NOTES ON METEORITES.[1]

II.

CHEMICAL ANALYSIS.

WE have seen that the main difference between the specimens of these bodies which have been collected is that some of them are mainly iron, some of them are mainly stone, and that there is a passage between these two conditions represented by falls in which we have a paste of iron including stony fragments.

We have now to enter into some points connected with their chemical constitution somewhat more in detail.

Of the chemical elements which are at present recognized as such, about one-fourth are found by chemical analysis to exist in meteorites. These, according to the tables given by Maskelyne,[2] Fletcher,[3] Smith, and others are as follows:—

Those that occur most constantly are:—

Hydrogen
Iron
Nickel
Magnesium
Cobalt[4]
Copper[4]
Manganese
Calcium
Aluminium
Carbon
Oxygen
Silicon
Phosphorus
Sulphur;

while the following occur less frequently or in smaller quantities:—

Lithium
Sodium
Potassium
Strontium
Titanium
Chromium
Tin
Arsenic
Antimony
Chlorine
Nitrogen.

Of these elementary bodies only hydrogen, nitrogen, and carbon occur in an elementary condition.

Hydrogen and nitrogen are asserted to be occluded as gases by the stones. Carbon exists both in the form of graphite and diamond.

From the above lists it will be seen that among the elements most common in meteorites are recognized many which have a very wide distribution and exist in great quantities in the surface and envelopes of our planet. But this is true only of the elements.

Many mineral compounds terrestrially common are absent; perhaps the most striking case of all is the absolute absence of free quartz, whether crystallized or not, from meteorites, while terrestrially it is the most prevalent compound known, and enters into the composition of such common rocks as trachyte, felsite, syenite, gneiss, and granite.

Again, many of the chemical combinations met with are unknown to terrestrial mineralogy. The chemical compounds found in meteorites which are new to our mineralogy may be briefly referred to. Some are combinations with sulphur, as follows:—

$$\begin{array}{llcl} \text{Sulphur} & + \ \text{Iron} & = & \text{Troilite} \\ & + \ \text{Calcium} & = & \text{Oldhamite} \\ & + \left\{\begin{array}{l}\text{Calcium}\\ \text{Titanium}\end{array}\right\} & = & \text{Osbornite} \\ & + \left\{\begin{array}{l}\text{Iron}\\ \text{Chromium}\end{array}\right\} & = & \text{Daubréelite.} \end{array}$$

Phosphides of iron and nickel, forming varieties of so-called schreibersite, are met with.

It has already been stated that carbon in some form or other exists in most meteorites. Some of them are partly composed of this element compounded with hydrogen and oxygen.

This exists as a white or a yellowish crystallizable matter, soluble in ether and partly so in alcohol, and exhibiting the characters and the composition of one or more hydrocarbonaceous bodies with high melting-points.

The meteorites of Alais and Cold Bokkeweld are instances of this group. The former is of a black colour both internally and externally, is combustible, and contains sulphates of magnesium, calcium, sodium, and potassium, which are all soluble in water. The latter, after being experimented upon, left a residue which gave out a very bituminous smell; this substance was yellow, and it was found that it was only another form of carbon in a state of intimate mixture, amounting to about 1·67 per cent.

Some carbonaceous stones are dark gray in colour, have little lustre, and are soft; they contain no visible meteoric iron, but an abundance of light gray rounded bodies, among which are occasionally some with a dull metallic lustre and of a greenish-yellow colour, and others of a dark gray compact substance and of earthy character.[1]

Various *alloys* of nickel and iron also occur.

The different alloys which play the most important part have, according to Meunier, the following composition:—

	Density.		Formula.
Tænite	7·380	...	Fe_6Ni
Plessite	7·850	...	$Fe_{10}Ni$
Kamacite	7·652	...	$Fe_{14}Ni$
Braunine	(?)	...	$Fe_{16}Ni$

Among other minerals we may name—
Lawrencite, protochloride of iron;
Maskelynite, with the composition of labradorite;
Silica (as asmanite).

We now come to the common ground.

