6. The most casual study of "partial impact" shows that for a long time after impact, at least, streams and sprays of fragments must exist, and also that there should be considerable community of motion. Proctor has demonstrated this to be the case.

7. Original rotation of mass would tend to take material slightly out of the ecliptic as streams. Original orbital rotation of smaller bodies would tend still more to take these bodies out of the general plane, but more irregularly. This appears to explain much of the definite irregularity of the visible universe.

Besides these general agreements, all the minor observations I have mentioned seem to point quite to the same conclusion. How like a continuance of the original motion does the clustering of the stars at opposite points in the ring appear.

The varied motion in the plane of the ring must produce many collisions, resulting in temporary and variable stars, and nearly every one of these is in this plane. Nebulæ of definite structure, such as planetary and annular, probably originate in the same way, at least partial collision offers a perfectly intelligible account of them, and I know of no other that does. These are also in the same small area in the heavens.

Speculation concerning the origin of the hollows in the milky way, also in the milky-way nebulæ, and relating to these bodies themselves, as well as the Magellanic clouds, so also discussions relating to the available energy, the cause of the extinction of light and of the stability of the cosmogony, although belonging to this subject, must be left to future papers.

I cannot conclude the brief account of this wonderful and beautiful galaxy, of which our earth forms so minute a portion, without hoping that it may induce others to enter this fascinating and extensive field of research; —workers whose time and skill in observing, and whose higher mathematical training may enable them to deal exhaustively with some of the many and original difficult problems which this view of the universe suggests.

ART. XIV.—*Partial Impact (Paper No. 4): On the General Problem of Stellar Collision.* By Prof. A. W. BICKERTON, F.C.S., President of the Philosophical Institute of Canterbury.

Plate VI.

[*Read before the Philosophical Institute of Canterbury, 27th February,* 1879.]

THE papers I have presented to the Institute on the possible phenomena connected with the partial collision of cosmical bodies, show that this variety of impact is deserving of very careful study. I shall, therefore, in this paper, attempt to demonstrate that, with the known distribution of motions of the stars, collisions are inevitable, and that nearly all these must be partial. Secondly, I shall show that there are a large number of influences which will tend to modify and to give variety to the phenomena of partial impact. But that, nevertheless, there are several well-marked peculiarities associated with all such cases of collision which render them perfectly characteristic. Lastly, I shall refer to some of the variety of cosmical phenomena which these peculiarities may give rise to.

For some time an idea was common that the whole of the visible Universe was a stable system, and that all the stars in the heavens, including our own, were rotating around a certain definite place in the heavens. This opinion was shared in by nearly all who took part in the discussion on my first paper. Doubtless there is considerable community of motion in some parts of the heavens, and it is not improbable, looking at Proctor's stellar motion chart, that, taking the whole galaxy, there may be a tendency to motion, more in one direction in the galactic ring than in the opposite; yet it is certain that the stars of the galaxy are far from being a really stable system in which all the motions are exactly recurrent in definite periods. I will give the opinions of a few astronomers on this point.

Newcombe says:—"We may first assert, with a high degree of probability, that the stars do not form a stable system." * * * "But the most conclusive proof that the stars do not revolve around definite attracting centres is found in the variety and irregularity of their proper motion." * * * "The motion of each individual star is generally so entirely different from that of its fellows as seemingly to preclude all reasonable probability that these bodies are revolving in definite orbits around great centres of attraction." * * * "And thus it (each star) may keep up a continuous dance, under the influence of ever-varying forces, as long as the Universe shall exist under its present form." Again, Herschel says of Madler's suggestion, that the stars revolve around the *Pleiades*:—"That the situation is in itself utterly improbable, lying as it does no less than 26 degrees out of the plane of the galactic circle, out of which plane it is almost inconceivable that any general circulation can take place."

Proctor unfavourably reviews this hypothesis in several of his works. In one place, after a full discussion, he says:—"These and other considerations have led all the most eminent of our modern astronomers to look upon Madler's hypothesis as one which in the present state of our knowledge we have no right to look upon with favour."

