our materials for making brass are as good as any in the world. The quantity of charcoal which is used, is not the same at all works, it is generally about a fourth part of the weight of the calamine; an excess of charcoal can be attended with no other inconvenience than that of uselessly filling up the pots in which the brass is made; but powdered pitcoal, which is used at some works in conjunction with,

with, or in the place of charcoal, greatly injures the malleability of the brass. As to black jack, the other ore of zinc, it is not so commonly used as calamine for the making of brass. The manufacturers have been somewhat capricious in their sentiments concerning it, some have preferred it to calamine, and others have wholly neglected it; and the same persons at different times have made great use of it, or intirely laid it aside. There must have been some uncertainty in the produce or goodness of brass made by this mineral, to have occasioned such different opinions concerning it, and this uncertainty may have proceeded either from the variable qualities of the mineral itself, or from the unskilfulness of the operators in calcining, &c. a mineral to which

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they

they had not been much accustomed. Several ship loads of it were sent a few years ago from Cornwall to Bristol, at the price of 40 shillings down to a moidore a ton*. Upon the whole, however, experience has not brought it into reputation at Bristol.

For many purposes brass is more useful than copper: it is lighter, harder, more sonorous, more fusible, less liable to scale in the fire, and to rust in the air. It is not malleable when hot, and in this respect it is inferior to copper; but when cold it may be beat out into thin leaves, as may be seen in the brass leaf which emulates in colour and thinness gold leaf. If a brass leaf be held in the flame of a candle, the metallic part of the calamine will be inflamed, and
the

* Miner. Cornu. p. 47.

the brass will be changed into copper. This change of brass into copper will take place in the largest masses as well as in thin leaves of it, if the brass be kept a sufficient time in a state of fusion. The varieties in the colour, malleability, and ductility of brass, proceed from the quantity and quality of the calamine imbibed by the copper; and the quality of the copper itself is a circumstance of no small importance in the making of brass. "I have observed," says Dr. Lewis*, in a large set of experiments on this subject, that a little of the calamine (that is, of the zinc contained in the calamine) dilutes the colour of the copper and renders it pale; that when the copper has imbibed about one twelfth of its own weight,

* Newman's Chem. by Lewis, notes, p. 65.

weight, the colour inclines to yellow; that the yellowness increases more and more till the proportion comes almost to one half; that on further augmenting the calamine, the brass becomes paler and paler, and at last white." As to the different qualities of different kinds of copper, they are sufficiently known to workmen employed in fabricating it; and philosophers have so far observed them as to distinguish the different sorts of copper by the different weights which appertain to equal bulks of them. The lightest copper which Muffchenbroeck has noticed, is that which is precipitated from the copper waters in *Hungary*; a cubic foot of this sort weighed, when melted, 7242 ounces; and the heaviest sort he mentions is the *Japan* copper, a cubic foot of it, when

when simply melted, weighing 8726 ounces. The difference of the weights of equal bulks of these two sorts of copper is very considerable; but yet it is much less than what may be observed between two specimens of the same sort of copper, one of which has been *cast*, and the other has been *wrought*: the same Hungarian copper, which, when barely melted, weighed 7242 ounces to the cubic foot, when it had been condensed by being long hammered, weighed 9020. Many of our English writers estimate the weight of a cubic foot of copper at 9000 ounces*, but they do not say, whether the copper was melted merely, or hammered; nor from what mine it was procured. I found the weight of a cubic foot of plate-brass from

* Cotes, Ferguson, Martin, Campbell.

from Bristol to be 8441 ounces; and that of a cubic foot of old brass from the bottom of an old kettle to be 8819, which shews that it approached to the weight of copper, and indeed from the redness of its appearance it seemed as if all the zinc had been burned away. I had a present made me of a fine *celt*, (the antiquaries are not agreed concerning the uses to which the celts were applied, nor whether they are to be esteemed British or Roman instruments) it was covered over with a thick *patina*; I heated it in the fire, in order to get rid of this precious patina, or green rust, and took the specific gravity of it when quite freed from its rust with great care; a cubic foot of it would have weighed only 6290 ounces. It was not malleable either when hot or cold:

cold: I then melted it, when in a state of fusion it emitted a blue flame, and a thick white smoke, which are esteemed certain marks of zinc; I melted it a second time, but there was no appearance of either flame or smoke, the zinc having been all consumed; I could not observe any lead in it; a cubic foot of it, after it was gently cooled from its state of fusion, weighed 8490 ounces, and it was now malleable as cold brass always is; it was composed, I think, of copper, calamine, and tin; and I have heard that some celts contain a little silver. The change of texture which it had undergone, by being long buried in the earth, occasioned its comparative levity; this diminution of weight, which decaying brass sustains, is not peculiar to brass, it probably belongs

to iron, and other metallic substances subject to decay, and it certainly belongs to many species of stones. I have in another place observed, that a cubic foot of *toadstone* has different weights, according as the stone is more or less decayed; that which is most decayed being the lightest. We have a stratum of bluish gray *ragstone* in *Westmoreland*, which lies under the limestone; large cobbles of this sort of stone, which are exposed to the air, are decayed to a certain depth from the surface, whilst the inward part seems intire; a cubic foot of the outward part of one of these stones weighed 2378, when the inward part of the same stone weighed 2603 ounces to the cubic foot. This *ragstone* is very hard, but the same phenomenon may be noticed in a stone
 still

still harder. The *Cambridgeshire* black flint weighs 2592 ounces to the cubic foot; the same flint being in *part* decayed and become *externally* white, though black within, weighed 2414, and when become *wholly* white, 2400 ounces to the cubic foot: the general reason of this seems to be, that the pores of the decayed body are augmented. Mr. Kirwan has well explained the manner in which nature operates in decomposing stones: “Flints, jaspers, petro-filex, felspar, granites, lavas and ferrugineous stones, have frequently been said to be decomposed by the air, and the observations of Mr. Greville and Sir W. Hamilton have removed every doubt I entertained on this head. With regard to ferrugineous stones, in which the calx of iron is not much
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dephlogisticated, this decomposition is easily understood, for this calx gradually becomes more dephlogisticated by the action of water and air, attracts water and fixed air, and loses its adherence with the siliceous, or other stony particles: this is seen to happen to basaltes, toadstone, ferruginous limestone, &c. In other stones this decomposition may arise from their containing calcareous earth in a caustic state, or manganese, for these will gradually attract water and fixed air, and then swell, burst and loosen the whole texture of the stone, as we see happen to bricks that contain lime. Thus also glass is decomposed by long exposure to the air, the alkali attracting water and aerial acid. Mortar on the contrary hardens by long exposure to the air, because,

cause, though the aerial acid be attracted, yet a great part of the water exhales*." The changes produced by the long exposure of bodies to the air, and the causes of them, deserve a more minute investigation than has hitherto been bestowed on them; some advantage might, perhaps, be derived from the inquiry to our manufacturers, for I have cause to think that iron, which has been exposed to the air for three or four years, is a very different substance from the same iron when just made: and the same observation will probably hold with respect to copper and brass.— But to return from this digression.

The calamine of *Bohemia* contains iron; most of our English calamine contains lead; and there are some
 forts

* Elements of Min. by R. Kirwan, p. 111.

Sorts which contain both iron and lead, and other metals in different proportions: these sorts can seldom be freed from the extraneous metals, and hence, in the ordinary method of making brass, they will be mixed with it, being fusible in the degree of heat usually employed in making brass. *Cramer* mentions a very ingenious method of making brass, by which, if it should be thought necessary to do it, the brass may be preserved pure from these heterogeneous mixtures. He orders the calamine and charcoal to be mixed with moistened clay, and rammed to the bottom of the melting pot, and the copper mixed with charcoal to be placed upon the clay; then, the proper degree of heat being applied, the vapour of the zinc contained in the calamine

lamine will ascend through the clay, and attach itself to the copper, but the iron, or lead contained in the calamine, not being volatile, will remain in the clay, and the brass when the whole is melted will not be mixed with them, but rest pure on the surface of the clay. Mr. *John Champion*, brother to him who first established the manufactory of zinc at Bristol, is a very ingenious metallurgist, and he has lately obtained a patent for making brass by combining zinc in vapour with heated copper plates, and the brass is said to be very fine; whether the process he uses has any correspondence with this mentioned by Cramer, or not, his brass will certainly be free from the mixture of lead, &c. But the care to purify brass from such metallic

mixtures as may be accidentally contained in the calamine, is, or is not necessary, according to the purposes to which brass is applied. These mixtures may probably injure the malleability of the brass, but they may at the same time increase its hardness, or render it susceptible of a better polish, or give it a particularity of colour, or some other quality by which it may be more useful in certain manufactories, than if it was quite free from them, and consisted of nothing but of the purest metallic part of the calamine, united to the purest copper. This may be illustrated from what is observable in other metals. The red iron ore from *Furness* in *Lancashire* produces an iron, which is as tough as *Spanish* iron, it makes very fine wire; but when

when converted into bars, it is not esteemed so good as that which is made in the forest of *Dean*, and other places. There are but few sorts of iron which, though useful in other respects, are fit for being converted into steel: some sorts of iron will admit an high polish, as may be seen in many expensive grates which are sold as grates of polished steel, though they are nothing but iron, whilst others take but a very indifferent polish; the *Swedish*, *Russian*, and *English* irons, and even the irons made at different furnaces in the same country are respectively fit for some purposes, and unfit for other; he who should attempt to use the same iron for the making of wire, and for coach and waggon wheels, would betray great ignorance in his business.

In like manner, a notable difference may be observed in different sorts of copper, yet all of them have their respective uses: the Swedish copper is more malleable than the copper of Hungary; the copper of Anglesey differs from the copper of Cornwall and of Staffordshire. The braziers prefer that copper which they can work with the greatest facility, but the malleability of copper should not be esteemed the only criterion of its goodness; for the copper which is less malleable may admit a finer polish, and may last longer when exposed, as in breweries, in the navy, &c. to the action of the fire, than the copper which is more malleable. This has been proved by experiment. Three plates of copper, equal to each other in surface and thickness, were
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exposed, for the same length of time, to a violent fire, with a view of seeing which would best sustain its action; one plate was made of copper which had been purified by a chemical process, another was made of copper from Hungary, and the third of Swedish copper. The purified copper, when freed from the calcined scales, had lost 5 grains of its weight, that of Hungary had lost 8, and that of Sweden 11 grains*.

Queen Elizabeth, in 1565, granted by patent all the calamine in England and within the English Pale in Ireland to her assayer master *William Humphrey*, and one *Christopher Shutz* a German, and, as the patent sets forth, a workman of great cunning, knowledge and experience, as well in
the

* Mem. de Brux. Vol. IV.

the finding of calamine, as in the proper use of it for the composition of the mixt metal called *latten* or *brass* *. With these patentees were soon after associated some of the greatest men in the kingdom, as Sir Nicholas Bacon, the Duke of Norfolk, the Earls of Pembroke and Leicester, Lord Cobham, Sir William Cecil, and others, and the whole were incorporated into a society, called, The Society for the Mineral and Battery Works in the year 1568. Mines of *latten*, whatever may have been at that period meant by the word,

* Opera Mineralia explicata, p. 34. This work was written by Moses Stringer, M. D. in 1713, and contains a complete history of the ancient corporation of the city of London, of and for the *mines*, the *mineral* and *battery works*.

word, are mentioned in the time of Henry VI. who made his chaplain John Bottwright, comptroller of all his mines of gold and silver, copper, latten, lead, within the counties of Devon and Cornwall*; yet I am disposed to think, that the beginning of the brass manufactory in England may be properly referred to the policy of Elizabeth, who invited into the kingdom various persons from Germany, who were well skilled in metallurgy and mining. In 1639, a proclamation was issued prohibiting the importation of brass wire †; and about the year 1650, one *Demetrius*, a German, set up a brass work in Surrey, at the expence of six thousand pounds ‡; and above eight thousand men.

* Id. p. 20.

† Id. p. 147.

‡ *Essays on Metal. Words — Brass.*

men are said to have been employed in the brass manufactories, which were established in Nottinghamshire, and near London, yet Sir John Pettus, in his account of royal mines, published in 1670, observes that these brass works were then decayed, and the art of making brass almost gone with the artists*. But though the art was then *almost* gone, yet it was never, after its first establishment, altogether lost; for about the year 1708, we find that there were brass manufacturers in England, and that they presented a memorial to the House of Commons, setting forth several reasons for continuing the brass manufactory in this kingdom, and soliciting for it the protection of parliament †. In this memorial they stated

* Fodinæ Regal. p. 33.

† Oper. Min. exp. p. 156.

stated that England, by reason of the inexhaustible plenty of calamine, might become the staple of brass manufactory for itself and foreign parts; that the continuing the brass works in England would occasion plenty of rough copper to be brought in, and make it the staple (in time) of copper and brass; that the Swedes had endeavoured to subvert the English brass manufactory, by lowering the price of Swedish brass wire, inveigling away workmen, and other means. In compliance with the purport of this memorial, an act of parliament was passed in the same year, by which the former duties payable on the exportation of copper of the produce of Great Britain, and of *brass wire*, were taken off, and these articles were allowed to be exported free of duty.

In

In 1720 it was remarked, that this nation could supply itself with copper and brass of its own produce sufficient for all occasions, if such duties were laid on foreign copper and brass, as would discourage their importation, and at the same time encourage the sale of our own metals *. At present the brass manufactory is established amongst us in a very great extent; we are so far from being obliged to have recourse to any of our neighbours for this commodity, that we annually export large quantities of manufactured brass to Flanders (it was formerly called Flanders metal) France, Germany,

* State of the Copper and Brass Manufactures, by W. Wood. — The same person whom Swift handled so roughly in his Drapier's Letters.

many, Portugal, Spain, Ruffia, Africa, and most other parts of the world. In 1783, a bill was passed by the House of Commons for repealing certain statutes prohibiting the exportation of brass. In the reign of Edward III. the exportation of iron, either made at home or brought into England, had been prohibited upon the pain of forfeiting double the value of the quantity exported *. And in the reigns of Henry VIII. and Edward VI. several acts of parliament had been passed, prohibiting the exportation of brass, copper, latten, bell-metal, pan-metal, gun-metal, shrof-metal, under the same penalty †. The general reason for
passing

* 28 Ed. III. c. 5.

† 21 Hen. VIII. c. 10.—33 Hen. VIII. c. 7.
— 2 & 3 Ed. VI. c. 37.

passing these acts certainly does not apply to the present state of our mines and manufactures, for the reason was this,—lest there should not be metal enough left in the kingdom fit for making of guns and other engines of war, nor for household utensils. The forementioned acts of parliament were partially repealed, by an act passed in the sixth year of William and Mary, by which it was rendered lawful to export, after the 25th of March, 1694, all manner of iron, copper, or mundick metal; but the prohibition of the other metals was continued. The brass-makers in 1783 applied for the same liberty, which had been granted to the iron and copper smelters, a liberty of exporting the crude commodity; this liberty was not granted them by the legis-

legislature, for the bill which had passed the House of Commons, was thrown out by the Lords. The *Birmingham* manufacturers presented a petition to the house of commons against the bill which was then pending; in which petition it was represented — that frequent attempts had been made to erect manufactures similar to those of Birmingham in different parts of Europe, and that the excellence of some of the Birmingham articles depended upon brass of very different qualities, and that, fortunately for this country, there were several sorts of brass that were peculiarly adapted to the different branches of their manufactures; so that the sort which was suitable for one article, was improper for another: and that they had reason to believe,

believe, that the manner of adapting the various sorts of English brafs to different articles in their manufactures, was not known to foreigners; but that if free liberty was given to export brafs, every maker might be induced to discover the peculiar uses of his sort, and that very disagreeable consequences to their manufactures might thereby be produced. The petitioners also represented — that brafs-makers, in different provinces of this kingdom, had not succeeded in making the sorts of brafs made in other provinces; and that one great company of brafs-makers had not succeeded in making brafs suitable for the Birmingham market, though they had professed an earnest desire to do so. And they humbly apprehended, that there never had
been

been such a quantity of brass exported as to render it a national object, and that there was not a probability of any such quantity being exported, though so much might be as to raise a ruinous competition to their manufactures, &c.

The brass-makers, it may be said, suffer an injury in being prohibited from exporting a commodity by which they might be gainers, merely lest the great brass manufacturers should lose somewhat of their profit, by having a less extensive trade. But this is not a proper state of the case; it is not for the sake of the great brass manufacturers that the prohibition of exporting brass is continued, nor is there any want of that metal in the kingdom; but lest foreigners should rival us in a trade which, in affording
em-

employment to many thousands of people, is of the greatest consequence to the kingdom in general. The proprietors of *Fuller's Earth* have been prohibited from exporting that material, not out of any partial regard of the legislature for the great woollen manufacturers, but lest the number of persons employed in that manufacture should be much lessened, if foreigners were supplied with an article so essentially necessary to its perfection, as fuller's earth is found to be; and though other nations have fuller's earth, yet that which is met with in England is reckoned to be fitter for the woollen manufactory, than any other which has yet been found in any part of the world. This observation may be applied to the subject we are speaking of.

of. Great quantities of good brass are made by most nations in Europe, as well as by the English; but the English brass is more adapted to the Birmingham manufactories, than any other sort is; and hence in *France*, *Portugal*, *Russia*, and *Germany*, our *unmanufactured* brass is allowed to be imported *free of duty*, but heavy duties are imposed in those countries on manufactured brass when imported. The manner of mixing different sorts of brass, so as to make the mixture fit for particular manufactures, is not known to foreigners; though this is a circumstance of the greatest importance; but there can be little doubt that if foreign nations were possessed of all the sorts of English brass, they would soon seduce our workmen to instruct them in the manner of mixing them, and in some other little

circumstances, which are not generally known, but on which the success of the manufacture depends in a great degree. On these and other accounts, till commerce puts on a more liberal appearance than it has hitherto done in Europe, till different nations shall be disposed to consider themselves, with respect to commercial interest, as different provinces only of the same kingdom, it may, probably, be thought expedient to continue the acts prohibiting the exportation of unwrought brass, though the reasons which induced the legislature to pass them have long since ceased to exist. I do not enter into the inquiry, when the custom house officers began to make a distinction between *wrought* and *unwrought* brass, so as to admit the former to an entry for exportation,

tion, and not the latter; but I apprehend it was in the year 1721, when various goods and merchandizes of the product or manufactures of Great Britain were allowed, by act of parliament, to be exported free of duty: *lapis calaminaris*, lead, and several other articles are enumerated in the act, on which the duty was to be continued; but in this enumeration there is no mention made of *unwrought* brass, though it may properly be considered as a merchandize of the product of Great Britain; but the quantity of brass which was then made in the kingdom was so small, that it did not, probably, enter into the contemplation of the legislature to forbid an exportation, which did not seem likely ever to take place. Brass is made in various parts of Great Britain; but the *Bristol*, *Macclesfield*,

and *Warrington* companies are the only ones, I believe, which go through all the processes of smelting the copper from its ore, of preparing the calamine, and of uniting it with copper for the making of brass. The trade of brass-making has within these few months been much deranged throughout the nation, by an agreement which has been entered into by some of the principal copper companies, to the exclusion of others, to buy up all the copper of the mines now at work in the kingdom. The effect of this plan is not yet generally either felt or foreseen.

The following Essay was written several years ago; it is now printed, with little alteration, from a copy which I transmitted in 1783 to *The Literary and Philosophical Society at Manchester*, as a small Tribute of Gratitude for the unsolicited and unexpected honour they had done me, in electing me one of their members.

ESSAY



ESSAY II.

On Orichalcum.

WE have a proof, from the writings of *Cicero*, that the *Romans*, in his time, understood by the term *Orichalcum*, a metallic substance resembling gold in colour, but very inferior to it in value. He puts the following case — “ Whether, if a person should offer a piece of *gold* to sale, thinking that he was only disposing of a piece of *orichalcum*, an

honest man ought to inform him that it was really gold, or might fairly buy for a penny what was worth a thousand times as much *." It is not contended, that the argument, in this place, required any great accuracy in ascertaining the relative values of gold and orichalcum; yet we may reasonably conclude from it, that orichalcum might by an ignorant person be mistaken for gold, and, that it was but of small estimation when compared with it.

Julius Cæsar robbed the capitol of three thousand pound weight of gold, and substituted as much gilded copper in its stead †; in this species of sacrilege, he was followed by *Vitellius*, who despoiled the temples of their gifts

* Cicer. de Off. L. III.

† Suet. in Jul. Cæs. C, LIV.

gifts and ornaments, replacing the gold and silver by tin and orichalcum*. From this circumstance also, we may collect, that the Roman orichalcum resembled gold in colour, though it was far inferior to it in value.

It is probable, that the orichalcum here spoken of, was a metallic substance greatly analogous to our brass, if not wholly the same with it. The value of our brass is much less than that of gold, and the resemblance of brass to gold in colour, is obvious at first sight. Both brass and gold, indeed, are susceptible of a variety of shades of yellow; and, if very pale brass be compared with gold mixed with much copper, such as the foreign goldsmiths, especially, use in their toys, a dis-

* Id. in Vitel. C. VI.

disparity may be seen; but the nearness of the resemblance is sufficiently ascertained in general, from observing that substances gilded with brass, or, as it is commonly called, Dutch leaf, are not easily distinguished from such as are gilded with gold leaf.

The *Romans* were not only in possession of a metallic substance, called by them orichalcum, and resembling gold in colour, but they knew also the manner of making it; and the materials from which they made it, were the very same from which we make brass. I am sensible, that in advancing this opinion, I dissent from authors of great credit, who esteem the art of making brass to be wholly a modern invention. Thus *M. Cronstedt* (though I differ in opinion from him) “ does not think it just to
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conclude from old coins and other antiquities, that it is evidently proved, that the making of brass was known in the most ancient times* ;” the authors of the French *Encyclopedie* assure us, that “our brass is a very recent invention † ;” and Dr. Laughton ‡ says, “the vessels here called brazen, after ancient authors, cannot have been of the materials our present brass is composed of, the art of making it is a modern discovery.”

Pliny, speaking of some copper which had been discovered near *Corduba* in the province of *Andalusia* in *Spain*, says, “this of all the kinds of copper, the *Livian* excepted, absorbs most *cadmia*, and imitates the goodness

* *Miner.* p. 218. † *Art. Orichalque.*

‡ *Laughton's Hist. of Ancient Egypt*, p. 58.

ness of *aurichalcum**." The expression, 'absorbs most *cadmia*,' seems to indicate, that the copper was increased in bulk, or in weight, or in both, by means of the *cadmia*. Now it is well known, that any definite quantity of copper is greatly increased, both in bulk and in weight, when it is made into brass by being fluxed in conjunction with *calamine*. The other attribute of the copper when mixed with *cadmia*, was, its resembling *aurichalcum*. We have seen from *Cicero*, that the term *orichalcum* was applied to a substance far less valuable than gold, but similar to it in colour; and it is likely enough, that the *Romans* commonly called the mixture of copper and *cadmia* *orichalcum*, though *Pliny* says, that it

only

* *Hist. Nat. L. XXXIV. S. II.*

only resembled it; he, as a naturalist, speaking with precision, and distinguishing the real orichalcum, which in his time, he says, was no where produced, from the factitious one, which, from its resemblance to it, had usurped its name.