The following compounds are identical in composition and crystallographic character with minerals found on our globe:—

Magnetic pyrites ... ... Fe_7S_8.
Magnetite ... ... Fe_3O_4.
Chromite ... ... $(Fe,Cr)_3O_4$.
Silicates, viz.—
  Olivine varieties.
  Enstatite and bronzite.
  Diopside and augite.
  Anorthite and labradorite.
  Breunnerite.

Among gaseous compounds, the oxides of carbon have been detected in many meteorites, and it is asserted that these gases have been occluded by them in the same manner as the elementary gases hydrogen and nitrogen.

In the "irons" we deal chiefly with nickel-iron, magnesium, manganese, and copper, as metals.

In the "stones" we deal with combinations of magnesium, iron, oxygen, and silicon. One of the most usual substances is called olivine, and sometimes the olivine is in a slightly changed form, in which the quantity of iron is increased, and we get bronzite. Nickel-iron, manganese, and other substances are also found in the stones.

Chemical analysis of the irons has established in them, taken as a whole, the existence of the following mineral species.

(1) The general metallic mass, which consists of certain alloys, in which iron and nickel predominate to such an extent that the term nickel-iron is by common consent applied to it.

The nickel-iron is an alloy or compound special to meteorites, and the irons are chiefly composed of it. The tracery to which I have referred, observed on the metallic surface heated with acids, was discovered by Widmanstätten. The figures are caused by the crystallization of the mass: with the iron and nickel magnesium is always associated, *so that we get magnesium in all meteoric irons* as well as in the stones.

(2) Compounds of iron and carbon, principally campbelline and chalypite (Fe_2C).

(3) Troilite $(FeNi)_7S_8$, generally appearing as kidney-shaped masses.

(4) Schreibersite (Fe_4Ni_2P).

(5) Graphite.

(6) Stony grains, generally magnesium and iron silicates.

(7) Occluded gases.

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[1] Continued from p. 428.

[2] NATURE, vol. xii. p. 505.

[3] "Introduction to Study of Meteorites," p. 30.

[4] With regard to the presence of cobalt and copper, Dr. L. Smith says ("Mineralogy and Chemistry," p. 352):—"In every analysis that I have made of meteoric irons (over one hundred different specimens) cobalt has been invariably found, along with a minute quantity of copper."—Flight, "History of Meteorites," p. 164.

[1] Flight, *op. cit.* p. 211.

(8) The crust or varnish. This has been found to be due entirely to the oxidation of the metal. The formula of the crust of the Toluca meteorite is $Fe_2O_3(FeNi)O$, according to Meunier.

The quantities of occluded gases vary considerably. Hydrogen is the first to come out when a vacuum is produced, and in the cold—that is, when the tube containing the meteorite is not heated.

Thus, Graham found in the Lenarto meteorite, and in a comparative experiment with clean horse-shoe nails made of iron :—[1]

	Meteorite.	Nails.
Hydrogen	85·68	35·0
Carbonic oxide... ...	4·46	50·3
Carbonic acid	—	7·7
Nitrogen	9·86	7·0
	100·00	100·0

Mallet subsequently found in the meteorite picked up in Augusta County—[2]

Hydrogen	85·68
Carbonic oxide	4·46
Nitrogen	9·86

Dr. A. Wright subsequently determined the composition of the gases given off at different temperatures, using the Iowa meteorite. The results were as follows :—

	Hydrogen.	Carbonic oxide.	Carbonic acid.	Nitrogen
Cold	49	14	35	—
At 100° C. ...	4·54	0 (?)	95·46	—
At 200° C. ...	5·86	1·82	92·32	—
Red heat ...	87·53	0	5·56	6

As regards the so-called occluded gases, iron and stony meteorites, according to Wright, show a marked distinction. While the gases of the Lenarto iron contained 85·68 per cent. of hydrogen, those obtained from cosmical masses of the stony kind, such as the Iowa meteorite, are characterized by the presence of carbonic acid, which constitutes nine-tenths of the gas evolved at the temperature of boiling water, and about one-half of that given off at a low red heat.