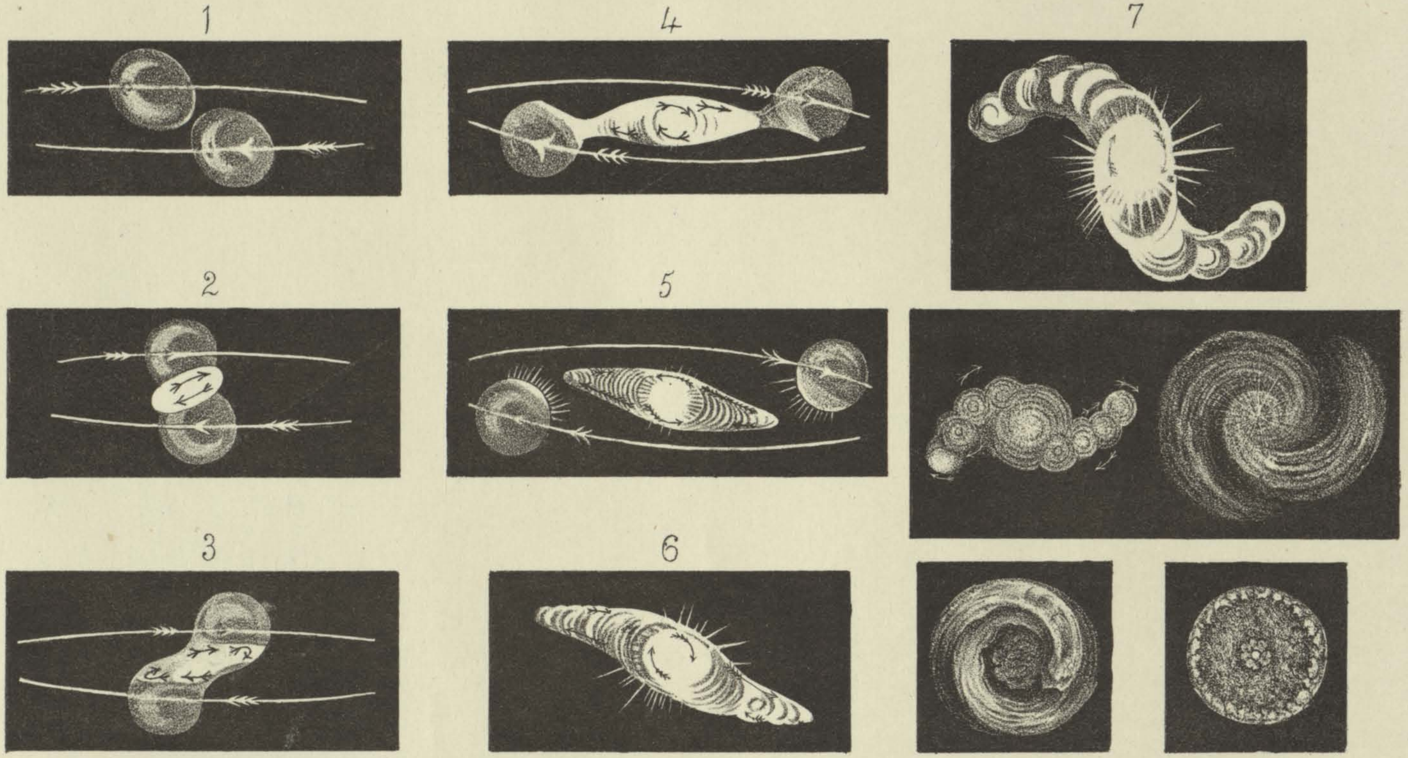
Newcombe says of Madler's hypothesis:—"But not the slightest weight has ever been given to it by astronomers, who have always seen it to be an entirely baseless speculation."

This evidence seems to be indisputable. The stars appear to be something like the molecules of a heated gas, in motion in all directions, and like these necessarily sometimes coming into impact. But many stars will come within the effective attraction of other stars, and this attraction will be enormously more effectual than mere chance in producing collision. Thus the star *Alpha Cygni* is almost directly approaching our sun, and it is extremely likely that in one or two hundred thousand years it will be for thousands of years the nearest star, by many times in the heavens, during which time, by their mutual attractions, the Sun and this star will probably be deflected several diameters towards each other out of their respective independent paths. That stars are thus brought within each others' attraction is borne out by the fact observed by Mr. J. W. Wilson, of Rugby, that the constituents of the double-star *Castor* are moving in hyperbolic orbits, and it would be well worthy of careful observation to ascertain if any other of the binary stars are thus connected. I will not prolong this discussion, for it appears certain that cosmical collisions must occur. That they do occur on a small scale is evident by the stupendous number of meteorites which strike the earth every year, and Proctor's idea of the small craters on the Moon's surface is that they have been formed by meteors falling on its surface during the Moon's viscous condition; clearly what occurs on a small scale, analogy suggests should also occur on a larger one.