Sextus Pompeius Festus abridged a work of *Verrius Flaccus*, a grammarian of considerable note in the time of *Augustus*. In this abridgement, he defines *cadmia*, to be an earth which is thrown upon copper, in order to change it into orichalcum*. The age in which *Festus* flourished is not ascertained: he was unquestionably posterior to *Martial*, and some have thought that he lived under the Christian Emperors. But leaving
that

* *Cadmia-Terra quæ in æs conjicitur, ut fiat orichalcum. Fes. de Ver. Seq.*

that point to be settled by the critics, if he expressed himself in the words of the author, whose work he abridged, we have from him a decisive proof, that *cadmia* was considered as a species of earth, and that the Romans used it for the converting of copper into a metallic substance called, in the Augustan age, orichalcum.

In opposition to this, it ought to be remarked, that some understand by the *cadmia* of *Pliny*, not calamine, but native arsenic. They seem to have been led into this opinion, from observing that *Pliny* says, *lapis ærosus* was called *cadmia*. For, apprehending that by *lapis ærosus*, *Pliny* understood a kind of stone which caused ulcers and erosions in the flesh of those who were occupied in working it, and knowing that arsenic produced

duced such an effect, they have concluded that cadmia was native arsenic*. This, probably, is a mistake, arising from a misinterpretation of the word, *ærosus*. Pliny usually, if not constantly, applies that word to substances in which copper is contained, without having any respect to the actions of such substances on the flesh of animals. Arsenic, moreover, when mixed with copper, does not give a gold, but a silver like appearance to copper. And lastly, Pliny † in

* - - - nous soupçonnons que Pline a voulu designer par lapis ærosus, une pierre qui mange et fait des ulceres ou érosions a ceux qui la travaillent, et qui est probablement l'arsenic vierge. Miner. par M. Valmont de Bomare, V. II. p. 64.—If the word had been *erosus*, this criticism might have been admitted.

† Hist. Nat. L. XXXIV. 10.

in another place expressly says, that the stone from which brass (*æs*) was made, was called *cadmia*; now it is impossible to make either brass or copper from arsenic.

Ambrose, bishop of *Milan* in the fourth century, says, that copper, mixed with certain drugs, was kept fluxed in the furnace till it acquired the colour of gold, and that it was then called *aurichalcum* *. *Primasius*, bishop of *Adrumetum* in *Africa*, in the sixth century, observes, that *aurichalcum* was made from copper, brought to a golden colour by a long continued heat, and the admixture of a drug †. *Isidorus*, bishop of *Seville* in

* *Æs* namque in fornace, quibusdam medicaminibus admixtis, tamdiu conflatur, usque dum colorem auri accipiat, et dicitur *aurichalcum*. Amb. in Apoc. C. I.

† *Aurichalcum* ex ære fit, cum igne multo ;
et

in *Spain*, in the seventh century, describes aurichalcum as possessing the splendour of gold, and the hardness of copper, and he uses the very words of Primasius respecting the manner of its being made *. The drug spoken of by these three bishops was probably *cadmia*. Prepared *cadmia* is highly commended by Pliny as useful in disorders of the eyes †, and it is still with us, under the more common appellation of *calamine*, in some repute for the same purpose. Hence, considering the testimonies of

Festus

et medicamine adhibito, perducitur ad aureum colorem. Prima. in Apoc. C. I.

* Aurichalcum dictum, quod et splendorem auri, et duritiam æris possideat, fit autem ex ære et igne multo, ac medicaminibus perducitur ad aureum colorem. Isid. Orig.

† Hist. Nat. L. XXXIV. C. X.

Festus and *Pliny* to the application of *cadmia* in making either orichalcum, or a substance imitating the goodness of orichalcum, we cannot have much doubt in supposing, that *cadmia* was the drug alluded to by *Ambrose*, and by those who seem to have borrowed, with some inaccuracy of expression, his description of the manner of making orichalcum.

What we call brass, was anciently in the French language called *archal*, and brass wire is still not unfrequently denominated *fil d' archal*. Now if we can infer, from the analogy of languages, that *archal* is a corruption of *aurichalcum*, we may reasonably conjecture, that our brass, which is the same with the French *archal*, is the same also with the Roman *aurichalcum*.

Though

Though we may, from what has been advanced, conclude, without much apprehension of error, *that the Romans knew the method of making brass, by melting together calamine and copper*; yet the invention was probably derived to them from some other country.

We meet with two passages, one in *Aristotle*, the other in *Strabo*, from which we may collect, that brass was made in *Asia*, much after the same manner, in which it appears to have been made at Rome.

Strabo informs us, that in the environs of *Andéra*, a city of *Phrygia*, a wonderful kind of stone was met with, which being calcined became iron, and being then fluxed with a certain earth, dropped out a silver-looking metal, which, being mixed

with copper, formed a composition, which some called orichalcum *. It is not improbable, I think, that this stone resembled *black jack*, or some other ore of zinc. *Black jack* may, in a common way of speaking, be called a stone. It abounds in iron; and, when calcined, looks like an iron earth: it yields zinc by distillation, sometimes mixed with silver and lead; and both the metallic substance which may be extracted from *black jack*, and the sublimate which arises from it, whilst it is smelted, will, when mixed with copper, make brass.

The *Mossynæci* inhabited a country not far from the *Euxine* Sea, and their copper, according to *Aristotle*, was said to have become splendid and white, not from the addition of tin,

but

* Strab. Geo. L. XIII.

but from its being mixed and *cement-
ed* with an *earth* found in that coun-
try*. This cementing of copper
with an earth, is what is done, when
brass is made, by uniting copper with
calamine, which is often called, and,
indeed, has the external appearance
of, an *earth*: and that *Asia* was cele-
brated for its *cadmia* or *calamine*, we
have the testimony of Pliny †. The
copper of the *Mossynæci* is said to
have become *white* by this operation.
Whiteness appertains to brass, either
absolutely, or relatively: for brass is not
only much whiter than copper; but
when it is made with a certain quan-
tity of a particular sort of *calamine*,
for there are very various sorts of it,
its ordinary yellow colour is changed
into

* Arif. de Mirab. Op. Tom. II. p. 721.

† Hist. Nat. L. XXXIV. C. II.

into a white. Cicero, we have seen, supposes that orichalcum might have been mistaken for gold, and as such, it must have been yellow; yet Virgil applies the epithet white to orichalcum,

*Ipse dehinc auro squalentem alboque orichalco
Circumdat loricam humeris* *.

Aristotle also speaks of having heard of an *Indian* copper, which was shining, and pure, and free from rust, and not distinguishable in colour from gold †; and he informs us, that amongst the vessels of *Darius* there were some, of which, but for the peculiarity of their *smell*, it would have been impossible to say, whether they were made of gold or copper. This account seems very descriptive of

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* Virg. *Æn.* L. XII. 87.

† Arif. de Mirab. T. II. p. 719.

common brass, which may be made to resemble gold perfectly in colour, but which, upon being handled, always emits a strong and peculiar *smell*, not observable either in gold or gilded copper.

The kings of *Persia*, who preceded the *Darius* mentioned by *Aristotle*, were in possession of similar vessels; but they seem to have been rare, and of course were held in high estimation. Among the magnificent presents of gold and silver vessels, which *Artaxerxes* and his counsellors gave to *Ezra*, for the service of the temple at *Jerusalem*, there were twenty basons of gold, and but two vessels of *yellow* shining copper, precious as gold, or, as some render the words, resembling gold*. “Sir John Char-

din,

* *Ezra* viii. 27.

din, in his MS. note, has mentioned a mixt metal used in the east, and highly esteemed there; and, as the origin of this composition is unknown, it might, for aught we know, be as old as the time of *Ezra*, and be brought from those more remote countries into *Persia*, where these two basons were given to be conveyed to Jerusalem. 'I have heard,' says the note, 'some Dutch gentlemen speak of a metal in the island of Sumatra, and among the Macassars, much more esteemed than gold, which royal personages alone might wear. It is a mixture, if I remember right, of gold and steel, or of copper and steel.' He afterwards added to this note (for the colour of the ink differs) 'Calm-bac is this metal composed of gold and copper. It in colour nearly resembles

seembles the pale carnation rose, has a very fine grain, the polish extremely lively. I have seen something of it, &c. Gold is not of so lively and brilliant a colour; I believe, there is steel mixed with the gold and copper.* He seems to be in doubt about the composition; but very positive as to its beauty and high estimation*.”

The supposition of brass having been anciently made in *India*, seems to be rendered improbable by both *Pliny* and *Strabo*; *Pliny* expressly saying, that the Indians had no copper †, and without copper we are certain that brass cannot be made; and *Strabo* representing them as so ignorant of the art of fluxing metals ‡, that,

* Harmer's Obs. on Scrip. Vol. II. p. 491.

† Hist. Nat. L. XXXIV. C. XVII.

‡ Geo. L. XIV.

that, according to him, if they had been possessed of the materials, they would not have had the ability to use them for the composing of brass. But these writers, it is apprehended, knew very little of India. Strabo, in particular, laments his want of materials to compose a consistent account of India; and few of the authors, from whose works Pliny compiled his natural history, can be supposed to have had any intercourse with that country. Strabo, moreover, contradicts both Pliny's observation, and his own. In describing the great pomp with which some of the Indians were accustomed to celebrate their festivals, he speaks of huge gilt kettles, cups, and tables made of *Indian copper**; from which it appears,

* Id. LXXVI.

pears, not only that the Indians were not destitute of copper, but that they were skilful metallurgists, since they knew how to flux it, to form it into vessels of various kinds, and to gild it. Perhaps, this Indian copper, of which the vessels were made, instead of being gilt, only resembled gold in colour, and was really a sort of brass. It is granted, that this is but a conjecture, but it is not devoid of probability; for, not to mention that the author, whoever he was, from whom Strabo extracted this account, might, in a public exhibition, have easily mistaken polished brass for gilt copper, nor the little probability, that cauldrons, and kettles, and such vessels as were in constant use, would be gilded in any country, we have reason to believe, from what has been
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observed before, that a peculiar kind of vessels, probably resembling some of those exhibited in the Indian festivals, had been long in use in *Persia*, and that they were made of Indian copper without any gilding. We know that there is found in India, not only copper strictly so called, but zinc also, which being mixed with copper constitutes brass, pinchbeck, tombac, similor, and all the other metallic mixtures which resemble gold in colour. On the whole, it appears probable to me, *that brass was made in the most remote ages in India, and in other parts of Asia, of copper and calamine*, as it is at present.— If the *celt* be allowed to be a *British* instrument, then may we be certain, from what was observed concerning it in the last Essay, that our ancestors
knew

knew the method of mixing together calamine and copper; for though tin and copper when melted together, in certain proportions, will give a bluish green flame, yet that flame is not accompanied with a thick white smoke, and there are but few proportions in which any flame at all is to be seen.

With respect to orichalcum, it is generally supposed that there were two sorts of it, one factitious, the other natural; the factitious, whether we consider its qualities or composition, appears to have been the same with our brass. As to the natural orichalcum, there is no impossibility in supposing, that copper ore may be so intimately blended with an ore of zinc, or of some other metallic substance, that the compound, when smelted, may yield a mixt metal of a paler hue than

than copper, and resembling the colour of either gold or silver. In *Du Halde's* history of *China*, we meet with the following account of the Chinese *white copper*. “The most extraordinary copper is called *Pe-tong*, or white copper: it is white when dug out of the mine, and still more white within than without. It appears, by a vast number of experiments made at *Peking*, that its colour is owing to no mixture; on the contrary all mixtures diminish its beauty; for, when it is rightly managed, it looks exactly like silver, and were there not a necessity of mixing a little *tutenag*, or some such metal with it, to soften it, and prevent its brittleness, it would be so much the more extraordinary, as this sort of copper is, perhaps, to be met with no where but in China,
and

and that only in the province of *Yunnan* *.” Notwithstanding what is here said, of the colour of this copper being owing to no mixture, it is certain, that the Chinese white copper, as brought to us, is a mixt metal; so that the ore, from which it is extracted, must consist of various metallic substances, and from some such ore it is possible that the natural orichalcum, if ever it existed, may have been made. But, though the existence of natural orichalcum cannot be shewn to be impossible, yet there is some reason to doubt, whether it ever had a real existence or not: for I pay not much attention to what father Kircher has said of orichalcum being found between *Mexico* and the straits of *Darien*, because no other

* Fol. Trans. Vol. I. p. 16.

other author has confirmed his account, at least none on whose skill in mineralogy we may rely*.

We know of no country in which it is found at present; nor was it any where found in the age of *Pliny*; nor does he seem to have known the country where it ever had been found. He admits, indeed, its having been formerly dug out of the earth; but — it is remarkable, that in the very passage, where he is mentioning by name the countries most celebrated for the production of different kinds of copper, he only says, in general, concerning orichalcum, that it had been found in other countries, without specifying any particular country. *Plato* acknowledges, that orichalcum was a thing only talked of
even

* Kirch. Mund. Sub.

even in his time; it was no where then to be met with, though in the island of *Atlantis* it had been formerly extracted from its mine. The *Greeks* were in possession of a metallic substance, called orichalcum, before the foundation of *Rome*; for it is mentioned by *Homer*, and by *Hesiod*, and by both of them in such a manner as shews, that it was then held in great esteem. Other ancient writers have expressed themselves in similar terms of commendation; and it is principally from the circumstance of the high reputed value of orichalcum, that authors are induced to suppose the ancient orichalcum to have been a natural substance, and very different from the factitious one in use at *Rome*, and, probably, in *Asia*, and

which,

which, it has been shewn, was nothing different from our brass.

But this circumstance, when properly considered, does not appear to be of weight sufficient to establish the point. Whenever the method of making brass was first found out, it is certain that it must have been for some time, perhaps for some ages, a very scarce commodity; and this scarcity, added to its real excellence as a metallic substance, must have rendered it very valuable, and intitled it to the greatest encomiums. *Diodorus Siculus* speaks of a people, who willingly bartered their gold for an equal weight of iron or copper*; and the Europeans have long carried on a similar kind of commerce with various nations. Gold, in some
views,

* Lib. III.

views, is justly esteemed the most valuable of metals; in other, and those the most important to the well-being of human kind, it is far inferior to iron, or copper, or brass. An individual, whose life depended upon the issue of a single combat, to be decided by the sword, would have no hesitation in preferring a sword of steel, to one of gold; and an army, which should be possessed of golden armour, would not scruple to exchange it, in the day of battle, for the iron accoutrements of their enemies. The preference of the harder metals to gold, is not less obvious in agriculture, than in war; a plough-share, spade, mattock, chisel, hammer, saw, nail, of gold, is not for use so valuable, as an instrument of the same kind made of iron or

VOL. IV. H brass.

brass. Hence, there is no manner of absurdity in supposing that orichalcum, when first introduced among the ancients, might have been prized at the greatest rate, though it had been possessed of no other properties, than such as appertain to brass. When iron was either not at all known, or not common in the world, and copper instruments, civil and military, were almost the only ones in use *, a metallic mixture, resembling gold in splendour, and preferable to copper, on account of its superior hardness, and being less liable to rust, must have greatly excited the attention of mankind, been eagerly sought after, and highly extolled by them. The *Romans*, no doubt, when it had been stipulated in the league which *Porfenna* made with them, af-
ter

* Hesiod.

ter the expulsion of the *Tarquins*, that they should not use iron, except in agriculture, must have esteemed a metallic mixture such as brass, at a rate not easily to be credited*. It is not here attempted to prove, that there never was a metallic substance called orichalcum, superior in value and different in quality from brass; but merely to shew, that the common reason assigned for its existence, is not so cogent as is generally supposed.

Con-

* In fœdere quod, expulsis regibus, populo Romano dedit Porfenna, nominatim comprehensum invenimus, ne ferro nisi in agricultura uterentur Plin. Hist. Nat. Vol. II. p. 666. Was Porfenna induced to prohibit the Romans the use of iron arms, from the opinion, which seems to have prevailed in Greece two hundred years afterward — that wounds, made with copper weapons, were more easily healed, than those made with iron? Arif. Op. L. IV. p. 43.

Considering the few ancient writers we have remaining, whose particular business it was to speak with precision concerning subjects of art, or of natural history, we ought not to be surprized at the uncertainty in which they have left us with respect to orichalcum. Men have been ever much the same in all ages; or, if any general superiority in understanding is to be allowed, it may seem to be more properly ascribed to those who live in the manhood or old age of the world, than to those who existed in its infancy or childhood: especially as the means of acquiring and communicating knowledge are, with us, far more attainable than they were in the times of either Greece or Rome. The Compass enables us to extend our researches to every quarter of the globe

globe with the greatest ease *; and an historical narration of what is seen in distant countries, is now infinitely more diffused than it could have been, before the invention of printing; yet, even with these advantages, we are, in a great measure, strangers to the natural history of the earth, and the civil history of the nations which inhabit it. He who imports *tutenag* from the East Indies, or *white copper* from *China* or *Japan*, is sure of meeting with a ready market for his merchandize in *Europe*, without being asked any questions concerning the manner how, or the place where, they

* Buffon quotes Homer's *Odyssley*, and some Chinese authors, to prove that the use of the mariner's compass in navigation was known to the ancients, at least three thousand years ago. *Nat. Hist.* by Buffon, Vol. IX. p. 17. Smellie's Transf,

they are prepared in. An ingenious manufacturer of these metallic substances might wish, probably, to acquire some information about them, in order to attempt a domestic imitation of them; but the merchant who imports them, seems to be too little interested in the success of his endeavours, to take much pains in procuring for him the requisite information. Imitations, however, have been made of them, and we have an European *tutenag*, and an European *white copper* *, differing, in some qualities, from those which are brought from

* The ingenious Dr. *Higgins* has been honoured by the Society for the Encouragement of Arts, &c. with a gold medal for *white copper* made with English materials, in imitation of that brought from the East Indies. His process has not, I believe, been yet made public. Mem. of Agricul. Vol. III. p. 459.

from Asia, but resembling them in so many other, that they have acquired their names. Something of this kind may have been the case with respect to orichalcum, and the most ancient Greeks may have known no more of the manner in which it was made, than we do of that in which the Chinese prepare their white copper: they may have had too an imitation of the original, and their authors may have often mistaken the one for the other, and thus have introduced an uncertainty and confusion into their accounts of it.

There is as little agreement amongst the learned concerning the etymology of orichalcum, as concerning its origin. Those who write it *aurichalcum*, suppose that it is an hybridous word, composed of a Greek term signifying

copper, and a Latin one signifying gold. The most general opinion is, that it ought to be written *orichalcum*, and that it is compounded of two Greek words, one signifying copper, and the other a mountain, and that we rightly render it by, Mountain Copper. I have always looked upon this as a very forced derivation, inasmuch as we do not thereby distinguish *orichalcum* from any other kind of copper; most copper mines, in every part of the world, being found in mountainous countries. If it should be thought, that some one particular mountain, either in Greece or Asia, formerly produced an ore, which being smelted yielded a copper of the colour of gold, and that this copper was called *orichalcum*, or the mountain copper, it is much to be

won-

wondered at, that neither the poets nor the philosophers of antiquity have bestowed a single line in its commendation; for as to the *Atlantis* of *Plato*, before mentioned, no one, it is conceived, will build an argument for the existence of natural orichalcum, on such an uncertain foundation: and, if there had been any such mountain, it is probable, that the copper it produced would have retained its name, just as at this time of day we speak of *EElon* copper in *Staffordshire*, and of *Paris-mountain* copper in *Anglesey*.

Some men are fond of etymological inquiries, and to them I would suggest a very different derivation of orichalcum. The Hebrew word *or*, *aur*, signifies *light, fire, flame*; the Latin terms *uro* to burn, and *aurum* gold,

gold, are derived from it, inasmuch as gold resembles the colour of flame; and hence, it is not improbable, that orichalcum may be composed of an Hebrew, and a Greek term, and that it is rightly rendered, *flame-coloured copper*. In confirmation of this it may be observed, that the Latin epithet *lucidum*, and the Greek one $\Phi\alpha\epsilon\beta\text{-}\nu\omicron\nu$, are both applied to orichalcum by the ancients; but I would be understood to submit this conjecture, with great deference, to those who are much better skilled, than I am, in etymological learning.



E S S A Y . III.

*Of Gun-metal—Statuary-metal—
Bell-metal—Pot-metal, and Spe-
culum-metal.*

BESIDES brass there are many other metallic mixtures, into which copper enters as the principal ingredient; the most remarkable of these are *gun-metal*, *bell-metal*, *pot-metal*, and *speculum-metal*.

It has been remarked of Queen Elizabeth, that she left more brass ord-

ordnance at her death, than she found of iron on her accession to the throne. This must not be understood, as if gun-metal was in her time made chiefly of brass; for the term brass, was sometimes used to denote copper, and sometimes a composition of iron, copper, and calamine, was called brass, and we at this day commonly speak of brass cannon, though brass does not enter into the composition used for the casting of cannon. *Aldrovandus** informs us, that one hundred pounds weight of copper with twelve of tin, made *gun-metal*; and that, if instead of twelve, twenty pounds weight of tin was used, the metal became *bell-metal*. The workmen were accustomed to call this composition, metal or *bronze*, according

* Aldrov. p. 108.

ing as a greater or a less proportion of tin had been used. Some individuals, he says, for the sake of cheapness, used brass or lead instead of tin, and thus formed a kind of bronze for various works. I do not know whether connoisseurs esteem the metal, of which the ancients cast their *statues*, to be of a quality superior to our modern bronze; but if we should wish to imitate the *Romans* in this point, Pliny has enabled us to do it; for he has told us, that the metal for their statues, and for the plates on which they engraved inscriptions, was composed in the following manner. They first melted a quantity of copper; into the melted copper, they put a third of its weight of old copper, which had been long in use; to every hundred pounds weight of
 e this

this mixture, they added twelve pounds and an half of a mixture, composed of equal parts of lead and tin*.

In *Diego Ufano's* Artillery, published in 1614, we have an account of the different metallic mixtures then used for the casting of cannon, by the principal gun-founders in Europe.

Copper 160—100—100—100 parts.

Tin 10—20—8—8

Brass 8—5—5—0

The best possible metallic mixture cannot be easily ascertained, as various mixtures may answer equally well the rude purpose to which ordnance is applied. Some mixtures, however, are unquestionably better adapted to this purpose than other,

in

* Hist. Nat. L. XXXIV. S. XX.

in some particular points. Of two metallic mixtures, which should be equally strong, the lightest would have the preference: at the last siege of *Prague*, part of the ordnance of the besiegers, was melted by the frequency of the firing; the mixture of which it was made, contained a large portion of lead, and it would have been less prone to melt, and consequently preferable had it contained none.

Woolwich, I believe, is the only place in England, where there is a foundery for the casting of brass cannon. The metallic composition there used, consists of *copper* and *tin*. The proportion, in which these two metals are combined, is not always the same, because the copper is not always of equal purity, and the finest
cop-

copper requires the most tin: they seldom use more than 12, or less than 8 parts of tin to every 100 of copper. This metallic mixture is sold, before casting, for 75*£*. a ton, and *Government* pays for casting it 60*£*. a ton. The guns of the *East India Company* are less ornamented than those of *Government*, on that and other accounts they are cast for 40*£*. a ton. I have here put down the weights of the brass ordnance, now most generally in use as cast at Woolwich.