This view of Wright's has been called in question by Mallet, who refers to his examination of the gases of the iron of Augusta Co., Virginia, where the ratio of the oxides of carbon to hydrogen is 4·3, and to his having pointed out in 1872 that hydrogen could no longer be regarded as the characteristic gaseous ingredient of meteoric iron.[3]

In the siderites, the iron varies from 80 to 98 per cent., and the nickel from 6 to 10 per cent. Sometimes the nickel is found in larger quantities, as in the iron of d'Octibbeha Co., Mississipi, found in the year 1854, which contained as much as 59 per cent., while the iron was only 37 per cent.

There is a singular circumstance connected with the varnish of stony meteorites which was observed by Reinsch in the meteorite of Krähenberg. The grains of metallic iron and troilite contained in the varnish show no signs of oxidation. In the meteorite of Morbihan, also, grains of nickel-iron project not only through the smooth inner but also the rough outer crust. It has been suggested that the surface of these meteorites was vitrified before it entered our air, or at all events those lower strata of it in which oxygen is abundant.[4]

In many cases minute chemical analysis has been most useful in showing that meteorites which have been found in different localities really belong to the same fall.

Prof. Nordenskjöld, on examining the Ställdalen meteorites (Sweden, June 28, 1876), found that they resembled some eight or nine others which he had before examined, although they were entirely unconnected as regards their date of appearance ; and that together they would form a well-marked group, but which, he observes, will probably be found to be only one among many similar groups of aërolites which will hereafter be detected.

The following short table brings together in a compact form the chief substances met with in meteorites. It will indicate the cause of the continued reference to the spectra of magnesium iron, and manganese in what follows.

Siderites.

Nickel-iron, manganese, copper.
Troilite = FeS.
Graphite.
Schreibersite = iron and nickel phosphide, with which magnesium is always associated.
Daubréelite = iron and chromium sulphide.

Siderolites.

Chondritic—
(α) Non-carbonaceous ... Olivine = chrysolite = peridot = $(MgFe)_2O_4Si$ = SiO_2 41·3, MgO 50·9, FeO 7·7.
Enstatite MgO_3Si = SiO_2 60, MgO 40.
Bronzite = enstatite, in which some magnesium is replaced by iron.
Nickel-iron, manganese.
Troilite.
Chromite = iron protoxide 32, chromium sesquioxide 68, + aluminium and magnesium.
Augite = pyroxene, SiO_2 55, CaO 23, MgO 16, MnO 0·5, FeO 4.
Silicate of calcium, sodium, and aluminium.
(β) Carbonaceous ... Carbon in combination with H and O.
Sulphates of Mg, Ca, Na, and K.

Non-chondritic—
Troilite.
Olivine.
Enstatite.
Bronzite.
Augite.
Anorthite

SPECTRAL ANALYSIS.

It is imperative that we should know what spectroscopic phenomena are presented by meteorites when they are exposed to temperatures either high or low, such that luminous effects are produced, however the heat which is associated with luminosity is caused.

To this end a great many investigations have been made, and one method of investigation has been the following.

A small portion of any particular meteorite, or still better some dust or filings is inserted in an end-on tube, which is placed in front of a spectroscope, so that a spectroscopic record of the luminosity may be obtained. The tube is at the same time attached to a Sprengel pump, so that in this way a vacuum can be obtained, and is supplied with poles, so that an electric current can be sent through it. Supposing that such bodies as meteorites exist in free space, we must understand that they exist practically in a vacuum, so that it is a fair thing to begin the laboratory work by getting as nearly a vacuum as possible. The next thing to do is to try the effect of the lowest temperature, and for that purpose the central part of the tube containing the little fragments is heated by a Bunsen burner.

If any effect is produced by this application of heat it will after some little time be evidenced by the commencement of a spectrum or by some change in the pre-existing one. What has been found is that there is scarcely any meteorite which can be examined in this way which does not give off a sufficient quantity of hydrogen to allow the hydrogen spectrum, when a feeble electric current is made to travel along the tube, to be very beautifully visible.

If the temperature of the meteoric particles is kept sufficiently low, we see practically the spectrum of hydrogen alone. That is a demonstration of the very well known fact that with those bodies generally acknowledged to enter into the composition of meteorites, hydrogen is always associated.

