XII. *An Analysis of the magnetical Pyrites; with Remarks on some of the other Sulphurets of Iron. By* Charles Hatchett, *Esq. F.R.S.*

Read May 17, 1804.

§ I.

Of the various metallic sulphurets which constitute one of the grand divisions of ores, none appear to be so universally dispersed throughout the globe, as the sulphuret of iron, commonly called Martial Pyrites; for the species and varieties of this are found at all depths, and in all climates and soils, whether ancient, or of alluvial and recent formation. It is remarkable also, that, under certain circumstances, this sulphuret is daily produced in the humid way; an instance of which, a few years back, I had the honour, in conjunction with Mr. Wiseman, to lay before this Society;* and although, in regard to pecuniary value, the pyrites of iron may be considered as comparatively insignificant, yet there is every reason to believe, that in the operations of nature, it is a substance of very considerable importance.

§ II.

The species and varieties of martial pyrites, are in general so well known, and have been so frequently and accurately described, as to figure, lustre, colour, and other external characters,

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* Phil. Trans. for 1798, p. 567.

that it would be totally superfluous here to give any detailed account of them. One of the species, however, merits peculiar notice, as possessing the remarkable property of strong magnetic polarity; and, although it has been described by modern mineralogists,* it does not appear to have been as yet subjected to any regular chemical examination; so that, whether it be a sulphuret of iron inherently endowed with the magnetical property, or a sulphuret in which particles of the ordinary magnetical iron ore are simply but minutely interspersed, has to this time remained undecided.

This species is known by the name of Magnetical Pyrites, and is called by the Germans *Magnet-Kies*, or *Ferrum mineralisatum magnetico-pyritaceum.*

It is most frequently of the colour of bronze, passing to a pale cupreous-red.

The lustre is metallic.

The fracture is unequal, and commonly coarse-grained, but sometimes imperfectly conchoidal.

The fragments are amorphous.

The trace is yellowish-gray, with some metallic lustre.

It is not very hard; but, when struck with steel, sparks are produced, although with some difficulty.

It is brittle, and is easily broken.

This pyrites has been hitherto found only in some parts of Norway, Silesia, Bavaria, and especially at Geier, Meffersdorf, and Breitenbrunn in Saxony; but, having received some specimens from the Right Hon. CHARLES GREVILLE, F.R.S. I

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* KIRWAN, Vol. II. p. 79. WIDENMANN, p. 792. EMMERLING, 2d edit. Tom. II. p. 286. KARSTEN, p. 48. BROCHANT, Tome II. p. 232.

was struck with their resemblance to the pyrites of Breitenbrunn, which happened at that time to be in my possession; and, upon trial, I found that they were magnetical, and agreed with the latter in every particular. Their magnetic power was such as strongly to affect a well-poized needle, of about three inches in length; a piece of the pyrites, nearly two inches square, acted upon the needle at the distance of four inches.

The powder (which is blackish-gray, with but little metallic lustre) is immediately taken up by a common magnet; but the pyrites does not act thus on the powder, nor on iron filings, unless it has been placed for some time between magnetical bars; then indeed it acts powerfully, turns the needle completely round, attracts and takes up iron filings, and seems permanently to retain this addition to its original power.

In the specimens which I obtained, the north pole was generally the strongest.

This pyrites was found in Wales, about the year 1798, by the Hon. ROBERT GREVILLE, F. R. S. who sent the specimens above described to his brother, the Right Hon. C. GREVILLE, with the following account.

" It is found in great abundance in Caernarvonshire, near " the base of the mountain called Moel Elion, or probably with " more accuracy Moel Ælia, and opposite to the mountain " called Mynydd Mawr. These mountains form the entrance " into a little close valley, which leads to Cywellin lake, near " Snowdon, a little beyond the hamlet of Bettws.

" The vein appears to be some yards in depth and breadth, " and seems to run from north to south, as it is found on " Mynydd Mawr, which is across the narrow valley, and " opposite to Moel Ælia."

Mr. R. GREVILLE, in another part of his letter, states that copper ore has been worked in several of the adjacent places, and that, many years ago, Capt. WILLIAMS, of Glan yr Avon, employed some miners at the place where this pyrites is found, but the undertaking proved unproductive. Yellow copper ore is certainly in the vicinity; for some portions of it were adhering to the specimens which have been mentioned; and I shall here observe, that the stone which accompanies the magnetical pyrites, is a variety of the lapis ollaris or pot-stone, of a pale grayish-green, containing smooth cubic crystals of common pyrites.

§ III.

From the appearance of those parts of the magnetical pyrites which have been exposed to the weather, it seems to be liable to oxidizement, but not to vitriolization.

The specific gravity, at temperature 65° of FAHRENHEIT, is 4518.

When exposed to the blowpipe, it emits a sulphureous odour, and melts into a globule nearly black, which is attracted by the magnet.

500 grains, in coarse powder, were exposed, in a small earthen retort, to a red heat, during three hours. By this operation, the weight of the powder was very little diminished; neither was there any appearance of sulphur in the receiver, which however smelt strongly of sulphureous acid.

500 grains of the same were put into a flat porcelain crucible, which was kept in a red heat, under a muffle, during four hours. The powder then appeared of a dark gray, with a tinge of deep red, and weighed 432.50 grains. The loss was therefore 67.50

$=13.50$ *per cent.* but, upon examining the residuum, I found that only part of the sulphur had been thus separated.