Weight of brass cannon now in use.

	C.	q.	lb.
42 pounders -	61	2	10
24 - - -	51	0	0
12 - - -	29	0	0
6 - - -	19	0	0

These were on board the *Royal George* in 1780, but had been removed,

moved, I believe, before she was
lost.

Battering cannon.

42 pounders	-	61	2	10
32	-	55	2	10
24	-	51	0	0
18	-	48	0	0
12	-	29	0	0
9	-	25	0	0
6	-	19	0	0

Field pieces.

24 pounders	-	16	3	13
12	-	8	3	8
6	-	4	3	10
3	-	2	3	10

Howitzers.

10 inches	-	31	2	16
8	-	12	1	16
5 $\frac{1}{2}$	-	4	0	18

Mortars (Land Service).

13 inches	-	-	25	0	0
10	-	-	10	2	8
8	-	-	4	0	10
5 $\frac{1}{2}$	-	-	1	1	0
4 $\frac{2}{3}$	-	-	0	3	0

Mortars (Sea Service).

13 inches	-	-	81	1	8
10	-	-	32	3	7

In casting these pieces of cannon, they generally make the thickness of the sides near the muzzle half the diameter of the shot, and at the touch-hole, or charging cylinder, three fourths of the diameter. Brass cannons are dearer than such as are made of iron; and, which is a disadvantage, they give a louder report at the time of explosion, so as to occasion a tingling in the ears of the persons

Sons on shipboard, which takes away for a time the faculty of hearing.

Cannon might be cast of copper alone; but the mixture of tin and copper is harder and denser, and less liable to rust than pure copper is, and upon these accounts it is preferable to copper. Tin melts with a small degree of heat, copper requires a very great heat to melt it; a mixture of copper and tin melts much easier than pure copper, and upon this account also, a mixture of copper and tin is preferred to pure copper, not only for the casting of cannon, but of statues, &c.; for pure copper, in running through the various parts of the moulds, would lose so much of its heat as to set before it ought to do.

Bell-metal consists also of tin and

copper. Authors do not agree in the proportions: some ordering 1 part of tin to be melted with 4 parts of copper*; others making the proportion for bell-metal to be the same as that for gun-metal, or 1 part of tin to about 10 parts of copper, to which they order a little brass to be added †. It may in general be observed, that a less proportion of tin is used for making church bells than clock bells, and that they add a little zinc for the bells of repeating watches, and other small bells. This zinc becomes manifest on melting these bells, by the blue flame which it exhibits.

There

* Pemb. Chem. p. 321.

† Waller. Miner. Vol. II. p. 242. New: Chem. by Lewis, p. 66. Macq. Chem. Vol. I. p. 70. Eng. Transf.

There is a very remarkable experiment mentioned by *Glauber* *. — “Make,” says he, “two balls of copper, and two of pure tin not mixed with lead, of one and the same form and quantity, the weight of which balls observe exactly; which done, again melt the aforesaid balls or bullets into one, and first the copper, to which melted add the tin, lest much tin evaporate in the melting, and presently pour out the mixture melted into the mould of the first balls, and there will not come forth four, nor scarce three balls, the weight of the four balls being reserved.” This subject has been prosecuted since *Glauber*’s time †, and it has been discovered,

* *Glauber’s Works*, fol. Ed. 1689. p. 81.

† *Gellert’s Chy. Metal. & Chem. Dict.* art. Allay.

covered; that when metallic substances are melted together, it seldom happens that a cubic inch of each of the two ingredients, will form a mass exactly equal to two cubic inches; the mixture will in some instances be greater, and in other less than two cubic inches. In the instance of tin and copper, where the bulk of the mixture is so much less than the sum of the bulks of the two component parts, it might be expected that the compound metal would possess properties, not merely intermediate between those of copper and tin, but essentially different from them both. And accordingly we find, that this mixture is not only more brittle, more hard, and more sonorous, than either copper or tin; but it is more dense also, than either of them; a
cubic

cubic foot of it weighing, not only more than a cubic foot of tin, but than a cubic foot of copper itself.

Pot-metal is made of copper and lead, the lead being one fourth or one fifth the weight of the copper. In Pliny's time pot-metal (*ollaria temperatura*) was made of a pound and an half or two pounds of lead, and an equal portion of tin, mixed with 100 parts of copper. Copper and lead seem not to be combined together in the same way that copper and tin are, for when pot-metal is exposed to a melting heat, the lead is first fused, and shews itself in little drops over the surface of the pot-metal, whilst the copper remains unfused.

It is reported of *James II.* that he melted down and coined all the brass guns in Ireland, and afterwards pro-

ceeded to coin the pewter with this inscription — *Melioris tessera fati.* — The Congress in America had recourse to the same expedient; they coined several pieces of about an inch and half in diameter, and of 240 grains in weight; on one side of which was inscribed in a circular ring near the edge — *Continental Currency, 1776* — and within the ring a rising sun, with — *fugio* — at the side of it, shining upon a dial, under which was — *Mind your business.* — On the reverse were thirteen small circles joined together like the rings of a chain, on each of which was inscribed the name of some one of the thirteen states; on another circular ring, within these, was inscribed — *American Congress* — and in the central space — *We are One.* — I have been particular in the mention of

of this piece of money, because like the leaden money which was struck at *Vienna*, when that city was besieged by the Turks in 1529, it will soon become a great curiosity. I estimated the weight of a cubic foot of this Continental currency, it was equal to 7440 ounces: this exceeds the weight of a cubic foot of our best sort of pewter, and falls short of that of our worst; I conjecture that the metal of the Continental currency consisted of 12 parts of tin and of 1 of lead. Plautus*, and other Roman authors, make mention of leaden money; some are of opinion that we ought to understand by that expression,

cop-

* Tace sis, faber, qui cudere soles plumbeos nummos. Plau. Mos. A. IV. S. II. L. XI. et Casin. A. II. S. III. L. XL. et Mart. L. X. E. LXXIV.

copper mixed with lead; but that cannot be the meaning, if it be true, that the Romans did not mix lead with their copper currency till the age of Septimius Severus, for Plautus lived many years before that emperor. I will not enter into the controversy, and I have introduced this observation relative to the leaden money of the Romans, merely to shew the correspondence, which some of the Roman copper medals bore to our pot-metal; for those which were struck after the age of *Septimius Severus*, being exposed to a proper degree of heat, sweat out drops of lead, as it has been remarked our pot-metal does: but medals of greater antiquity have no such property*.

The

* Illi enim qui studii hujus amore teuentur, cum monetam æream ante Septimum Severum
rum

The sex have in all ages used some contrivance or other to enable them to set off their dress to the best advantage; and the men were probably never without their attention to that point. We find *Juvenal** satirizing the emperor *Otho* for making a *speculum* part of his camp equipage.

Res memoranda novis annalibus, atque recenti Historia, *speculum* civilis sarcina belli.

Homer, in describing *Juno* at her toilet †, makes no mention of a *speculum*;

rum cufam igne probent nihil plumbi inde secerni deprehendunt. Aliter autem comparata sunt numismata post ætatem Severi cufa, quippe ex quibus guttulæ quædam plumbi, vel modico ignis calore diversis in locis exprimuntur. Savot de Num. Ant. P. II. C. I. These pot-metal medals were probably *cast*.

* Sat. II. l. 102.

† Il. L. XIV. l. 170.

lum; but in *Callimachus* * we see, though it suited not the majesty of *Juno*, nor the wisdom of *Pallas* to use a *speculum* before they exhibited their persons to *Paris*, who was to determine the prize of beauty; that *Venus*, on the same occasion, had frequent recourse to one, before she could adjust her locks to her own satisfaction. The most ancient account we have of the use of *specula* is that in *Exodus* (xxxviii. 8.) “And he made the laver of brass [copper, or a mixture of copper and tin] and the foot of it of brass of the *looking glasses* of the women.” The English reader may wonder how a vessel of *brass* could be made out of *looking glasses*, the Hebrew word might properly be rendered by *specula*, or *metallic mirrors*.

The

* Hym. in Lavac. Pallad.

The *Jewish* women were, probably, presented with these mirrors, as they were with other articles of value by their *Egyptian* neighbours, when they left the country; for it was the custom of the Egyptians, when they went to their temples, to carry a mirror in their left hand*: it is remarkable, that the *Peruvians*, who had so many customs in common with the *Egyptians*, were very fond also of mirrors; which they ordinarily formed of a sort of *lava* that bore a fine polish.

Pliny † says, that the best specula were anciently made at *Brundusium* of copper and tin; that *Praxiteles*, in the time of *Pompey* the Great, was the first who made one of silver, but that

silver

* Cyril. de Ado.

† Hist. Nat. L. XXXIII. S. XLV.

silver ones were in his time become so common, that they were used even by the maid servants. The metallic mixture of tin and copper was known long before the age of Pliny; it is mentioned by Aristotle *, incidentally, when he is describing a method of rendering copper white, but not by tin; and from its great utility, it will probably never fall into disuse. We have ceased, indeed, since the introduction of glass mirrors, to use it in the way the ancients did; but it is still of great use amongst us, since the specula of reflecting telescopes are commonly made of it. Mr. *Mudge* has ascertained †, not only the best proportion in which the copper and tin should be

* De Mirab.

† Philos. Trans. 1777. p. 296.

be mixed together, but has found out also a method of casting the specula without pores. He observes, that the perfection of the metal, of which the speculum should be made, consists in its hardness, whiteness, and compactness. When the quantity of tin is a third of the whole composition, the metal then has its utmost whiteness; but it is at the same time rendered so hard that it cannot be polished without having its surface splintered and broke up. After many experiments, he at length found that fourteen ounces and one half of grain-tin*, and two pounds of copper

* *Grain-tin* is worth ten or twelve shillings per hundred more than mine tin, because it is smelted from a pure mineral by a *charcoal* fire; whereas *mine tin* is usually corrupted with some portion of mundick, and other

per made the best composition; an addition of half an ounce more tin rendered the composition too hard to be properly polished. The casting the metal so as that it may be compact and without pores, is a matter of the greatest consequence; he hit upon the manner of doing it by accident. His usual way of casting a speculum metal, was to melt the copper and to add the tin to the melted copper; the mass when cast was seldom free from pores. After having used all his copper in trying experiments to remedy this defect, he re-collected

other minerals, and is always smelted with a bituminous fire, which communicates a harsh, sulphureous, injurious quality to the metal." Pryce, *Min. Cornu*, p. 137.—Mr. Mudge probably used what is called *grain-tin* in the shops, or the purest sort, which is usually sold in pieces like icicles.

collected that he had some metal which had been reserved, when one of the bells of St. Andrew had been re-cast: he added a little fresh tin to it, and casting a metal with it, it turned out free from pores, and in all respects as fine a metal as he ever saw. Upon considering this circumstance, he proceeded to form a metallic mass in the usual way, by adding tin to melted copper, this mass was porous, it was in the state of the bell-metal he had tried, and upon remelting it, it became, as the bell-metal had done, compact and free from pores. He accounts for this difference by observing, that the heat necessary to melt copper, calcines part of the tin, and the earthy calcined particles of the tin, being mixed in the mass of the metal, render it

porous, but the composition of tin and copper, melting with less than half the heat requisite to melt the copper, the tin is not liable to be calcined in the second melting, as in the first. I am rather disposed to think, that the absence of the pores is to be attributed to the more *perfect fusion* of the metal: for I have observed at *Sheffield*, that the same weight of melted steel, will fill the same mould to a greater or less height, according to the degree of fusion the steel has been in; if it has been in a strong heat, and thin fusion, the bar of cast steel will be an inch in 36 shorter than when the fusion has been less perfect. Upon breaking one of the bars, which had been made from steel in an imperfect fusion, its inside was full of blebs; a shorter bar of the same

same weight and diameter, which had been in a thin fusion, was of a closer texture. Now the mixture of tin and copper melts far easier than copper does, and is likely on that account, to be in a thinner fusion when it is cast.

It may deserve to be remarked, and I shall have no other opportunity of doing it, that the melting or *casting* of steel was introduced at Sheffield, about forty years ago, by one *Waller* from London, and was afterwards much practised by one *Huntsman*, from whom steel so prepared, acquired the name of *Huntsman's cast steel*. It was at first sold for fourteen pence, but may now be had for ten-pence a pound; it costs three-pence a pound in being melted, and for drawing ingots of cast steel into bars

of the size of rasors, they pay only six shillings for a hundred weight, and ten shillings for the same quantity when they make the bars into a size fit for small files, &c. The cast steel will not bear more than a red heat, in a welding heat it runs away under the hammer like sand. Before the art of casting steel was introduced at Sheffield, all the cast steel used in the kingdom was brought from Germany; the business is carried on at Sheffield with greater advantage, than at most other places, for their manufactures furnish them with great abundance of broken tools, and these bits of old steel they purchase at a penny a pound and melt them, and on that account they can afford their cast steel cheaper than where it is made altogether from fresh bars of steel.



E S S A Y IV.

Of Tinning Copper—Tin—Pewter.

UNHAPPILY for mankind, the fatal accidents attending the use of copper vessels, in the preparation of food and physick, are too common, and too well attested to require a particular enumeration or proof: scarce a year passes, but we hear of some of them, especially in foreign countries; and many slighter maladies, originating from the same

K 3

source,

source, daily escape observation, or are referred to other causes in our own.

In consequence of some representations from the *College of Health*, the use of *copper* vessels in the fleets and armies of *Sweden* was abolished in the year 1754; and *tinned iron* was ordered to be substituted in their stead *. The Swedish government deserves the greater commendation for this proceeding, as they have great plenty of excellent copper in the mines of that country, but no tin. An intelligent surgeon suggested, in 1757, the probability of the use of copper vessels in the navy, being one of the causes of the sea scurvy, and recommended the having them

* Mem. de l'Acad. de Prusse par M. Paul.
Vol. IV. Dis. Prel. p. 63.

them changed for vessels of iron; he remarked, that of the 200 sail of ships which went to sea from *Scarborough*, most of them used iron pots for boiling their victuals, and that the symptoms called *highly scorbutic*, were never seen, except in some few of the larger ships in which copper vessels were used*. Notwithstanding this hint, and the example of Sweden, I do not know that any other European state has prohibited the use of copper vessels for the dressing of food on board their ships; but many of them have shewn a laudable attention to prevent its malignity; by inquiring into the best manner of covering its surface with some metallic substance, less noxious,

or

* Medical Observ. by a Society of Phys. in Lond. Vol. II. p. 1.

or less liable to be dissolved than itself. This operation is usually called *tinning*, because tin is the principal ingredient in the metallic mixture, which is made use of for that purpose; and, indeed, since the year 1755, it has been frequently, in this country at least, used alone. In that year, *The Society for the Encouragement of Arts, Manufactures and Commerce*, thought it an object deserving their attention, to offer a premium for the tinning copper and brass vessels with pure tin, without lead or any other alloy. There were several candidates for the premium; and since that time, the tinning with pure tin, and hammering it upon the copper, has become very general in England. But this mode of tinning does not appear to have been known, or at least

least it does not appear to have been adopted in other countries; for in the Memoirs of the Royal Academy at *Brussels*, for the year 1780, *M. L'Abbé Marci* recommends, as a new practice, the tinning with pure *block-tin* from England; though, he says, *block-tin* is a compound body, even as it is imported from England; but he thinks it a much safer covering for copper than what is ordinarily used by the braziers; and he gives some directions as to the manner of performing the operation. The *Lieutenant-General* of the Police at *Paris*, gave it in commission to the College of Pharmacy, in 1781, to make all the experiments which might be necessary for determining — whether pure tin might or might not be used for domestic purposes, without danger

ger to health? The researches which were made, in consequence of this commission, by Messieurs *Charland* and *Bayen* with great ability, were published by order of the French government; and they have greatly contributed to lessen the apprehensions relative to the use of tin, which had been generally excited by the experiments of *Marggraf*; published first in the *Berlin* Memoirs for 1747. That gentleman, in pursuing an experiment of *Henckel*, who first discovered arsenic in tin, shewed, that, though there was a sort of tin, which being fluxed from an ore of a particular kind, contained no arsenic, the *East India* tin, which is generally esteemed the purest of all others, contained a great deal of arsenic. *M. Bosc d'Antic* in his works,
 which

which were published at Paris, 1780, sets aside the authority of *Marggraf*, *Cramer*, and *Hellot*, relative to the existence of arsenic in tin; and is not only of opinion, that the *Cornish* tin does not conceal any arsenic in its substance, but that its use as kitchen furniture is not dangerous. Messieurs Charland and Bayen found that neither *East India*, nor the *purest* sort of *English* tin, contained any arsenic; but that the English tin, usually met with in commerce, did contain arsenic; though in so small a proportion that it did not amount, in that species of tin which contained the most of it, to more than one grain in an ounce; that is, it did not constitute more than one five-hundredth and seventy-sixth part of the weight of the tin, there being 576 grains in a
 French

French ounce. This proportion of arsenic is so wholly inconsiderable, that it is very properly concluded, that the internal use of such small portions of tin, as can mix themselves with our food, from being prepared in tinned vessels, can be in no sensible degree dangerous on account of the arsenic which the tin may contain. But though tin may not be noxious, on account of the arsenic which it holds, it still remains to be decided, whether it may not be poisonous of itself; as lead is universally allowed to be, when taken into the stomach. The large quantities of tin, which are sometimes given in medicine with much safety, and the constant use which our ancestors made of it in plates and dishes, before the introduction of china or other earthen ware,

ware, without experiencing any mischief, render all other proof of the innocent nature of pure tin superfluous. And hence it may be proper to add a few observations concerning the purity of tin.

The ores of metallic substances, often contain more substances than that particular one, from which they receive their denomination. *M. Eller* of Berlin, had in his collection an ore, which contained *gold*, and *silver*, and *iron*, and *quicksilver*, closely united together in the same mass. Lead ore, it has been remarked, so often contains silver, that it is seldom found without it; it is often also mixed with a sulphureous pyrites, which is a sort of iron ore, and with black jack, which is an ore of zinc; so that *lead*, and *silver*, and *iron*, and
Zinc,

Zinc, are commonly enough to be met with in the same lump of lead ore. Tin ore, in like manner, though it is sometimes unmixed, is often otherwise; it frequently contains both tin, and iron, and copper. The fire with which tin ore is smelted, is sufficiently strong to smelt the ores of the other metals which are mixed with it; and hence the reader may understand, that, without any fraudulent proceeding in the tin smelter, there may be a variety in the purity of tin, which is exposed to sale in the same country; and this variety is still more likely to take place, in specimens of tin from different countries, as from the *East Indies*, from *England*, and from *Germany*. This natural variety in the purity of tin, though sufficiently

ciently

ciently discernible, is far less than that which is fraudulently introduced. Tin is above five times as dear as lead; and as a mixture consisting of a large portion of tin with a small one of lead, cannot easily be distinguished from a mass of pure tin; the temptation to adulterate tin is great, and the fear of detection small. In *Cornwall*, the purity of tin is ascertained, before it is exposed to sale, by what is called its *coinage*: the tin, when smelted from the ore, is poured into quadrangular moulds of stone, containing about 320 pounds weight of metal, which, when hardened, is called a *block* of tin; each block of tin is coined in the following manner:—“the officers appointed by the Duke of Cornwall, assay it, by taking off a piece of one of the
under

under corners of the block, partly by cutting and partly by breaking; and if well purified, they stamp the face of the block with the impression of the seal of the Duchy, which stamp is a permission for the owner to sell, and at the same time an assurance that the tin so marked has been purposely examined, and found merchantable*." This rude mode of assay, is not wholly improper, for if the tin be mixed with lead, the lead will by its superior weight sink to the bottom, and thus be liable to be discovered, when the bottom corner of the block is examined. But though the seal of the Duchy may be some security to the original purchasers of block tin, it can be none at all to those foreigners who purchase our tin
from

* Borlase's Nat. Hist. of Corn. p. 183.

from *Holland*; for, if we may believe an author of great note, — “in *Holland* every tin founder has English stamps, and whatever his tin be, the inscription, block tin, makes it pass for English *.” This foreign adulteration of English tin may be the reason that *Musschenbroeck*, who was many years Professor of Natural Philosophy at *Utretch*, puts the specific gravity of what he calls *pure tin* equal to 7320, but that of English tin, and he has been followed by *Wallerius*, equal to 7471 †; for it will

* Newman's Chem. by Lewis, p. 89.

† *Musschen. Ess. de Phys.* 1739. French Transf. *Wallerii Min.* Vol. 1. p. 154. There is a very good Table of Specific Gravities, published in the second volume of *Musschenbroeck's, Introductio ad Philosophiam Naturalem*, 1763, in which the author does

will appear presently, that such sort of tin must have contained near one tenth of its weight of lead.

Weight of a cubic foot of English tin, according to different authors.

Cotes, Ferguson, Emerson	7320 oz. avoird.
Boerhaave's Chem. by Shaw	7321
Musschenbroeck & Wallerius	7471
Martin	7550

From the following experiments it may appear probable, that not one of these authors, in estimating the specific gravity of tin, has used the purest sort, but rather a mixture of that with lead, or some other metal.

A

more justice to English tin, putting the weight of a cubic foot of the *purest* sort equal to 7295 avoird. ounce. One specimen of the purest sort of *Malacca* tin gave 7331, and another 6125 ounces a cubic foot, which is the lightest of all the tins which he examined.

A block of tin, when it is heated till it is near melting, or after being melted, and before it becomes quite fixed, is so brittle that it may be shattered into a great many long pieces like icicles, by a smart blow of an hammer*: tin in this form is called by our own manufacturers *grain tin*, by foreigners *virgin tin*, or *tears* of tin: and they tell us, that its exportation from Britain is prohibited under pain of death †. The tin
which

* This property is not peculiar to tin, I have seen masses of lead which, under similar circumstances, exhibited similar appearances, and it has been observed, that zinc, when heated till it is just ready to be fused, is brittle.

† Ency. Fran. and Mr. Baumé calls it *étain en roche à cause que sa forme ressemble*

which I used in the following experiments, was of this sort, but I first melted it, and let it cool gradually; a circumstance, I suspect, of some consequence in determining the specific gravity not only of tin, but of other metals. I have put down in the following table, the specific gravity of this tin, and of the lead I mixed with it by fusion, and of the several mixtures when quite cold; the water in which they were weighed was 60°.

Weight

à des stalactites; he says also, that its exportation is prohibited, but that he does not see the reason for the prohibition, as it is not more pure than Cornish tin: and in this observation he is right, it is nothing but Cornish tin in a particular form, Chym. par M. Baumé, Vol. III. p. 422.

Weight of a cubic foot of lead,
tin, &c.

