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CONSIDERATIONS ON THE PHENOMENA ATTENDING THE FALL OF METEORITES ON THE EARTH.

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PART I.

THE only falls of meteorites which I propose to take into consideration in this paper, are those which have been observed as accurately as possible. Generally in such cases dates and particulars that can be perfectly relied upon are not common. The phenomena taking place without warning and occupying so short a period of time, it is only from persons accustomed to receive impressions promptly that we can obtain trustworthy observations. Dr. Gustavus Scheffczik, whilst on a hunting-excursion, saw near Strakowitz in Bohemia, on the 29th of November, 1859, at $10^h\ 45'$ A.M., a luminous star-like point appearing suddenly on a clear sky, due north 15° zenith-distance, increasing gradually to an intensely luminous globe, equal in size to one-third of the full moon (about one-third of her diameter), and passing along a parabolic path towards S. 60° E. When under an angle of altitude of 25° (azimuth =65°) it assumed an oval shape, the pointed end bent downwards and forwards, and lastly, apparently dissolved into many large sparks, one of which evidently fell down in a vertical direction. Dr. Scheffczik estimates the phenomenon to have lasted from four to five seconds. A noise as if myriads of birds were flying through the air attracted his attention. According to his watch, $1\frac{1}{4}$ minute passed in silence after the disappearance of the luminous appearances; then followed, quickly after each other, four detonations (the last the most intense), resembling the

* A translation by Count Marshall, of a paper read before the Imperial Academy of Sciences at Vienna, on the 14th of March, 1861; communicated by R. P. Greg, Esq., F.G.S.

discharges from heavy ordnance. The ground shook under the observer's feet, as was corroborated by three other gentlemen in company with Dr. S., who likewise heard the four detonations.

I have received some other observations concerning the same phenomenon; but I consider Dr. Scheffczik's observation most valuable, from the excellent account it gives of the first approach of the "star-like" luminous body, and of its subsequent progression.

Scarcely any fall of aërolites has ever been so exactly and fully observed as that which fell at New Concord, Muskingum Co., Ohio, on May 1st, 1860*. Professor Evans, of Marietta College, Ohio, calculated several elements of the orbit. The meteor, first seen as a fiery globe at a horizontal distance of 20 to 30 (English) miles, appeared like the full moon. An altitude of 40 miles, derived from other observations, would give to it a real diameter of $\frac{3}{8}$ths of a mile. It moved from S.E. to N.W. The final velocity was about 4 miles a second. Nearly thirty stones, of about 700 lbs. total weight, were found to have fallen; the largest of them, weighing 103 lbs., is now in the Museum of Marietta College. All these stones taken together would fall far short of the apparent size of the meteor, as is the case with many other observations of a similar nature, especially with that of Agram in Croatia, May 26th, 1751, where two masses of native iron, the one of 71 lbs., the other of 16 lbs., were the only material residuum of a meteor whose apparent diameter was scarcely under 3000 feet†! At first the New Concord stones were warm, so that particles of the moist ground on which one of them had fallen, soon dried up, at least in the case of one weighing 71 lbs.

Its greatest heat was not more than that which the stone would have had if exposed for some time to the natural heat of the sun's rays. The largest of the stones (103 lbs.) was found about three weeks after the fall, beneath the root of an oak tree. It had gone through another root in an oblique direction, and had penetrated to the depth of nearly 3 feet into a hard argillaceous ground: no mention is made of its probable temperature at the time of falling. Those who witnessed the fall, only perceived that the stones were "black," they did not mention the appearance of any fireball‡. At the moment of the fall they

* See Silliman's American Journal, vol. xxx. for July 1860.

† See "Der Meteorstein-Fall v. Hrashina bei Agram, 26 Mai, 1751," by W. Haidinger, Proceedings of the Vienna Imperial Academy, Class of Mathematics and Natural Sciences, 1859, vol. xxxv. p. 361 (283).

‡ "No one of the many persons who saw the stones fall, and who were in the immediate vicinity at the time, noticed anything of the luminous appearance described by those who saw it from a distance."—*Silliman's Journal.*

heard hissing sounds, and that before the chief detonation had attracted their attention. All the stones were covered with a black crust bearing evidence of fusion, and presented angular and fragmentary shapes; their interior resembled grey solid rocks*. The American naturalists inferred from the collated accounts about the igneous globe, the acoustic phenomena, and the fall itself, that the first and chief detonation took place at an altitude of about 40 miles (English) above the southern portion of Noble County, at a distance of about 30 miles from New Concord; and that the fall of the stones themselves commenced about one mile S.E. of that place, extending over an area of 10 miles in length by 2 to 3 in breadth, the largest ones falling last. The sound perceived was supposed to have been explosive in its nature; and the meteor, after having ceased to be visible, must have continued its course towards the North-west. These are some of the most important facts relating to the phenomenon. Desirable as it is to pursue induction step by step, it is impossible to give a clear exposition without sketching previously the succession in time of each event as they are observed and perceived by our senses. Nobody who has ever examined meteorites with more than superficial attention, can have doubted that their interior and their exterior present two different periods of formation. The general form of meteorites is that of *fragments*, the constitution of their external crust is the consequence of *superficial fusion*. They are fragments coming from remote cosmical regions, which having entered the earth's atmosphere, are first perceived by us as stars, increasing in size as they come nearer to us. Great care should be taken to observe and note the moment or time with as much exactitude as possible, as, combined with the time of the year and the hour of the day, it gives us the direction of the meteor. The direction and the velocity of our globe in its circum-solar orbit (19 English miles per second, while a point on the equator by diurnal rotation moves 1464·7 Vienna feet in a second, or 900 nautical miles per hour), are well known.

Many observations have proved meteorites to travel 16 to 40 English miles in a second. Humboldt, in his 'Cosmos,' has even, from the observations of J. Schmidt, Heis, and Houzeau, calculated a velocity of 95 miles a second.

These orbits cross and oppose each other in every conceivable direction. Important consequences may be deduced from these enormous velocities, as compared with what takes place on the surface of our globe. A devastating hurricane takes place in

* "Viewed from most positions, this stone (that of 103 lbs. at Marietta College) is angular, and appears to have been quite recently broken from a larger mass."

our atmosphere whenever an air-current is progressing at the rate of 92 miles (English) per hour. A point on the equator, by diurnal rotation progresses at the rate of 1464·7 Vienna feet per second without disturbance of the atmospheric equilibrium, on account of the general atmospheric pressure being nearly equal in places lying very near each other. According to Sir John Herschel, the movement of a "devastating hurricane" is equivalent to a pressure of 37·9 lbs. Vienna (32·81 lbs. English) weight, on one square foot Vienna measure. The atmospheric pressure (=32 feet of water) on one Vienna square foot is 1804·8 lbs., or, compared with that of the most powerful hurricane, as 55 to 1.

I am glad to see these details, as I give them from sources most within reach, confirmed by Prof. E. E. Schmidt's, of the University of Jena, in his copious and excellent 'Manual of Meteorology' (vol. xxi. of the *Allgemeine Encyklopädie der Physik*), edited by Dr. G. Kersten and other eminent physicists). The following synoptic Table, calculated by Mr. Rouse (Report of the Tenth Meeting of the British Association, held at Southampton in Sept. 1846, p. 344) is found on page 483 of Prof. Schmidt's Manual:—

Velocity of wind.		Pressure per square foot in lbs. avoirdupois.	Character of wind.
English miles per hour.	English feet per second.		
60	88·02	17·715	Great storm.
80	177·36	31·490	Hurricane.
100	146·70	49·200	Destructive hurricane.
913–916	1340·0	1 atmosphere.	

The wind-scale of the Smithsonian Institute (published by the Smithsonian Institute, Nov. 1853, Washington, p. 173) offers analogous results.

It is the best proof in favour of the use of such extensive and elaborate synoptic works as Prof. Schmidt's Manual, that they gave me complete confidence in the *data* I had so laboriously compiled from other sources, and this, thanks to the author's kind attention to me, just at the moment when I felt most in want of such.