Having thus shown that cosmical collisions are necessary events with such a system as the galaxy has been proved to be, I shall attempt to show that, except in the collision of bodies of very different volumes, complete collision is of extreme improbability, or, in other words, that almost all considerable cosmical impacts will be partial collisions. If we suppose two bodies of very great mass, and of excessively minute volume, collision can only occur when by their motions the two are tending to occupy the same point in space at the same time. In most other cases the bodies will tend to take hyperbolic orbits with a common focus, hence they escape each other. Suppose each to retain the same mass, but the volume of each to be expanded beyond the common focus, collision is of course inevitable, and it is clear that the impact must be partial. Those parts of each which lie in each other's path will mutually destroy each other's motion, whilst the remainder of each of the two bodies will pass on in orbits more curved than before, but which may still be hyperbolic; or, if the original proper motion of the bodies were small, or the part struck off of large mass, the new orbits may be elliptical, and one or both of the parts will return and remain in permanent orbits, as double stars. I may mention that I have already demonstrated, I believe, with sufficient clearness, that the mere work of shearing the bodies when they come into impact, is such an excessively small fraction of the total energy, in cases of large masses, that it may be absolutely disregarded. As the whole of this reasoning holds good for all cases of the collision of approximately equal large bodies, it becomes evident therefore that these collisions are partial.

There is, however, one exception, that where the larger body extends so as to include the smaller body completely in its path. The impact in this case is complete as regards the small body, and tangential on the larger, and although tending to produce rotation possesses none of the definite properties of partial impact. It is clear that collisions may vary from the mere graze of the atmosphere of the two bodies, through the stage of cutting off a considerable ratio, up to the extreme case of complete impact, all of which possibilities tend to vary the result. Again, the two bodies may be intensely hot, or one hot and one cold; either or both may be solid, liquid, or gaseous, or mixtures of these physical conditions. They may have an original rotation of their own, and may have smaller bodies revolving around them. They may have had very different original proper motions, and may be of considerably different mass. Any of these peculiarities tends to alter the result attained at and after impact. Still, on the other hand, there are many broad well-marked generalizations which are sufficiently characteristic to mark out these partial collisions as a clearly defined genus, the phenomena resulting from them being easily recognizable to a skilled observer.

The accompanying diagrams probably represent with some degree of accuracy the stages of a medium case of partial collision. I have attempted to draw these diagrams from independent reasoning on dynamical principles, and have consulted others as to the accuracy of the reasoning. I must acknowledge my indebtedness for several valuable hints from Mr. N. K. Cherrill. The first figure (*Pl. VI.*) shows two bodies coming into impact—it will be seen that the bodies are distorted to an egg shape. The idea of this distortion was first suggested to me by Mr. Beverly, of Dunedin, who has been studying the various mathematical problems of complete cosmical impact for more than a dozen years. It will ultimately be found, when this question is discussed in detail, that this distortion produces some very interesting phenomena. The two following figures show the process of impact, and it is perfectly evident, from the mode of impact, the rare outside of each body meeting with the denser inside of the other, that the two sides of the coalesced mass have a great deal of unbalanced momentum, acting in different directions, and tending to spin the mass on its centre. It is generic of partial impact that it must produce rotation. It will also be seen that this same residual motion, and the attraction of the retreating masses, tend to draw the mass into a spindle shape. It is also evident, all



To illustrate PARTIAL IMPACT, Article IV.

Prof: Bickerton, del. J.B. lith.

motion of translation being originally in the plane of the paper, that all motion but heat motion and original rotation will still tend to occupy that plane, and that it is consequently the plane of the rotation of the mass. According to the modern theory of heat, all those parts, whose motion of mass is destroyed, will have an equivalent heat energy given them.

