SCIENCE.—SUPPLEMENT.

FRIDAY, AUGUST 20, 1886.

METEORITES, METEORS, AND SHOOTING-STARS.

You are kindly giving to me an hour to-night in which I may speak to you. I do not have enough confidence in myself to justify me in speaking to such an audience as this upon one of those broad subjects that belong equally to all sections of the association. The progress, the encouragements, and the difficulties in each field are best known to the workers in the field, and I should do you little good by trying to sum up and recount them. Let me rather err, then, if at all, by going to the opposite extreme.

Two years ago your distinguished president instructed and delighted us all by speaking of the pending problems of astronomy, what they are, and what hopes we have of solving them. To one subject in this one science, a subject so subordinate that he very properly gave it only brief notice, I ask your attention I propose to state some propositions which we may believe to be probably true about the meteorites, the meteors, and the shooting-stars.

In trying to interest you in this subject, so remote from the studies of most of you, I rely upon your sense of the unity of all science, and at the same time upon the strong hold which these weird bodies have ever had upon the imaginations of men. In ancient times temples were built over the meteorite images that fell down from Jupiter, and divine worship was paid them; and in these later days a meteorite stone that fell last year in India became the object of daily anointings and other ceremonial worship. In the fearful imagery of the Apocalypse, the terrors are deepened by there falling 'from heaven a great star burning as a torch,' and by the stars of heaven falling "unto the earth as a fig tree casteth her unripe figs when she is shaken of a great wind." The "great red dragon having seven heads and ten horns, and upon his heads seven diadems," is presented in the form of a huge fire-ball. "His tail draweth the third part of the stars of heaven, and did cast them to the earth." Records of these feared visitors, under the name of flying dragons, are found all through the pages of the monkish chroniclers of the middle ages. The Chinese appointed officers to record the passage of meteors and comets, for they were thought to have somewhat to say to the weal or woe of rulers and people.

By gaining in these later days a sure place in science, these bodies have lost their terrors; but so much of our knowledge about them is fragmentary, and there is still so much that is mysterious, that men have loved to speculate about their origin, their functions, and their relations to other bodies in the solar system. It has been easy, and quite common too, to make these bodies the cause of all kinds of things for which other causes could not be found.

They came from the moon; they came from the earth's volcanoes; they came from the sun; they came from Jupiter and the other planets; they came from some destroyed planet; they came from comets; they came from the nebulous mass from which the solar system has grown; they came from the fixed stars; they came from the depths of space.

They supply the sun with his radiant energy; they give the moon her accelerated motion; they break in pieces heavenly bodies; they threw up the mountains on the moon; they made large gifts to our geological strata; they cause the auroras; they give regular and irregular changes to our weather.

A comparative geology has been built up from the relations of the earth's rocks to the meteorites; a large list of new animal forms have been named from their concretions; and the possible origin of life in our planet has been credited to them.

They are satellites of the earth; they travel in streams, and in groups, and in isolated orbits about the sun; they travel in groups and singly through stellar spaces; it is they that reflect the zodiacal light; they constitute the tails of comets; the solar corona is due to them; the long coronal rays are meteor streams seen edgewise.

Nearly all of these ideas have been urged by men deservedly of the highest repute for good personal work in adding to human knowledge. In presence of this host of speculations it will not, I hope, be a useless waste of your time to inquire what we may reasonably believe to be probably true. And if I shall have no new hypotheses to give you, I offer as my excuse that nearly all possible ones have been already put forth. This as-

Address to the American association for the advancement of science at Buffalo, Aug. 18, 1886, by Prof. H. A. Newton, of New Haven, the retiring president of the association.

sociation exists, it is true, for the advancement of science, but science may be advanced by rejecting bad hypotheses as well as by framing good ones.

I begin with a few propositions about which there is now practical unanimity among men of science. Such propositions need only be stated. The numbers that are to be given express quantities that are open to revision and moderate changes.