What is the state of the single particles of air composing our atmosphere in the elevated regions, where meteorites, first entering it, are capable of producing luminous phenomena as intense as observed at New Concord, even at the enormous altitude of 40 English miles? In these elevated regions the temperature may probably not exceed that of the interplanetary space, *i. e.* 100° Reaumur. Movements of particles may be supposed indeed to take place in the higher regions of the atmosphere, as on these depend the changes of atmospheric pressure nearer to the earth's surface, the causes of the winds, &c. Whenever solid bodies move through them, so abnormal an event goes on with such enormous rapidity, that these particles, quite isolated from each other, must be positively pushed aside. In the van of the progressing meteorite a stratum of atmospheric particles is formed, having no time to escape before the progressing body, but by streaming back alongside of it. The velocity of a meteorite, supposed on an average to be seven German miles (24,000 × 7 feet) per second, is to that of a hurricane of 134·72 feet per second as 1247 to 1. Suppose the pressure to increase in the same proportion, it would be per square foot, for the hurricane =32·8 lbs., and for the meteorite 40901·6 lbs., or more than 22 atmospheres.

It may be supposed that such a sudden compression (action and reaction continually remaining equal) must have the same effect as the compression of air in the old tinder-boxes alluded to by Prof. Benzenberg. It might not here be out of place to quote *in extenso* a passage from a book published fifty years ago*, expounding views still far from being cleared up:—

"The incandescence perceived around fireballs in a state of ignition may be the result either of *combustion*, although with difficulty admissible in air so very rarefied, or of *friction*, as generally believed. I think it results still more from the *compression* of air, as in our newly invented tinder-boxes air produces fire by mere compression. Could not *electricity* become free in the same way? Suppose a cubic mile of air to be suddenly compressed to a volume of one cubic foot, would not then the electricity originally contained in it be set at liberty? The circumstances attending the explosion of igneous globes seem to be in accordance with this supposition. These globes, when first seen, do not appear larger than bright stars; as they approach the terrestrial surface (generally in an oblique direction) they increase to the size of the full moon, and at last, when at a few miles distant, explode with a violent detonation. The cause of this explosion is probably an excessive accumulation of electric matter, streaming from compressed air into the igneous globe of about 3000 feet in size of (?) metallic substance. The distance being still too considerable to admit of a discharge to the earth, this takes place in the open air, or within a cloud.

"Probably the place of the discharge depends less on the proximity of the terrestrial surface than on the density of air regulating the *maximum* of compression and accumulation of electricity. Subsequently to the explosion, the single fragments

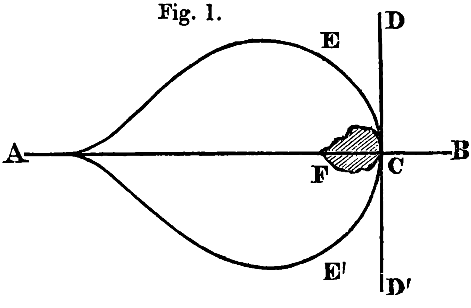
* *Briefe geschrieben auf einer Reise durch die Schweiz im Jahre* 1810, von J. F. Benzenberg. 1 vol. Düsseldorf, 1811.

fall to the surface of the earth, with a velocity probably inferior to that of a bullet shot from a gun, the air increasing in density as it becomes nearer the surface of the globe, resistance increasing proportionally, so that there may be but a slight difference in the final velocity, whether the body fall from a height of one or of five miles."

I have here quoted views somewhat opposed to those which I myself intend to propose (as those relating to the explanation of the explosion of fireballs); yet some of the above-quoted assertions may perhaps be worth further consideration.

The following exposition of the way in which this may occur may not be altogether devoid of probability. Compression, first of all, developes heat and light. Immediately in front of the meteorite is formed a centre of expansion, from which the compressed air tends to expand in every direction. Whatever lies in the direction of the orbit, is left in the rear of the progressing meteorite; whatever lies opposite to it, contributes to the fusion of the superficial crust, or by its resistance either retards its progress, or gives rise to a rotatory movement around an axis coinciding with the meteorite's orbit, even if it should have undergone such a motion only on entering the terrestrial orbit. A part of the air made luminous by compression, is forced out as at C, in every direction perpendicularly to the orbit AB (fig. 1). Resistance continues against this luminous disc, forces it backwards, overcomes it gradually at some distance from the centre towards EE′, and rounds it off behind the meteorite in the shape of an igneous globe, either round, or as frequently happens oviform; occasionally extended so far back as to form even an actual tail.

Fig. 1.



Instances of two or more luminous bodies behind each other have been observed, as those seen at Elmira, Long Island, United States, July 20, 1860; at Littau in Moravia, end of August 1848 or 1849; at Collioure in France, February 21st, 1846. In these cases we may suppose that the single fireball first seen contained already a certain number of fragments, acted upon differently by the resistance of the air, according to their differences in size, shape, and perhaps specific gravity, so that the heavier among them found less obstruction in pursuing their way than the lighter ones.

M. Julius Schmidt observed at Athens, July 27th, 1859, a magnificent green meteor, moving slowly in twelve seconds through an arc of 28°, commencing with a faint light, and ending as faintly, while about the middle of its course it expanded into a ball of 8–10 minutes in diameter, casting an intense light over the whole town and neighbouring hills.

An orbit having its convexity turned towards the earth's surface, as that of the meteor of 20th July, 1860, seen in the United States, may be indicative of a degree of specific gravity inferior to that generally the case in meteorites. In this case the motion of meteorites may become slower and slower, and at last be completely stopped; while there is little chance of their again returning into the cosmical space, from whence they entered our atmosphere.

The meteorite in question evidently entered the more rarefied strata of the atmosphere, and, perhaps influenced by the short duration of the igneous globe surrounding it, continued on its course into space. Its speed, though somewhat diminished, was certainly not annihilated.

Hitherto we have left out of consideration the altitude of the atmospheric strata in which a meteor is supposed to move; nor is this omission objectionable: suppose the meteorite moved along close to the surface of the earth under the pressure of a whole atmosphere, answering to a column of mercury 30 inches in height, and at the rate of seven miles per second, it would act on every square foot of resisting air with a pressure of 22 atmospheres*; this pressure would only amount to 11 atmospheres at a height of between 18,000 and 19,000 feet, where the barometer would indicate an atmospheric pressure of only 15 inches. It must, however, not be lost sight of, that under such circumstances the resistance of the surrounding air is also notably diminished, and that consequently the atmospheric particles forcibly driven out before the centre of elasticity will find the same facility for streaming along, or flowing in the directions C D, C D′ (fig. 1).

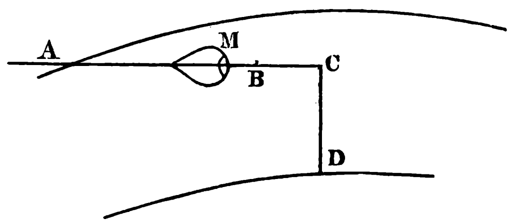
If electric tension in the extremely rarefied strata of our atmosphere is really as energetic as it is generally admitted to be, we are entitled to suppose a high development of electrical light. The expressions used by Benzenberg in the above-quoted passage, suggest no idea adequate to our present mode of viewing this subject. The view recently enounced in a totally different direction by one of the first of living physicists, Professor Plücker, seems to be in exact accordance with the subject considered here.

* See E. E. Schmidt's *Lehrbuch der Meteorologie*, page 913.

In his paper on the constitution of the electric spectra of certain gases and vapours (see Poggendorff's *Annalen*, 1859, vol. cvii. p. 505), the illustrious Professor says, "What is the thing emitting light when an electrical discharge takes place through the narrow passage of a Geisslerian tube, as much exhausted of air as possible, and including gas or vapour? There is no light unless some ponderable substratum emits it; *there is consequently no electrical light in the abstract sense of the word.* All my observations have confirmed me in this persuasion. But how is electricity acting here on the gaseous particles? In my opinion only as an exciter of heat. *The gaseous particles become incandescent.* The thick glass in the narrower portion of the Geisslerian tube is very notably heated when the discharge from Ruhmkorff's apparatus passes through the gas contained in it. If, then, the heat transmitted to the glass from the dispersed gaseous particles, whose tension is often measurable by fractions of millimetres, increases to a notable degree, to what a degree of intensity must these particles be heated!"

The cosmical orbit of the meteorite M entering the terrestrial atmosphere A (fig. 2) terminates at C; from this moment the meteorite belongs to our earth, and falls straight down from C (where, after exploding, its light is extinguished) to D on the earth's surface. The line C D represents its terrestrial orbit.