The magnetical pyrites, when digested in dilute sulphuric acid, is partially dissolved, with little effervescence, although there is a very perceptible odour of sulphuretted hydrogen.

The solution is of a very pale green colour.

Pure ammonia produced a dark green precipitate, tending to black; and prussiate of potash formed a very pale blue precipitate, or rather a white precipitate mingled with a small portion of blue. The whole of the latter, however, by exposure to the air, gradually assumed the usual intensity of Prussian blue; and the blackish green precipitate, formed by ammonia, became gradually ochraceous. These effects therefore fully prove, that the iron in the solution was, for the greater part, at the minimum of oxidizement, so as to form the green sulphate, and white prussiate, of iron;* and, consequently, that the iron of the magnetical pyrites is either quite, or very nearly, in the state of perfect metal.

This pyrites, when treated with nitric acid, of the specific gravity of 1.38, diluted with an equal quantity of water, is at first but little affected; but, when heat is applied, it is dissolved, with much effervescence, and discharge of nitrous gas; the effervescence, however, is by no means so violent as when the common pyrites are treated in a similar manner. It is also worthy of notice, that if the digestion be not of too long duration, a considerable quantity of sulphur, *in substance*, is separated; whilst, on the contrary, scarcely any can be obtained from the common pyrites, when treated in a similar manner; although I

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* *Récherches sur le Bleu de Prusse,* par M. Proust. *Annales de Chimie,* Tome XXIII. p. 85.

shall soon have occasion to prove, that the real quantity of sulphur is much more considerable in the latter than in the former.

As soon as muriatic acid is poured on the powder of the magnetical pyrites, a slight effervescence is produced, which becomes violently increased by the application of heat; a quantity of gas is discharged, which, by its odour, by its inflammability, by the colour of the flame, by the deposition of sulphur when burned, and by other properties, was proved to be sulphuretted hydrogen.

During the digestion, sulphur was deposited, which so enveloped a small part of the pyrites, as to protect it from the farther action of the acid.

The solution was of a pale yellowish-green colour. With prussiate of potash it afforded a pale blue precipitate, or rather a white precipitate mixed with blue; and with ammonia it formed a dark blackish-green precipitate, which gradually became ochraceous; so that these effects corroborated the conclusions which were founded on the properties of the sulphuric solution, namely, that the iron contained in the pyrites, is almost, if not quite, in the metallic state.

Other experiments were made; but, as they merely confirm the above observations, I shall proceed to give an account of the analysis.

§ IV.

ANALYSIS OF THE MAGNETICAL PYRITES.

A. One hundred grains, reduced to a fine powder, were digested with two ounces of muriatic acid, in a glass matrass placed in a sand bath. The effects already described took place; and a pale yellowish-green solution was formed. The residuum was then again digested with two parts of muriatic acid mixed with one of nitric acid; and a quantity of pure sulphur was obtained, which, being dried, weighed 14 grains.

B. The acid in which the residuum had been digested, was added to the first muriatic solution; some nitric acid was also poured in, to promote the oxidizement of the iron, and thereby to facilitate the precipitation of it by ammonia, which was added after the liquor had been boiled for a considerable time. The precipitate thus obtained was boiled with lixivium of potash; it was then edulcorated, dried, made red-hot with wax in a covered porcelain crucible, was completely taken up by a magnet, and, being weighed, amounted to 80 grains.

C. The lixivium of potash was examined by muriate of ammonia, but no alumina was obtained.

D. To the filtrated liquor from which the iron had been precipitated by ammonia, muriate of barytes was added, until it ceased to produce any precipitate; this was then digested with some very dilute muriatic acid, was collected, washed, and, after exposure to a low red heat for a few minutes in a crucible of platina, weighed 155 grains. If therefore the quantity of sulphur, converted into sulphuric acid by the preceding operations, and precipitated by barytes, be calculated according to the accurate experiments of Mr. Chenevix, these 155 grains of sulphate of barytes will denote, nearly, 22.50 of sulphur; so that, with the addition of the 14 grains previously obtained in substance, the total quantity will amount to 36.50.

E. Moreover, from what has been stated it appears, that the iron which was obtained in the form of black oxide, weighed 80 grains; and, by adding these 80 grains to the 36.50 of sulphur, an increase of weight is found = 16.50. This was evidently owing to the oxidizement of the iron, which, in the magnetical pyrites, exists quite, or very nearly, in the metallic state, but, by the operations of the analysis, had received this addition. The real quantity of iron must, on this account, be estimated at 63.50.

One hundred grains, therefore, of the magnetical pyrites, yielded,

$$\begin{array}{lll} \text{Sulphur}\left\{\begin{matrix}\text{A.} & 14 \\ \text{D.} & 22.50\end{matrix}\right\} & 36.50 & \text{grains.} \\ \text{Iron} \quad \text{E.} \quad = & \underline{63.50} & \\ & 100. & \end{array}$$

This analysis was repeated in a similar manner, excepting that the whole was digested in nitric acid, until the sulphur was intirely converted into sulphuric acid. To the liquor which remained after the separation of the iron by ammonia, muriate of barytes was added, as before, and formed a precipitate which weighed 245 grains. Now, as the sulphuric acid in sulphate of barytes is estimated by Mr. CHENEVIX at 23.5 *per cent.* and the sulphur which is required to form the sulphuric acid contained in 100 parts of sulphate of barytes, at 14.5,[*] it follows, that 245 grains of dry sulphate of barytes, contain sulphuric acid equal, very nearly, to 36 grains of sulphur; so that the two analyses corroborate each other. The proportion of sulphur in the magnetical pyrites, may therefore be stated at 36.50, or indeed at 37 *per cent.* if some small allowance be made for the occasional presence of earthy particles; a minute portion of quartz having been found, by the last analysis, after the complete acidification of the sulphur.