If under these same conditions the temperature is increased, the spectrum of carbon begins to be visible, indicating that associated with the hydrogen there is some compound or com-

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[1] Graham, "Chemical and Physical Researches," p. 283.
[2] *Chemical News*, June 21, 1872.
[3] Flight, *op. cit* p. 80.
[4] Flight, *Geol. Mag.*, January 1875.

pounds of carbon in the meteorite which require a higher temperature to bring them out, but which come out when that higher temperature is employed. The carbonaceous structure of some meteorites has already been determined on other grounds.

If we carry the heating a little further still, and instead of leaving the particles relatively cold and dark while the current is passing we apply a higher temperature outside the tube by means of the Bunsen burner, then we get the luminous vapours of some constituents of the meteorite added to the spectra of hydrogen and carbon.

What luminous vapours do we get first, and which last? The experiment is a very interesting one, and may certainly be carried on in a tube such as that described until a pretty considerable development of the spectrum is obtained. The first substance which makes itself visible obviously after the hydrogen and carbon when particles of a meteorite are treated in this way is magnesium derived from the olivine, that substance which exists in the greatest quantity in the stones, and in the schreibersite, which exists in the irons.

From such a method of research as this we can pass to one in which, by means of the oxy-coal-gas flame, we can determine the spectrum of any vapour given off, provided any vapour is given off, at a still higher temperature. That work has been done, and the main result is that in the case of an "iron," the first substance to make its appearance is manganese, and the next substance to make itself obvious is iron.

Here a very important remark must be made. The substance which will give us the predominant spectrum at lowest temperature must be that substance the volatility of which at that temperature is greatest. If, however complicated the chemical constitution of one of these meteorites may be, there is one substance which volatilizes out of it more readily than another at a low temperature, that substance will be the first to give us its characteristic spectrum at that temperature—and in fact we may get the spectrum of that substance alone, although its percentage in the meteorite may be extremely small. It is therefore an important result to find that in meteorites in which the quantity of iron is very considerable it is always the manganese that makes itself visible first, because its volatility is greater than that of iron. The point to bear in mind is that when we pass to the temperature of the oxy-coal-gas flame we get predominant evidence of the existence of manganese, and afterwards of iron.

Many diagrams of observations made in this way have been constructed of the oxy-coal-gas flame of meteorites and of olivine, and not only the flame but the "glow,"—glow being the name given to the luminosity produced in the tube under the conditions stated. There are some points of similarity, and other points of difference. One of the results which is most constant is a line at 500 on the wave-length scale which appears to run through all the observations until we come to deal with such meteorites as the Limerick and Nejed. On the other hand some lines and flutings do not make their appearance generally.

If we wish to extend our inquiry into the function of a still higher temperature we can use the electric arc; that also has been done. For this purpose specimens of iron meteorites have been cut into poles, the spectra of which have been observed and photographed, so that the vapours produced have been the vapours of the pure iron meteorites; that is to say, a small portion of a meteorite has *not* been placed in an impure carbon pole, so that the impurities of the carbon would be observed and photographed with the pure vapours of the meteorites. In addition to this method—in the case of the stony meteorites—the lower pole after its spectrum has been well studied has been utilized in this way: the upper pole remaining constant as an iron pole, pretty big particles of various stony meteorites have been inserted into the lower pole, and the added result has been recorded. Further, composite photographs of the spectra of many meteorites have been obtained. Half a dozen different stony meteorites have been rendered incandescent by their insertion into the lower pole during the exposure of a single photographic plate.

It is pretty obvious that if we can get detailed information on such points as these, and provided there are meteorites in space at the temperatures at which we are able to determine their spectra in the laboratory, such data should be of extreme value, for at present we know of no reason why the spectra should differ according to locality.

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(*To be continued.*)

MOLECULAR PHYSICS: AN ATTEMPT AT A COMPREHENSIVE DYNAMICAL TREATMENT OF PHYSICAL AND CHEMICAL FORCES.[1]

II.