Fig. 2.



Terrestrial attraction is quite an insignificant element compared to the planetary or cosmical impulsion peculiar to any meteorite; and but for the resistance offered by the atmosphere, few or no meteorites would reach the surface of our earth, except those whose orbits were directly aimed towards it.

Meteoric stones after falling appear black; and their enamelled crust proves them to have undergone superficial fusion from exposure to high temperature. Their interior is frequently not more heated than would permit of their being held in the hand without inconvenience.

This is no matter for surprise, as the stone having quite recently come from the cold regions of interplanetary space, a compensation may be supposed to take place between the outside and the inside.

Fragments of the Dhurmsala meteorite (Punjab, 14th July, 1861), probably from the extreme cold of the interior, showed, at the moment of their fall, a temperature notably below congelation*. Meteoric *iron*, however, being a good conductor of heat, comes down far more heated, and even in a state of intense incandescence, as was the case with the iron of Corrientes in Caritas Paso, near the river Mocorita, in January 1844, mentioned by Mr. Gregt†, which fell at 2 A.M. in the shape of a lengthened globe, a fiery streak marking its passage through the air. The mass fell down at a distance of about 1200 feet from Mr. Symonds, who indeed first made known this fall. Later in the morning it could not be approached nearer than ten or twelve yards, on account of the heat emanating from the mass, which projected several feet out of the ground. During the fall the atmosphere was evidently in a state of motion, as if repelled by the falling body, producing a whirlwind of short duration.

This description is quite consistent with the facts to be derived from the preceding considerations. In this case the meteoric iron-mass struck the earth nearly point blank, falling under an acute angle of 60°.

Another very characteristic phenomenon connected with the vanishing of meteoric light, is the accompaniment of intense explosive *sound*, resembling the ignition of gunpowder fired from guns or mines. Generally one detonation is strikingly loud, frequently followed by others of a "rattling" character. The meteor "explodes," as it is commonly called, and lets fall from it one or more stones, disproportionally small in quantity as compared with the probable size of the fireball itself.

What could then have become of a body so luminous as that of a large meteor, which, according to Prof. Laurence Smith's experiments, might indeed appear far larger than the solid matter contained in it could justify one in supposing possible?

According to Prof. Smith's experiments—made, 1st, with the electric light between carbon points; 2nd, with the oxy-hydrogen light falling on lime; and 3rd, with the light from steel burning in oxygen,—the irradiation of a luminous point gives the following numbers for the apparent size at four different distances :—

Distance...	10 inches.	600 feet.		1320 feet or ¼ mile.		2640 feet or ½ mile.	
1. Carbon	0·3 line	½	Diameter of the moon.	3	Diameter of the moon.	3½	Diameter of the moon
2. Lime ...	0·4 „	⅓		2		2	
3. Steel....	0·2 „	¼		1		1	

Though persons struck by any uncommon sight are generally

* Proceedings of the Imperial Academy of Vienna, sitting of the 29th Nov. 1860.

† Philosophical Magazine for July 1855.

inclined to overrate the size of an object, the reports or accounts of fireballs showing a half or the whole of the full-moon's diameter, when seen from a distance of 20, 40, 60, or 100 miles, cannot, however, entirely rest on self-delusion*. A large space may be occupied by the igneous globe, surrounding a far smaller nucleus, consisting of one or more fragments.

On coming with enormous velocity from planetary space into our atmosphere, the acoustic phenomenon may be accounted for by supposing that the fireball includes, as we have attempted to explain, a real vacuum maintained by the *resistance* of the *atmosphere* against it. The original velocity having at length been sufficiently retarded by the air, the meteor becomes almost stationary; at this moment the vacuum suddenly collapses in the already rather dense air, and detonation ensues from repercussion of the air filling up the vacuum. The intensity of the sound ceases to be a matter of wonder when we consider the explosions caused by setting fire to bubbles filled with oxy-hydrogen gas suspended in the air. The so-called "consecutive explosions," or series of smaller detonations, may depend on the more or less gradual diminution of the cosmical velocity†.

Hitherto only *one* solid body has come into question. When, however, meteorites arrive in flocks or groups, as when 3000 stones (the largest 17 lbs.) fell from a detonating meteor at L'Aigle in France, on the 26th of April, 1803, nearly 200 at Stannern in Moravia, 22nd May, 1808, and some 30 or 40 near New Concord, Ohio, on May 1st, 1860, it may be supposed that even if one principal explosion "had commenced the action," subsequent detonations of the several isolated portions could likewise have taken place. I do not, however, believe that in the above-

* The meteor of Feb. 11, 1850, seen in England at a distance subsequently calculated at 50 miles, appeared, as at Hartwell, as large as the full moon; at places 100 miles distant from its vertical passage, as large as Venus. That of July 20, 1860, seen in the United States, had a decided apparent diameter nearly equal to that of the full moon, when at a height of 41 miles. That of October 18, 1783, at a height of 60 miles, over Lincolnshire, presented a similar appearance.—R. P. G.

† It may be here fair to mention that Mr. Benj. W. Marsh, of the United States, considers (in his Report in the Journal of the Franklin Institute, on the daylight meteor of Nov. 15, 1859, seen in New Jersey) that the aërolitic *detonation* arises from a series of decrepitations caused by the sudden expansion of the surface of the stony fragment, the whole time of flight not being sufficient to penetrate the mass. At the forward end these explosions would take place under great pressure, which might account for the loudness of the sound. The force of these explosions, directed backwards, would likewise tend to check the forward velocity of the mass. He also considers that the audible explosion, often lasting several minutes, is the result of the actual bursting of the meteor; for though the explosion might only occupy in reality half a second of time, yet in that interval the noise might be distributed over a distance of twenty or thirty miles.—R. P. G.

cited instances the stones were formed by the bursting or explosion of one large stone, but that they actually entered the atmosphere as a group or swarm of separate individuals, surrounded, as I have ventured to suggest, by what appears to us the luminous fireball*. I must here shortly allude to some peculiarities common both to *stone* and iron meteorites. One is the "pitted" or indented appearance usually presented on their surfaces. This "pitted" surface is particularly evident on the meteoric stone of Gross-Divina, which fell July 24th, 1837, in Hungary; and in the meteoric iron of Nebraska (Transactions of the Acad. of Sciences of St. Louis, vol. i. no. 4, plate 21). They are best developed on the side supposed to have lain backwards (see F in fig. 1). The side turned towards C is constantly more uneven and rough, as though it had pressed against a homogeneous mass of air, while air-currents may, like pointed flames, turn alternately towards the plane F. Marginal seams, as on the stones of Stannern, owing to the fusibility of the crust, give place to similar conjectures. As for the general form, the centre of gravity must have been in the forepart or front, as long as the meteorite was moving through space. When rotation round an axis had once commenced, and become accelerated in consequence of the propulsory movement diminishing, the point next in gravity must have taken its place in the plane of rotation, so that an iron mass of a flat form, as that of Agram is, could be propelled lying on its flat side. This iron is indeed of very different aspect on each of its broader planes; the rougher of them was certainly directed forward, as long as propulsion continued, the smoother surface remained turned backward, and not acted upon by external agents. The flat shape of the whole characterizes the Agram iron as having originally filled up a vein-like narrow cavity.

A disruptive explosion is only indubitable where, as in the stone-fall of Pegu (December 27, 1857), two fragments of the same stone, fitting each other exactly, have been found at a certain distance (in the case in question, 10 English miles!)†; such a disruption may cause a sound, as would a millstone under analogous circumstances, but certainly of less intensity

* See Haidinger on "eine Leitform [typical form] der Meteoriten," Vienna Acad. Proceedings, vol. xl. 1860, page 525, note. It yet by no means seems proved that meteorites do enter our atmosphere in groups, and that then an explosion again scatters them as they fall to the earth; it seems more probable, and certainly as possible, on the other hand, that one large friable mass, constituting probably the nucleus of the *single* fireball, as that of L'Aigle, bursts into many pieces, sometimes, no doubt, into hundreds of small fragments, as well as occasionally into the finest dust.—R. P. G.