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[*] Transactions of the Royal Irish Academy, Vol. VIII. p. 240.

The increase produced, by the operations of the analysis, in the weight of the iron, arose, as I have already remarked, from the addition of oxygen; for the iron, as obtained by the analysis, was in the state of black oxide; but in this, and indeed in all pyrites, it undoubtedly exists very nearly, or quite, in the state of perfect metal. Now the black oxide of iron, called Protoxide by Dr. THOMSON,* has been proved, by LAVOISIER and PROUST, to consist of 100 parts of metallic iron combined with 37 of oxygen, thus forming 137 of black oxide; the exact proportion of oxygen is therefore 27 *per cent.* and 80 grains of this oxide must contain 21.6 of oxygen. But, in the above analyses of the magnetical pyrites, the increase of weight did not amount to more than 16.5; and we may therefore conclude that, in all probability, a quantity of oxygen = 5.1 was previously combined with some part, or with the general mass, of the iron in the pyrites. A small part of the abovementioned increase of weight, must likewise have arisen from another cause; for, although the true proportions of the black oxide of iron are 27 of oxygen and 73 of iron, (so that 100 parts of the latter absorb 37 of the former,) yet, in actual practice, it is difficult to obtain it exactly in this state, and there is commonly a small excess of weight: this I have repeatedly observed, in many experiments, some of which were purposely made. When, for instance, 100 parts of fine iron wire were dissolved in muriatic acid, and afterwards precipitated by ammonia, edulcorated, dried, and made red-hot with a small quantity of wax in a covered porcelain crucible, the weight, instead of 137, usually amounted to 139 or 140. The quantity of wax employed, certainly did not afford a ponderable quantity of coal, or other residuum; but the real cause of the increase of

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* System of Chemistry, 2d edition, Vol. I. p. 147.

weight, appears to be the air, which can scarcely be completely excluded, and which, after the wax is burned, combines with the superficial part of the oxide, and converts a portion of it into the red or peroxide; so that the surface in the crucible appears brown, when compared with the interior.

To this cause, therefore, I am inclined also to attribute a small part of the increase observed in the weight of the iron obtained by the preceding analyses.

§ V.

Before I make any observations on the nature of the sulphuret which has been proved to constitute the magnetical pyrites, it may be proper to state some comparative analyses which I have made, of several of the common pyrites; and, as the method employed was precisely the same as that which has been described, all that seems to be requisite, is to give an account of the results.

In each analysis, the whole of the sulphur was converted into sulphuric acid, which was precipitated by barytes; and, in the selection of the specimens, great attention was paid, to take the internal parts of the fragments, and not to make use of any which exhibited an appearance of decomposition, or of extraneous substances.

The iron was, as before, reduced to the state of black oxide; and the addition of weight in each separate analysis, corresponded, within a few fractional parts, with the proportion of oxygen requisite to form into black oxide a given quantity of metallic iron, equal to that which in each pyrites was ascertained to be the real proportion, by deducting the quantity of sulphur from the total quantity of each pyrites.

The iron, therefore, in these is completely metallic, and as such is stated in the following results.

No. 1. Pyrites in the form of dodecaedrons with pentagonal faces. - Specific gravity 4830.	Sulphur	52.15
	Iron	47.85
		100.
No. 2. Pyrites in the form of striated cubes.	Sulphur	52.50
	Iron	47.50
		100.
No. 3. Pyrites in the form of smooth polished cubes, found in the lapis ollaris which accompanies the magnetical pyrites. Specific gravity 4831.	Sulphur	52.70
	Iron	47 30
		100.
No. 4. Radiated pyrites. - - - Specific gravity 4698.	Sulphur	53.60
	Iron	46.40
		100.
No. 5. A smaller variety of radiated pyrites. Specific gravity 4775.	Sulphur	54.34
	Iron	45.66
		100.

Considering the difference in the figure, lustre, and colour of these pyrites, I expected to have found a much greater difference in the proportions of their component ingredients; but, as the results are the average of several experiments, I have not any reason to doubt their accuracy.

The pyrites crystallized in regular figures, such as cubes and dodecaedrons, according to the above analyses, contain less sulphur, and more iron, than the radiated pyrites, and perhaps than others which are not regularly crystallized. This difference, however, is not considerable; for the dodecaedral pyrites, which afforded the smallest quantity of sulphur of any of the regularly crystallized pyrites, yielded 52.15; and the radiated pyrites, No. 5, gave 54.34; the difference, therefore, is only 2.19. So that the mean proportion of sulphur, in all the pyrites which were examined, is 53.24 *per cent.* and, taking the proportion of sulphur in the magnetical pyrites at 36.50 or 37, the difference between this and the mean of the common pyrites will be 16.74 or 16.24. The magnetical pyrites, therefore, is quite distinct, as a sulphuret of iron, from the common martial pyrites; and, in the following observations I shall prove, that a sulphuret consisting of the proportions last mentioned, has till now been unknown as a product of nature.

§ VI.