1. The luminous meteor tracks are in the upper part of the earth's atmosphere. Few, if any, appear at a height greater than one hundred miles, and few are seen below a height of thirty miles from the earth's surface, except in rare cases where stones and irons fall to the ground. All these meteor tracks are caused by bodies which come into the air from without.

2. The velocities of the meteors in the air are comparable with that of the earth in its orbit about the sun. It is not easy to determine the exact values of those velocities, yet they may be roughly stated as from fifty to two hundred and fifty times the velocity of sound in the air, or of a cannon ball.

3. It is a necessary consequence of these velocities that the meteors move about the sun and not about the earth as the controlling body.

4. There are four comets related to four periodic star-showers that come on the dates April 20, August 10, November 14, and November 27. The meteoroids which have given us any one of these star-showers constitute a group, each individual of which moves in a path which is like that of the corresponding comet. The bodies are, however, now too far from one another to influence appreciably each other's motions.

5. The ordinary shooting-stars in their appearance and phenomena do not differ essentially from the individuals in star-showers.

6. The meteorites of different falls differ from one another in their chemical composition, in their mineral forms, and in their tenacity. Yet through all these differences they have peculiar common properties which distinguish them entirely from all terrestrial rocks.

7. The most delicate researches have failed to detect any trace of organic life in meteorites.

These propositions have practically universal acceptance among scientific men. We go on to consider others which have been received with hesitation, or in some cases have been denied.

With a great degree of confidence, we may believe that shooting-stars are solid bodies. As we see them they are discrete bodies, separated even in prolific star-showers by large distances one from another. We see them penetrate the air many miles, that is, many hundred times their own diameters at the very least. They are sometimes seen to break in two. They are sometimes seen to glance in the air. There is good reason to believe that they glance before they become visible.

Now these are not the phenomena which may be reasonably expected from a mass of gas. In the first place, a spherical mass of matter at the earth's distance from the sun, under no constraint, and having no expansive or cohesive power of its own, must exceed in density air at one-sixth of a millimetre pressure (a density often obtained in the ordinary air pump), or else the sun by his unequal attraction for its parts will scatter it. Can we conceive that a small mass of gas, with no external restraint to resist its elastic form, can maintain so great a density?

But suppose that such a mass does exist, and that its largest and smallest dimensions are not greatly unequal; and suppose further that it impinges upon the air with a planetary velocity; could we possibly have as the visible result a shooting-star? When a solid meteorite comes into the air with a like velocity, its surface is burned or melted away. Iron masses and many of the stones have had burned into them those wonderful pittings or cupules which are well imitated, as M. Daubrée has shown, by the erosion of the interior of steel cannon by the continuous use of powder under high pressure. They are imitated also by the action of dynamite upon masses of steel near which the dynamite explodes. Such tremendous resistance that mass of gas would have to meet! The first effect would be to flatten the mass, for it is elastic; the next to scatter it, for there is no cohesion. We ought to see a flash instead of a long burning streak of light. The mass that causes the shooting-star can hardly be conceived of except as a solid body.

Again, we may reasonably believe that the bodies that cause the shooting-stars, the large fireballs, and the stone-producing meteor all belong to one class. They differ in kind of material, in density, in size. But from the faintest shooting-star to the largest stone-meteor, we pass by such small gradations that no clear dividing lines can separate them into classes. See wherein they are alike:—

1. Each appears as a ball of fire traversing the apparent heavens, just as a single solid but glowing or burning mass would do.

2. Each is seen in the same part of the atmosphere, and moves through its upper portion. The stones come to the ground, it is true, but the luminous portion of their paths generally ends high up in the air.

3. Each has a velocity which implies an orbit about the sun.

4. The members of each class have apparent motions which imply common relations to the horizon, to the ecliptic, and to the line of the earth's motion.

5. A cloudy train is sometimes left along the track, both of the stone-meteor, and of the shooting-star.

6. They have like varieties of colors, though in small meteors they are naturally less intense and are not so variously combined as in large ones.

In short, if the bodies that produce the various kinds of fire-balls had just the differences in size and material which we find in meteorites, all the differences in the appearances would be explained; while, on the other hand, a part of the likenesses that characterize the flights point to something common in the astronomical relations of the bodies that produce them.