† Haidinger, vol. xlii. p. 301 of the Proceedings of the Imperial Academy of Vienna, "Die Meteoritenfälle von Quenggouk bei Bassein in Pegu."

than that caused by the sudden collapse of the vacuum within a large fireball.

I have left unnoticed many other particulars concerning this class of phenomena, as well as attempts at explanations, and the views of others respecting them; and I even abstain from mentioning their connexion with M. Coulvier-Gravier's long-continued and accurate investigations. Meantime I have received through the editor's particular kindness, a copy of Dr. Laurence Smith's paper on the late fall of stones at New Concord, before referred to in this paper, and published in Prof. Silliman's American Journal (Jan. 1861, vol. xxxi. p. 87). In a letter addressed to me, Dr. Smith, for a long time a most careful investigator of meteorites, writes as follows:—"The method hitherto used in studying meteorites is still very deficient. To obtain tolerably accurate notions concerning their nature and origin, it would be necessary to submit to stricter criticism than is generally done the phenomena attending their fall, together with their physical properties, mineralogical as well as chemical. We have no right to speak of the explosion of large bodies within our atmosphere, while the so-called fragments of them show no marks of any explosion; nor should we speak of superficial heating to fusion in our atmosphere, while masses of 50 lbs. weight were found, ten minutes after their fall, not warmer than any stone exposed to the sun's rays, while others fell on dry leaves without leaving on them any traces of combustion or heating. So I could point out several other erroneous views relative to the fall of meteorites, and fully refuted by the chemical and physical facts proved by the stones themselves, and about which my account of the Ohio fall in Silliman's Journal is to give some hints."

I have overcome, I believe, this difficulty by placing in the first period, viz. that of cosmical motion within the atmosphere, the formation of the crust by superficial fusion, and in the second period (that of telluric motion, or simple falling to the earth) the compensation between the internal and external temperatures. At all events, I may feel satisfied to see my own views to some extent corroborated by the independent assent of such a distinguished and competent observer as Prof. Laurence Smith.

Particles separated from the surface of meteorites, appearing perhaps to observers in the shape of sparks, may again be covered with a thinner crust, and belong to a later but still cosmical portion of the orbit, as B C (fig. 2).

It would be desirable to ascertain in new cases, and as far as possible in those of older date, what is the direction of the line C D with respect to the diurnal movement (west to east) of the terrestrial surface, as the supposition of a tangential force adequate to the elevation required for experiments on free fall close to the earth's surface would prove inadmissible in the present case. At all events, observations on such fugitive phenomena require an uncommon amount of manifold circumspection.

Professor Laurence Smith concludes his above highly important memoir with the following propositions :—

1st. " The *luminous* phenomena attending the appearance of meteorites are not caused by *incandescence*, but rather by electricity, or some other agent.

2nd. " The sound comes not from the explosion of any solid body, but rather from *concussion* caused by its rapid movement through the atmosphere, partly also from electric discharge.

3rd. " Meteoric *showers* owe not their existence to fragments caused by the rupture of a single solid body, but to the division of *smaller* aërolites entering the atmosphere in groups.

4th. " The *black crust* is not of atmospheric origin, but is already formed in cosmical space, before the meteorites enter our atmosphere."

I think (says M. Haidinger) I have now given some explanation applicable to each of these four propositions ; some in the same sense (2nd and 3rd), the others (1st and 4th) in a somewhat different sense, without actually excluding mutual compromises. At all events, I would recommend the utmost accuracy in the observations of future meteoric falls, as well as in all investigations concerning those already known.

Part II.

Considerations respecting the Original Formation of Aërolites.

If the phenomena attending the fall of meteorites upon our own earth offer serious difficulties, considerations concerning the condition of their previous existence is by far a more arduous task. It must not be forgotten that there are two cosmical or planetary bodies in question ; the one a large one (our own globe), and a comparatively minute one (the meteorite). M. Leverrier, to whose talents and genius as an astronomer and mathematician we chiefly owe the discovery of the planet Neptune, felt himself authorized to pronounce, before the Paris Academy (October 1, 1860), a view or suspicion which he himself designates as "strange at the first aspect, but very possibly a reality*," viz. that in comparatively recent times new and small planets have been formed out of planetary matter existing at different distances around the sun, and possessing various degrees of density and volume†, but that their existence had remained unperceived till, during the last few years, the extraordinary amount of attention bestowed on the subject had at length been rewarded by a number of discoveries ‡.

The original formation and constitution of cosmical bodies have of late become the subject of the most diversified consideration. Some have tried to develope peculiarities previously more or less neglected; others (as my respected friend Prof. C. F. Naumann, in his classical 'Manual of Geology,' chapter on the Temperature of the Interior of the Globe, 2nd edit. 1857, vol. i. p. 36) have endeavoured to treat the question in a lucid and exhaustive synopsis, and to collect into a whole the opinions of men of the highest authority, rather for the purpose of respectful study, than to be made the subject of control or contradiction. Proceeding from simple correlations, I humbly venture to enunciate some few considerations respecting the formation of meteorites, which, eminently diversified as they are if taken individually, I must yet consider, along with Sir David Brewster, Prof. Laurence

* "Une idée, un soupçon, étrange peut-être au premier abord, mais qui peut très-bien être une réalité."—Moigno's *Cosmos*, 1860, vol. ix. p. 476.

† "L'espace autour du soleil est, on le sait, rempli de matière cosmique, et de matière cosmique de tous degrés de ténuité et de grosseur."—Ibid.

‡ As closely related to this portion of M. Haidinger's paper, the following extract from the 'Annual Register of Facts and Occurrences' for August 1861, may be here appropriately inserted:—"M. Leverrier, from the perturbations observed in the orbits of the planets Mercury, Venus, the Earth, and Mars, has still more recently come to the conclusion that there exists in our own system a considerable quantity of matter which has not hitherto been taken into account. In the *first* place, he supposes that there must exist within the orbit of Mercury, at about 0·17 of the Earth's distance from the Sun, a mass of matter nearly equal in weight to Mercury. As this mass of matter would probably have been observed before this, either in transit over the Sun's disc, or during total eclipses of the Sun, if it existed as one large planet, M. Leverrier supposes that it exists as a series of asteroids. *Secondly,* M. Leverrier sees reason to believe that there must be a mass of matter, equal to about one-tenth of the mass of the Earth, revolving around the Sun at very nearly the same distance as the Earth. This also he supposes split up into an immense number of asteroids [? meteorites]. *Thirdly,* M. Leverrier's researches have led him to the conclusion that the group of asteroids which revolve between Mars and Jupiter, sixty of which have already been seen and named, and had their elements determined, must have an aggregate mass equal to one-third of that of the Earth. He likewise thinks it is not unlikely that similar groups of asteroids exist between Jupiter and Saturn, Saturn and Uranus, and between Uranus and Neptune." See also *Cosmos* for June 1861, p. 639.—R. P. G.

Smith, and other naturalists, to be fragments of a larger or more voluminous body.

The formation of crystals requires a movement of molecules. This is a general and most irrefragable theorem. We see crystals deposited from gaseous and liquid solutions, or wherever the single molecules have acquired mobility under the influence of high temperature, as in substances in a state of fusion.

Whenever solid bodies are undergoing metamorphic changes, crystals form out of pulverulent, as well as out of relatively solid substances, when they undergo influences that make their intimate particles moveable. We do not know that crystallization can take place under any other circumstances, so long as the laws of nature, as now known to us, remain in force. We are entitled therefore to conclude that these bodies, coming from cosmical space into our atmosphere, took their point of departure from matter either in a gaseous, liquid, or pulverulent condition. The real point of departure then is matter in the form of an *impalpable powder,* assumed to be the initial deposit of any substance suspended in a gaseous or liquid solution.

Meteoric *stones,* almost pulverulent in their nature, with opake, nearly earthy fracture (as those of Reichenbach's second family), others whitish, without rounded particles, or dark-coloured (as those of Bokkeveld), are connected, by a long series of intermediate forms, with the highly crystalline meteorites of Chassigny, Juvenas, Shalka, and the solid compact ones of Seres, Tabor, Chantonnay, Segowlee, Parnallee, &c. In the same way a long series of structural transitions connect the non-crystalline meteoric *irons* of the Cape of Good Hope and Hemalga with the beautifully crystalline varieties of Agram, Elbogen, Lenarto, Lockport, Red River, Nebraska, ending with the most perfect type, that of Braunau. The crystals of olivine contained in the meteorites of Hainholz, Brahin, Atacama, and Krasnojarsk prove the power of crystallization to have remained active during a long period of time.