Although pyrites is one of the most common of mineral substances, yet the discovery of its real nature is comparatively of a late date; for it appears, that even AGRICOLA (whose knowledge of mineral bodies was certainly great, considering the state of science in his time) was not acquainted with its characteristic ingredient, namely, *iron*. According to HENCKEL, this was first noticed by our countryman MARTIN LISTER, a member of this learned Society, who says "*Pyrites purus putus ferri metallum* "*est.*"

From the time of HENCKEL, pyrites seems little to have attracted the notice of chemists, until Mr. PROUST, the learned professor of chemistry at Madrid, published two memoirs, in which he states, that there are two sulphurets of iron, the one being artificial, and the other natural. The first is the sulphuret which is formed in laboratories, by adding sulphur to red-hot iron, or by exposing both of them to heat in a retort. This is distinguished from the second sulphuret, (which is the common martial pyrites,) by its easy solubility in acids, especially in muriatic acid, by the formation of sulphuretted hydrogen gas during the solution of the sulphuret in the last named acid, by its colour, and by its inferior density.

According to Mr. PROUST, the first or artificial sulphuret is composed of 60 parts of sulphur, combined with 100 parts of iron; whilst the second sulphuret, or common pyrites, consists of 90 parts of sulphur and 100 of iron.

He moreover observes, that the sulphur of the first sulphuret is difficultly separated; but that the excess which is in the second sulphuret, or common pyrites, is easily expelled, and is that portion which is obtained by distillation, the residuum being then reduced to the state of the first sulphuret.[*] 100 parts, therefore, of this substance, are composed of 62.50 of iron and 37.50 of sulphur; and 100 parts of common pyrites are, according to this statement, composed of 52.64 of iron and 47.36 of sulphur.

These proportions, Mr. PROUST considers as the minimum and maximum of the sulphurets of iron. For the latter, he allows

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[*] *Journal de Physique,* Tome LIII. p. 89, and Tome LIV. p. 89. From pp. 91 and 92 of Tome LIV. it is evident, that the author does not mean to assert, that the first sulphuret contains 60 *per cent.* of sulphur; but that 100 parts of iron are combined with 60 of sulphur, and form 160 of the sulphuret. In like manner, when 90 of sulphur are united with 100 of iron, a substance analogous to common pyrites is formed, which weighs 190 grains or parts.

some variation; but the composition of the former, he regards as fixed by the invariable law of proportions;* although he observes, that *it has not as yet been discovered in the mineral kingdom.*†

In support of these assertions, Mr. PROUST states,

1. That the pyrites found near Soria, when distilled in a retort heated to redness, afforded nearly 20 *per cent.* of sulphur.

2. That the residuum of the above distillation, had lost the external characters and chemical properties of pyrites, and had assumed those of the artificial sulphuret of iron.

3. That when to this residuum a quantity of sulphur was added, and the whole was distilled in a degree of heat not too great, the 20 *per cent.* of sulphur, which had been separated by the first distillation, was, by this, again restored; and the mass in the retort thus recovered nearly the original colour, lustre, and chemical properties of the pyrites.

4. That, by adding sulphur to iron filings, or fine iron wire, heated to a low red in a retort, a compound is obtained, in which the proportion of sulphur amounts only to about 20 or 30 parts; but, if this compound is again treated with sulphur in a red heat, a sulphuret is formed, which is readily dissolved in acids, and plentifully affords sulphuretted hydrogen gas.

This is the real minimum of the sulphurets of iron, fixed by the invariable law of proportions, (according to Mr. PROUST,) at 59 or 60 of sulphur and 100 of iron, the former being (as I have already observed) in the proportion of 37.50 *per cent.*

5, and lastly. That when this sulphuret is again mixed and

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* *Journal de Physique,* Tome LIII. p. 90.

† "La regne minéral, jusqu'ici, ne nous a point encore présenté le fer sulfuré au "minimum." *Journal de Physique,* Tome LIV. p. 93.

distilled with sulphur, (due attention being paid to the degree of heat,) the product is found to have assumed most of the chemical and external properties of the natural common pyrites, density alone being excepted.

The application of the above observations, to the principal subject of the present Paper, is sufficiently obvious; for, when it is considered, that the magnetical pyrites is so different from the common pyrites, in colour, hardness, solubility in sulphuric acid, and more especially in muriatic acid, with the copious production of sulphuretted hydrogen gas; when, by analysis, it has been found to consist of 36 or 37 of sulphur, combined with about 63 of metallic iron; and, when the artificial sulphuret of iron which has been lately described, is proved to agree with the magnetical pyrites in the nature and proportions of its component ingredients, and in every one of the abovementioned properties; it is evident that the magnetical pyrites is identically the same with this sulphuret, which hitherto has remained undiscovered in nature, and has only been known as a product of our laboratories. In order however more fully to satisfy myself, I made experiments on the artificial sulphuret, which I formed with sulphur and fine iron wire.

This substance agreed, in all the properties which have been noticed, with the magnetical pyrites; and the precipitates obtained by adding prussiate of potash, and ammonia, to the muriatic and sulphuric solutions, were precisely similar. The specific gravity was 4390, whilst (as I have already remarked) that of the magnetical pyrites is 4518.

§ VII.