This likeness of the several grades of luminous meteors has not been admitted by all scientific men. Especially it was not accepted by your late president, Prof. J. Lawrence Smith, who by his studies added so much to our knowledge of the meteorites. The only objection, however, so far as I know, that has been urged against the relationship of the meteorites and the star-shower meteors, and the only objection which I have been able to conceive of that has apparent force, is the fact that no meteorites have been secured that are known to have come from the star-showers. This objection is plausible, and has been urged, both by mineralogists and astronomers, as a perfect reply to the argument for a common nature to all the meteors.

But what is its real strength? There have been in the last hundred years five or six star-showers of considerable intensity. The objection assumes that if the bodies then seen were like other meteors, we should have reason to expect that among so many hundreds of millions of individual flights a large number of stones would have come to the ground and have been picked up.

Let us see how many such stones we ought to expect. A reasonable estimate of the total number of meteors in all of these five or six star-showers combined makes it about equal to the number of ordinary meteors which come into the air in six or eight months. Inasmuch as we can only estimate the numbers seen in some of the showers, let us suppose that the total number for all the star-showers was equal to one year's supply of ordinary meteors. Now the average annual number of stone-meteors of known date from which we have secured specimens has, during this hundred years, been about two and a half.

Let us assume, then, that the luminous meteors are all of like origin and astronomical nature; and further assume that the proportion of large ones, and of those fitted to come entirely through the air without destruction, is the same among the star-shower meteors as among the other meteors. With these two assumptions, a hundred years of experience would then lead us to expect two, or perhaps three, stone-falls from which we secure specimens during all the half-dozen star-showers put together. To ask for more than two or three is to demand of star-shower meteors more than other meteors give us. The failure to get these two or three may have resulted from chance, or from some peculiarity in the nature of the rocks of Biela's and Tempel's comets. It is very slender ground upon which to rest a denial of the common nature of objects that are so similar in appearance and behavior as the large and small meteors.

It may be assumed, then, as reasonable that the shooting-stars and the stone-meteors, together with all the intermediate forms of fire-balls, are like phenomena. What we know about the one may with due caution be used to teach facts about the other. From the mineral and physical nature of the different meteorites, we may reason to the shooting-stars, and from facts established about the shooting-stars we may infer something about the origin and history of the meteorites. Thus it is reasonable to suppose that the shooting-stars are made up of such matter and such varieties of matter as are found in meteorites. On the other hand, since star-showers are surely related to comets, it is reasonable to look for some relation of the meteorites to the astronomical bodies and systems of which the comets form a part.

This common nature of the stone-meteor and the shooting-stars enables us to get some idea, indefinite but yet of great value, about the masses of the shooting-stars. Few meteoric stones weigh more than one hundred pounds. The most productive stone-falls have furnished only a few hundred pounds each, though the irons are larger. Allowing for fragments not found, and for portions scattered in the air, such meteors may be regarded as weighing a ton, or it may be several tons, on entering the air. The explosion of such a meteor is heard a hundred miles around, shaking the air and the houses over the whole region like an earthquake. The size and brilliancy of the flame of the ordinary shooting-star is so much less than that of the stone-meteor that it is reasonable to regard the ordinary meteoroid as weighing pounds, or even ounces, rather than tons.

Determinations of mass have been made by measuring the light and computing the energy needed to produce the light. These are to be regarded as lower limits of size, because a large part of the energy of the meteors is changed into heat and motion of the air. The smaller meteors visible to the naked eye may be thought of without serious error as being of the size of gravel stones, allowing, however, not a little latitude to the meaning of the indefinite word 'gravel.'

These facts about the masses of shooting-stars have important consequences. The meteors, in the first place, are not the fuel of the sun. We can measure and compute within certain limits of error the radiant energy emitted by the sun. The meteoroids large enough to give shooting-stars visible to the naked eye are scattered very irregularly through the space which the earth traverses; but in the mean each is distant two or three hundred miles from its near neighbors. If these meteoroids supply the sun's radiant energy, a simple computation shows that the average shooting-star ought to have a mass enormously greater than is obtained from the most prolific stone-fall.