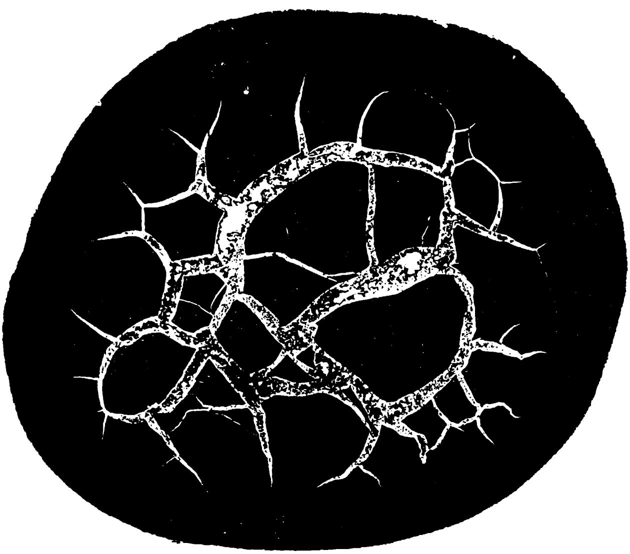
With our present knowledge of natural laws, these characteristically crystalline formations could not possibly have come into existence except under the action of *high temperature* combined with *powerful pressure;* though we have to search in vain for a *heated cosmical space,* as supposed by Poisson.

If we suppose within the glacial cold of space the existence of a pulverulent aggregate of all the substances found in meteorites, these could not be brought to crystallize gradually without some means or source by which heat could subsequently act upon them; and it may be questionable how far the *mutual pressure of masses,* or the attraction of a great whole on its isolated and still unconnected particles, may possibly suffice to produce such an effect.

I may here anticipate that a mere pulverulent aggregate having a rotatory movement in space must necessarily also acquire a spheroidal form dependent upon rotation, exactly like a liquid (according to Professor Plateau's experiments) not acted on by terrestrial attraction, and consequently in a state of free suspension.

A *septaria,* an object familiar to mineralogists and geologists, may serve to convey an idea of the effects of pressure acting from the circumference to the centre. Septariæ are spheroidal tuberiform bodies, occasionally slightly compressed in one direction (see fig 3), consisting of an external solid shell or crust of compact argillaceous sphærosiderite, filled up with the same substance, and intersected by numerous and somewhat imperfect veins of calcareous and magnesio-calcareous spar. Fig 3 is an autotype, taken from a specimen in the Imperial Museum of

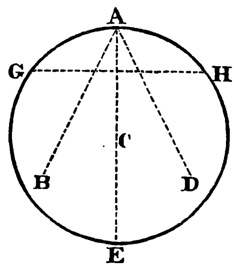
Fig. 3.



Vienna. The formation of such a septaria may be explained as follows:—within a stratum of clay, the particles richest in the carbonate of oxide of iron agglomerate or coalesce: the clay-stratum, and with it the sphærosideritic agglomeration, undergoes pressure, which, if sufficient, leaves in the interior a softer portion, more impregnated with water than the external crust from which that element has been squeezed more completely out. The sphærosiderite is naturally inclined to assume throughout the consistence of the external crust, which, like a vault or arch, acts in every direction against further contraction. Contraction ensues, and the fissures produced in consequence are subsequently filled up with crystalline deposits of substances held in solution by liquids penetrating, or *already contained* within, the interstices. At first magnesian carbonate of lime, then calcareous spar (occasionally also iron pyrites) are separated and deposited. Certainly there seems to exist a great analogy between the process of formation of such septariæ and that admissible as going on within a large pulverulent globe freely suspended in space. There is indeed no external pressure, but every stratum of ponderable matter exercises compression on the whole.

The following figure (fig. 4) is taken from Professor C. Koppe's "Physik und Meteorologie" (in Bädeker's collective publication, *Die gesammten Naturwissenschaften*). A point A, attracted at the surface by a material point B as a sum of many others, undergoes also attraction from another point D in a similar situation. The resulting line of direction falls between B and D, and passes through the centre C, along the line C E.

Fig. 4.



No determinate direction could prevail in the centre itself, where the mass of the sphere is uniformly distributed, and there the action of gravitation would completely cease (or be in equilibrium). As each particle on the surface tends to sink towards the centre, it finds an obstacle from another immediately subjacent, this from a third, &c., and this obstacle must be overcome or removed. The particles, at first unconnected, join or approximate more and more slowly; *pressure* is beginning and increasing. As on the surface of our globe, so we may suppose to have existed in meteorites, combinations of heterogeneous elements very different from each other in their specific gravities. Among other substances found in meteorites are oxygen, sulphur, phosphorus, carbon, chromium, silicium, hydrogen, cobalt, nickel, iron, aluminium, magnesium, calcium, potassium,—all of them extremely discrepant in density and other physical qualities. It is doubtful whether these existed as elementary particles, or in chemical combinations. In the present case, that first supposed may in reality have been precedent to the second mode or condition of existence.

Such a supposition may be considered more admissible than the views now more prevalent, that cosmical space possessed such an elevated temperature that the whole of matter existed in a gaseous state at the rate (as Vogt has calculated*) of only $\frac{13}{1,000,000}$ ths of a grain within the space of one cubic (German) mile. Such a supposition, however, lies far beyond us as regards experimental proof, even should we succeed, by connecting the past with the present, in producing correlations that might comparatively be considered "initial" ones. If the heavier metallic particles tend downwards along with others of less density which are pushed aside or even forced to ascend, while the whole surface pressing towards the centre is consequently continually diminishing in bulk, friction must unavoidably follow, and with it (as experience teaches) development of electricity and heat. We are, however, sufficiently acquainted with the phenomena attending the mutual combination of several among the above-named substances, as connected with combustion, oxidation, and chemical action in general, to enable us to pursue this part of our examination further.

On a former occasion (in "eine Leitform der Meteoriten," &c., Imp. Acad. Proceedings, vol. xl. p. 539) I mentioned an important communication from my respected colleague, Professor Schrötter, concerning the fact that substances whose mutual action under ordinary temperature goes on violently and with every appearance of intense combustion (as chlorine acting upon phosphorus, antimony, arsenic, or ammonia), when refrigerated to —80° in a mixture of solid carbonic acid and ether (so that chlorine is liquified under ordinary barometric pressure), remain in a state of complete mutual indifference. Under these circumstances, a slight elevation of temperature, especially if care has not been taken to keep up a low temperature by rapid evaporation, may be the cause of dangerous explosions.

The same is the case with *alcohol* and chromic or chlorochromic acid, with *ammonia* and chloride of phosphorus, with iodine or bromine and phosphorus (see Professor Schrötter's *Die Chimie nach ihrem gegenwärtigen Zustande, &c.*, Vienna, 1847 vol. i. p. 129). Professor Dumas reported on this fact in the Paris Academy (*Comptes Rendus*, January 1845, No. 3, p. 193), remarking that he had not been able to observe a complete inactivity,—probably, as Professor Schrötter now objects, because, accelerated evaporation having not been duly provided for, the elevation of temperature in conducting the experiment took place too rapidly.

When chemical action has once commenced, a continuous

* Nöggerath in "Geognosie und Geologie," in Bädeker's above-quoted 'Collective Publication.'

increase of temperature easily takes place, till, beneath the uppermost dry and pulverulent surface still exposed to the intense cold of cosmical space, a crust or shell has been formed, within which the atoms of matter, following the influence of their own peculiar forces and properties, unite in chemical combinations, and individualize themselves into separate crystals whose elevated temperature (chemical action having ceased) effects more or less lithoid consistence.