So far, therefore, as can be proved by similarity in chemical properties and analysis, the magnetical pyrites is indisputably a natural sulphuret, completely the same with that which till now has been only known as an artificial product; but, that the mind may be perfectly satisfied, another question must be solved, namely, how far do they accord in receiving and retaining the property of magnetism? Common pyrites do not appear to affect the magnetic needle, or, if some of them slightly act by attraction, (which however I never could perceive, nor recollect to have read in works expressly relating to magnetism,) yet they do not possess, nor appear capable of acquiring, any magnetic polarity. As, therefore, the iron of pyrites is undoubtedly in the metallic state, and in a considerable proportion, the destruction of this characteristic property of metallic iron, must be ascribed to the other ingredient, sulphur.

But we have lately seen, that a natural combination of iron with 36.50 or 37 *per cent.* of sulphur, is in possession of all the properties supposed hitherto to appertain (in any marked degree) almost exclusively to the well known magnetic iron ore; and that the combination alluded to is strictly chemical, and not (as at first might have been imagined) a mixture of particles of magnetic iron ore with common pyrites.*

This is certainly very remarkable; and it induced me to examine the effects produced by sulphur, on the capacity of metallic

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* This has been sufficiently proved, by the facts which have been stated; I shall however add, that upon digesting a mixture of the powder of common pyrites and iron filings in muriatic acid, I only obtained hydrogen gas, exactly as if I had employed the iron filings without the pyrites.

iron for receiving and retaining the magnetic properties. I therefore prepared some sulphuret of iron, by adding a large quantity of sulphur to fine iron wire, in a moderate red heat.

The internal colour and lustre of the product, were not very unlike those of the magnetical pyrites; and, after the mass had been placed during a few hours between magnetical bars, I found that it possessed so strong a degree of polarity, as to attract or repel the needle completely round upon its pivot; and, although several weeks have elapsed since it has been removed from the magnetical bars, it still retains its power, with little diminution; like the magnetical pyrites, however, in its natural state, it is not sufficiently powerful to attract and take up iron filings.

But this sulphuret did not contain so much sulphur as the magnetical pyrites; I therefore mixed some of it, reduced to powder, with a large quantity of sulphur, and subjected it to distillation in a retort, which was at length heated until the intire bulb became red.

The sulphuret, by this operation, had assumed very much the appearance of the powder of common pyrites, in respect to colour; but, in its chemical properties, such as solubility in muriatic acid, with the production of sulphuretted hydrogen gas, as well as in the nature of the precipitates it afforded with prussiate of potash and with ammonia, it perfectly resembled the magnetical pyrites. Moreover, by analysis, it was found to consist of 35 parts of sulphur and 65 of iron; and although (being in a pulverulent state) its power, as to receiving and retaining the magnetic property, could not so easily be examined, yet, by being powerfully attracted by the magnet, with some other circumstances, there was every reason to conclude, that in this respect also it was not inferior.

Another portion of sulphuret was formed, as above described; it was placed between magnetical bars, and, in like manner, received and retained the magnetic power.

It is certain, therefore, that when a quantity of sulphur equal to 35 or 37 *per cent.* is combined with iron, it not only does not prevent the iron from receiving the magnetic fluid, but enables it to retain it, so that the mass acts in every respect as a permanent magnet.

Black oxide of iron, by one operation, does not appear to combine with sulphur so readily as iron filings; a second operation, however, converts it into a sulphuret, very much resembling that which has just been described, including the chemical as well as the magnetical properties; but, undoubtedly, by these processes, it is progressively converted, perfectly or very nearly, into the metallic state.

Iron combined with a larger proportion of oxygen, such as the fine gray specular iron from Sweden, will not form a sulphuret by the direct application of sulphur, in one operation; although it becomes of a dark brown colour, partly iridescent, and is moderately attracted by a magnet.

50 grains of the magnetical pyrites, reduced to powder, and mixed with three times the weight of sulphur, were distilled in a retort, until the bulb became moderately red-hot. After the distillation, the pyrites weighed 54.50; consequently, the addition of sulphur was 9 *per cent.* making the total =45.50 or 46 *per cent.* The powder was become greenish-yellow, very like that of the common pyrites; it did not afford any sulphuretted

hydrogen, when digested in muriatic acid; but it nevertheless was partially dissolved, and the solution, when examined by prussiate of potash, and by ammonia, was not different from that of the crude magnetical pyrites.

The powder which had been distilled with sulphur, and which had thus received an addition of 9 *per cent.* to its original quantity, *was still capable of being completely taken up by a magnet.*

From the whole of the experiments which have been related, it is therefore evident, that iron, when combined with a considerable proportion of sulphur, is not only still capable of receiving the magnetic property, but is also thereby enabled to retain it, and thus (as I have already remarked) becomes a complete magnet; and it is not a little curious, that iron combined (as above stated) with 45 or 46 *per cent.* of sulphur, is capable of being taken up by a magnet, whilst iron combined with 52 *per cent.* or more, of sulphur, (although likewise in the metallic state,) does not sensibly affect the magnetic needle; and hence, small as the difference may appear, there is reason to conclude, that the capacity of iron for magnetic action is destroyed by a certain proportion of sulphur, the effects of which, although little if at all sensible at 46 *per cent.* are yet nearly or quite absolute, in this destruction of magnetic influence, before it amounts to 52. But, what the exact intermediate proportion of sulphur may be, which is adequate to produce this effect, I have not as yet determined by actual experiment.

As carbon acts on soft iron, (which, although it most readily receives the magnetic influence, is unable to retain it so as to become a magnet, without the addition of a certain proportion of carbon, by which it is rendered hard and brittle, or, in other words, is converted into steel,) so, in like manner, does sulphur seem to act; for it has been proved, by the preceding experiments, that the brittle mass formed by the union of a certain proportion of this substance with iron, whether by nature or by art, becomes capable of retaining the magnetic virtue, and of acting as a complete magnet.