Lead	-	-	11270 oz. avoird.
Tin	-	-	7170
Tin 32 parts,	lead	1-	7321
Tin 16	-	lead 1-	7438
Tin 10	-	lead 1-	7492
Tin 8	-	lead 1-	7560
Tin 5	-	lead 1-	7645
Tin 3	-	lead 1-	7940
Tin 2	-	lead 1-	8160
Tin 1	-	lead 1-	8817

Blocks of tin are often melted by the pewterers into small rods; I think the rods are not so pure, as the grain tin; at least, I found that a cubic foot of the specimen I examined, weighed 7246 ounces; but even this sort exceeds in purity any of the kinds examined by the authors

above mentioned. Chemistry affords certain methods of discovering the quantity of lead with which tin is alloyed, but these methods are often troublesome in the application; an enlarged table, of the kind of which I have here given a specimen, will enable us to judge with sufficient precision of the quantity of lead contained in any mixture of tin and lead, of which we know the specific gravity. Pewterers, however, and other dealers in tin, use not so accurate a method of judging of its purity, but one founded on the same principle; for the specific gravities of bodies being nothing but the weights of equal bulks of them, they cast a bullet of pure tin, and another of the mixture of tin and lead, which they want to examine, in the same mould;

and

and the more the bullet of the mixture exceeds the bullet of pure tin in weight, the more lead they conclude it contains.

Pewter is a mixed metal; it consists of tin united to small portions of other metallic substances, such as lead, zinc, bismuth; and the *metallic part*, commonly called, *regulus of antimony*. We have three sorts of pewter in common use; they are distinguished by the names of *plate* — *trifle* — *ley*. The plate pewter is used for plates and dishes; the trifle chiefly for pints and quarts; and the ley-metal for wine measures, &c. Our very best sort of pewter is said to consist of 100 parts of tin, and of 17 of regulus of antimony*, though others allow only 10 parts of regulus to 100
of

* Med. Transf. Vol. I. p. 235.

of tin^{*}; to this composition the French add a little copper. Crude antimony, which consists of nearly equal portions of sulphur and of a metallic substance, may be taken inwardly with great safety; but the metallic part, or *regulus*, when separated from the sulphur, is held to be very poisonous. Yet *plate* pewter may be a very innocent metal, the tin may lessen or annihilate the noxious qualities of the metallic part of the antimony. We have an instance somewhat similar to this in standard silver, the use of which has never been esteemed unwholesome, notwithstanding it contains near one twelfth of its weight of copper. Though standard silver has always been considered as a safe metal, when
 used

* Pemb. Chem. p. 222.

used for culinary purposes; yet it is not altogether so, the copper it contains is liable to be corroded by saline substances into verdigris. This is frequently seen, when common salt is suffered to stay a few days in silver saltcellars, which have not a gold gilding; and even saline draughts, made with volatile salt and juice of lemons, have been observed to corrode a silver tea spoon, which had been left a week in the mixture.

The weight of a cubic foot of each of these sorts of pewter is,

Plate - 7248

Trifle - 7359

Ley - 7963.

If the plate pewter be composed of tin and *regulus* of antimony, there is no reason to expect, that a cubic foot
of

of it should be heavier than it appears to be; since *regulus* of antimony, according to the different ways in which it is made, is heavier or lighter than pure tin. A very fine silver-looking metal is said to be composed of 100 pounds of tin, 8 of *regulus* of antimony, 1 of bismuth, and 4 of copper. The *ley* pewter, if we may judge of its composition by comparing its weight with the weights of the mixtures of tin and lead, mentioned in the table, contains not so much as a third, but more than a fifth part of its weight of lead; this quantity of lead is far too much, considering one of the uses to which this sort of pewter is applied; for acid wines will readily corrode the lead of the flacons, in which they are measured, into sugar
of

of lead; this danger is not so great with us, where wine is seldom sold by the measure, as it is in other countries where it is generally sold so, and their wine measures contain, probably, more lead than ours do. Our English pewterers have at all times made a mystery of their art, and their caution was formerly so much encouraged by the legislature, that an act of parliament was passed, rendering it unlawful for any master pewterer to take an apprentice, or to employ a journeyman who was a foreigner. In the present improved state of chemistry, this caution is useless; since any one tolerably skilled in that science, would be able to discover the quality, and quantity of the metallic substances, used in any particular sort of pewter; and it is

a

not

not only useless now, but one would have thought it must have been always so; whilst tin, the principal ingredient, was found in no part of Europe in so pure a state, nor in so great plenty as in England.

Borlase and *Pryce*, who have written so minutely on the method of preparing the tin in *Cornwall*, are both of them silent, as to any operation the tin undergoes subsequent to its coinage; nor do they say any thing of its being mixed with other metallic substances previous to its coinage; but assure us, that the tin, as it flows from the ore, is laded into troughs, each of which contains about three hundred pounds weight of metal, called slabs, blocks, or pieces of tin, in which *size* and *form* it is sold in every market in Europe. Foreigners,
how-

however, in general assert, that our tin as exported is a mixed metal; and the *French Encyclopedists* in particular (article *etaïn*) inform us, on the authority of Mr. *Rouelle*, that the virgin tin is again melted and cast into iron moulds of half a foot in thickness; that the metal is cooled very slowly; that when cold it is divided horizontally into three layers; that the uppermost, being very soft pure tin, is afterwards mixed with copper, in the proportion of 3 pounds of copper to 100 of tin; that the second layer, being of a harsher nature, has 5 pounds of lead added to an 100 of the tin; and that the lowest layer is mixed with 9 pounds of lead to an hundred of the tin; the whole is then re-melted, and cooled quickly, and this, they say, is the ordinary tin

tin of England; and *Geoffroy* had formerly given much the same account *. There is, probably, no other foundation for this report, but that pewter has been mistaken for tin, these metals being sometimes called by the same name; and fine pewter being sometimes made from a mixture of 1 part of copper with 20 or 30 parts of tin.

The mixture generally used for the

tin-

* — fusores aperto furni ostiolo, metallum in formas quasdam ex arena paratas diffluere sinunt, ibique in massas grandiores concrefcit. Superior stannæ massæ pars adeo mollis est et flexilis ut sola elaborari nequeat sine cupri miscela, trium scilicet librarum super stanni libras centum. Massæ pars media binas tantum cupri libras recipit. Infima vero adeo fragilis est et intractabilis, ut cum hujus metalli centum libris plumbi libras octodecim confociare oporteat. *Geoff. Mat. Med. Vol. I. p. 282.*

tinning of copper vessels, consists of 3 pounds of lead, and of 5 pounds of pewter; when a finer composition is required, ten parts of lead are mixed with sixteen of tin; or one part of lead with two of tin; but the proportions in which lead and tin are mixed together, even for the same kind of work, are not every where the same; different artists having different customs. Vessels tinned with pure tin, or with the best kind of pewter, which contains no lead, do not stain the fingers when rubbed with them: whilst those which are tinned with a composition, into which lead enters as a constituent part, colour the fingers with a blackish tinge.

Zinc was long ago recommended for the tinning of copper vessels, in
pre-

preference both to the mixture of tin and lead, and to pure tin*: and zinc certainly has the advantage of being harder than tin, and of bearing a greater degree of heat before it will be melted from the surface of the copper; so that on both these accounts it would, when applied on the surface of copper, last longer than tin; just as tin, for the same reasons, lasts longer than a mixture of tin and lead. But whether zinc makes any part of the compound metal for tinning copper, so as to prevent the necessity of repeated tinning, for which a patent was granted some years ago, is what I cannot affirm. Whatever may be the excellence of that composition, or of any other composition, which may be invented

* Mem. de l'Acad. des Scien. a Par. 1742.

vented with respect to its durability, and its not contracting rust; still it ought not to be admitted into general use, till it has been proved, that it is not soluble in vegetable acids, or that its solutions are not noxious*. A method has of late years been introduced at *Rouen*, of applying a coat of zinc upon *hammered* iron sauce-pans. The vessels are first made very bright, so that not a black speck can be seen; they are then rubbed with a solution of sal ammoniac, and
after-

* This doubt with respect to zinc is said to have been removed.—M. de la Planche, a physician at Paris, tried the experiment on himself: he took the salts of zinc, formed by the vegetable acids, in a much stronger dose than the aliments prepared in copper vessels, lined with zinc, could have contained, and he felt no dangerous effects from them. Fourcroy's Chem. Vol. I. p. 442.

afterwards dipped into an iron pot full of melted zinc, and being taken out, the zinc is found to cover the surface of the iron; and if a thicker coat of zinc is wanted, it may be obtained by dipping the vessel a second time. This kind of covering is so hard, that the vessels may be scoured with sand without its being rubbed off*. Kitchen utensils, which are made of cast iron, are usually tinned to prevent the iron's rusting; and, as great improvements have been lately made in rendering cast iron malleable, it is not unlikely, but that tinned iron vessels may become of general use.

The common method of tinning, consists in making the surface of the copper vessel quite bright, by scraping
ing

* Journ. de Phy. Decem. 1778.

ing it, and by washing it with a solution of sal ammoniac; it is then heated, and the tin, or metallic mixture designed for tinning, is melted, and poured into it, and being made quickly to flow over every part of the surface of the vessel, it incorporates with the copper, and, when cold, remains united with it. Rosin or pitch are sometimes used, to prevent the tin from being calcined, and the copper from being scaled, either of which circumstances would hinder the sticking of the tin.

I had the curiosity to estimate the quantity of pure tin, which is used in tinning a definite surface of copper. The vessel was accurately weighed before and after it was tinned, its surface was equal to 254 square inches; its weight, before it

was tinned, was 46 ounces, and its weight, after the operation, was barely $46\frac{1}{2}$ ounces; so that half an ounce of tin was spread over 254 square inches, or somewhat less than a grain of tin upon each square inch. How innocent soever pure tin may be, yet the tenuity of the coat of it, by which copper vessels are covered, in the ordinary way of tinning, cannot fail to excite the serious apprehensions of those who consider it; for in the experiment which I have mentioned, the tin was laid on with a thicker coat than in the common way; instead of a grain, I suspect that not a quarter of a grain of tin is spread over a square inch in the common way of tinning. A discovery has been lately made at Paris of a method of giving to copper or iron a coat of
any

any required thickness, by tinning them; the composition used for the tinning is not mentioned, but it is said that a piece of copper, which in the common way of tinning only absorbed 21 grains of tin, absorbed of the new composition 432 grains, or above twenty times as much *. Till this discovery is generally known, our workmen should study to cover the copper with as thick a coat as they are able of pure tin. The danger from the *corrosion* or *solution* of the tin by vinegar, juice of lemons, or other vegetable acids, if any at all, cannot, it is apprehended, be sensibly felt, except in very irritable habits, or where sour broths, sauces, or syrups are suffered to stand long in tinned vessels before they are used.

And,

* L'Esprit des Journaux, Mai, 1785.

And, indeed, a proper attention to keeping the vessels clean, might render the use of copper itself, for the boiling of food, especially of animal food, wholly safe. The French may be allowed to excel us in cookery, but we probably excel them in cleanliness; for the melancholy accidents attending the use of copper vessels, are much less frequent in England than in France; and this difference proceeds, I conjecture, from the superior care of the English in keeping their vessels clean, and from the cheapness and purity of the tin we use in tinning copper. We are not certain that the art of tinning copper vessels was known to the *Jews*, when they came out of *Egypt*; the vessels used in the temple service, were made of copper by divine appointment; and

by

by being constantly kept clean, no inconveniences followed. The wort, from which malt liquor is brewed, is boiled in copper vessels; the distillers and confectioners, prepare their spirits and syrups in un-tinned vessels of the same metal, without our suffering any thing in our health from these practices; at least, without our being generally persuaded that we suffer any thing. A new copper vessel, or a copper vessel newly tinned, is more dangerous than after it has been used; because its pores, which the eye cannot distinguish, get filled up with the substances which are boiled in it, and all the sharp edges of the prominent parts become blunted; and are thereby rendered less liable to be abraded.

M. de la Lande, in describing the

cabinet at *Portici*, observes, that the kitchen utensils, which have been dug up at *Herculaneum*, are almost all of them made of a compound metal like our bronze, and that many of the vessels are covered with silver, but none of them with tin: and hence he concludes, that the useful art of applying tin upon copper, was unknown to the *Romans*; *cet art utile d'appliquer l'étain sur le cuivre manquoit aux Romains**. By the same mode of arguing, it might be inferred, that whatever is not met with in one house or town, is not to be found in a whole country: yet, should a town in England, in which there happened to be plenty of tinned, but no plated or silvered copper, be swallowed up
by

* Voyage d'un François en Italie, Vol. VII. p. 120.

by an earthquake, a future antiquary, employed in digging up its ruins, would make a bad conclusion, if he should thence infer, that the English understood, indeed, at that time the art of applying a covering of tin, but not one of silver upon copper. If the ingenious author had recollected what is said in the 34th book of *Pliny's* Natural History, he would have seen reason to believe, that the Romans, at least when Pliny wrote that book, did understand the method of tinning copper which is now in use; for this great naturalist assures us in express terms, that tin smeared upon copper vessels, rendered the taste more agreeable, and restrained the virulence of the copper rust. It is to no purpose to object, that the tin (*stannum*) of Pliny, was
a sub-

a substance different from our tin; for though it should be in some measure granted, that it was a mixture of lead and silver, yet the same author tells us, in the same place, that white lead (*plumbum album*), by which it is universally allowed our tin is meant, was so incorporated with copper by boiling, that the copper could scarcely be distinguished from silver*.

Nay,

* Stannum illitum æneis vasis, saporem gratiorem reddit, et compefcit æruginis virus, mirumque, pondas non auget—from the weight of the copper not being *sensibly* increased (for Pliny here speaks popularly) we may infer, that the covering of tin which the copper received was very slight, and the art alluded to by Pliny in this place, was probably the same with that of tinning now in use—album (scil. plumbum) incoquitur æneis operibus, Galliarum invento, ita ut vix discerni possit ab argento, eaque incoctilia vocant.

This

Nay, it appears that the Romans not only used pure tin, but the same mixture of tin and lead, which some of our workmen use at this time in tinning vessels. A mixture of equal parts of tin and lead, they called *argentarium*; a mixture of two parts of lead and one of tin, they call *tertium*; and with equal parts of *tertium* and tin, that is, with two parts of tin and one of lead, they tinned whatever vessels they thought fit. They, moreover, applied silver upon copper, in the same way in which they applied tin upon it*; and they used

This description seems to be expressive of the manner of tinning, by putting the copper into melted tin, as is practised in the tinning of iron plates. Plin. Hist. Nat. L. XXXIV. S. XLIII.

* — deinde et argentum incoquere simili modo

used this silvered copper (I do not call it plated, because copper is plated by a different process) in ornamenting their carriages, and the harness of their horses, as we now use plated copper; on this head Pliny observes, and a rigid philosopher will apply the observation to ourselves, that such was the luxury of the Romans, that it was then simply reckoned a piece of elegance to consume in the ornaments of coaches, and in the trappings of horses, metals, which their ancestors could not use in drinking vessels, without being astonished at their own prodigality: we are not yet, however, arrived at the extravagance of *Nero* and his wife, who shod

modo cœpere equorum maxime ornamentis,
&c. Id. ib.

their favourite horses with gold and silver.

Pliny mentions an experiment as characteristic of tin — that when melted and poured upon paper, it seemed to break the paper by its weight, rather than by its heat; and Aristotle, long before Pliny, had remarked the small degree of heat which was requisite to fuse *Celtic* (*British*) tin*. This metal melts with less heat than any other simple metallic substance, except quicksilver; it requiring for its fusion not twice the heat in which water boils; but compositions of tin and lead, which are used in tinning, melt with a still less degree of heat, than what is requisite to melt simple tin: and a mixture composed of 5 parts of
 lead,

* De Mirab.

lead, 3 of tin, and 8 of bismuth, though solid in the heat of the atmosphere, melts with a less degree of heat, than that in which water boils.

ESSAY



E S S A Y V.

*Of tinning Iron.—Of plating, and
gilding Copper.*

IRON is tinned in a different manner from copper. In some foreign countries, particularly in *France, Bohemia, and Sweden*, the iron plates, which are to be tinned, are put under a heavy hammer which gives, in some works, 76 strokes in a minute: they can in one week, with one hammer, fabricate 4320 plates; the iron
is

is heated in a furnace eight times, and put eight times under the hammer during the operation, and it loses near an eighth part of its weight. Iron and copper are both of them very apt to be scaled by being heated, and they thereby lose greatly of their weight. Twenty-four hundred weight of pure plate copper, will not, when manufactured into tea-kettles, pans, &c. give above twenty-three hundred weight. Twenty-one hundred weight of bar iron will give a ton, when split into rods, but taking into consideration all iron and steel wares, from a needle to an anchor, it is estimated that thirty hundred of bar iron will, at an average, yield a ton of wares*.

Thirty

* See an instructive pamphlet, intitled, A Reply to Sir L. O'Brien, by W. Gibbons, 1785.

Thirty hundred weight of *cast* iron is reduced to twenty, when it is to be made into *wire*; and twenty-six to twenty-two, when it is to be made into *bar* iron. Steel suffers a much less loss of weight in being hammered, than iron does. *Cast* steel does not lose above two parts, and *bar* steel not above four in 100, when drawn into the shape of rasors, files, &c. The iron plates in England, are not hammered, but rolled to proper dimensions by being put between two cylinders of cast iron cased with steel. This method of rolling iron is practised in *Norway*, when they form the plates with which they cover their houses; but whether it was invented by the English, or borrowed from some other country, (as many of our inventions in metallurgy have been,

especially from Germany,) I have not been able to learn. In the first account which I have seen of its being practised in England, it is said to have been an invention of Major *Hanbury* at *Pontypool*, the account was written in 1697, and many plates had then been rolled *. The *milling* of lead, however, which is an operation of the same kind, had been practised in the year 1670; for an act of parliament was passed in that year, granting unto Sir *Philip Howard*, and *Francis Watson*, Esq; the sole use of the manufacture of milled lead, for the sheathing of ships. A book was published in 1691, intitled, *The New Invention of Milled-Lead for sheathing of Ships, &c.* It appears from this book, that about 20 ships, belonging to the navy, had been

* Phil. Transf. Ab. Vol. V.

been sheathed with lead; but the practice was discontinued, on account of the complaints of the officers of the navy, that the rudder irons and bolts under water, had been wasted to such a degree, and in so short a space of time, as had never been observed upon any *unsheathed* or *wood-sheathed ships*. The persons then interested in sheathing with lead, published a sensible defence; and amongst other things, they remarked, that both the Dutch and English had ever been in the habit of sheathing the stern-posts and the beards of the rudders with lead or copper; and that the Portuguese and Spaniards did *then* sheath the whole bodies of their ships, even of their gallions, with lead, and had done it for many years. Copper sheathing has since taken

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place

place in the navy, but it is said to be liable to the same objections which were, above a century ago, made to lead sheathing. It is preferable, however, to lead, on account of its lightness. If the fact should be once well established, that ships sheathed with lead or copper, will not last so long as those which are unsheathed, or sheathed only with wood; it would be a problem well deserving the consideration of chemists, to inquire into the manner how a metallic covering operates in injuring the construction of the ships, and whether that operation is exerted on the iron bolts, or on the timbers of the ship. When the iron plates have been either hammered or rolled to a proper thickness, they are steeped in an acid liquor, which is produced from the

fermentation of barley meal, though any other weak acid would answer the purpose: this steeping, and a subsequent scouring, cleans the surface of the iron from every speck of rust or blackness, the least of which would hinder the tin from sticking to the iron, since no metal will combine itself with any earth, and rust is the earth of iron. After the plates have been made quite bright, they are put into an iron pot filled with melted tin; the surface of the melted tin is kept covered with fuel or pitch, or some fat substance, to prevent it from being calcined; the tin presently unites itself to the iron, covering each side of every plate with a thin white coat; the plates are then taken out of the melted tin, and undergoing some further operations, which

render them more neat and saleable, but are not essential to the purpose of tinning them, they are packed up in boxes, and are every where to be met with in commerce under the name of tin-plates; though the principal part of their substance is iron, and hence the French have called them *fer blanc*, or white iron: Sir *John Pettus* says, that they were with us vulgarly called *latten*; though that word more usually I think denoted brass.

Tin is not, but iron is liable to contract rust by exposure to air and moisture, and hence the chief use of tinning iron, is to hinder it from becoming rusty; and it is a question of some importance, whether iron of a greater thickness than the plates we have been speaking of, might not be advantageously tinned.

I desired a workman to break off the end of a large pair of pincers, which had been long used in taking the plates out of the melted tin; the iron of the pincers seemed to have been penetrated through its whole substance by the tin; it was of a white colour, and had preserved its malleability. It is usual to cover iron stirrups, buckles, and bridle bits, with a coat of tin, by dipping them, after they are made, into melted tin; and pins, which are made of copper wire, are whitened, by being boiled for a long time with granulated tin in a lye made of alum and tartar. Would the iron bolts used in ship building, be preserved from rusting by being long boiled in melted tin? — Would it be possible to *silver* iron plates by substi-

tuting melted silver for melted tin? I do not know that this experiment has ever been tried; but an intelligent manufacturer will see many advantages which would attend the success of it.

It is customary, in some places, to alloy the tin, used for tinning iron plates, with about one seventieth part of its weight of copper; foreigners make a great secret of this practice; I do not know whether any of our manufacturers use copper, some of them I have reason to believe do not. Too much copper renders the plates of a blackish hue, and if there is too little, the tin is too thick upon the plates; but this thickness, though it may render the plates dearer, or the profit of the manufacturer less, will make them last longer. When the
tin

tin is heated to too great a pitch, some of the plates have yellowish spots on them; but the coat of tin is thinner, and more even, when the tin is of a great, than of a moderate heat; and the yellowness may be taken away, by boiling the plates for two or three minutes in lees of wine, or, where they cannot be had, four small beer, or other similar liquors, may, probably, be used with the same success. The quantity of tin used in tinning a definite number of plates, each of a definite size, is not the same at different manufactories. In some fabrics in *Bohemia*, they use 14 pounds weight of tin for making 300 plates, each of them being $11\frac{1}{2}$ inches long by $8\frac{1}{2}$ broad; according to this account, one pound of tin covers a surface of $28\frac{1}{2}$ square feet:

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in other, where the tin is laid on thicker, one pound will not cover above 22 square feet; the thickness of the tin, even in this case, is small, not much exceeding the one thousandth part of an inch; though that is near twice the thickness which tin has upon copper in the ordinary way of tinning. I have inquired of our English manufacturers concerning the quantity of tin used by them in covering a definite surface of iron, and from what I could collect, it is very nearly the same with that used in Bohemia, from whence we derived the art of tinning, or 28 square feet to a pound of tin.