The attempts to explain the central heat of the Earth by means of electrical and chemical action come near the views enounced by Sir Charles Lyell, Prof. De la Rive, &c. (see Naumann, *loc. cit.* p. 63), while the compressive action of the uppermost terrestrial strata, here taken for a point of departure, is quite adequate to the conditions required by an uninterrupted process of induction. The above-named mobility of particles once admitted, the frequent occurrence of globules in meteorites is no longer a matter of surprise. These globules, sometimes rather regularly rounded (as in some oolites), and in other cases angular or fragmentary (with edges occasionally rounded at the same time, however), are imbedded in an agglomeration of looser and frequently arenaceous particles, for which I have proposed the name of "meteoric tufa*." The surface of these globules is characteristically surrounded with particles of iron, as in the meteorites of Seres, Assam, Renazzo, Parnallee, and others. The meteorites presenting the aspect of crystalline rocks unmixed with native iron, as in those of Chassigny, Juvenas, Shalka, &c., stand far higher in the scale of development than even those most compact meteorites which include minute particles of metallic iron dispersed through an arenaceous, granular, or tufaceous aggregate of lithoid substance. The highest stage of development is exemplified by the pure and highly crystalline meteoric irons, partially resembling the contents of metalliferous veins (as in the Agram iron), and partly surrounded in all directions with smooth surfaces, a still unexplained circumstance even if superficial oxidation during their progress through the terrestrial atmosphere is taken into account. Instances of a vein-like disposition of metallic iron (as in the Macao meteoric stone), or of iron pyrites (in those of Pegu, Allahabad), as well as genuine planes of fissure (Stannern), rough (Allahabad), or specular (Ensisheim, Lixna, &c), exactly like those in our terrestrial rocks, are of no rare occurrence in many meteorites. The meteoric iron of Tula, containing imbedded fragments of meteoric

* See Haidinger's paper, "Das von Herrn Dr. Auerbach entdeckte Meteoreisen von Tula," Imperial Academy, Meeting of November 29, 1860.

stone, discovered by Dr. Auerbach, proves beyond all doubt the occurrence of larger iron-masses in veins, and of their including fragments of the adjacent rocks*.

In his paper "On Meteorites in Meteorites" (Poggendorff's *Annalen*, 1860, vol. cxi. p. 353), Baron Reichenbach examines the mechanical composition of meteorites, paying particular attention to their rounded or angular particles, these last characterized as "fragments, broken and rolled pieces, and pebbles" (*loc. cit.* p. 384). Thirty-two meteorites (? stones), microscopically analysed, presented in their intimate or mechanical composition *five* distinct different substances, viz. sulphuret of iron (pyrites), native iron, oxidulated oxide of iron (magnetite), a grey, and a black substance†. Leaving aside some peculiarities in the terminology employed by Baron Reichenbach, as well as his criticism (p. 379) on the expression "secretion," stated to have been used by myself, while in fact I prefer the more neutral term "included substances," I could not give a better mode of considering in detail the structure of meteorites than has been rendered by Baron Reichenbach himself; and indeed the scientific world is obliged to him for it. There we have the character and nature of "meteoric tufa" pursued into their minutest details, indicating *successive* formation by the junction of the more intimate atoms of "cosmical dust,"—though, and this is the very foundation of either mode of consideration, this took place *not within the vaporous dust freely dispersed* through cosmical space, but within an *already* pre-existent and voluminous agglomeration, in which mutual attraction only became effective by producing real or absolute pressure. I really feel obliged to Baron Reichenbach for these statements, although undertaken with other intentions than to illustrate my own views on this matter.

The influence of solar heat has purposely been neglected in the preceding considerations, on account of the want of an atmosphere, in the strict sense of the term, in those spaces within which the formation of meteorites (in their *initial* condition or movement) may be admitted to take place. We know the temperature of planetary space to be far below that of the freezing-point, and we may assume an identical condition for the entire orbit of our globe, with a radius of 95,000,000 miles, as well as for the spaces beyond the orbit of Neptune (thirty times the distance of the Earth from the Sun); and even still further,

* See Haidinger's paper "On the Tula Meteoric Iron," *l. c.* note *ante.*

† These black and grey substances must refer to *stony particles.* I think Reichenbach's list might be extended so as to include magnetic pyrites (pyrrhotine), as well as a white substance.—R. P. G.

where probably more than one planet, and certainly comets, are pursuing their course, the solar distance of Neptune being itself only $\frac{1}{7000}$th of the interval between the Sun and the nearest fixed star*. During the period which the Earth takes to accomplish her annual revolution round the Sun, the latter, together with the whole solar system, has progressed (at the rate of about seven German miles a second) through a space of which the Earth's distance from the Sun is only the eleventh part†. Professor Koppe‡ says, "All circumstances agree in confirming the supposition that, for a period of 3300 years, the average temperature of Palestine has not undergone any notable change." During this period our globe has run in length some 36,300 times its own distance from the Sun—a course not to be achieved by light itself in less than 209 days, though this enormous distance is small indeed compared with the unlimited range of space itself!

Taking for granted that the weight of meteorites falling upon our earth's surface amounts yearly to 450,000 lbs. (Vienna weight), if not more§, and consequently to 450 millions of pounds in a millennial period, Baron Reichenbach has brought under consideration the question, whether in the course of ages such an increase of ponderable matter would not be without notable influence on other as well as physical correlations connected with our globe in the solar system‖. The length of such periods as are here taken into account is after all almost too enormous for our imagination to grasp: to accomplish the formation of a meteoric agglomeration equal in size to our globe would require 3000 trillions of years.

Another consideration, however, may here find appropriate notice. We may ask, if then our globe in the course of one solar revolution can thus admit of an increase of matter to the amount of 450,000 lbs., what would have ensued if it had followed a different path through space? Might not the increase have been nearly similar in amount in describing any orbit of equal length?

Mr. Greg's elaborate comparisons, indeed, prove meteoric falls to be less frequent at the time of perihelion than at the time of

* See Mädler's "Astronomie" in Bädeker's 'Collective Publication,' vol. iii. p. 595.

† See Mädler, *loc. cit.* p. 629. According to Arago and Herschel, the velocity of our sun in stellar space is only five English miles, or one German mile.—R. P. G.

‡ "Physik und Meteorologie," in Bädeker's 'Collective Publication,' vol. i. p. 169.

§ Probably too large an estimate by three-fourths. See Note at the end of this paper.—R. P. G.

‖ See Nöggerath's "Geologie und Geognosie," in Bädeker's 'Collective Publication,' p. 110.

aphelion. The Sun himself, however, as before shown, far from being stationary, is moving with considerable velocity through stellar space. While the Earth has received an increase of 450,000 lbs., it has completed its orbital movement round the Sun ($2r\pi$, r being the average distance of our globe from the Sun); and in the same space of time, by sharing in the progressive movement of the solar system as a whole, it has run through a space of $11r$. It may be sufficient to admit for the case in question, the approximative expression $r\sqrt{(121+4\pi_2)}$, and even $13r$ (instead of $12\cdot65r$). If we compare mutually the space (s) run through by the Earth, and the space (S) run through by the whole solar system in one year (even if we admit for s nearly double the diameter of Neptune's orbit—120 times the Earth's distance from the Sun,—and for the diameter of our globe itself, in round numbers say 2000 [German] miles, far exceeding it, its real value $=0\cdot0001r$), we obtain the following numbers:—

$$\begin{aligned} S : s &= 120^2 \times 11 : 13 \times 0\cdot0001^2 \\ &= 14{,}400 \times 100{,}100{,}100 \times 11 : 13 \\ &= 1{,}440{,}000{,}000{,}000 \times 11 : 13 \\ &= 15{,}840{,}000{,}000 : 13 \\ &= 1{,}218{,}460{,}000{,}000 : 1. \end{aligned}$$

The space-number of more than one billion, multiplied by 450,000 lbs. (the supposed yearly increase of our globe), gives in pounds the total weight or mass of meteoric matter existing and moving about in every direction within the space above assigned to our solar system. This sum, of over half a trillion of pounds, is, however, not very considerable when compared with the weight of our own globe, calculated to amount to 13½ quadrillions of pounds*. If we suppose these 450,000 lbs. of meteorites to be united into one sphere, the diameter of this sphere would be to the diameter of our globe as 1 to 290·8.