This remarkable coincidence, in the effects produced on iron by carbon and sulphur, induced me to try the effects of phosphorus; and my hope of success was increased by the remark of Mr. PELLETIER, who says, that "the phosphuret of iron is attracted by the magnet;"* and therefore, although certain bodies may be thus attracted, without being capable of actually becoming permanent magnets, I was desirous to examine what might be the power, in this respect, of phosphuret of iron.

I therefore prepared a quantity of phosphuret of iron, in the direct way, *viz.* by adding phosphorus, cut into small pieces, to fine iron wire made moderately red-hot in a crucible. The usual phenomena took place, such as the brilliant white flame, and the rapid melting of the iron, which, when cold, was white, with a striated grain, extremely brittle, hard, and completely converted into a phosphuret. The fragments of this were powerfully attracted by a magnet; and, after I had placed two or three of the largest pieces, during a few hours, between magnetical bars, I had the pleasure to find that these had become powerful magnets, which not only attracted or repelled the needle completely round, but were able to take up iron filings, and small

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* "Le Phosphure de Fer est attirable a l'aimant." *Annales de Chimie,* Tome XIII. p. 114.

pieces, about half an inch in length, of fine harpsichord wire; and, although they have now been removed from the magnetical bars more than three weeks, I cannot discover any diminution of the power which had thus been communicated to them.

The three inflammable substances, *carbon, sulphur,* and *phosphorus,* which, by their chemical effects on iron, in many respects resemble each other, have now therefore been proved alike to possess the property of enabling iron to retain the power of magnetism; but I shall consider this more fully in the following section.

§ VIII.

From the whole which has been stated we find,

1. That the substance called magnetical pyrites, which has hitherto been found only in Saxony and a few other places, is also a British mineral, and that, in Caernarvonshire, it forms a vein of considerable extent, breadth, and depth.

2. That the component ingredients of it are sulphur and metallic iron; the former being in the proportion of 36.50 or 37, and the latter about 63.50 or 63.

3. That the chemical and other properties of this substance are very different from those of the common martial pyrites, which however are also composed of sulphur and iron, varying in proportion, from 52.15 to 54.34 of sulphur, and from 47.85 to 45.66 of metallic iron; the difference between the common pyrites which were examined being therefore 2.19, and the mean proportions amounting to 53.24 of sulphur, and 46.75 of iron; consequently, the difference between the relative proportions, in

the composition of the magnetical pyrites and of the common pyrites, is nearly 16.74, or 16.24.

4. That, as the magnetical pyrites agrees in analytical results, as well as in all chemical and other properties, with that sulphuret of iron which hitherto has been only known as an artificial product, there is no doubt but that it is identically the same; and we may conclude, that its proportions are most probably subjected to a certain law, (as Mr. PROUST has observed in the case of the artificial sulphuret,) which law, under certain circumstances, and especially during the natural formation of this substance in the humid way, may be supposed to act in an almost invariable manner.

5. That, in the formation of common martial pyrites, there is a deviation from this law, and that sulphur becomes the predominant ingredient, which is variable in quantity, but which, by the present experiments, has not been found to exceed 54.34 *per cent.* a proportion, however, that possibly may be surpassed in other pyrites, which have not as yet been chemically examined.

6. That iron, when combined naturally or artificially with 36.50 or 37 of sulphur, is not only still capable of receiving the magnetic fluid, but is also rendered capable of retaining it, so as to become in every respect a permanent magnet; and the same may, in a great measure, be inferred respecting iron which has been artificially combined with 45.50 *per cent.* of sulphur.

7. That, beyond this proportion of 45.50 or 46 *per cent.* of sulphur, (in the natural common pyrites,) all susceptibility of the magnetic influence appears to be destroyed; and, although the precise proportion which is capable of producing this effect, has not as yet been determined by actual experiment, it is

certain that the limits are between 45.50 and 52.15; unless some unknown alteration has taken place in the state of the sulphur, or of the iron, in the common martial pyrites.

8. That, as carbon, when combined in a certain proportion with iron, (forming steel,) enables it to become a permanent magnet, and as a certain proportion of sulphur communicates the same quality to iron, so also were found to be the effects of phosphorus; for the phosphuret of iron, in this respect, was by much the most powerful, at least when considered comparatively with sulphuret of iron.

9, and lastly, that as carbon, sulphur, and phosphorus, produce, by their union with iron, many chemical effects of much similarity, so do each of them, when combined with that metal in certain proportions, not only permit it to receive, but also give it the peculiar power of retaining, the magnetical properties; and thus, henceforth, in addition to that carburet of iron called steel, certain sulphurets and phosphurets of iron may be regarded as bodies peculiarly susceptible of strong magnetical impregnation.

Having thus, for the greater perspicuity, reduced the principal facts of this Paper into a concise order, I shall now make some general observations.

It is undoubtedly not a little singular, that a substance like the magnetical pyrites, which, although not common, has been long known to mineralogists, should not hitherto have been chemically examined, especially as mineralogical authors have mentioned the analysis of it as a desideratum. The result of this which I have attempted, proves that it is really deserving of notice; for thus we have ascertained, that the sulphuret of iron hitherto known only as an artificial product, is also formed by nature; and that the composition of this last, agrees with those proportions of the artificial sulphuret which have been stated by Mr. PROUST.