§ 6. *Double Refraction.*

ACCORDING to the theories both of Fresnel and of Neumann, double refraction is explained on the assumption that the elasticity of the ether in crystals which exhibit this phenomenon is different in different directions. The elasticity is proportional to the square of the velocity of propagation, and if a, b, c are the ratios of the elasticities, parallel to the principal axes of the crystal, of the ether within it to its density, the velocity in any direction α, β, γ will be given by the equation—

$$v^2 = a^2 \cos^2 \alpha + b^2 \cos^2 \beta + c^2 \cos^2 \gamma \quad . \quad . \quad . \quad . \quad (18)$$

According to the author's theory, the elasticity of the ether is the same in every direction, so that any difference in the velocities of propagation in different directions must be due to the mutual action between the ether and the molecules of the crystal being a function of the direction, and therefore the values of the quantities c_i for the molecules of the crystal, and hence also the value of μ, must depend on the direction.

Assuming, for simplicity, that the molecules have a single shell only, it follows from (8) and (9) that—

$$\mu^2 = \frac{1}{v^2} = \frac{\rho}{l} - \frac{c_1 T^2}{l} \left\{ 1 + \frac{c_1}{\frac{m_1}{T^2} - c_1 - c_2} \right\}$$

$$= \frac{1}{l} \left\{ \rho - c_1 T^2 \left[1 + c_1 \frac{T^2}{m_1} \frac{\kappa_1^2 R_1}{\kappa_1^2 - T^2} \right] \right\} \quad . \quad . \quad . \quad (19)$$

where $\kappa_1^2 = m_1/(c_1 + c_2)$ and $R_1 = m_1/\kappa_1^2(c_1 + c_2)$.

Let the values of c_i and μ for a second direction be c_i^1 and μ^1, then

$${\mu^1}^2 = \frac{\rho}{l} - \frac{c_1^1 T^2}{l} - \frac{{c_1^1}^2 T^4}{(c_1^1 + c_2^1)\left(\frac{m_1}{c_1^1 + c_2^1} - T^2\right)} \quad . \quad . \quad (20)$$

Now, as Thomson has pointed out, the dispersion accompanying double refraction is of very small amount, so that the difference $\mu^2 - {\mu^1}^2$ must be sensibly independent of T.

If T were less than κ, $\mu^2 - {\mu^1}^2$ would, from (12), be proportional to T^2. It must therefore be assumed that the critical period is at the extreme blue end of the spectrum, which will give T greater than κ_1 for all the rays. Then from (12*a*)—

$$\mu^2 - {\mu^1}^2 = \frac{c_1^2 m_1}{l(c_1 + c_2)^2} - \frac{{c_1^1}^2 m_1}{l(c_1^1 + c_2^1)^2}$$

$$- \left(c_1 - c_1^1 - \frac{c_1^2}{c_1 + c_2} + \frac{{c_1^1}^2}{c_1^1 + c_2^1} \right) \frac{T^2}{l}$$

$$+ \frac{c_1^2}{(c_1 + c_2)^3}, - \frac{{c_1^1}^2}{(c_1^1 + c_2^1)^3} \frac{m_1^2}{lT^2} + \quad . \quad . \quad . \quad . \quad . \quad (21)$$

In order that the coefficient of T^2 may be small, c_1 and c_1^1 must be small and nearly equal. The other terms of the series will then be also very small, especially if T is large in comparison with m_1, and the series may, to a first approximation, be replaced by its constant term.

Now let it be assumed that the manner in which c_1 and c_2 depend on the direction α, β, γ, is determined by an equation of the form—

$$\left(\frac{c_1}{c_1 + c_2} \right)^2 = C_1 \cos^2 \alpha + C_2 \cos^2 \beta + C_3 \cos^2 \gamma \quad . \quad . \quad (22)$$

Then from (19) and (12*a*)—

$$v^2 = \frac{1}{\mu^2} = \left(\frac{l}{\rho} - \frac{m_1}{\rho} C_1 \right) \cos^2 \alpha + \left(\frac{l}{\rho} - \frac{m_1}{\rho} C_2 \right) \cos^2 \beta$$

$$+ \left(\frac{l}{\rho} - \frac{m_1}{\rho} C_3 \right) \cos^2 \gamma,$$

an equation of the same form as (18), and which therefore gives a wave-surface identical with Fresnel's. It must, of course, be

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[1] A Paper read before the Physico-Economic Society of Königsberg, by Prof. F. Lindemann, on April 5, 1888. Continued from p. 407.