The weight of the terrestrial globe is always to the total weight (450,000 lbs.) of meteorites moving in every direction within the space annually run through by our solar system as 24 millions are to unity. These are then the calculated results arising out of the above-mentioned supposition. A far greater proportion of solid matter distributed into small bodies would be obtained, if we were allowed to take into account the great number of meteors visible within our atmosphere in the shape of shooting-stars, and bolides that do not apparently deposit solid matter, and whose light is probably developed by compression of air, or, if not in every case by actual combustion, as supposed by Reichenbach, at least (as regards meteoric iron) after the manner of

* See Nöggerath's "Geologie und Geognosie," in Bädeker's 'Collective Publication,' p. 110.

"Callum's drops or globules." Professor T. H. Newton of Yale College, New Haven, Conn. U.S., says (*New York Tribune*, August 22, 1860), "it is calculated from perfectly reliable observation, that not less than 10 millions of meteors enter the atmosphere every day, and are burnt up*."

This would then be 3650 millions per annum, which would again materially increase the total amount of meteoric matter contained within the above-mentioned space. But is there not some probability that beyond our own system of fixed stars, all space is replete with such bodies, of which only a proportional *minimum*, and that transitorily, make up part of our own solar system? Not that all of them may be burned away or melted; for the large 4 lb. stone of Segowlee, described by me, has its edges quite sharp and nearly unaltered, some of them being rounded only to a depth of not quite one-twelfth of an inch. Meteorites composed of less dense matter, while moving rapidly, may be frequently again repelled into space by the resistance of compressed air. For this reason meteorites of earthy or carbonaceous-like consistence, as those of Bokkeveld, Alais, &c., are of particular importance, as well as rare. Meteorites are far behind our terrestrial rocks with regard to diversity of mineralogical character. The minerals composing granite, gneiss, mica-schist, and others, representing the most solid basis of the terrestrial crust, are wanting in them; and, to name a particularly important species, they are totally destitute of pure silica or quartz †.

* If, as I presume he does, Prof. Newton means that this represents the total number of meteors which enter our atmosphere daily, and that all these are, as a matter of course, consumed in it, I think he is mistaken, the number of meteors so consumed being in all probability limited to such only as burst or become dissipated in sparks. These form but a small portion of those that apparently fly almost instantaneously through the upper strata of the air (at an average height of 65 miles, as recently proved by Prof. Secchi at Rome), and pass off again, perhaps tangentially, into interplanetary space. Prof. Vaughan of Cincinnati, U.S., thinks it probable that the solid nucleus of an ordinary shooting-star is no bigger than a hailstone; and this is only analogous to what takes place with large aërolitic meteors. There are cases of large and well-observed meteors, which after bursting, sometimes even with noise, into two or more parts at a height of 40 miles or so, have undoubtedly again passed into planetary space, —another proof also that the smaller shooting-stars may do the same.

It must not be forgotten in these rather speculative calculations, that the same groups of meteors may frequently repeat themselves, that is, return periodically without visible or material loss, and that, in fact, by far the greater number of meteors seen are doubtless those that are *periodical* and consequently belong to our own system. Unless it can be otherwise proved, it would seem premature to suppose otherwise than that by far the larger portion of meteors and meteorites of all kinds belong to the solar system, and not to stellar space.—R. P. G.

† Since these lines were written, my highly respected friend Prof. G.

The subject of progressive changes in the world of meteorites, as hitherto exemplified by specimens within our knowledge, is thus for the present confined within narrow limits. Are these progressive changes of a character likely to terminate the proper existence of a celestial body by its definitive division into fragments? or is the possibility of such a "breaking up" justified by any precedent not opposed to the laws of nature as known to us? A few considerations made from this point of view may serve to supply a real *desideratum*.

I intend to sketch them here as briefly as possible, taking my point of departure from a *septaria*, whose constitution I have already explained. As in such a terrestrial concretion, so the outward crust of a cosmical body may become solid, presenting a stony appearance, under the centripetal pressure of gravitation, long before its interior has undergone a like degree of compression. I take our own globe as a point of comparison for data expressed in figures. Originally the particles of the solid terrestrial crust lying next each other may possibly have enjoyed a certain amount of mobility; this of course no longer exists. The maximum of pressure has its seat at a depth where the greater and more solid mass rests on the interior compressed by it in a descending direction. We are entitled to suppose this underlying mass is maintained by this very pressure in a state of incandescent fusion. Atmospheric pressure represented by the weight of a column of water 32 feet high, amounts to 1804·8 lbs. per square foot. A column of 10 feet average height of any substance whose specific gravity is $= 3·0$, acts nearly with the same degree of force. At the height of 1 German mile (24,000 feet) the pressure is $=2400$ atmospheres; at 5 miles (25 miles English) (a measure generally adopted to express the solid terrestrial crust*) it would amount to no less than 12,000 atmospheres. A solid pressing on our globe with the weight of 1 lb. would in the Moon press only with $\frac{2}{13}$ lb., and if transported on to the Sun's surface with $28\frac{1}{3}$ lbs.† The pressure produced on

Rose of Berlin, has proved beyond doubt the occurrence of *quartz* in isolated crystals in the meteoric iron of Ziquipilco (Toluca).—W. H.

It may be here mentioned that Berzelius, Rammelsberg, and Dr. Laurence Smith have pointed out strongly and with much truth, the general resemblance that meteorites, in whole or part, not unfrequently bear to certain *volcanic* rocks. See Dr. Buchner's work, *Die Feuermeteore insbesondere Meteoriten, &c.*, p. 175.—R. P. G.

* Important and more recent researches on the question of the thickness of the earth's crust, as conducted by Professor Hopkins and others in this country, may necessitate our raising M. Haidinger's estimate of only 25 miles of a solid crust to something like a *minimum* of 300 miles. This is more a question of degree, however, and does not materially affect M. Haidinger's line of argument.—R. P. G.

† Mädler, *loc. cit.* pp. 577 and 556.

our globe by a solid crust of 5 German miles thick, would require in the Moon a crust of 32½ miles in thickness, and in the Sun a crust of only $\frac{3}{17}$ of a mile thick, or 4235 feet.

Original pressure takes place only so long as a body is not completely solidified; from that moment perfect equilibrium is established within it; pressure, however, must again take place whenever change of temperature modifies the state of rigidity. A rigid body is always apt to conduct heat. That kind of heat whose laws of increase we have to deal with while pursuing investigations on the central heat of the Earth, is *conducted* heat, transmitted from heat generated, or existing, at greater depths, as more immediately shown by volcanic eruptions. In the regions where volcanic vents open in great numbers on the surface, "the smelted interior of our planet," as Humboldt emphatically says, "stands most in permanent communication with the atmosphere." In our times this region is a zone between 75° W. and 125° E. long. of Paris, and 47° S. to 66° N. lat., running N.W. in the western portion of the Southern Ocean*. It deserves consideration, that the whole continent of the Old World lies westward of this zone, separated from it towards the south-west only by the Indian Ocean, offering eastwards (as in the Southern Ocean itself) considerable "areas of subsidence†," and that towards the east of the Southern Ocean the American continent is again fringed with a series of active volcanoes. A remarkable connexion exists between these circumstances and the fact that the altitude of atmospheric strata at the same time rapidly decreases as we approach the antarctic pole,—just as though a mass of solid highlands had in those parts pressed on the interior of the globe at some early period of its existence, and the terrestrial crust had been broken, and its parts mutually dislocated into the general and more marked outlines now visible on its surface. Should the solidification of the crust proceed so far as to become stationary before the particles of primitive cosmical matter enclosed in it have completed their approximation, these might indeed commence a new and independent process of formation, giving rise to a second shell concentric with the first or external one, and enclosing another internal focus of volcanic activity, the primitive one having become meanwhile extinct.

If the sum of 65 miles, expressing the thickness of the Moon's crust taken double, is subtracted from her diameter ($=\frac{264}{1000}$ of the Earth's), and with a density of about 3·37‡,

* *Physical. und geognost. Erinnerungen. Reise der Novara um die Erde*, p. 20.

† See Darwin's 'Theory of the Formation of Coral Reefs.' Humboldt, *loc. cit.*

‡ Arago's 'Popular Astronomy,' translated by Hankel, vol. iv. p. 35.

there would, at all events, remain an interior space of 403 miles, within which the formation of another such spherical shell might possibly proceed. Nevertheless it is not to be expected that further condensation out of the primitive molecular state should go on without some disturbance in a medium of such a temperature as prevails in planetary space. If contraction produces an actual internal vacuum, a *violent disruption* of the crust falls within the bounds of possibility. Admitting that a compensation of temperature by conduction or communication of heat to have already taken place, and supposing every solid shell to be hermetically sealed under a high temperature, an event quite opposite to the above-mentioned one might be expected with some degree of probability. Gases developed within this shell and brought to high tension, might indeed cause a violent explosion, exactly like that arising from ignited gunpowder enclosed within a hollow projectile.