There are various *tin plate* manufactories established of late years in different parts of England and Wales. *Saxony*, and part of *Bohemia* formerly
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supplied all the known world with
 this commodity; but England now
 exports large quantities of it to Hol-
 land, Flanders, France, Spain, Italy,
 and other places. About the year
 1670, *Andrew Yarranton* (he deserves
 a statue for the attempt) undertook,
 at the expence of some enterprising
 persons, a journey into Saxony, in
 order to discover the art of making
 tin plates; he succeeded to his ut-
 most wishes; and, on his return, se-
 veral parcels of tin plates were made,
 which met with the approbation of
 the tin men in London and Worces-
 ter*. Upon this success, prepara-
 tions were made for setting up a ma-
 nufactory, by the same persons who
 had expended their money in mak-
 ing

* England's Improvement by Sea and
 Land, by And. Yarranton, Gent. 1698.

ing the discovery; but a patent being obtained by some others, the design was abandoned by the first projectors, and the patentees never made any plates; so that the whole scheme seems to have been given up till the year 1720, when the fabricating of tin plates made one of the many very useful projects, (though they were mixed with some which were impracticable) for which that year will ever be memorable. How soon after that year the manufacture of tin plates gained a lasting establishment, and where they were first made, are points on which I am not sufficiently informed; an old *Cambridge* workman has told me, that he used them at *Lynn* in Norfolk in the year 1730, and that they came from *Pontypool*. The tin men, at the first introduction

tion of the English plates, were greatly delighted with them; they had a better colour, and were more pliable than the foreign ones, which were then, and still continue to be hammered; it being impossible to hammer either iron, or copper, to so uniform a thickness, as these metals are reduced to by being rolled. It is said, that a *Cornish* tin man flying out of England for a murder in 1243, discovered tin in *Saxony*, and that before that discovery, there was no tin in Europe, except in England*; a *Romish* priest, converted to be a *Lutheran*, carried the art of making tin plates from *Bohemia* into *Saxony* about the year 1620 †; and *Andrew Yarranton*, as we have seen, brought it from *Saxony* into *England* about the

* Heylin's Geog. † Yarranton.

the year 1670; Saxony at that time being the only place in which the plates were made. They are now made not only in England, but in France, Holland, Sweden, &c. though from the cheapness of our tin, and the excellency of some sorts of our iron, the greatest share of the tin plate trade must ever center with ourselves. Our *coal* is another circumstance, which tends to give Great Britain an advantage, over some other countries, in such manufactures as require a great consumption of fuel. *Wood* was scarce in Saxony above a century ago, and it is now still more scarce in France. They are beginning, it is said, in that country to use coal and coak, or charred pit-coal, called by them *Charbon de terre épuré*, and they have granted a pa-
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rent to an individual for the preparation of it *. Another individual has begun to distil tar from pit-coal, and he gets about 5 pounds weight of tar from an hundred of coal (which is pretty nearly what I suggested in 1781, as possible to be obtained from the same quantity, Vol. II. p. 352.). The French † expect great

* Acad. des Scien. à Paris, 1781; where M. Lavoisier gives an useful memoir on the comparative excellencies of pit-coal, coak, wood and charcoal as fuels.—Il suit de ces expériences, que pour produire des effets égaux, il faut employer: charbon de terre 600 livres; charbon de terre charbonné 552; charbon de bois mêlé 960; bois de hêtre 1125; bois de chêne 1089.

† Il suffit de dire qu'elle peut fournir à la capitale un nouveau chauffage, devenu nécessaire dans un moment où l'on est menacé d'une disette de bois; qu'elle peut ouvrir dans

great advantage from this mode of depurating coal, but we have nothing to apprehend on that score, for the patriotic zeal of the *Earl of Dundonald* has put us in possession of every advantage which can be expected from a discovery, which he has had the honour of bringing to perfection.

The plating of copper is performed in the following manner. Upon small ingots of copper they bind plates of silver with iron wire, generally allowing 1 ounce of silver to 12 ounces of copper. The surface of the plate of silver is not quite so large as that of the copper ingot; upon

dans le royaume une nouvelle brance de commerce; etablir de nouvelles manufactures; faire valoir des mines, restées jusqu' a présent inutiles. L'Esprit des Journ. Juillet, 1785.

upon the edges of the copper, which are not covered by the silver, they put a little borax; and exposing the whole to a strong heat, the borax melts, and in melting contributes to melt that part of the silver to which it is contiguous, and to attach it in that melted state to the copper. The ingot, with its silver plate, is then rolled under steel rollers, moved by a water wheel, till it is of a certain thickness; it is afterwards further rolled by hand rollers, to a greater or less extent, according to the use for which it is intended; the thinnest is applied to the lining of drinking horns. One ounce of silver is often rolled out into a surface of about 3 square feet, and its thickness is about the three thousandth part of an inch; and hence we need not wonder at the

silver being soon worn off from the sharp angles of plated copper, when it is rolled to so great an extent. Plated copper has, of late years, become very fashionable for the mouldings of coaches, and for the buckles, rings, &c. of horse harness. It might be used very advantageously in kitchen utensils, by those who dislike the use of tinned copper, and cannot afford to be at the expence of silver saucepans, &c. The silver, instead of being rolled on the copper to so great a thinness as it is in most works, might be left in kitchen furniture considerably thicker, so that an ounce of silver might be spread over one square foot; the silver coating would in this case still be very thin, yet it would last a long time. Fire does not consume silver, and the waste in
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thickness, which a piece of plate sustains from being in constant use for a century is not much; as may be collected from comparing the present weight of any piece of college plate, which has been daily used, with the weight it had an hundred years ago.

I do not know whether any attempt has ever been made to plate copper with tin instead of silver; I am aware of some difficulty, which might attend the operation, but yet it might, I think, be performed; and if it could, we might then have copper vessels covered with a coat of tin of any required thickness, which is the great *desideratum* in the present mode of tinning: but it ought to be remarked, that the thicker the coat of tin, the more liable it would be

to be melted off the copper by strong fires.

The art of plating copper, has not been long practised in England; nor do I know whether it was practised at an earlier period in any other country; for the Roman method of silvering copper was different, I think, from that now in use. *Thomas Bolsover* of *Sheffield*, in the year 1742, was the first person in England who plated copper; it was applied by him to the purposes only of making buttons and snuff-boxes: soon after it was used for various other works; a person of the name of *Hoyland*, at *Sheffield*, was the first who made a plated candlestick.

What is commonly called *French plate*, is not to be confounded with the plated copper of which we have
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been speaking; for though both these substances consist of copper covered with a thin coat of real silver, yet they are not made in the same way. In making French plate, copper, or more commonly brass, is heated to a certain degree, and *silver leaf* is applied upon the heated metal, to which it adheres by being rubbed with a proper burnisher. It is evident, that the durability of the plating, must depend on the number of leaves which are applied on the same quantity of surface. For ornaments which are not much used, ten leaves may be sufficient; but an hundred will not last long, without betraying the metal they are designed to cover, if they be exposed to much handling or frequently washed. After the same manner may gold leaf be fixed,

either on iron or copper. Gold is applied on silver, by coating a silver rod with gold leaf; and the rod being afterwards drawn into wire, the gold adheres to it; the smallest proportion of gold, allowed by act of parliament, is 100 grains to 5760 grains of silver; and the best double-gilt wire is said to have about 20 grains more of gold to the same quantity of silver*. It has been calculated, that when common gilt wire is flattened, one grain of gold is stretched on the flattened wire to the length of above 401 feet, to a surface of above 100 square inches, and to the thinness of the 492090th part of an inch: and *M. de Reaumur* says, that a grain of gold may be extended to 2900 feet, and cover a surface of more than 1400 square

* Lewis Com. Phil. p. 53.

square inches; and that the thickness of the gold, in the thinnest parts of some gilt wire, did not exceed the fourteen millionth part of an inch *. The gold, when thus applied, is thinner than when silver is gilt in the following manner, which is yet reckoned one of the cheapest ways, and is used in making various toys. Gold is dissolved in *aqua regia*; and linen rags being dipped into the solution, they take up some particles of gold; the rags being burned to ashes, and the ashes being rubbed on the silver, the gold adheres to it, and is rendered visible by being well burnished.

• Id. 60.



E S S A Y VI.

Of gilding in Or Moulu.—Of the Use of Quicksilver in extracting Gold and Silver from Earths.—Of Boerhaave's Experiments on Quicksilver.—Of silvering Looking-Glasses; and of the Time when that Art was discovered.

THERE is another method of applying gold on copper or silver, which is much practised; it is called

called gilding in *Or Moulu*. Quick-silver dissolves gold with great facility: if you spread a gold leaf (not what is called Dutch leaf, which is made of brass) on the palm of your hand, and pour a little quicksilver upon it, you will see the quicksilver absorbing the gold, just as water absorbs into its substance a piece of salt or sugar. Persons who have taken mercurial preparations internally, seldom fail to observe the readiness with which the mercury transudes through their pores, attaching itself to the gold of their watches, rings, sleeve-buttons, or ear-rings, and rendering them of a white colour. A piece of gold, of the thickness even of a guinea, being rubbed with quicksilver, is soon penetrated by it, and thereby made so fragile, that it may be broken
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between the fingers with ease: and if more quicksilver be added, the mixture will become a kind of paste, of different degrees of consistence, according to the quantity of quicksilver which is used. A piece of this paste is spread, by ways well known to the artists, upon the surface of the copper which is to be gilded in *or moulu*, and the metal is then exposed to a proper degree of heat: quicksilver may be evaporated in a far less degree of heat, than what is required to melt either gold or copper; when therefore the mixture of gold and quicksilver is exposed to the action of fire, the quicksilver is driven off in vapour; and the gold, not being susceptible of evaporation, remains attached to the surface of the copper, and undergoing the operations of
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burnishing, &c. too minute to be described, becomes gilt. This method of gilding copper, by means of quicksilver and gold, was known to the Romans *. Quicksilver will not unite with iron, yet by an easy operation, the foundation of which has been mentioned (Vol. I. Eff. VI.), iron may be gilded in the same way, that copper or silver may. The iron is first to be made bright, and then immersed in a solution of blue vitriol, its surface will thereby become covered with a thin coat of copper, and

* *Æs inaurari argento vivo, aut certe hydrargyro, legitimum erat.* Plin. Hist. Nat. L. XXXIII. Pliny understood by *argentum vivum*, native quicksilver, which is found in a fluid state in many mines; and by *hydrargyrum*, he understood quicksilver separated from its ore by fire; they are the same substance.

and it will then admit the gilding as if its whole substance was copper.

It is this property which quicksilver has of uniting itself with gold, and it does the same with silver, which has rendered it of such great use to the *Spaniards* in *America*. They reduce the earths or stones, containing gold or silver in their metallic states, into a very fine powder; they mix this powder with quicksilver; and the quicksilver, having the quality of uniting itself with every particle of these precious metals, but being incapable of contracting any union with any particle of earth, extracts these metals from the largest portions of earth. The quicksilver which has absorbed either gold, or silver, or a mixture of both, is separated from the substance it has absorbed by evaporation;

poration; the quicksilver flies off in vapour, and the substance remains in the vessel used in the operation. We have no mines of mercury in England; Sir *John Pettus*, indeed, says, that a little *cinnabar* is now and then met with in our copper mines; and Mr. *Pennant* observes, that quicksilver has been found in its native state on the mountains of Scotland; and I have been shewn a piece of clay, said to have been dug near *Berwick*, in which there were some mercurial globules; but there are no works at present, where mercury is procured in any part of Great Britain: nor are there many mines of mercury in any part of the world. In the *Philosophical Transactions* for 1665, we have an account of the quicksilver mines of *Idria*, a town situated in the country

try anciently called *Forum Julii*, now *Padria de Friouli*, subject to the regency, and included in the circle of the lower *Austria* in Germany. These mines have been constantly wrought for above 280 years, and are thought, one year with another, to yield above 100 tons of quicksilver. In *Hungary* also, there are mines which yield quicksilver, but not so copiously now as formerly. *Alonso Barba* mentions some quicksilver mines in *America* near *Potosi**, which he says, God Almighty provided to supply the loss of this mineral, which is very considerable in extracting the silver from the earths and stones with which it is mixed: but the mines of *Almaden* in Spain are the richest, and probably have

* Treatise on Metals, &c. by Alonso Barba, Eng. Transf. p. 112.

have been wrought for the longest time of any in the world. Pliny speaks of the *cinnabar* which the Romans, with so much jealousy, annually fetched from Spain, and 'tis very probable that they had it from *Almaden*. M. Jussieu informs us*, that in 1717, there remained above 1200 tons of quicksilver in the magazines at Almaden, after a great deal had been sent to *Seville* in order to be exported to *Peru*, where the quicksilver, which is lost in extracting the silver, is said to be at least equal in weight to the silver which is extracted. From 1574, when they began to register the quicksilver, which came to *Potosi* upon the king of Spain's account, to the year 1640, there had been received, according

* Hist. de l'Acad. des Scien. 1719.

According to Alonso Barba, 204600 quintals, besides a vast quantity irregularly brought in upon other accounts. This application of quicksilver to the extraction of gold and silver from the earths in which they are found, has rendered the consumption of it far more considerable since the discovery of the American mines, than it was amongst the ancients. *Hoffman* forms a calculation, and concludes, that fifty times as much gold as quicksilver was annually extracted from the bowels of the earth: *Cramer** admits the truth of this calculation, but insinuates a suspicion worth attending to — that mercury may often exist in minerals, and yet not be discovered by miners; since in the open fires in which minerals,

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* *Ars Docim. Cram. Vol. I. p. 231.*

whose properties are not known, are usually examined, the mercury would fly off in fume. Earths or minerals of any kind, containing mercury, are most accurately assayed by distilling them with iron filings; but whether a mineral contains mercury or not, may be easily discovered, by strewing it, when powdered, on a plate of hot iron, or on a hot brick covered with iron filings, and inverting over it a glass of any kind; the mercury, if the mineral contains any, will ascend and attach itself in small globules to the side of the glass. Mercury is divided by the writers of systems of mineralogy, into *native mercury*, and *mercury mineralised by sulphur*: native mercury is found in its *running* state, and quite *pure*, as it is said (though this may be doubted from

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the facility with which mercury dissolves gold, and silver, and other metals) in the mines of *Idria*, *Almaden*, &c.; it is more frequently, however, imbedded in calcareous earths, or clays of different colours, from which it may be separated either by trituration and lotion, the smaller globules coalescing by mutual contact into larger; or by distillation. The running native mercury, which requires no process for its extraction, is more esteemed, and thought to have some peculiar properties which do not belong to that obtained by simple distillation, though they both come under the denomination of virgin mercury. Mercury mineralised by sulphur, is called *cinnabar*, which some say is an African word denoting

the *blood of a dragon* *. Cinnabar is the most common ore of mercury, it is found in an earthy form resembling red ochre, sometimes in an indurated state, and, though generally red, it hath been observed of a yellowish or blackish cast; it is mostly opaque, but some pieces are as transparent as a ruby. This ore consists of mercury and sulphur combined together in different proportions; some cinnabars yielding as far as 7, other not 3 parts in 8 of their weight of mercury. Sulphur and mercury, being both volatile in a small degree of heat, would rise together in distillation, unless some substance, such as quicklime or iron filings, was added to the cinnabar, which, by its superior affinity, unites itself with and

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* Valmont de Bomare.

detains the sulphur; whilst the mercury, not being able to support the heat, is elevated in vapour, and condensed in various ways in different works. It sometimes happens, that the coarser cinnabarine ores are so much mixed with calcareous earth, that they require no addition in order to effect the separation of mercury from sulphur; this is the case in the mines of Almaden. The finer kinds of cinnabar, bearing a much higher price than mercury itself, are never wrought for mercury, but either used in medicine, or when levigated, under the name of *vermilion*, in painting; and often by the women as a substitute for *carmine*, which is prepared from *cochineal*. *Native* cinnabars are often mixed with small portions of arsenical, vitriolic, or

earthy substances, whence they become of uncertain or dangerous efficacy in medicine; for this reason *Geoffroy* recommends the use of *facitious* cinnabar, and the native, though formerly in great repute, has been left out of modern dispensatories. The finest cinnabar we know of is brought from *Japan*; though there is great reason to believe, that the *Dutch* impose upon the world a home manufacture, under the name of *Japan cinnabar*; the trade for gold, copper, and cinnabar to *Japan* is exceeding lucrative, and I believe wholly, as to *Europe*, in the hands of the *Dutch*.

Those, who are acquainted with the difficulty of making chemical experiments, will admire the great patience and industry with which

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Boerhaave investigated the nature of mercury. He was induced to undertake this task, from a desire of verifying or refuting the doctrines of the alchemists. These adepts had taught, that mercury was the matter of which all metals consisted; and that if it could be cleansed from some original impurities, with which, even in its virgin state, they held it to be polluted, it would then become fit nutriment for the seed of every metallic substance; for, according to them, every metal sprung from its peculiar seed, which, when it met with its proper *pabulum*, in a proper *matrix*, attended with a due fostering heat, by a vivifying principle multiplied itself, and received an augmentation of parts, in a manner similar to that by which plants and animals

are dilated in their dimensions. The investigation of nature is infinite, every age adds somewhat to the common stock, which renders the labours of preceding ages wholly useless. We no longer trouble ourselves with the works of the alchemists which remain, nor do we regret such of them, as have been devoured by time, or were burned by the order of Diocletian; nay, even the Herculean labours of Boerhaave are become less interesting to us, and probably never would have been undertaken by him, had he been aware, that mercury would, in a proper degree of cold, become, like other metals, solid and malleable. In the Transactions of our Royal Society for the year 1733, we meet with Boerhaave's first dissertation upon mercury: his first experiments

riments respect the change which the purest mercury undergoes from continual agitation; he included two ounces, which had been distilled above 60 times, in a clean bottle, and fastening the bottle to the hammer of a fulling mill which was almost constantly going, found in about eight months time above one eighth of the fluid, splendid, insipid mercury, changed into a black powder, of an acrid brassy taste. He next digested mercury in a gentle heat (180° of Fahrenheit's ther.) and found it, in a few months, changed into a powder, similar to what had been produced by agitation: both these powders in a greater degree of heat were revived, or became running mercury again. He then enquired into the change which repeated

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ed distillation could produce; after each operation he found a red acrid powder remaining in the retort; and he observes, that this powder was as copiously separated, after the mercury had been above 500 times distilled, as at first; and thence reasonably concludes, that it ought rather to be attributed to a change of the mercury itself, than to any impurity contained in it. This powder, like the preceding, by a superior degree of heat became running mercury; except about a 72d part, which, though fixed in a strong fire and vitrifiable with borax, could not support the action of lead, but vanished entirely, leaving no signs of any metallic substance upon the cupel: this shews the little probability of converting mercury into gold or silver

silver by the action of a violent fire. In the following year he presented a memoir to the Royal Academy of Sciences at Paris, upon the same subject. We there learn, that mercury kept in digestion for 15 years, with a constant heat of 100 degrees, was not fixed, nor any how changed, except that a little black powder (which by simple grinding in a mortar became running mercury) was found floating upon its surface. Hence is inferred, the impossibility of mercury's being changed in the bowels of the earth into any other metal, the heat in mines scarcely ever amounting to 100°. Though it might be impossible to change mercury into a metal, yet the philosophers by fire contended, that mercury, united to a particular kind of sulphur, entered
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into the composition of all metals, and might by art be extracted from them; lead was of all others thought the most likely, and the experiment had been reported to succeed by *Van Helmont*, and others; but *Boerhaave* is positive, that nothing can be expected from its combination with salts, and lead, or tin. It was still thought by the alchemists, that mercury could never be freed from its original impurity, but by being joined to some pure body of the same nature with itself, this they thought gold and silver to be. *Boerhaave*, in order fully to subvert their high pretensions, gave into the Royal Society another paper in the latter end of the year 1736, containing an account of the unchangeableness both of mercury and gold, how often soever they

they were distilled together. He repeated the distillation of mercury from gold above 850 times; the mercury was not in any respect changed; its specific gravity was the same as at first, nor had it lost the property of being converted into a red powder by a due degree of heat. These were all the tracts which were published during the life-time of Boerhaave; he died in September, 1738, and left his papers to his two brothers, and after their deaths, they fell into the hands of Charles Frederic Krusc, physician to the Empress of Russia; this gentleman hath published a short extract from Boerhaave's Diary, and promises a fuller account of still more laborious operations. We learn from this extract,

tract*, that Boerhaave had distilled the same mercury 1009 times, and its specific gravity was to that of water, as $13\frac{59}{100} : 1$; whilst that which had been but once distilled was as $13\frac{57}{100} : 1$; a difference which may easily be attributed to the different temperatures of the air when the experiments were made, or to other accidental circumstances, which the accuracy of *Gravesande*, with whom he made the experiment, could not provide against.

The mixture of quicksilver with gold, or silver, or lead, or tin, or copper, or any other metallic substance with which it is capable of uniting, is called an *amalgam*, and the operation by which the union is

* *Novi Commen. Petropo. Tom. IX. p. 381.*

is effected, is called *amalgamation*. Authors are not agreed as to the derivation of the word *amalgam*, some think that it is composed of two Greek words (*αμα* and *γαμεν*) by which the intimate union, or *marriage*, as it were, of the two metals is denoted; others are of opinion, that it ought to be written a *malagma*, and that it is derived from a Greek word (*μαλασσω*) signifying to soften, inasmuch as the metal, be it what it may, is always softened by its union with the mercury. An amalgam, made of four parts of tin and one of quicksilver, in the form of a ball, is used by some under the pretence of purifying water; it cannot, I think, contribute in any manner to that end; but as the ball is always boiled in the water, the seeds of vegetables, or the fish spawn,

Spawn, or the animalcules, &c. with which water is often polluted, may be precipitated by the action of boiling. But there is another purpose to which a mixture of tin and quicksilver is applied with great utility — the silvering of looking-glasses.

Tin may be beat out into leaves not thicker than paper, called *foils*; on tin foil, fitly disposed on a flat table, quicksilver is poured, and gently rubbed with an hare's foot; it soon unites itself with the tin, which then becomes very splendid, or, as the workmen say, is quickened: a plate of glass is then cautiously slid upon the tin leaf, in such a manner as to sweep off the redundant quicksilver, which is not incorporated with the tin: leaden weights are then placed on the glass, and in a
little

little time the quicksilvered tin-foil adheres so firmly to the glass, that the weights may be removed without any danger of its falling off. The glass thus silvered is a common looking-glass. About two ounces of quicksilver are sufficient for covering three square feet of glass.

It is generally believed, that the art of making looking-glasses, by applying to their back surface a metallic covering, is a very modern invention. *Muratori* expressly says, that glass *specula*, such he means as are now in use, are not of any great antiquity. — *Seræ autem antiquitati novimus fuisse specula, quorum usus nunquam desit; sed eorum fabricam apud Italos unice forsan Veneti per tempora multa servarunt et adhuc servant: quæ tamen alio translata nunc*

in aliis quoque regnis floret*.—The authors of the *French Encyclopedie* † have adopted the same opinion, and quoted a *Memoir* printed in the 23d vol. of the Academy of Inscriptions, &c.—Il est d'autant plus étonnant que les anciens n'aient pas connu l'art de rendre le verre propre à conserver la représentation des objets, en appliquant l'étain derrière les glaces, que les progrès de la découverte du verre furent, chez eux, poussés fort loin.—Mr. *Nixon*, in speaking of the glafs *specula* of the ancients, says, “before the application of quicksilver in the construction of these glasses (which I presume is of no great antiquity) the reflection of images by such specula, must have been

* Muratori Antiq. Vol. II. p. 393.