But, from this sulphuret or magnetical pyrites, I have not, by analysis, as yet been able to discover any regular or immediate gradations into the common pyrites; for the least proportion of sulphur in these amounted to 52.15, and the greatest proportion to 54.34; so that, between the magnetical and the common pyrites, the difference is considerable, in the proportions of their component substances, as well as in their physical and chemical properties; whilst the difference which I have hitherto been able to detect in the proportions of some of the common pyrites, (very dissimilar in figure, lustre, colour, and hardness,) has only amounted to 2.19.

Mr. PROUST, in a general way, considers common pyrites to differ from the first sulphuret, or that composed of 60 parts of sulphur and 100 of iron, (= 37.50 *per cent.)* by containing a farther addition of half the above quantity of sulphur, or 90 parts of sulphur and 100 of iron, (= 47.36 *per cent.*) but this opinion he appears to have formed, in consequence of results obtained by synthetical experiments made in the dry way. Now, when we consider how difficult it is to regulate the high degrees of temperature, and what a numerous chain of alterations in the relative order of affinities most commonly result from alterations in these degrees of heat, it seems to me that we cannot rely, with absolute certainty, on synthetical experiments made in the above way, unless they are corrected, and contrasted with analytical experiments made on the same substances. But it does not appear, from the two memoirs published by Mr. PROUST, to which I have so frequently alluded, that that gentleman did more, in respect to analysis, than distil the cubic and dodecaedral pyrites found near Soria, from which he obtained about 20 *per cent.* of sulphur; and, having observed that the residuum possessed the properties of the sulphuret which has been commonly prepared in laboratories, he concluded that the sulphur obtained from the pyrites, is the excess of that proportion which is requisite to form the sulphuret, the proportions of which, therefore, he by synthesis ascertained to be, as I have above stated, = 37.50 of sulphur, and 62.50 of iron, or 60 of sulphur combined with 100 of iron; and lastly, having formed 318 grains of this sulphuret from 200 grains of iron filings, he distilled the sulphuret with an additional quantity of sulphur, in an inferior degree of heat, and obtained 378 grains of a substance which, excepting density, was similar to the common martial pyrites.*

It is however to be regretted, that Mr. PROUST did not make a regular analysis of the pyrites of Soria, and of the residuum after distillation; for (unless these pyrites are very different from those which I have examined) he would most probably have found the proportion of sulphur greater than that which he has assigned to natural pyrites in general. This at least there is great reason to suppose, if we allow that most or all of the pyrites have been formed in the humid way, by which, we may conceive, a larger proportion of sulphur may be introduced into the compound, than can take place in high degrees of temperature. And this opinion is corroborated by the results of

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* *Journal de Physique,* Tome LIV. p. 92.

my analyses; for, instead of finding the general proportions to be 47.36 of sulphur and 52.64 of iron, the mean result of these analyses is very nearly the reverse, being 53.24 of sulphur and 46.76 of iron.

Mr. PROUST is also of opinion, that the pyrites which contain the smallest quantity of sulphur, are those which are most liable to vitriolization; and, on the contrary, that those which contain the largest proportion, are the least affected by the air or weather.* This opinion of the learned professor, by no means accords with such observations as I have been able to make; for the cubic, dodecaedral, and other regularly crystallized pyrites, are liable to oxidizement, so as to become what are called hepatic iron ores, but not to vitriolization; whilst the radiated pyrites (at least those of this country) are by much the most subject to the latter effect; and therefore, as the results of the preceding analyses show that the crystallized pyrites contain less sulphur than the radiated pyrites, I might be induced to adopt the contrary opinion. But I am inclined to attribute the effect of vitriolization observed in some of the pyrites, not so much to the proportion, as to the state of the sulphur in the compound; for I much suspect, that a predisposition to vitriolization, in these pyrites, is produced by a small portion of oxygen being previously combined with a part, or with the general mass, of the sulphur, at the time of the original formation of these substances, so that the state of the sulphur is tending to that of oxide, and thus the accession of a farther addition of oxygen becomes facilitated. We have an example of similar effects in phosphorus, when (as is commonly said) it is half burned, for the

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* *Journal de Physique.* Tome LIII. p. 91.

purpose of preparing the phosphorus bottles; and the propensity to vitriolization, observed in many of the half-roasted sulphureous ores, appears to me to arise from this cause, rather than from the mere diminution of the original proportion of sulphur, or the actual immediate conversion of part of it into sulphuric acid; nevertheless, I offer this opinion, at present, only as a probable conjecture, which may be investigated by future experiments and observations.

The magnetical properties of the sulphuret of iron which forms the principal subject of this Paper, must be regarded as a remarkable fact; for I have not found, in the various publications on magnetism which I have had the means of consulting, even the most remote hint, that iron when combined with sulphur, is possessed of the power of receiving and retaining the magnetic fluid; and, judging by the properties of common pyrites, we might have supposed that sulphur annihilated this power in iron, as indeed seems to have been the opinion of mineralogists, who have never enumerated magnetical attraction amongst the physical properties of those bodies; and, although WERNER, WIDENMANN, EMMERLING, and BROCHANT, have arranged the magnetical pyrites with the sulphurets of iron, yet the magnetical property could not with certainty be stated as inherent in the sulphuret, for, at that time, this substance had not been subjected to a regular chemical analysis, and the magnetical property might therefore be suspected to arise from interspersed particles of the common magnetical iron ore. This probably has been the opinion of the Abbé HAÜY; for, in his extensive Treatise on Mineralogy lately published, I cannot find any mention made of the magnetical pyrites, either amongst the sulphurets or amongst the other ores of iron.