Moreover, if these meteoroids are the source of the solar heat, their direct effect upon the earth's heat by their impact upon our atmosphere ought also to be very great: whereas the November star-showers, in some of which a month's supply of meteoroids was received in a few hours, do not appear to have been followed by noticeable increase of heat in the air.

Again, the meteoroids do not cause the acceleration of the moon's mean motion. In various ways, the meteors do shorten the month as measured by the day. By falling on the earth and on the moon, they increase the masses of both, and so make the moon move faster. They check the moon's motion, and so, bringing it nearer to the earth, shorten the month. They load the earth with matter which has no momentum of rotation, and so lengthen the day. The amount of matter that must fall upon the earth in order to produce in all these ways the observed acceleration of the moon's motion, has been computed by Professor Oppolzer. But his result would require for each meteoroid an enormous mass, one far too great to be accepted as possible.

Again, the supposed power of such small bodies,—bodies so scattered as these are, even in the densest streams,—to break up the comets or other heavenly bodies; and also their power, by intercepting the sun's rays, to affect our weather, must, in absence of direct proof to the contrary, be regarded as insignificant. So, too, their effect in producing geologic changes by adding to the earth's strata has, without doubt, been very much over-estimated. During a million of years, at the present rate of, say, fifteen millions of meteors per day, there comes into the air about one shooting-star or meteor for each square foot of the earth's surface.

To assume a sufficient abundance of meteors in ages past to accomplish any of these purposes, is, to say the least, to reason from hypothetical and not from known causes. The same may be said of the suggestion that the mountains of the moon are due to the impact of meteorites. Enormously large meteoroids in ages past must be arbitrarily assumed, and, in addition, a very peculiar plastic condition of the lunar substance, in order that the impact of a meteoroid can make in the moon depressions ten, or fifty, or a hundred, miles in diameter, surrounded by abrupt mountain walls two, and three, and four miles high, and yet the mountain walls not sink down again.

The known visible meteors are not large enough nor numerous enough to do the various kinds of work which I have named. May we not assume that an enormous number of exceedingly small meteoroids are floating in space, are falling into the sun, are coming into our air, are swept up by the moon? May we not assume that some of these various results, which cannot be due to meteoroids large enough for us to see as they enter the air, may be due to this finer impalpable cosmic dust? Yes, we may make such an assumption. There exist, no doubt, multitudes of these minute particles travelling in space. But science asks not only for a true cause, but a sufficient cause. There must be enough of this matter to do the work assigned to it. At present we have no evidence that the total existing quantity of such fine material is very large. It is to be hoped that through the collection and examination of meteoric dust we may soon learn something about the amount which our earth receives. Until that shall be learned, we can reason only in general terms. So much matter coming into our atmosphere as these several hypotheses require would, without doubt, make its presence known to us in the appearance of our sunset skies, and in a far greater deposit of meteoric dust than has ever yet been proven.

A meteoroid origin has been assigned to the light of the solar corona. It is not unreasonable to suppose that the amount of the meteoroid matter should increase toward the sun, and that the illumination of such matter would be much greater near the solar surface. But it is difficult to explain upon such a hypothesis the radial structure, the rifts, and the shape of the curved lines, that are marked features of the corona. These seem to be inconsistent with any conceivable arrangement of meteoroids in the vicinity of the sun. If the meteoroids are arranged at random, there should be a uniform shading away of light as we go from the sun. If the meteoroids are in streams along cometary orbits, all lines bounding the light and shade in the coronal light should evidently be projections of conic sections of which the sun's centre is the focus. There are curved lines in abundance in the coronal light, but, as figured by observers and in the photographs, they seem to be entirely unlike such projections of conic sections. Only by a violent treatment of the observations can the curves be made to represent such projections. They look as though they were due to forces at the sun's surface rather than at his centre. If those complicated lines have any meteoroid origin (which seems very unlikely), they suggest the phenomena of comets' tails rather than meteoroid streams or sporadic meteors. The hypothesis that the long rays of light which sometimes have been seen to extend several degrees from the sun at the time of the solar eclipse are meteor streams seen edgewise, seems possibly true, but not at all probable.