† Art. Miroir.

been effected by their being besmeared *behind*, or tinged *through* with some dark colour, especially black *." I have bestowed more time in searching out the age in which the applying a metallic covering to one side of a looking-glass was introduced, than the subject, in the estimation of many, will seem to deserve; and, indeed, more than it deserved in my own estimation; but the *difficiles nugæ*, the *stultus labor ineptiarum*, when once the mind gets intangled with them, cannot be easily abandoned: one feels, moreover, a singular reluctance in giving up an unsuccessful pursuit. The reader would pardon the introduction of this reflection, if he knew how many musty volumes I turned over before I could meet with any infor-

* Philof. Transf. 1758, p. 602.

information which could satisfy me, in any degree, on this subject; I am not yet *quite* satisfied, though I take the liberty to say, in opposition to *Muratori*, and the other respectable authorities which I have quoted, that the applying a metallic covering to looking-glasses is not a modern invention; — it is probable it was known in the first century, if not sooner, and it is certain, I apprehend, that it was known in the second.

The Romans, before the time of the younger Pliny, not only used glass, instead of gold and silver, for drinking vessels, but they knew how to glaze their windows with it, and they fixed it in the walls of their rooms to render their apartments more pleasant. Now a piece of flat glass, fixed in the side of a room, is a
 fort

fort of looking-glass, and if the *stucco* into which it is fixed, be of a dark colour, it will not be a very bad one. And hence I think the Romans could not fail of having a sort of *glass specula* in use: but this, though admitted, does not come up to the point; the question is, Whether they covered the posterior surface of the glass with a metallic plate? It has been observed before, that the Romans knew how to make a paste of gold and quicksilver, and it appears from Pliny also, that they knew how to beat gold into thin leaves, and to apply it in that state both on wood and metal: now there is a passage in Pliny, from whence it may be collected, that the Romans began in his time to apply a coat of metal to glass *specula*, and that this coat was of gold. The

passage occurs in the very place where Pliny professes to finish all he had to observe concerning specula *. An opinion, says he, has lately been entertained, that the application of gold to the back part of a speculum, renders the image better defined. It is hardly possible that any one should be of opinion, that a plate of gold put *behind* a *metallic* speculum, could have any effect in improving the reflected image; but supposing Pliny (whose transitions in writing are often abrupt) to have passed from the mention of *metallis*, to that of *glass specula*, then

* Atque ut *omnia* de speculis peragantur hoc loco. Optima apud majores fuerant Brundusina stanno et ære mixta. Præolata sunt argentea. Primus fecit Praxiteles, magni Pompeii ætate. Nuper credi captum certiorém imaginem reddi auro appposito averfis. Hist. Nat. L. XXXIII. S. XLV.

then the propriety of the observation relative to the improved state of the image is very obvious. If we suppose the Romans in Pliny's age to have simply applied some black substance to the back surface of the glass, or even to have known how to put tin behind it, yet the observation of the image being rendered more distinct by means of gold, might have been made with more justice than is generally supposed; for *Buffon* is of opinion, that a looking-glass made with a covering of gold and quicksilver, would reflect more light than one made in the ordinary way with tin and quicksilver *; and hence

Pliny's

* Ou pourroit trouver le moyen de faire un meilleur étamage, et je crois qu'on parviendroit en employant de l'or et du vif-argent. *Hist. Nat. Buffon. Sup. Tom. I. p. 451.*

Pliny's expression, *certiorem imaginem reddi auro appposito averfis*, will be accurately true.

Alexander Aphrodisseus flourished towards the end of the second century, he wrote several works in Greek, and amongst the rest, two books of Problems, one of his problems is this* :

Δια τι τα υελινα καλοπτρα λαμπρσι αγαν ;
Why are glass specula so very resplendent ?

The only part of the answer which we are concerned with, is,

Οτι ενδοθεν αυλα χρυσι κασσιτερω.

Because they besmear the inside of them with tin.

The Greek word which I have here rendered *besmear*, does not clearly point

* ΑΛΕΞΑΝΔΡΟΥ ΑΦΡΟΔΙΣΕΩΣ ιατρικα απορηματα και φυσικα προβληματα. Parisii, 1541.—If there be any doubt concerning the authenticity of these problems, I leave it to be discussed by the Critics.

point out the manner in which the operation of fixing the tin upon the glass was performed. Pliny uses a Latin word (*illitum*) of exactly the same import as this Greek one, when he speaks of copper vessels being tinned; and as in that operation, tin is melted and spread over the surface of the copper, I see no difficulty in supposing, that the tin may have been, in the time of Alexander Aphrodisæus, melted and spread over the surface of the glass, when previously heated.

Having carried up the invention of covering glass specula with a metallic coating to the second century, we may be the more ready to admit that the *Sydonians* possessed this art, before Pliny wrote his Natural History: for in that work, he not only praises them

for

for their former ingenuity in various glass manufactures, but he adds — and they had invented specula also *.

— Now there is some reason to think, that if the Sydonians had only invented the art of using a flat piece of glass as a speculum, without knowing how to give it a metallic coating, on which its excellency chiefly depends, they would not have merited the mention which Pliny makes of them; for their looking-glasses must have been inferior to the metallic mirrors then in use at Rome. There seems to be but one objection of any consequence to this conclusion, — had the method of giving a metallic covering

* Aliud (vitrum) flatu figuratur, aliud tornō teritur, aliud argenti modo cœlatur, Sydone quondam iis officinis nobili, siquidem etiam specula excogitaverat. Hist. Nat. L. XXXVI.

vering to plates of glass been known, at least to the Romans, (for it might have been known in *Asia* long before it was known in *Italy*) it seems probable, that the metallic specula would have fallen into general disuse, much sooner than there is cause to think they did; for it would have been much easier to make a looking-glass, than to polish a metallic mirror; and the image from the glass would have been superior to that from the metal, and on both accounts the mirrors would have become unfashionable.

The first mode of fixing a coat of *tin* on a looking-glass, I suspect to have been that of pouring the melted metal on the glass; and I have some reason, not now to be insisted on, to think, that this mode was not disused in the fourteenth century. — *Baptista Porta*

Porta lived in the fifteenth, and died towards the beginning of the sixteenth century; he gives us a very accurate description * of the manner in which looking-glasses were *then* silvered; it differs from that now in use only in this, that the tin-foil, when silvered, was taken up and gently *drawn* upon the glass. *J. Maurice Hoffman* published his *Acta Laboratorii Chemici* in 1719; he there speaks † of a mixture of 1 part of tin with 3 of quicksilver, which sometime ago, he says, was usually applied to the back surfaces of looking-glasses; although the *Venetians* did *then* make looking-glasses by pouring quicksilver upon tin-foil placed on the back surface of the glass.—This mode of silvering the

* *Magia Nat.* L. IV. C. XVIII.

† Pag. 245.

the glafs was not *then* invented by the *Venetians*, as appears from what Baptista Porta had advanced above two hundred years before; though the mode of silvering the tin-foil, when *laid* upon the glafs, was an improvement on that prescribed by Baptista Porta, just as the mode now in use, is a great improvement on that practised by the *Venetians* in the time of Hoffman.

The men who are employed in silvering looking-glasses often become paralytic, as is the case also with those who work in quicksilver mines; this is not to be wondered at, if we may credit Mr. Boyle, who assures us, that mercury has been several times found in the heads of artificers exposed to its fumes*. In the Philosophical

* Boyle's Works, Vol. III. p. 330.

Philosophical Transactions*, there is an account of a man, who having ceased working in quicksilver for six months, had his body still so impregnated with it, that by putting a piece of copper into his mouth, or rubbing it with his hands, it instantly acquired a silver colour. This, though a surprising, is not a fact of a singular nature; it is well known, that sulphur, taken inwardly, will blacken silver which is carried in the pocket; and I have somewhere read of a man whose keys were rusted in his pocket, from his having taken, for a long time, large quantities of diluted acid of vitriol. I remember having seen at Birmingham, a very stout man rendered paralytic in the space of six months, by being employed in fixing
an

* 1665.

an amalgam of gold and quicksilver on copper; he stood before the mouth of a small oven strongly heated, the mercury was converted into vapour, and that vapour was inhaled by him. A kind of chimney, I believe, has of late been opened at the farther side of the oven, into which the mercurial vapour is driven, and thus both the mercury is saved, and the health of the operator is attended to. The person I saw was very sensible of the cause of his disorder, but had not courage to withstand the temptation of high wages, which enabled him to continue in a state of intoxication for three days in the week, instead of, what is the usual practice, two.



E S S A Y VII.

*Of the transmutability of Water
into Earth.*

SIR *Isaac Newton* and *Dr. Bentley* met accidentally in London; and on Sir *Isaac's* inquiring what philosophical pursuits were carrying on at *Cambridge*, the Doctor replied — None — for when you go a hunting, Sir *Isaac*, you kill all the game: you have left us nothing to pursue. Not so, said the philosopher, you may start

a variety of game in every bush, if you will but take the trouble to beat for it. And so in truth it is; every object in nature affords occasion for philosophical experiment; and every experiment which is made, even with an express view to any particular investigation, incidentally suggests matter for new inquiry. But as in contemplating the civil history of the world, we are under the necessity of being contented with abridgments of its several parts, with remembering the great revolutions which have in fact taken place; without minutely exploring all the secret causes, all the fortuitous circumstances by which they were effected; so in the present state of experimental philosophy, we must rest satisfied, as to many subjects, with knowing the general conclusions,

clusions, without attempting to scrutinize all the particular experiments, on which they are founded. All the works of the writers of *Greece* and *Rome*, which have come down to our time, do not equal a third part of the bulk of those which have been published by individuals, and by the several philosophical societies of Europe on experimental philosophy alone, since the middle of the last century: nor does the nature of things prescribe any limit to human industry, exerted in the prosecution of such inquiries. There is not an animal, or a vegetable substance that we feed on; nor a saline substance that we taste; nor a beverage that we drink; nor the air that we breathe; nor a metal that we handle; nor a stone that we tread on, but what may furnish matter for an

infinity of experiments. What a source of natural knowledge is water alone? Who can understand all the properties that belong to it as a body, that is fluid in a certain degree of heat; solid in a less; and convertible into an elastic vapour of incredible force in a greater; as capable of dissolving all kinds of salts; as absorbing and detaining in its substance the air of the atmosphere; as being itself absorbed by, and suspended in the air; as constituting the principal part not only of blood, urine, milk, wines, oils, spirits, and all fluid bodies; but as entering, in a large proportion, into the constitution of the solid parts of all animal, and vegetable, and of many mineral substances; as being resolvable, according to the most recent discoveries,

ries,

ries, into two different sorts of air; and as being transmutable into earth? It is concerning the experiments which have been made relative to this last property, that I mean, in this Essay, to give a brief historical account. Men advance very slowly in the attainment of physical knowledge: the trouble of making experiments is great, but short relations of their results cannot fail of being entertaining to minds imbued with any taste for such kind of investigation; and there are few questions of greater importance in the estimation of speculative philosophers, than that which respects the transmutability of water into earth. If but one particle of water can by any means be changed into a particle of earth, the whole doctrine of the *Peripatetic* sect, concerning

cerning the *Elements* of things, will be utterly subverted: the diversities of the bodies subsisting in the universe, will no longer be attributed to the different combinations of *earth, air, fire, and water*, as distinct, uncompounded, immutable principles; but to the different magnitudes, figures, and arrangements of particles of matter of the same kind.

Those who maintain the transmutability of water into earth, support their opinion, principally, by arguments deduced from the result of two very different kinds of experiments. In the one they appeal to the mechanism of nature, and contend, that vegetation, however inexplicable it may be in its manner of operation, is certain in its effect, and invariably changes water into earth. In the other, they have
 recourse

recourse to the assistance of art, and by so simple a process as that of distillation, indefinitely repeated, they hold it possible to exhibit any determinate quantity of water under the form of a white, impalpable, opaque, insipid powder.

When the vast genius of *Bacon* had rendered the authority of *Aristotle* less respectable, and men's minds were every where alarmed with a suspicion, that Truth and *He* might possibly be on different sides; several appearances in nature, which had either escaped the observation, or, from seeming repugnant to the established maxims of the Schools, had been deemed unworthy the animadversion of philosophers, began to be examined with a minute attention: we have

an instance of the truth of this observation in the subject before us.

The purest water could never have been wholly distilled in glass vessels, but the operator might have had an opportunity of observing a thin pellicle of earth, tarnishing the transparency, and adhering to the bottom of the vessel employed in the process. This appearance is constant, it presents itself not only when the water is first distilled, but after it has been purged, as much as possible, from every foreign impurity by reiterated distillation. Yet notwithstanding the invariable uniformity of this phenomenon, I know not whether it was noticed by any one before *Borrichius*, as furnishing an incontrovertible proof of the transmutability of water into earth.

earth. Why, says he, should we dwell upon the possibility of chemical principles being converted into one another, when the very elements of Aristotle are not exempt from change? He then proceeds to observe, that water, how frequently soever he had distilled it from fresh glass vessels, still left at the end of each successive operation, a slender coating of earth sticking to the side of the vessel, and he attributes the production of this earth, not to any extraneous impurity accidentally mixed with, and obstinately adhering to the water, but to a transmutation of the water into a true, firm, fixed, insipid earth*. In saying that *Borrichius*

* Et quid chemica moramur? Ipsa Aristotelis elementa non sunt ab his immunia mutationibus.

chius was the *first* person who made this observation, I may, perhaps, be guilty of some inaccuracy. The *imprimatur* for Borrichius' book, here referred to, is dated at *Copenhagen* in 1673: now it is certain, that *Boyle's* treatise concerning the Origin of

Qua-
tationibus. Enimvero aqua, etiam limpidissima, et, si placet, vel decies per destillationes ab omni fœce libera in veram, firmam, fixam, et inspidam terram mutabitur, si eandem iterum, iterumque frequentissimè ex recentibus semper vasis vitreis lente destillando evoces; quavis enim vice tenella quædam cuticula terrea, sed elegans, ex aquâ illa enata superficiè interiori vitri agglutinabitur, quod frequentibus experimentis didici; cumque illud ipsum ante hos X annos nar-rarem Cl. Oxoniensis Academiæ Medico Edmundo Dickenfotino, idem sibi comper-tum centesimâ destillatione asseruit. Her-metis Ægypt. et Chem. Sapien. per Ol. Bor-richium, p. 397.

Qualities and Forms, in which the transmutation of water into earth by distillation, is distinctly mentioned, was published at Oxford in 1666; yet as Borrichius had spoken of this experiment to a physician at Oxford ten years before he published his book, and as it is very probable, that Boyle was unacquainted with this experiment when he first published his Sceptical Chemist in 1661, Borrichius may, perhaps, be properly enough esteemed prior to Boyle in the invention and application, though posterior to him in the publication of the experiment.

Boyle, however, examined the matter with greater precision than Borrichius had done. In his treatise concerning the Origin of Qualities and Forms, he acquaints us with the first

first occasion of his making the experiment*. A gentleman who, in order to discover the grand *arcanum*, had employed, among other things, great quantities of purified rain water, complained to him, that instead of obtaining what he looked for, he met with a great deal of a whitish excrementitious matter, which he knew not what to make of. The great plenty and some peculiar qualities of this matter, which had so much perplexed the old chemist, suggested to Mr. Boyle a suspicion, that it was not owing to any accidental foulness of the water, and put him upon trying, — whether water, which had been previously purified by distillation, would not, by being re-distilled, leave, at the end of the operation, a portion

* Boyle's Works, fol. Vol. II. p. 519.

of earth. The result of his experiment confirmed him in his conjecture, that the earthy powder obtained by distilling rain water, might be a transmutation of some parts of the water into earth: and he was much strengthened in this belief by conversing with a physician (probably the same person mentioned by *Borrichius*) who assured him, that he had frequently found a white earth in distilled rain water, even after he had distilled the same numerical liquor a great many times.

Boyle seems to have been very cautious in admitting this transmutation, the oddness of it he owns still kept him in suspense; and it was not without much delight, that he was informed by an ingenious person of unsuspected credit, who, with a medical view, had been long working upon

upon rain water, that water which he had distilled near *two hundred times*, still afforded a white earth; and that more *copiously*, at least more conspicuously in the *latter* distillations, than in the *former*. This gentleman out of one ounce of distilled rain water, had obtained, by reiterated distillation, near three quarters of an ounce, if not more, of earth. The physician *Dickenson*, mentioned by *Borrichius*, was probably the person alluded to by *Boyle* in this account; for *Houghton* says in his Collection, "I have heard that Dr. *Dickenson* has turned eighteenth parts of water out of twenty parts into earth, only by repeated distillation." Yet, even this account, conclusive as one might think it, could not extort from *Boyle* a full conviction of the possibility of transforming

muting water into earth by distillation; he calls the hypothesis a bold conjecture, and expressly mentions some scruples which still remained with him. Two of these scruples are worthy of particular notice, inasmuch as they contain the two principal objections, which have been made, by subsequent philosophers, to the doctrine which he endeavoured to establish. The first respects the *vessels* in which the experiment had been usually tried; the second has relation to the water itself. — “It were fit to know,” says he, “whether the glass body, wherein all the distillations are made, do lose of its weight, any thing near so much as the obtained powder amounts to.”—And again, “I could wish that it were demonstrably determined, what is on all hands taken
for

for granted, that distilled rain water is a perfectly homogeneous body *.

It does not appear that Boyle was ever fully satisfied with respect to these doubts, he resumes indeed the subject in a tract, intitled, Experiments and Notes about the produceableness of Chemical Principles, published at Oxford in 1680, and mentions a new trial which he had made; yet he there repeats his scruple concerning the homogeneity of water, and though upon the whole he appears willing to believe, that water might be transmuted into earth by distillation, and the nature of his subject led him to make the most of so remarkable an experiment, yet he candidly owns, that some of his experiments afforded strong probabilities, rather than conclusive proofs.

Not:

* Id. p. 522.

Notwithstanding the diffidence with which Boyle himself proposed his opinion concerning the transmutability of water into earth, it appears to have been very generally admitted from his time to *Boerhaave's*; and even *Newton** so far believed it, as to think it possible that water might be made red hot †.

Boer-

• “Water by frequent distillations changes into fixed earth, as Mr. Boyle has tried, and then this earth being enabled to endure a sufficient heat, shines by heat like other bodies.” *Newton's Optic. Quæ.*

† Another method is mentioned, by which water may be made red-hot. If a spoonful of water be thrown upon the surface of a large quantity of melted glass, in a glass-house furnace, it will assume a globular form, and appear to roll about on the surface of the glass as if it was a melted metal; it will make no explosion, but becoming red-hot, it will by

Boerhaave opposed the general persuasion ||; he did not deny, that earth was always found at the bottom of the glass vessel in which water had been distilled, nor that the quantity of

little and little be diminished in bulk, and at length be totally dissipated *. The author of this observation attempts to explain the phenomenon; *M. Bosc d'Antic* †, thinks the explanation improper; but he allows the existence of the little globes, and says they are hollow, and of an earthy nature: when this appearance has been more fully examined, it is probable that it will be considered as an argument in support of the transmutability of water into earth; though *Dr. Priestley* has remarked, “ that *water* after being heated red-hot, was still water, there being no change in its sensible properties ‡.”

|| *Boerh. Chem. Vol. I. p. 627.*

* *Rozier's Journ. Jan. 1778.*

† *Ouvres de M. B. d'Antic, Vol. II. p. 276.*

‡ *Phil. Trans. 1785, p. 291.*

of earth was constantly increasing with the increase of the number of distillations which the water had undergone; but he thought that this earth did not proceed from the water itself, but from the dust which is always floating in the atmosphere, especially in the atmosphere of laboratories. It could not be imagined, that the atmosphere included in the vessels used for distillation, could furnish any considerable quantity of dust in one operation, yet being renewed by the opening of the vessels, as frequently as the distillation was repeated, it seemed to him to be a cause fully adequate to the effect.

It is a matter of wonder, that Boerhaave should assign such a reason for this phenomenon, considering the result of an experiment mentioned by

Boyle, in which he exposed the same water, in the same vessel *hermetically* sealed, to a *digestive* heat for above a year *: after it had continued a good while, little concretions, heavier than the water, began to be formed, and he expressly remarks, that the longer the glass was kept in the digestive furnace, the more of this fine terrestrial substance was produced; an event

• When the neck or hollow stem of a glass vessel is so softened by fire, that the two sides of it may be pinched together, the vessel is said to be *hermetically* sealed; thus the upper end of the tube of a mercurial thermometer, is hermetically sealed.— A *digestive* heat, is, in general, any degree of heat above that in which water freezes, and below that in which it boils: but 150° of Fahrenheit's thermometer is commonly called a digestive heat. The operation called *digestion*, consists in exposing liquids, or liquids and solids, to a digestive heat in suitable vessels for a due time.

event impossible to be explained from the dust floating in the atmosphere; as the vessel, by being hermetically sealed, effectually excluded the minutest particle of dust from coming in contact with the water.

Though this experiment, properly considered, was certainly conclusive against Boerhaave's hypothesis, yet *Marggraf* undertook to shew its insufficiency in another manner*. He contrived a retort and a receiver of the same piece of glass, and through an hole in the receiver, which he afterwards closed with a glass stopple; he poured an ounce of water which had been carefully distilled thirteen times; this water he re-distilled, without suffering any air to enter into
the

* *Opus. Chy. de M. Marggraf, Vol. II. p. 176.*

the retort, thirty times more, and observed that the water, which was at first exceedingly transparent, became more and more troubled by the admixture of a fine white earth, as the number of distillations was increased. The refutation of Boerhaave's hypothesis, was not the only point which Marggraf had in view in making his experiments on water; he was desirous also of obviating the objections of those who were disposed to attribute the origin of the earth to an abrasion of the parts of the glass, rather than to a transmutation of the particles of water. In order to this he has not only remarked, that the vessels in which he had distilled water so frequently, were, as far as microscopes could inform him, as perfectly polished as when new, and that they

they were of the very best sort of glafs, in which spirit of falt might be kept for many years without its injuring them, but he has shewn that fire is not essential to the production of the effect; an earth being separable from distilled water by the simple action of the sun evaporating the water, and even without any heat by a long continued agitation. Sir Isaac Newton was of opinion, that the water upon the surface of the earth was daily diminished by vegetation, and if we may rely upon these experiments of Marggraf, we see that there are two other causes which have a tendency to produce the same effect; for the water of the ocean is incessantly raised into the atmosphere by evaporation, and agitated by the action of the winds and tides; and if it be by

both these causes converted in part into earth, we may admit that the *Caspian* sea is less now than it was formerly, and that the *Mediterranean* sea has retired from the coasts of France, Spain, Portugal, and Italy, without having recourse, with *Buffon*, to the sinking of immense caverns within the bowels of the earth, into which the sea has from time to time retired. With respect, however, to this supposed diminution of the sea, it may be observed, that it is well understood that the sea has encroached upon the shore in some places, and deserted it in other; but I do not know whether geographers are able, on solid grounds, to say,—whether the quantity of land throughout the whole globe, is, or is not, the same now that it was 4000 years ago.