In the mineral kingdom, a great variety of substances, and even some of the gems, exert a feeble degree of attraction on the magnetic needle, and sometimes also acquire a slight degree of polarity;[*] but, as this wonderful property has only been observed conspicuously powerful in one species of iron ore, this has been always emphatically called *the Magnet*,[†] and is said to consist of metallic iron combined with from 10 to 20 *per cent.* of oxygen.

From the facts, however, which have been recently stated, we now find that there is another natural substance, apparently very different from the magnet in chemical composition, but nevertheless approaching very nearly to it in power, which is found in several parts of our globe, and particularly in a province of this kingdom, where it constitutes a vein, running north and south, of considerable extent, and several yards in width and thickness.

From the experiments also, which have been made on the artificial preparation of this substance, we find, that it is capable of receiving the magnetic properties when the proportion of sulphur amounts to 37 *per cent.* and is still powerfully attracted when a much larger quantity of sulphur is present. There is, however, some point at which all these effects cease, and this point appears to be, when the sulphur is in some proportion between 45 or 46 and 52 *per cent.* The preceding experiments have also proved, that iron when combined with phosphorus, likewise possesses the power of becoming a magnet to a very remarkable degree; and, by the similarity, in this respect, of the

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[*] CAVALLO on Magnetism, page 73.

[†] In a future Paper, it is my intention to give an account of some comparative analyses of the varieties of this substance.

carburet of iron called steel, to the above sulphuret and phosphuret, a very remarkable analogy is established between the effects produced on iron, by carbon, sulphur, and phosphorus.

Carbon, when combined in a very large proportion with iron, forms the carburet of that metal, called plumbago; a brittle substance, insoluble in muriatic acid, and destitute of magnetical properties. But, smaller proportions of carbon, with the same metal, constitute the various carburets included between black cast iron and soft cast steel;* bodies which are more or less brittle, soluble in muriatic acid, and more or less susceptible of magnetical impregnation; some of them form the most powerful magnets hitherto discovered.

Sulphur, in like manner, combines with iron in a large proportion, forming the common pyrites, which are brittle, almost or quite insoluble in muriatic acid, and devoid of magnetical properties. Sulphur in smaller proportions, forms sulphurets

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* "When the carbon exceeds, the compound is carburet of iron or plumbago: when "the iron exceeds, the compound is steel, or cast iron, in various states, according to "the proportion. All these compounds may be considered as subcarburets of iron." THOMSON's System of Chemistry, Vol. I. p. 165.

Mr MUSHET, in the following Table, exhibits the proportion of charcoal which disappeared, during the conversion of iron to the different varieties of subcarburet known in commerce.

"Charcoal absorbed.	Result.
$\frac{1}{120}$	Soft cast steel.
$\frac{1}{100}$	Common cast steel.
$\frac{1}{90}$	The same, but harder.
$\frac{1}{50}$	The same, too hard for drawing.
$\frac{1}{25}$	White cast iron.
$\frac{1}{20}$	Mottled cast iron.
$\frac{1}{15}$	Black cast iron.

"When the carbon amounts to about $\frac{1}{60}$ of the whole mass, the hardness is at the maxi- "mum." THOMSON, Vol. I. p. 166; and Phil. Magazine, Vol. XIII. pp. 142 and 148.

which are also brittle, but are soluble in muriatic acid, and strongly susceptible of magnetical impregnation.

Phosphorus also, when combined with iron, makes it brittle, and enables it powerfully to receive and retain the magnetical properties; so that, considering the great similarity which prevails in other respects, it may not seem rash to conclude, that phosphorus, (like carbon and sulphur,) when combined with iron in a very large proportion, may form a substance incapable of becoming magnetical, although, in smaller proportions, (as we have seen,) it constitutes compounds which are not only capable of receiving, but also of retaining, the magnetical properties, even so far as, in some cases, to seem likely to form magnets of great power; and, speaking generally of the carburets, sulphurets, and phosphurets of iron, I have no doubt but that, by accurate experiments, we shall find that a certain proportion of the ingredients of each, constitutes a maximum in the magnetical power of these three bodies. When this maximum has been ascertained, it would be proper to compare the relative magnetical power of steel (which hitherto has alone been employed to form artificial magnets) with that of sulphuret and phosphuret of iron; each being first examined in the form of a single mass or bar of equal weight, and afterwards in the state of compound magnets, formed like the large horse-shoe magnets, by the separate arrangement of an equal number of bars of the same substance in a box of brass.

The effects of the above compound magnets should then be tried against others, composed of bars of the three different substances, various in number, and in the mode of arrangement; and, lastly, it would be interesting to make a series of experiments on chemical compounds, formed by uniting different proportions of carbon, sulphur, and phosphorus, with one and the same mass of iron. These quadruple compounds, which, according to the modern chemical nomenclature, may be called carburo-sulphuro phosphurets, or phosphuro-sulphuro-carburets, &c. of iron, are as yet unknown as to their chemical properties, and may also, by the investigation of their magnetical properties, afford some curious results. At any rate, an unexplored field of extensive research appears to be opened, which possibly may furnish important additions to the history of magnetism, a branch of science which of late years has been but little augmented, and which, amidst the present rapid progress of human knowledge, remains immersed in considerable obscurity.