What is the actual cause of the densities of the planetary bodies within our solar system being so different from each other? Does it merely arise from the natural correlation of the elements composing them, as in our globe, or from a progressive development in the earlier stages of their existence? The densities of these bodies are expressed by the following numbers:—Mercury, 6·71; Earth, 5·44; Mars, 5·15; Venus, 5·02; the Moon, 3·37; Sun, 1·37; Jupiter, 1·29; Neptune, 1·2; Uranus, 0·98; Saturn, 1·75.

Olbers is known to have first enounced the hypothesis that the minor planets Ceres and Pallas, discovered by Piazzi and himself, were probably mere fragments of a pre-existing and larger planet. After the discovery of Juno and Vesta, Lagrange* investigated the intensity of an explosive force sufficient to rend a planet into pieces, in order to permit a fragment of it to become a comet, or, to use a more accurate expression, move in an orbit similar to a comet. He found that an impulsion equal to the velocity of a cannon-ball multiplied by 12–15, that is 16,800–21,000 feet per second (the velocity of a cannon-ball being 1400 feet a second, and equal to that of a point at the equator in its diurnal rotation), would be sufficient to throw the fragments of a planet (the radius of its orbit being supposed to be equal to the distance of our globe from the Sun multiplied by 100) into progressive or retrogressive, elliptical or parabolical comet-orbits—the greater number of them even into hyperbolical ones, so that, after their first perihelion, they would disappear for ever from our system†.

* "Sur l'Origine des Comètes." Lu au Bureau des Longitudes, le 29 Janvier, 1812.—*Connaissance des Tems, &c.* pour l'an 1814, Avril 1812, p. 211.

† Baron Reichenbach has expressed an opinion that meteorites may

Certainly there is great difficulty in forming an idea where and how fragments of genuine solid rocks (as meteorites undoubtedly are) could be first violently broken from their parent repository and then hurled into distant solar systems; nevertheless their characteristic fragmentary form, together with the cosmical velocity of their course, leaves no room for any other solution. So daring a supposition, paying, however, due attention to Nature's laws as far as they are known to us, must, however, from time to time, provoke reiterated criticism.

I thought it desirable therefore to give here a short conspectus of such views concerning meteoric phenomena as have from time to time crossed my mind, or been the subject of distinct communications to the Academy, though at the same time I freely admit I may have been intruding into a region of natural science for the investigation of which I am but very imperfectly prepared. I must ask for some indulgence in this attempt to trace the outlines of views in some way different from current ones—the more so since they are intended to establish merely a kind of programme for more accurate investigations.

In an earlier period of development in human society, the "*nonum prematur in annum*" may have been more easily obeyed than it is in our times. Accelerated publication, however, has also its advantages, as contemporaneous investigators familiarized with the matter find in it a point of comparison for their own either analogous or contradictory views. For myself, some portion or other of my views have been more than once the subject of conversation and epistolary intercourse.

At least I hope I may have been successful in my endeavours to follow the strict rules of scientific induction for arriving at the result aimed at in this paper. During the whole course of these considerations I have made it my duty implicitly to obey the precept of our great master, Humboldt, that, "even within merely conjectural regions, uncontroled or arbitrary opinions, independent of induction, should never be allowed to prevail."

Note.—Baron Reichenbach's estimate of an annual meteoric deposit on the surface of our globe, amounting to 450,000 (Vienna) pounds, is certainly considerably over the mark. In his paper on this

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originally have been condensed from comet-dust; that this is quite contrary to M. Haidinger's opinion, I have good reason to believe. It may perhaps appear a little difficult to believe that, were any small planet or satellite of a planet to burst, some of the fragments would for ever be hurled beyond the influence of the sun,—though, as in the case possibly of the sixty asteroids, the original orbital conditions of the parent mass might become a good deal modified.—R. P. G.

subject (see Poggendorff's *Annalen*, vol. cv. p. 554 *et seq.*) he calculates there are 4500 meteoric falls per annum, averaging 100 lbs. per fall in weight. Assuming, as we perhaps may do, that he has not materially over-estimated the weight of each fall, he has certainly exaggerated their annual number. Supposing, in the first place, as I believe we may, that detonating meteors are equally aërolitic, whether stones are picked up or not, since most meteoric stones have resulted from a detonating meteor in the first instance, then for the last sixty years, over an area of 900,000 square miles, comprising the countries of Great Britain and Ireland, France, Germany (inclusive of Austria, Prussia, Hungary, &c.), and Italy, we find recorded (see my "Catalogue of Meteorites and Meteors" in the last volume of the British Association Report for the Oxford Meeting, p. 48) *sixty-nine* actual stone-falls, and *seventy-two* meteors accompanied with detonations from which no material *residuum* was obtained; say in all 144 cases of aërolitic phenomena. That is about $2\frac{1}{3}$ recorded instances per annum for an area of 900,000 square miles; and taking the superficial area of the whole globe at 197,000,000 square miles, we obtain rather over *five hundred* falls (511) as the number likely to be observed, were all the world covered by land and peopled in like manner by Europeans.

Now, what proportion this number would bear to those that absolutely do fall annually, but which are never noticed or not recorded in scientific works, it is not very easy to say; but from various reasons it may be fairly estimated at more than half of the entire number. Chladni and Humboldt have estimated the total number at 700.

There are several reasons for inducing us to increase the annual number of observed and recorded falls, viz. 500, to 800 or 900, as the *actual* number that fall, and not more. First, the fact that one-half the human race are supposed to be asleep or in their houses nearly twelve hours out of the twenty-four, must tend to limit considerably the number of observations; on the other hand, we are not without instances of stone-falls and other aërolitic phenomena, detonating meteors more especially, occurring during the night-time; while again, as I have shown in the tabulated results of my large Catalogue, p. 118, the greatest number of stone-falls seem to occur in the afternoon about 4 o'clock, not only as against falls taking place during the night, but as compared even with the corresponding hours in the forenoon, equally favourable as a time for such observations. Though stones have not frequently been picked up during the night-time, we may bear in mind that the night is a most favourable time for seeing large and brilliant aërolitic meteors, and that the darkness does not prevent us from hearing the violent detonations usually accompanying the explosion of an aërolitic meteor. Then, again, it is not unusual for an aërolitic meteor to pass overhead some hundreds of miles, and for the detonation to be heard over from twenty to forty miles square; and some persons would probably notice one or the other. Now as I have included as *aërolitic*, meteors from which no stones have been picked up, it will I think be admitted that to double the entire number of both classes actually recorded in catalogues drawn from every available source is a reasonable estimate, especially when based on observations made in civilized and densely peopled countries like England, France, and Germany. How few persons, I may also add, are there who have ever in their lifetime either seen a meteoric stone fall, or even heard the always violent detonation of an exploding aërolitic meteor. There seems to have been of the latter only three instances recorded as observed in England during the last ten years, and no well-authenticated instance of a meteoric-stone fall since 1835, and that a single one of about 2 lbs. in weight! To know whether a meteoric stone has fallen, it is then not exactly necessary to calculate the proportions of waste or forest ground, &c. that exists even in Europe, as Baron Reichenbach argues, in order to arrive at the number of stones *not* picked up, if we assume that aërolitic detonating meteors are seen and heard as a rule over very large areas, and count as actual falls in our calculations. So striking indeed are the phenomena usually attending the fall and appearance of aërolites and aërolitic meteors, that I much question whether fully *two-thirds* of the real number would not certainly be recorded in the daily or scientific journals, say of England and France. Instead, therefore, of placing the total weight of meteoric matter annually deposited on the earth as high as 450,000 lbs., as calculated by Baron Reichenbach, I am inclined to estimate it at probably less than 100,000 lbs. This is, however, more a question of degree, and does not vitally affect the ulterior argument involved in the problem proposed by Baron Reichenbach and M. Haidinger—a problem not without importance and interest, though somewhat speculative.—R.P.G.