M. *Eller*

M. *Eller* had, in 1746, obtained earth from water by triturating it in a glass mortar*; and *Wallerius*, in 1760, with a view of removing the suspicions of *Pott*, who thought the earth proceeded from the mortar itself, varied in some measure *Eller's* experiment, by triturating water in mortars of iron and bronze †. The old proverb — *gutta cavet lapidem* — would render experiments of this kind very suspicious, if the authors did not assure us, that the earths obtained by trituration, were not of the nature of the vessels in which the experiments were made: and *Marggraf* also affirms, that the earth which he procured from water by repeated distillation,

* Mem. de l'Acad. de Berlin, 1746.

† Recueil des Mem. de Chy. Vol. II. P. 542.

stillation, had properties very different from those of pounded glass.

In opposition to the opinion of these philosophers, M. *Le Roi* has undertaken to shew*, that the very experiments produced by Marggraf and others, in proof of the transmutability of water into earth, do not, though they be admitted in their full extent, sufficiently establish the fact. His reasoning turns chiefly upon the second of Boyle's scruples before mentioned: he apprehends that rain water ought not to be esteemed an homogeneous fluid, but that it contains an earth subtilely mixed with, or dissolved in the water, from which it cannot be separated by any number of distillations, however great. — Marggraf himself was quite
aware

* Hist. de l'Acad. des Scien. a Par. 1767.

aware of this difficulty; he says he suspected, that water which had been distilled but once by the retort, might probably contain some portion of attenuated earth which had risen in the distillation, but which did not belong to the water; and he therefore distilled the water, on which he made his experiment, thirteen times, and six of them with the gentle heat of boiling water. That rain water, collected with every possible precaution, contains not only a portion of earth, but small quantities also of the acids of nitre and sea salt, is proved beyond a doubt by the experiments of Marggraf himself; the only point in dispute is, whether these heterogeneous admixtures can be separated from water by reiterated distillation or not? M. Le Roi thinks, that
y they

they cannot; according to him the vapour of water, which rises in distillation, carries with it a portion of the impurities contained in the water. This objection may recur for ever, let the number of distillations be what they may, nothing short of a complete transmutation of a definite quantity of water can wholly obviate it.

The experiment before mentioned, in which Boyle's friend obtained from an ounce of water, near three quarters of an ounce of earth by 200 distillations, approaches the nearest of any that has ever been made to a complete transmutation: but this experiment has of late been considered by M. Le Roi and others, as meriting no manner of attention; principally because it does not correspond with
 similar

Similar experiments of more modern chemists, especially of Marggraf, whose accuracy is above all question. He could not obtain from 72 ounces of pure rain water, by 13 distillations, above 12 grains of earth; a quantity very inconsiderable; in comparison of what it ought to have been, in order to have agreed with the quantity obtained by Boyle's friend.

I have no intention to enter into a formal defence of this famous experiment mentioned by Boyle; it may be observed, however, that neither Marggraf, nor any other chemist, ever distilled the same identical water so frequently, as the author of this experiment did*: his relation of it
then,

* This observation is not, I believe, true;
Boer-

then, it is evident, is not contradicted from observation, but from inference, and the inference has been founded on a principle, rather taken for granted, than proved. The principle is this, — that if any number of distillations, suppose ten, yield a certain portion of earth, twenty times that number, or 200 distillations, would yield twenty times as much, at least not more, earth. — Now there are some reasons to believe, that this principle is not true; for not to insist on what Boyle, however, intimates, of the earth being more plentifully

Boerhaave is said to have distilled the same water 500 times; I have not seen all the works of Boerhaave, nor does the author, who makes this remark concerning him, refer to the particular part of his works where the fact is mentioned. Fourcroy's Chem. Eng. Transf. Vol. I. p. 115.

tifully afforded in the latter distillation, than in the former, Marggraf himself has made two observations, which, when taken together, seem to prove the same thing. He affirms, and Wallerius agrees with him, that more earth is separated when water is kept boiling with a *strong* than with a *gentle* heat; and he observes also, and esteems it a fact altogether singular, that water which has been *often* distilled, requires for its elevation, especially towards the end of the operation, when but a small quantity remains in the retort, a degree of heat exceedingly strong, when compared with that which any other water requires *. From these observations,

* — pendant la distillation, il faut entretenir continuellement l'eau que la retorte
con-

tions I would argue thus; if it be true, that *more* earth is separated when water is distilled with a *strong* than with a *gentle* heat; and if it be true also, that the *degree* of heat necessary to distil water is *stronger*, as the number of distillations it has previously undergone is *greater*, will it not be a just consequence, that the quantity of earth separable by a single distillation, or by any definite num-

contient, dans une *forte* coction. Ou trouvera que, par ce moyen, il se sépare toutes les fois plus de terre de l'eau, que quand la distillation se fait lentement.—Ou doit remarquer comme quelque chose de tout-à-fait particulier, que plus souvent une semblable eau est distillée, et plus l'opération devient difficile, sur-tout à la fin, quand une partie de la liqueur a distillé; car alors le résidu demande un degré de feu *très-véhément* en comparaison de toute autre eau. Opus. de Marg. Vol. II. p. 193.

number of distillations, will be greater as the number of previous distillations has been greater? If this be admitted, it easily follows, that the quantity of earth separable by 200 distillations, cannot be properly calculated by the rule of proportion, from what actually has been separated by 13, or any other number of distillations so greatly short of 200. Moreover, this experiment is not destitute of a kind of collateral proof; for Wallerius has observed, that the quantity of earth which he obtained by triturating a certain quantity of water in a glass mortar for four days, agrees pretty exactly with the quantity procured by the 200 distillations mentioned by Boyle.

M. *Lavoisier* * rejects the notion of
the

* Hist. de l'Acad. des Scien. a Paris, 1770.
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the transmutability of water into earth by distillation, as well as M. *Le Roi*; but he rejects it upon different principles: he has endeavoured to remove the other scruple mentioned by Boyle, and has done, what it is surprising no chemist ever thought of doing before his time, considering that the hint had been given above 100 years ago; he has weighed the glass vessel in which the operation was performed, and has found that its weight after the operation, is less than it was before the operation; and this loss of weight he attributes to the abrasion, or solution of the parts of the glass. M. Lavoisier's experiment resembles that of Boyle before mentioned, in which water was exposed to a digesting heat, in a vessel hermetically sealed; but he conducted

ed it with more accuracy. I have three reasons for hesitating concerning Mr. Lavoisier's opinion, which refers the earth found in the vessel after the distillation of water, to the abrasion of the glass. In the first place, the earth procured by distillation, is not of the same kind, has not the same chemical properties, as pounded glass has. Secondly, Mr. Lavoisier did obtain 3 grains of earth, above the loss of weight which his vessel had sustained, and this quantity may, perhaps, be as much as ought to be expected from such an experiment, supposing that water is convertible into earth; for the heat he made use of in the operation was small. And lastly, I have slowly distilled water in a silver retort, and afterwards evaporated the distilled

water on a polished silver plate, there remained on the plate a small pellicle of earth. When a drop of water, arising from the vapour condensed in the top of a silver tea vase, happens to fall upon the body of the vase, it is presently evaporated; but it always tarnishes the spot on which it has fallen. I am aware it may be contended, that the earthy pellicle in both these cases, may be attributed to a precipitation of the dust floating in the atmosphere, or to an attenuated earth, which is mixed with the water and carried up by the vapour. On the whole, the possibility of converting water into earth by distillation, remains, I think, still an undecided problem; M. Lavoisier's experiment staggers the confidence I had reposed in the conclusions of Marggraf,

graf,

graf, but it must be repeated with success before it will utterly subvert it.

With respect to the conversion of water into earth by *vegetation*, many philosophers of great eminence have admitted it without scruple. *Van Helmont* * derived not only vegetables; but all substances whatever from water, and boasted that he was the first author of that hypothesis. It may be observed, however, that in the earliest systems of philosophy, we have the plainest allusions to this doctrine, and to the *Mosaic* account of the creation. Thus *Berosus*, the famous priest of Babylon, held *water* and *darkness*;
(*dark-*

* De Lithiasi, C. I. S. IV. — Ast ad me usque nescitum fuit, cuncta corpora, quæ mista creduntur, materialiter duntaxat ex sola aqua esse, nullo excepto.

(*darkness* was upon the face of the deep, Gen. i. 2.), the Phenicians *darkness*, a *choas*, and *wind*; the Persians *light*, to have been the first principles from which all things proceeded. The most ancient *Greeks*, if the opinion of *Homer* be of any weight in this matter, derived the origin of all things from *water*; this doctrine was followed about 300 years afterwards by *Thales* of *Miletus*; who, travelling into Egypt and conversing, as *Dio-genes Laertius* tells us, with the priests of that country, heard from them, probably, some tradition concerning the creation; by which means he improved much upon the poet, teaching, as *Cicero* observes, *Deum eam mentem esse, qui ex aqua omnia fingeret.*

Val *Helmont* * produced a singular

* *Opera omn.* p. 105.

lar experiment in support of his opinion, that water became earth by vegetation. He took an earthen vessel and put into it 200 pounds weight of earth, which had been previously dried in an oven; he wetted the earth with rain water, and planted in it the trunk of a willow which weighed five pounds. In the space of five years, the willow weighed 169 pounds 3 ounces: the earth was watered, when it was necessary, during the whole of the time with either rain or distilled water; the vessel was spacious, and was sunk into the ground, and, to prevent any dust from falling into it, its mouth was covered with tin plates, which were pierced with many holes. No account was taken of the leaves which fell in four successive autumns. The earth was taken out of the ves-

sel, dried, and weighed at the expiration of the five years, and it had lost only about 2 ounces, so that 164 pounds of wood, of bark, and of roots, of which the tree consisted, had arisen from the water. I have related this experiment at full length, as it is the first of the kind which was made, and is as conclusive as any of those which have been made since by *Boyle*, *Du Hamel*, *Eller*, and others. *Beccher* admits the fact as stated by *Van Helmont*, but he objects to the conclusion; water, says he, will never become earth, except so far as it carries some earthy particles along with it*. *M. Le Roi* adopts the

* — nec sufficit solis verbis omnium rerum originem aquæ tribuere, aut experimentum Helmontii in vegetatione arboris, quod Robertus

the same notion, when he attributes the increase in the weight of the willow, to the earthy and saline particles from which water cannot be freed, even by distillation. It is, moreover, well known, that plants suck in nutriment from the air by their leaves, and

bertus Boyle in *chemista sceptico* citat. Aqua profecto nunquam terra fiet nisi in quantum corpuscula terrea secum vehat. Beccher *Phy. Sub.* p. 87.—Calcined plasterstone, and the materials used in making earthen ware, absorb much water, and are increased in weight, as vegetables are by absorbing water in vegetation; and some are of opinion, that water, by being united to what is called (from the substance which yields it by a peculiar process) *sparry acid*, may be changed into a flinty earth; but in all these, and in other similar cases, it may be questioned, whether the particles of water may not be *wholly* disunited from the substances with which they are combined, and again exhibited under the form of water.

and this nutriment is not a pure water, since the purest atmospherical water contains both *oily*, *saline*, and *earthy* principles, if we may trust the analyses which have been made of it. In addition to this remark, I would observe, that though the willow gained an increase of 164 pounds in weight, yet a very small portion of that weight was earth; since much the greatest part of all vegetables, and especially of succulent ones, consists of water and air. I cut a leaf from the *mitre aloe*, it weighed 1644 grains; it was cut into slices, and exposed to the heat of the atmosphere in September; in 15 days it had lost 1558 grains: I then burned it to a black ash, it weighed in that state 26 grains, and being burned to a white ash, it weighed only 16 grains, which
 were

were composed only in part of earth; for they contained, though I omitted to examine them, a portion of fixed alkaline salt. A fresh *pumpkin*, which weighed 200 ounces, being cut into slices and dried in the sun, lost in nine days 190 ounces of its weight; the remaining 10 ounces being reduced to ashes, did not yield one ounce of earth. Had Van Helmont reduced his willow to ashes, I think it would not have yielded one pound of earth; this small quantity of earth, added to the uncertainty there is as to the earth, wherein the willow was planted, being equally free from moisture when it was weighed, before and after the willow had acquired its increase, renders the conclusion which is drawn from the experiment wholly questionable.

Count

Count Gyllenberg*, in order to prove that *vegetables derive all their constituent parts from water, even their oils and salts, as well as their earthy particles*, makes the following observation. — “ Four thousand different plants can grow in twenty pounds weight of earth, and in each of them shall be found a different *oil* and a different *salt*. Let us suppose these plants to be chemically analyzed, near an *ounce of oil and salt* will be found in each. If this *oil* and this *salt* had proceeded from the earth, there must have been in that earth four thousand ounces, or 250 pounds of *oil and salt*,
 whereas

* Count Gyllenberg's Elements of Agriculture, translated by Mills, p. 72.— This work is attributed by Mr. Mills to Count Gyllenberg, by the French translator to Wallerius; see the Ed. quoted in Vol. II. p. 76.

whereas in fact there was not a grain of either of them in it." This observation does not prove, that simple water is converted into *earth*, or *salt*, or *oil* by vegetation; it merely shews, that plants by vegetating acquire such an increase of weight, as cannot be derived from the earth in which they grew, and become bodies, whose constituent parts are different from both earth and water: but it neglects the consideration of two substances, as necessary to vegetation as either earth or water — *light* and *air*. The *air* is a fluid whose constituent parts are not yet fully ascertained; besides water, there are reasons to think that it contains an oily and a saline principle; and as to *light*, opticians have discovered not only that the same ray of it has different properties on

its

its different sides, but that it is by no means an homogeneous fluid, though no experiments have yet sufficiently shewn, whether that fluid be a saline or phlogistic substance, or both. The rays of the sun seem to be acted upon by every body in nature, and they may be capable of being combined with air, or water, or earth; and in that state of combination they may enter as constituent parts into vegetables, &c. form airs, salts, and oils of various kinds. There may be an igneous and elastic fluid, as well as an aerial one universally dispersed, and on which the fluidity of the air itself may depend; and this fluid, being imbibed by vegetables, may be a principal component part of them, and being restored to its fluidity by combustion, fermentation, and other causes,

causes, it may produce heat or flame, according to the circumstances under which it endeavours to discharge itself. There is a curious experiment which will illustrate the efficacy of air and light in promoting vegetation.

Mr. Eller took a large quantity of water which had been twice distilled, and having filled a cylindrical glass vessel with it, he bound a sheet of paper over the mouth of the vessel, and set it in the sun in the middle of summer for several weeks. He soon observed that the water began to be troubled, that it emitted small bubbles, that its surface became somewhat frothy, and that the bottom of the vessel was covered with a *green matter*. He afterwards distilled the water, and from the last portion of
it,

it, containing the green matter, he obtained an acid and an oil, and, though he does not mention it, there remained, probably, a portion of earth. I remember having seen a glass tube, which, after having been hermetically sealed and nearly filled with water, had been left for some months on a table on which the sun occasionally shone, that side of the tube on which the rays of the sun had fallen, was covered with *green matter*, whilst the other side was free from it. Dr. Priestley, with his accustomed ingenuity, has investigated the nature of the green matter which is thus formed, and shewn that it is a vegetable, whose seeds are constantly floating in the atmosphere, and that *light* is absolutely requisite to its production, mere heat not being sufficient

cient for the purpose; but that light itself will not produce it in water which has no communication with the air; probably because in that case the water is deprived of the seeds from which the vegetable springs, and hence we may infer, that the action of the sun's light is not alone sufficient to generate salts and oils in water, though it be instrumental in enabling the seed of the vegetable to expand itself into the form of a plant. The vegetable thus formed, certainly contains more *acid*, more *oil*, and more *earth*, than existed in the seed from whence it sprung, but it would be a rash conclusion to say, that simple water has been converted into any of these substances, though it seems to be a just one to say, that either the water, or the air in the water, or

the solar light, have jointly or severally been changed into them. Is it possible so far to purify a portion of atmospherical air from the small seeds of vegetables, that distilled water, though in contact with this purified air, and exposed to the action of the solar rays, shall not produce any green matter, or undergo such a change, as to yield by distillation either a saline or an oily principle? — I have now given an account of the most noted arguments which have been brought in support of, or in opposition to the doctrine of the transmutation of water into earth, and I am forced to conclude, from this view of the subject, that the question is not clearly decided either way: as to my own opinion, I beg leave to say, that I am rather disposed

to

to believe that water is converted into earth, though I own that no experiment has yet been produced, to which reasonable objections may not be made. The point I am sensible cannot be decided by authority; yet I will put an end to the disquisition by mentioning the opinion of Newton. — *Vegetabilia omnia ex liquoribus omninò crescunt, dein magna ex parte in terram aridam per putrefactionem abeunt, et limus ex liquoribus putrefactis perpetuò decedit. Hinc moles terræ aridæ indies augetur; et liquores, nisi aliunde augmentum sumerent, perpetuo decrescere deberent et tandem deficere* *.

* Newtoni Oper. Vol. III. p. 157. Ed. Horsley.—Buffon, another philosopher of no small eminence, is of opinion, that the elements may be changed into each other, and that water may even become air. “ Comme

je suis très persuadé que toute la matière est convertible, et que les quatre elemens peuvent se transformer, je serois porté a croire, que l'eau peut se transformer en air lorsqu'elle est assez rarifié pour s'élever en vapeurs." Suppl. Vol. I. p. 100.



E S S A Y V I I I .

*Of Westmoreland Slate, and some
other Sorts of Stones.*

WE have in the mountainous parts of *Westmoreland* various sorts of slate; all of which are used by the inhabitants of that county for covering the roofs of their buildings; and the best of them are either carried by sea to *London, Liverpool, Hull,* and *Lynn*, or by land into the bi-
shoprick

shoprick of *Durham, Cumberland, Northumberland, and Lancashire*. The different sorts of slate are distinguished from each other by the fineness of their grain, by the thickness into which they are split, by their colour, and by their weight. The most general colour is blue; there are many shades of it, from a very pale to a deep blue. The blue of some slates has a greenish cast, this is very observable after a shower in a building which has been recently slated, if any of the greenish slates happen to have been used along with the blue. We have also a purple slate, and one which is nearly black, or at least is so dark, that it is used for writing on. With respect to the comparative weights of different sorts of slate, the following table, which was made with

suffi-

sufficient care, will give the reader some notion of the subject.

Weight of a cubic foot of different
sorts of slate.

	Ounces.
Purple slate, Kentmere near Kendale	2797
Pale blue, Coniston Water Head -	2791
Dark blue, Troutbeck - -	2781
Pale blue, Throng Crag -	2780
Pale blue, White Moss - -	2779
Deep blue, Old Cauldron -	2778
Pale blue, greenish, near Ambleside	2768
Pale blue, Ingleton, Yorkshire -	2767
Dark, writing slate, Bannisdale -	2765
Blackish, used for flooring, Head of Winander Mere -	} 2758
Deep blue, Longdale - -	2752
Greenish blue, Kentmere -	2750
Blackish, Cartmel, Lancashire -	2740
Very pale blue, fine grained Ambleside	2732
Medium weight of a cubic foot	<hr/> 2767 <hr/>

I have not in this table included all the varieties of slate which may

be met with in Westmoreland; but it is not probable, that those which I have omitted differ more from each other, than these which I have mentioned do, either with respect to colour or weight. *Wallerius* speaks of a bluish slate which weighed 3300 ounces to the cubic foot; this sort, probably, contained a large portion of iron; the bluish iron stone, called *Cat-scope*, weighs 3309 ounces to the cubic foot. In the slate quarries, some of the fissures are filled with spar, which has often an iron or copper pyrites adhering to it; in the very middle of the blocks of slate there are many little hollows, each of them big enough to hold a large hazel nut; these hollows are filled with clay; and in one of the quarries I saw a considerable quantity of clay
fit

fit for pipes, between two layers of slate.

It appears from the table, that the difference in weight between a cubic foot of the heaviest, and a cubic foot of the lightest of the fourteen sorts of slate there enumerated, is only 65 ounces; or about one forty third part of the weight of a cubic foot of the heaviest sort; hence, supposing the different sorts of slate to be split to equal thicknesses, the difference of the weights sustained by the timbers of slated buildings, is very inconsiderable, whatever sort of slate be used.

That sort of slate, other circumstances being the same, is esteemed the best, which imbibes the least water; for the imbibed water not only increases the weight of the covering,

vering, but in frosty weather, being converted into ice, it swells and shivers the slate. This effect of frost is very sensible in tiled, but it is scarcely felt in slated houses; for good slate imbibes very little water; and when tiles are well glazed, they are rendered in some measure, with respect to this point, similar to slate. — I took a piece of Westmoreland slate, and a piece of a common tile, and weighed each of them carefully; the surface of each was about 30 square inches; both the pieces were immersed in water for ten minutes, and then taken out and weighed, as soon as they had ceased to drip; the tile had imbibed above a seventh part of its weight of water; and the slate had not imbibed a two hundredth part of its weight; indeed the wetting of the slate was merely

merely superficial. I placed both the wet pieces before the fire; in a quarter of an hour the slate was become quite dry, and of the same weight it had before it was put into the water; but the tile had lost only about 12 grains of the water it had imbibed, which was as near as could be expected the very quantity which had been spread over its surface; for it was the quantity which had been imbibed by the slate, the surface of which was equal to that of the tile: the tile was left to dry in a room heated to 60° , and it did not lose all the water it had imbibed in less than six days.

Some of our old buildings in Cambridge are covered with a whitish kind of slate, which is dug at *Collyweston* in *Northamptonshire*; this slate is, as to its principal component
part,

part, a calcareous earth, very similar to the *Barneck* stone of which *Peterborough* cathedral and part of *King's Chapel* in Cambridge are built; and the stratum of stone, which may be seen on the road side between *Oxford* and *Burford*, and from thence towards *Gloucester*, is not very different from it. This Collyweston slate imbibes more water, and retains it for a longer time, than the Westmoreland slate does; but it does not imbibe half so much, nor retain it a quarter of the time, that a common tile does. The manner of its being formed into slate deserves to be noticed. Large blocks are dug in autumn, and these blocks being placed in a position different from that they had in the quarry, the rain insinuates itself between the layers of which the stone is

com-

composed; and in frosty weather the water swelling, as it becomes ice, splits the block of stone into plates of a proper thickness. We have a stone which is of a calcareous nature, and is called *clunch*, in this neighbourhood; it is soft and easily wrought, and when properly placed in a building is very durable; but if the position of the stone in the building, be different from what it was in the quarry, that is, if the side of the stone which in the quarry was parallel to the horizon, be either perpendicular, or inclined to it, in the building, it soon cracks and moulders away; and I am not certain but the durability of *Portland* stone itself, may have some dependence on its position in a building, being similar to or dissimilar from that, which it had

had

had in the quarry: and this may be one reason why we see in *Black Friars* bridge, and in some houses and other edifices in London, which are made of Portland stone, a few stones which are more decayed than the rest.

The stone or metal, as the workmen call it, of which the Westmoreland slate is made, though it does not split equally in all directions, yet is it not formed into slate by the action of the frost, as the calcareous slate of Northamptonshire is: it is dug, or blasted from the quarry in large masses, and split by workmen furnished with tools suited to the purpose. Though the weights of equal bulks of the different sorts of Westmoreland slate, do not differ much from each other, yet all the sorts are not equally capable of being split to
an

an equal degree of thinness: the quality of the slate varies also with the depth of the quarry, that being the best which is raised from the greatest depth.