The observed life of the meteor is only a second, or at most a few seconds, except when a large one sends down stones to remain with us, What can we learn about its history and origin ?

Near the beginning of this century, when small meteors were looked on as some form of electricity, the meteorites were very generally regarded as having been thrown out from the lunar volcanoes. But as the conviction gained place that the meteorites moved not about the earth but about the sun, it was seen that the lunar volcanoes must have been very active to have sent out such an enormous number of stones as are needed in order that we should so frequently encounter them. When it was further considered that there is no proof that lunar volcanoes are now active, and that when they were active they were more likely to have been open seas of lava, not well fitted to shoot out such masses, the idea of the lunar origin of the meteorites gradually lost ground.

But the unity of meteorites with shooting-stars, if true, increases a hundred fold the difficulty, and would require that the comets have the same origin with the meteorites. No one claims that the comets came from the moon.

That the meteorites came from the earth's volcanoes is still held by some men of science, particularly by the distinguished astronomer-royal for Ireland. The difficulties of the hypothesis are, however, exceedingly great. In the first place, the meteorites are not like terrestrial rocks. Some minerals in them are like minerals in the rocks. Some irons are like the Greenland terrestrial irons. But no rock in the earth has yet been found that would be mistaken for a meteorite of any one of the two or three hundred known stone-falls. The meteorites resemble the deep terrestrial rocks in some particulars, it is true, but the two are also thoroughly unlike.

The terrestrial volcanoes must also have been wonderfully active to have sent out such a multitude of meteorites as will explain the number of stone-falls which we know, and which we have good reason to believe have occurred. The volcanoes must also have been wonderfully potent. The meteorites come to us with planetary velocities. In traversing the thin upper air, they are burned and broken by the resisting medium. Long before they have gone through the tenth part of the atmosphere the meteorites usually are arrested and fall to the ground. If these bodies were sent out from the earth's volcanoes, they left the upper air with the same velocity with which they now return to it. What energy must have been given to the meteorite before it left the volcano, to make it traverse the whole of our atmosphere and go away from the earth with a planetary velocity. Is it reasonable to believe that volcanoes were ever so potent, or that the meteorites would have survived such a journey ?

No one claims that the meteors of the star-showers, or their accompanying comets, came from the earth's volcanoes. To ascribe a terrestrial origin to meteorites is, then, to deny the relationship of the shooting-star and the stone-meteor. Every reason for their likeness is an argument against the terrestrial origin of the stones. To suppose that the meteors came from any planets that have atmospheres, involves difficulties not unlike to, and equally serious with, those involved in the theory of a terrestrial origin.

The solar origin of meteorites has been seriously urged, and deserves a serious answer. The first difficulty which this hypothesis meets, is that solid bodies should come from the hot sun. Besides this, they must have passed without destruction through an atmosphere of immense thickness. Then there is a geometric difficulty. The meteorite shot out from the sun would travel, under the law of gravitation, nearly in a straight line out and back again into the sun. If in its course it enters the earth's atmosphere, its relative motion, that which we see, should be in a line parallel to the ecliptic, except as slightly modified by the earth's attraction. A large number of these meteors, that is, most if not all well-observed fire-balls, have certainly not travelled in such paths. These did not come from the sun.

It has been a favorite hypothesis that the meteorites came from some planet broken in pieces by an internal catastrophe. There is much which mineralogists can say in favor of such a view. The studies of M. Stanislas Meunier, and others, into the structure of meteorites, have brought out many facts which make this hypothesis plausible. It requires, however, that the stone-meteor be not regarded as of the same nature as the star-shower meteor, for no one now seriously claims that the comets are fragments of a broken planet. The hypothesis of the existence of such a planet is itself arbitrary; and it is not easy to understand how any mass that has become collected by the action of gravity, and of other known forces, should, by internal forces, be broken in pieces and these pieces sent asunder. The disruption of such a planet by internal forces, after it has by cooling lost largely its original energy, would be specially difficult to explain.