We learn from Dr. *Borlase**, that the gray blue slate of *Denyball* in Cornwall, weighs only 2512 ounces to the cubic foot, which is greatly less than the lightest of the Westmoreland slates, that I have met with. This Cornish slate for its lightness and enduring weather (though I have no reason to think that in the last particular it excels the Westmoreland slate) is generally preferred to any slate in Great Britain, and “is perhaps the finest in the world †.” This sort is split to

about :

* Hist. Corn. p. 93.

† Woodward's Cat. Vol. II. p. 5.

about the thinness of an eighth of an inch, when it is applied to the covering of a roof, and it then weighs rather more than 26 ounces to the square foot: the very pale blue, fine grained slate from near Ambleside, when an eighth of an inch in thickness, weighs about 28 ounces to the square foot, or about 2 ounces more than the Cornish slate here spoken of.

The finest sort of blue slate is sold at Kendale for 3*s.* 6*d.* a load, which comes to 1*£.* 15*s.* a ton, the load weighing two hundred weight. The coarsest may be had for 2*s.* 4*d.* a load, or 1*£.* 3*s.* 4*d.* a ton. Thirteen loads of the finest sort will cover 42 square yards of roof, and eighteen loads of the coarsest will cover the same space: so that there is half a ton less weight put upon 42 square yards

yards of roof when the finest slate is used, than if it was covered with the coarsest kind, and the difference of the expence of the material is only 3*s.* 6*d.* To balance in some measure the advantage arising from the lightness of the finest slate, it must be remarked, that it owes its lightness, not so much to any diversity in the component parts of the stone from which it is split, as to the thinness to which the workmen reduce it; and it is not able to resist violent winds so well as that which is heavier.

A covering of lead is heavier than a covering of fine slate, but not greatly so. Thirteen loads or 26 hundred weight of fine slate will cover, as has been observed, 42 square yards: when plumbers cast sheet lead for covering of houses or churches,

they seldom run it thinner than to about 7 pounds to the square foot. On the *south* side of a building, they make, or should make, the lead a pound in a square foot thicker, than when it is used in places not exposed to the meridian sun; for the power of the sun in calcining lead is very great: in the torrid zone, a lead covering of the ordinary thickness will not last above five or six years, before it is calcined into a white pellicle resembling white lead. In a sheet of *cast* lead there is a great inequality in the thickness of the several parts of it; if the thinnest part weighs 7 lb. to the square foot, the thickest part will often weigh 9 lb.; let it be supposed then, that a sheet of cast lead, the thinnest part of which weighs 7 lb., weighs at a medium 8 lb. to the square

square

square foot; then will a square yard, or nine square feet, weigh 72 pounds, and 42 square yards will weigh 3024 pounds, or 27 hundred weight; which is one hundred weight more than the weight of the slate. But this is not the whole weight of the lead which is requisite to cover 42 square yards, an addition is to be made to it, equal to the weight of the lead which is used in lapping one sheet over another. *Milled* lead may be not only *rolled* out to a greater thinness, than sheet lead can possibly be *cast* to, but it has also a much greater uniformity of thickness, than cast lead. The plumbers say, that milled lead may indeed form a lighter and more uniform covering than sheet lead, but that it will not last so long. I know not how that may be,

but the milled lead company, near 100 years ago, offered to enter into a covenant to keep a covering of their milled lead of 7 lb. to the square foot, in good and constant repair, for a term of 41 years, at 5s. a year, for every covering of 100£. in value. A term of 41 years is not a quarter of the period, which many coverings of Westmoreland slate have lasted with very inconsiderable repairs; and as a ton of slate will cover a larger surface than a ton of lead, and does not cost in any part of the kingdom, to which there is water carriage, one fourth of the price of the lead, it seems as if it might be generally used instead of lead with very great advantage.

In *Russia* they cover their houses with iron, and in *Sweden* with copper; and some architects have been
fond

fond of introducing the use of copper covering into Great Britain. I have no knowledge of the duration of a copper covering; but I should conjecture, from the thinness of the copper which is used for the purpose, that it would not last so long as slate; it has certainly the advantage of being much lighter, and where there is danger of straining the walls by the weight of timber in the roof, it may be used with great advantage. All the plates of copper of four feet in length and two in breadth, which weigh less than 10 pounds, are called thatch copper, from their use in covering buildings; these plates are in general a penny in the pound weight dearer than the thicker plates, on account of the greater trouble in rolling them. A square foot of thatch cop-

per does not weigh quite 20 ounces, and hence 42 square yards of such copper will not weigh much above four hundred weight, and its thickness will be about the fortieth part of an inch.

A common Cambridge tile weighed 37 ounces; they use at a medium 700 tiles for covering 100 square feet, or above $2\frac{1}{2}$ tons of tile to 42 square yards. Hence, without including the weight of what is used in lapping over, &c., when a building is covered with copper or lead, it will follow, from what has been said, that 42 square yards of building will be covered by

Copper	-	4 hundred weight.
Fine slate	-	26
Lead	-	27
Coarser slate	-	36
Tile	-	54

The

The Northamptonshire slate (not to speak of several other sorts) not being sold by weight like that from Westmoreland, nor having a definite size like tile, it is not an easy matter to estimate the weight of it which is requisite to cover 42 square yards, or any other definite surface; a cubic foot of it weighs 2592 ounces, so that it is, bulk for bulk, near one twentieth part lighter than the lightest of the Westmoreland slate, but its thickness is, at a medium, much greater; hence its weight in a definite surface of roof, is greater, I apprehend, than that of the coarsest kind of Westmoreland slate; its durability is very considerable, as may be collected from the time it has lasted on some of our college buildings.

A common slate is a very compound
 X. 4. body;

body; it contains iron, to which it owes its colour, calcareous earth, magnesia, flint earth, and clay combined in different proportions in the different forts. Mr. *Kirwan* is the only person who has analyzed any of the forts: the fort he analyzed was the bluish purple, which is principally used in London, and which is brought thither from Devonshire and Wales. A cubic foot of it weighed 2876 ounces, which is near 150 ounces more than the weight of a cubic foot of the finest fort of Westmoreland slate: he found that 100 grains of it consisted of about 46 grains of flint, 26 of clay, 8 of magnesia, 4 of calcareous earth, and 14 of iron, and that it lost, by being heated red hot, 2 grains.

I took a piece of *Throng Crag* slate,
 which

which is the sort *Newgate* is covered with, weighing 446 grains, and heated it red hot; it had lost 4 grains of its weight, by that degree of heat; I kept it for half an hour in a red heat, it had then lost 38 grains of its original weight; I continued it in the same heat for three hours more, and it had then lost 43 grains, or near one tenth part of its weight. I calcined the bluish green *Ambleside slate* in a degree of heat, which would have reduced the same weight of calcareous earth to lime; 446 grains of it lost 41 grains; on a repetition of the experiment, I found that 446 grains had lost 42. The same weight of *White Moss* slate, treated in the same way, lost 42 grains; and the same weight of slate from *Coniston* lost 44 grains. I tried several other
 slates

flates in the same manner, and the general conclusion is, — that Westmoreland slate loses, by being calcined in a red heat for several hours, about one tenth part of its weight.

All these flates, when reduced to a fine powder, are acted upon with great violence by acids, a considerable portion of fixed air is discharged, and a calcareous earth is dissolved in the acid. I poured a diluted acid of sea salt on 446 grains of Throng-Crag slate in powder, 30 grains of fixed air escaped during the solution. We have seen that the same weight of the same sort of slate lost by calcination 43 grains, the difference is 13 grains; but whether these 13 grains are water, or a part of the earthy substance of the slate which is driven off during the calcination, is

is what I do not pretend to determine.

The calcined slate being put into water, there is formed in a few days a strong lime water; this water deposits, as other lime water does, an earth which effervesces with an acid. It has been proved, in the *Essay on calcareous earths*, that 20 parts of calcareous earth contain about 9 parts of fixed air; and hence, as the slate is supposed to lose about one tenth of its weight of fixed air by calcination, the crude calcareous earth (supposing the air to have proceeded *solely* from calcareous earth) which it contains, may amount to about 22 parts in an 100 of slate. I have met with some slate, much resembling the Westmoreland slate, which does not lose above a twenty-fifth

fifth part of its weight by calcination. Beds of limestone are generally incumbent on the beds of slate; and, however philosophers may account for the original formation of these beds, it may easily be admitted, that the component parts of the upper stratum may be mixed with those of the lower; and if the fact was examined, I think, it would be found, that the slate is more mixed with calcareous earth, the nearer it approaches to the limestone stratum.

I distilled five ounces of *White Moss slate* in a very strong fire for three hours; there came over a great deal of air, but scarce a drop of water, (though it is possible that in this, and other distillations of a like kind, some water may escape with the air,) and there was a slight smell of sulphur.

The

The mass remaining in the retort was reduced into a black cellular glass, of so hard a texture, that it struck fire with steel; it adhered so much to the retort, that I could not separate it so perfectly as to be able to see what loss of weight the slate had suffered by being vitrified. We have no coal in Westmoreland, except a little of a bad quality near *Shap*, or *glass-houses* might be established at the *slate quarries* with great prospect of advantage; for though the materials of which *bottle glass* is made, cost but little in any country, yet there they would cost nothing. Very good glass might, *probably*, be made from the slate alone, for the cellular texture would disappear, either on keeping the glass longer in the fire, or on re-melting it; but *certainly* it might be made from
the

the slate mixed with fern ashes, or with kelp ashes, or with other substances containing fixed alkali:—this hint, I hope, will not be given in vain.

Pliny speaks of a kind of *fossil glass*, which one *Obsidius*, he says, found out in *Ethiopia*; it was of a black colour and sometimes transparent: and *Herodotus*, in the third book of his history, reports, that the *Ethiopians* had a custom of drying the carcasses of their dead, of covering them when dried with gypsum, or plaster of Paris (*γυψωσαύτες*), of painting their portraits on the plaster, and, lastly, of depositing them in cells made of transparent glass, which in that country was dug in great plenty. This account has been looked upon as fabulous; because glass, it is said,

is

is not a natural but a factitious substance; and the learned, for the same reason, have been much puzzled about Pliny's *lapis Obsidianus*, or, as some will have it, *opsianus*, on account of its transparency. The word (*υελας* in Herodotus) here rendered glass, may, perhaps, denote *lapis specularis*; which is now, and has in all ages, been dug out of the earth, and is found frequently along with gypsum; I do not believe, indeed, that it has been ever found in pieces large enough to make coffins of: but, supposing it to mean glass strictly so called, I see no difficulty at all in admitting the existence of fossil glass. A subterraneous fire, of a proper degree of strength, would convert a stratum of Westmoreland slate into a vitreous mass of a black colour.

Nor

Nor is Westmoreland slate the only substance which might be converted into fossil glass; the gray *rag stone*, before mentioned *, admits a similar change; so does the blue *whin-stone*, and the Derbyshire *toadstone*, and several other sorts of stones. The reason of the fusibility of these stones is explained, in some measure, by an experiment related in another place †; it is there proved, that two species of earth, separately unvitriifiable, may be vitrified when mixed together; the two earths there mentioned are clay and chalk, but the observation is true concerning some other earths. Now the slate and stones, of which we have been speaking, are all compound bodies, consisting of siliceous, argillaceous, calcareous earths, &c.

com-

* Pag. 60. † Vol. II. p. 183.

combined in different proportions, and the fusibility arises from their mixture.

Some reasons have been given* (though I do not think they prove the point) for considering the Derbyshire *toadstone* as a species of *lava*, which has undergone a semi-vitrification; however that may be, I have met with pebbles (rounded, probably, by ante-diluvian waters) which resembled toadstone in colour, weight, and consistence, in the *gravel-pits* of *Cambridgeshire*; in the *marl-pits* of *Cheshire*; in the clay which is situated under the *grit*, and above the *shale* of *Derbyshire*; on the sides of the mountains, and in the beds of the rivers of *Westmoreland*: and I doubt not similar ones will be detected, by future obser-

* Vol. III. p. 299.

observation, in many other places. — The following table cost me some trouble in the making, I am unwilling that it should be lost, and there are some readers who will be gratified with a sight of it.

Weight of a cubic foot of different
forts of stones.

N.	oz.	18	2688
1	2999	19	2682
2	2936	20	2681
3	2927	21	2681
4	2921	22	2675
5	2907	23	2669
6	2852	24	2659
7	2821	25	2657
8	2800	26	2653
9	2797	27	2651
10	2778	28	2643
11	2776	29	2631
12	2770	30	2625
13	2760	31	2605
14	2710	32	2593
15	2708	33	2556
16	2695	34	2399
17	2690	35	2277

No. 1.

No. 1. *Guernsey* pebble, from the pavement of one of the streets of Westminster. 2. I met with this stone on *Hale-Fell*, near *Beetham*, in *Westmoreland*; it is of a dark brown colour, and admits a very fine polish, but it is not calcareous. The block was some tons in weight, and situated on the surface of the earth, every where surrounded with limestone rocks; I think it was a block of *basaltes*, in which many crystals of black *shoerl* were to be seen. 3. Dark gray cobble, from the gravel-pits near *Cambridge*; it much resembles No. 4. Dark gray *toadstone* from *Derbyshire*; free from those sparry specks (which in mouldering away by exposure to the air, often leave the toadstone as if it was worm-eaten) and

striking fire with steel. 5. Lead coloured cobble, with black specks, and of a vitreous texture from *Hearfam Head*, in *Westmoreland*. *Hearfam Head* is a hill composed of calcareous strata; but there are found on its surface, and in other parts of the county, detached round pieces of a blue rag-stone, of granite, and of a very hard compound stone, called by the masons of the country *callierde*; probably so denominated either from the earth (*erde*) of which it is composed, resembling flint (*caillou*) in hardness, or from its being composed of different sorts of earth coagulated (*caillè*) together. Mineralists, I think, would class the *callierdes*, for they are not all of the same kind, amongst the *porphyries*, *hornstones*, &c. 6. Similar to toadstone in texture, but darker in colour,

colour, from a marl-pit near *Tabley*, in Cheshire. 7. Much the same as the preceding, a large block found in a field near the mills at *Millthrop*, in Westmoreland. I do not venture to call these two last stones volcanic productions, yet the surfaces of them looked as if they had been formed by the cooling of the mass. 8. Round toadstone pebble, from a bed of clay under the *grit* stone in Derbyshire; I write this only from recollection of its appearance; I may have mistaken a blackish limestone for toadstone. 9. Purple slate, *Kentmere*, near *Kendale*; the heaviest of any of the Westmoreland slates, but not so heavy as the purple slate used in London. 10. A callierde with a deep green ground, and specks of a lighter green, from the *sea shore* near *Lancaster*.

caster. I have seen these callierdes in various other parts of *Great Britain*, but I do not know whether we have any strata in the *Island* which could have furnished them. 11. A greenish cobble, of an uniform texture, gravel-pit in the road from *Cockeran* to *Lancaster*. 12. Like No. 10. marl-pit, *Cheshire*. 13. Blue *whin-stone* from *Scotland*; in a fire which would convert an equal bulk of marble to lime, a ton of whin-stone would lose $2\frac{1}{2}$ hundred weight. 14. Greenish cobble, *Wier-side*, *Lancashire*: this and No. 11. have some resemblance to *Westmoreland* slate, but I do not know where the stratum is situated that has furnished these detached pieces. 15. Blue rag-stone, forest near *Mansfield*. 16. *Granite* from *Aberdeen*. A cubic foot of *Guernsey* pebble

ble (No. 1.) contains, it is evident, above 300 ounces of matter more than is contained in a cubic foot of *Aberdeen* granite; but from that circumstance alone it must not be inferred, that a pavement made with Guernsey pebbles, will last longer than one made with *Aberdeen* granite: for the durability of a body exposed to friction, does not depend so much on the number of particles which enter into its composition, as on its hardness, or firm adhesion of its parts. But in bodies equally hard, that will last the longest which contains the greatest quantity of matter in a definite bulk; and hence, supposing the Guernsey stone to be only as hard as the *Aberdeen* granite, it must last longer when exposed in the streets to the friction of the car-

riage wheels; on inquiring into the fact, a paviour, told me, — that the Guernsey pavement was a very bad pavement for a poor man — because it seldom wanted repairing. 17. *Gray blue rag-stone*, Westmoreland. 18. The same after being calcined to a red colour. 19. *Gray rag-stone* from *Ilvay* crag, near Millthrop. 20. The same calcined to a red colour. — These rag-stones, I apprehend, lose somewhat of their weight by calcination, but, their bulk being diminished in the same proportion, their density or specific gravity remains nearly unaltered; in a stronger fire they are changed into a blackish glass. 21. *Shale-bind*. This is the name of a stratum, consisting principally of calcareous earth impregnated with bitumen, which is situated both above and below the
beds.

beds of *shale* in Derbyshire. The *bind* is various in thickness from a few inches to some feet: one sort of it is called by the miners *treacle bind*, from their finding lodged in its cavities a bitumen of the colour and consistence of treacle: this bitumen is most abundant where there is the greatest quantity of shale incumbent on the bind. There are in the stratum of bind many round stones called, probably from the rotundity of their figure, *boulders*; some of which weigh only a few ounces, other half a ton. Whether all round stones, met with in the strata of the earth, or upon its surface, have received their figure from the action of water is uncertain; but that many of them have, the situation in which they are found, will not suffer us to doubt. Not far from *Pontypool* there is a
large

large mountain, the bottom of which is washed by the river *Ufk*; this mountain contains coal and iron stone. At *Newport* a considerable trade is carried on with coal, which has been washed from the sides of this and other mountains by the river: the coal is found in the channel of the river, in round, flat, smooth pieces, so perfectly resembling in shape river pebbles, that they clearly indicate the manner in which these pebbles have been formed. 22. What some call white toadstone, *Youlgrave*, Derbyshire. 23. Brown quartz pebble, from the forest between *Mansfield* and *Newark*. 24. Black pebble with red spots, same place. 25. Reddish rag-stone, *Helm-End*, near *Kendale*. 26. *Pennarth* limestone, washed in large cobbles from the cliffs on the *Welch* side of *Bristol* channel; the lime made

made from it is highly esteemed in that country from its setting under water; it is called *lion lime* (perhaps *lien*) from its binding quality: the stone is of a gray colour, and, besides the proper earth of lime, contains a large proportion of clay and iron. 27. Transparent white quartz, gravel-pits, near Cambridge. 28. Transparent white quartz, forest about Mansfield. 29. White opake quartz; same place. The crystals, called *Bristol stone*, are esteemed the purest sort of quartz. It is commonly known that two pieces of quartz, when rubbed together in the dark, emit a phosphoric light, accompanied with a strong smell. The difference between quartz and common flint, consists not so much in the colour, for both quartz and flint are of various colours, as in this, that quartz

(though

(though it be not perhaps an absolutely pure siliceous earth) contains a less proportion of *clay* and *calcareous* earth, than flint does. I have observed on the sea coast at *Yarmouth*, quartz pebbles beginning to be decomposed, and verging towards the state of a white argillaceous earth: most of the sand in every part of the world consists of quartz or flint in powder; and, as matter is infinitely divisible, the imagination can set no bounds to the minuteness of the grains of sand; but I have sometimes doubted, whether, after they are reduced below a certain standard, they may not constitute some other species of earth. 30. *Granite*, from the *marl-pits* in *Cheshire*. The roads in many parts of *Lancashire* and *Cheshire* are paved with granite, and other hard round pebbles, which are found
in

in their marl-pits, or fetched from the Welch coast; the pavement costs a thousand, or twelve hundred pounds a mile in making. 31. Granite, from a large block near *Dallam Tower*, in Westmoreland. Large masses of a *reddish* granite are found on the sides of the hills, in the vallies, and in the beds of the rivers, not only about *Shap*, but in various other parts of Westmoreland. It is a question of no small difficulty to account for the manner of their being placed there: some will have it that they have been left there by water; and others think they have been ejected from the bowels of the earth by the force of a volcanic explosion. *Beds* of granite are found in many, and *detached pieces* in most parts of *Europe*. The highest mountains on the globe are formed from the lowest strata of the earth,
and

and the tops of the highest mountains are composed of granite; and hence granite mountains are called *primitive* mountains; inasmuch as the strata of granite, being situated below the strata of rag-stone, shale, limestone, &c. of which many other (called *secondary*) mountains are composed, must have existed before them. All granites are compound bodies, they consist of two, of three, of four, or of five distinct substances denominated, by writers of systems of mineralogy, *quartz*—*fels spar*—*mica*—*steatites*—and *shoerl*. It belongs to the higher chemistry to analyze the component parts of granite, to explain their origin, and the manner of their combination; and to enquire whether they are subject to a spontaneous separation, and what kinds of substances

stances will arise from a stratum of decomposed granite. 32. Red granite, from a Cheshire marl-pit, resembling the red oriental granite. All the varieties of *red* and *gray* granites, which may be seen in the works of the ancients remaining in *Italy*, might be found, I believe, in different parts of Great Britain; without any thought of making a collection of them, I have accidentally picked up near twenty different sorts. 33. *Shale* from Derbyshire. 34. Quartz, white, with many small irregular holes: there are quarries of it in France, and we import mill-stones made of it. The holes are remarkable; it looks as if the stone had been worm-eaten; but the holes are formed, I conjecture, from some of the principles of the stone being decayed,

cayed, whilst the rest remain intire. I have frequently seen pieces of *rag-stone*, and even some sorts of *granite*, which have been externally, and indeed to a very sensible depth below the surface, studded with little holes from the same cause. 35. A *cellular lava*, of which the mill-stones, called *Rhenish*, are made; it is very porous, of a brown dirty colour, and in external appearance like a piece of coak, but it is hard enough to strike fire with steel. *Strabo*, in speaking of an eruption of mount *Etna*, very accurately describes the formation of this species of stone, which in his time was applied to the same purpose it is now; I quote the Latin translation of the passage — *lapide in crateribus colliquato ac deinde sursum egesto, humor vertici superfusus cœnum est nigrum,*

grum, per montem deorsum fluens: deinde ubi concrevit, lapis fit molaris.*

The analyzing the various stones which are met with, either in large beds in the earth, or in detached pieces at the bottoms of the rivers, or on the sea coasts of the kingdom; and the lodging the specimens in some public Receptacle, where they might be seen by the *Students in Natural History*, might occupy very usefully the leisure of a philosophical Chemist. He would find a far greater variety of *jaspers, porphyries, granites, flints, limestones, slates, lavas, &c.* than at the first view of the subject he would probably expect. Experimental investigations of this sort, made with ability and caution, in different parts of the world, are the
only

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only sure foundations on which we can ever hope to build any probable system concerning the formation of mountains, the antiquity of the present form of the globe, and the causes of the vicissitudes which it has undergone. It is the proper province of natural philosophy to explore *secondary causes*; they are the steps on which the mind of man ascends from Earth to Heaven: for the more distinctly we apprehend the number and connexion of the secondary causes operating in this little system which is submitted to our view, the more certainly shall we perceive the necessity of their ultimately depending, like the links of *Homer's* chain, on a **FIRST.**

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p. 48. l. 4. *for centuries, read years. — p.*

207. l. 12. *for 1768, read 1778.*









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