We cannot, then, look to the moon, nor to the earth, nor to the sun, nor to any of the large planets, nor to a broken planet, as the first home of the meteoroids, without seeing serious if not insuperable objections. But since some of them were in time past certainly connected with comets, and since we can draw no line separating shooting-stars from stone-meteors, it is most natural to assume that all of them are of a cometary origin. Are there any insuperable objections that have been urged against the hypothesis that all of the meteoroids are of like nature with the comets, that they are in fact fragments of comets, or it may be sometimes minute comets themselves? If such objections exist, they ought evidently to come mainly from the mineralogists, and from what they find in the internal structure of the meteorites. Astronomy has not as yet furnished any objections. It seems strange that comets break in pieces, but astronomers admit it, for it is an observed fact. It is strange that groups of these small bodies should run before and follow after comets along their paths, but astronomers admit it as fact in the case of at least four comets. Astronomically, there would seem to be no more difficulty in giving such origin to the sporadic meteor, and to the large fire-ball, and to the stone-meteor, than there is in giving it to the meteor of the star-shower. If, then, the cometic origin of meteorites is inadmissible, the objections must come mainly from the nature and structure of the meteoric stones and irons. Can the comet in its life and history furnish the varied conditions and forces necessary to the manufacture or growth of these peculiar structures?

It is not necessary, in order to answer this question, to solve the thousand puzzling problems that can be raised about the origin and the behavior of comets. Comets exist in our system, and have their own peculiar development, whatever be our theories about them. It will be enough for my present purpose to assume as probably true the usual hypothesis that they were first condensed from nebulous matter; that that matter may have been either the outer portions of the original solar nebula, or matter entirely independent of our system and scattered through space. In either case, the comet is generally supposed, and probably must be supposed, to have become aggregated far away from the sun. This aggregation was not into one large body, to be afterwards broken up by disruption or by solar action. The varieties of location of the cometic orbits seem inexplicable upon any such hypothesis. Separate centres of condensation are to be supposed, but they are not *a priori* unreasonable. This is the rule rather than the exception everywhere in nature.

Assume, then, such a separate original condensation of the comet in the cold of space, and that the comet had a very small mass compared with the mass of the planets. Add to this the comet's subsequent known history, as we are seeing it in the heavens. Have we therein known forces and changes and conditions of such intensity and variety as the internal structure of the meteorites calls for? What that structure is, and, to some extent, what conditions must have existed at the time and place of its first formation, and during its subsequent transformations, mineralogists rather than astronomers must tell us. For a long time it was accepted without hesitation that these bodies required great heat for their first consolidation. Their resemblance to the earth's volcanic rocks was insisted on by mineralogists. Prof. J. Lawrence Smith, in 1855, asserted without reserve that "they have all been subject to a more or less prolonged igneous action corresponding to that of terrestrial volcanoes." Director Haidinger, in 1861, said, "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." The likeness of these stones to the deeper igneous rocks of the earth, as shown by the experiments of M. Daubrée, strengthened this conviction. Mr. Sorby, in 1877, said, "it appears to me that the conditions under which meteorites were formed must have been such that the temperature was high enough to fuse stony masses into glass; that the particles could exist independently one of the other in an incandescent atmosphere subject to violent mechanical disturbances; that the force of gravitation was great enough to collect these fine particles together into solid masses, and that these were in such a situation that they could be metamorphosed, further broken up into fragments, and again collected together."

Now, if meteorites could come into being only in a heated place, then the body in which they were formed ought, it would seem, to have been a large one. But the comets, on the contrary, appear to have become aggregated in small masses. The idea that heat was essential to the production of these minerals was at first a natural one. All other known rock formations are the result of processes that involve water or fire or metamorphism. All agree that the meteorites could not have been formed in the presence of water or free oxygen. What conclusion was more reasonable than that heat was present in the form of volcanic or of metamorphic action?

The more recent investigations of the meteorites and kindred stones, especially the discussions of the Greenland native irons and the rocks in which they were imbedded, are leading mineralogists, if I am not mistaken, to modify their views. Great heat at the first consolidation of the meteoric matter is not considered so essential. In a late paper, M. Daubrée says: "It is extremely remarkable that, in spite of their great tendency to a perfectly distinct crystallization, the silicate combinations which make up the meteorites are there only in the condition of very small crystals, all jumbled together as if they had not passed through fusion. If we may look about us for something analogous, we should say that instead of calling to mind the long needles of ice which liquid water forms as it freezes, the fine-grained texture of meteorites resembles rather that of hoar-frost, and that of snow, which is due, as is known, to the immediate passage of the atmospheric vapor of water into the solid state." So Dr. Reusch, from the examination of the Scandinavian meteorites, concludes that "there is no need to assume volcanic and other processes taking place upon a large heavenly body formerly existing but which has since gone to pieces."

The meteorites resemble the lavas and slags on the earth. These are formed in the absence of water, and with a limited supply of oxygen, and heat is present in the process. But is heat necessary? Some crystallizations do take place in the cold; some are direct changes from gaseous to solid forms. We cannot in the laboratory reproduce all the conditions of crystallization in the cold of space. We cannot easily determine whether the mere absence of oxygen will not account fully for the slag-like character of the meteorite minerals. Wherever crystallization can take place at all, if there is present silicon and magnesium and iron and nickel, with a limited supply of oxygen, there silicates ought to be expected in abundance, and the iron and nickel in their metallic form. Except for the heat, the process should be analogous to that of the reduction of iron in the Bessemer cupola, where the limited supply of oxygen combines with the carbon and leaves the iron free. The smallness of the comets should not, then, be an objection to considering the meteoric stones and irons as pieces of comets. There is no necessity of assuming that they were parts of a large mass, in order to provide an intensely heated birth-place.

But although great heat was not needed at the first formation, there are many facts about these stones which imply that violent forces have in some way acted during the meteorites' history. The brecciated appearance of many specimens, the fact that the fragments in a breccia are themselves a finer breccia, the fractures, infiltrations, and apparent faultings seen in microscopic sections and by the naked eye—these all imply the action of force. M. Daubrée supposes that the union of oxygen and silicon furnishes sufficient heat for making these minerals. If this is possible, those transformations may have taken place in their first home. Dr. Reusch argues that the repeated heating and cooling of the comet, as it comes down to the sun and goes back again into the cold, is enough to account for all the peculiarities of structure of the meteorites. These two modes of action do not, however, exclude each other. Suppose, then, a mass containing silicon, magnesium, iron, nickel, a limited supply of oxygen, and small quantities of other elements, all in their primordial or nebulous state (whatever that may be), segregated somewhere in the cold of space. As the materials consolidate or crystallize, the oxygen is appropriated by the silicon and magnesium, and the iron and nickel are deposited in metallic form. Possibly the heat developed may, before it is radiated into space, modify and transform the substance. The final result is a rocky mass (or possibly several adjacent masses), which sooner or later is no doubt cooled down throughout to the temperature of space. This mass, in its travels, comes near to the sun. Powerful action is there exerted upon it. It is heated. How intense is that heat upon a cold rock, unprotected apparently by its thin atmosphere, it is not possible to say. We know that the sun's action is strong enough to develop that immense train, the comet's tail, that sometimes spans our heavens. It is broken in pieces. We have seen the portions go off from the sun, to come back, probably, as separate comets. Solid fragments are scattered from it to travel in their own independent orbits. What is the condition of the burnt and crackled surface of a cometic mass or fragment as it goes out from the sun again into the cold? What changes may not that surface undergo before it comes back again, to pass anew through the fiery ordeal? We have here forces that we know are acting. They are intense, and act under varied conditions. The stones subject to those forces can have a history full of all the scenes and actions required for the growth of such strange bodies as have come down to us. Some of our meteors, those of the star-showers, have certainly had that history. What good reason is there for saying that all of them may not have had the like birthplace and life?

The pieces which come into our air in any recurring star-shower belong to a group whose shape is only partly known. It is thin, for we traverse it in a short time. It is not a uniform ring, for it is not annual, except possibly the August sprinkle. How the sun's unequal attraction for the parts of a group acts as a dispersive force to draw it out into a stream, those most beautiful and most fruitfull discussions of Signor Schiaparelli have shown. The groups that we meet are certainly in the shape of thin streams.

It has been assumed that the cometic fragments go continuously away from the parent mass, so as to form, in due time, a ring-like stream of varying density, but stretched along the entire elliptic orbit of the comet. The epochs of the Leonid star-showers in November, which have been coming at intervals of thirty-three years since the year 902, have led us to believe that this departure of the fragments from Tempel's comet (1866, I.) and the formation of the ring was a very slow process. The meteors which we met near 1866 were therefore thought to have left the comet many thousands of years ago. The extension of the group was presumed to go on in the future until, perhaps tens of thousands of years hence, the earth was to meet the stream every year. Whatever may be the case with Tempel's comet and its meteors, this slow development is not found to be true for the fragments of Biela's comet. It is quite certain that the meteors of the splendid displays of 1872 and 1885 left the immediate vicinity of that comet later than 1840, although at the time of those showers they had become separated two hundred millions of miles from the computed place of the comet. The process, then, has been an exceedingly rapid one, requiring, if continued at the same rate, only a small part of a millennium for the completion of an entire ring, if a ring is to be a future form of the group.

It may be thought reasonable in view of this fact about Biela's comet, established by star-showers of 1872 and 1885, to revise our conception of the process of disintegration of Tempel's comet also. The more brilliant of the star-showers from this comet have always occurred very near the end of the thirty-three year period. Instead of there being a slow process which is ultimately to produce a ring along the orbit of the comet, it certainly seems more reasonable to suppose that the compact lines of meteors which we met in 1866, 1867, and 1868 left the comet at a recent date. A thousand years ago this shower occurred in the middle of October. By the precession of the equinoxes and the action of the planets the shower has moved to the middle of November. One-half of this motion is due to the precession, the other half to the perturbing action of the planets. Did the planets act upon the comet before the meteoroids left it, or upon the meteoroid stream? Until one has reduced the forces to numerical values, he may not give to this question a positive answer. But I strongly suspect that computations of the forces will show that the perturbations of Jupiter and Saturn upon that group of meteoroids hundreds of millions of miles in length,—perturbations strong enough to change the node of the orbit fifteen degrees along the ecliptic,—would not leave the group such a compact train as we found it in 1866. If this result is at all possible, it is because the total action is scattered over so many centuries. But it seems more probable that the fragments are parting more rapidly from the comet than we have assumed, and that, long before the complete ring is formed, the groups become so scattered that we do not recognize them, or else are turned away so as not to cross the earth's orbit.

Comets, by their strange behavior and wondrous trains, have given to timid and superstitious men more apprehensions than have any other heavenly bodies. They have been the occasion of an immense amount of vague and wild and valueless speculation by men who knew a very little science. They have furnished a hundred as yet unanswered problems which have puzzled the wisest. A world without water, with a strange and variable envelope which takes the place of an atmosphere, a world that travels repeatedly out into the cold and back to the sun, and slowly goes to pieces in the repeated process, has conditions so strange to our experience, and so impossible to reproduce by experiment, that our physics cannot as yet explain it. But we may confidently look forward to the answer of many of these problems in the future. Of those strange bodies, the comets, we shall have far greater means of study than of any other bodies in the heavens. The comets alone give us specimens to handle and analyze. Comets may be studied, like the planets, by the use of the telescope, the polariscope, and the spectroscope. The utmost refinements of physical astronomy may be applied to both. But the cometary worlds will be also compelled, through these meteorite fragments, —with their included gases and peculiar minerals, —to give up some additional secrets of their own life, and of the physics of space, to the blowpipe, the microscope, the test-tube, and the crucible.