Here I approach one of the striking peculiarities of this theory. For the temperature developed will not be in any way dependent on the proportion struck off. It will depend upon the molar velocity destroyed, and this, again, chiefly upon the mass of the attracting bodies, and the nearness of their centres of gravity. Thus the merest graze will develope nearly as high a temperature in the coalesced part as though one half of each were struck off. But in these two cases the gravitating powers of the coalesced mass are altogether different, and hence, in some cases, where a small ratio is struck off, the molecular velocity may carry every particle away into free space, and, in other cases, where the collision is more complete, the great attractive powers of the body may hold the gaseous mass in a definite position. I need not refer to the fact that the former case is typical of temporary stars, and the latter of nebulæ of definite form. On reference to fig. 4, it will be seen that the wounded retreating stars are considerably heated in and about the plane of section. On escaping the influence of the other bodies they would recover their sphericity, exhibiting a very highly-heated part on one side. I hope, in a future paper, to bring before the Institute a number of facts and conclusions which, I believe, will actually demonstrate that in these bodies we recognize the variable stars which stud our galaxy. It is powerful evidence in favour of this theory, that many variable stars are in pairs. In figure 5, the arrows show the general tendency of the motion in the several parts of the spindle-shaped mass of heated matter. I need scarcely mention that the mass in this form is a figure of a large number of the characteristic nebulæ, such as the nebulæ of *Andromeda*. In figure 6, the rotation of the centre of the mass has begun to give itself a spiral form, and an almost exact figure of Herschel's drawing of the nebulæ of the Lion is produced. The other figures trace the later possible phenomena which the various motions may produce. They represent systems of bodies, spiral, annular, and planetary nebulæ. I again state, that these figures were geometrically drawn on a well-considered estimation of the probable residual motion and attractions left in the mass. When some discussion has elicited all the difficulties which beset the question, I hope to offer you an approximate geometrical demonstration of the problem. I believe, however, that it is only in the impact of rare bodies, such as nebulæ, that nebulæ showing a spiral reaching near the centre could be produced.

In addition to the rotary motion in the plane of the paper, it will be seen that, from the distribution of the attractions and of the matter, pressure due to developed heat will act at first chiefly in a line passing through the centre of gravity and perpendicular to the plane of the paper, so that doubtless, in the majority of cases, a considerable proportion of gaseous matter will be found at the extremities of this axis. There appears considerable evidence that this is really the case with nearly all the ring nebulæ. But more careful investigation is needed on this point, as the drawings of different observers show considerable difference in this respect. It is certain that in the visible Universe nebulous matter lies chiefly at the poles of the galaxy.

But the heat-motion acts in another way in addition to mere pressure. Heat is caused by the motion of molecules, and this motion tends to give an outward direction to the whole mass of the gas. This motion tells most in the lighter molecules, so that when any particle leaves its fellow, it proceeds directly outwards away from the mass. This action, in many cases, would doubtless convert the whole into a mere spheroidal shell, and it is extremely probable that this is the condition of the planetary nebulæ. But whenever the ratio, struck off at collision, is large, or there is a large ratio of heavy molecules present, these latter return again and form the star so often seen in the centre of these bodies. It would be worth while for members to consider a variety of the many cases which partial impact offers. A particularly interesting case is offered in which an impact is so considerable that the escaping parts are mere shells, doubtless this would break up, and strew the spiral with stars. And again, as regards the problem of the subsequent state of the ends of the spindle, a careful inspection will show that the forward velocity is very different on their two sides, doubtless tending to cause them sometimes to separate into a number of rotating masses, giving rise to multiple systems, having the peculiarity so characteristic of the motion of our Solar System.

Thus it appears that rotation, matter chiefly in one plane, and high temperature proportional to mass, are the most striking general properties in partial impact, but that the many modifying causes may sometimes produce spirals or ring systems, in other cases mere gaseous shells, or in other cases densely-crowded systems, or complete dissipation of the whole matter into space. In fact, the field of possibilities appears nearly infinite.

I think I have shown that it is almost certain that partial impact is at once the most frequent of definite cosmical phenomena, and at the same time a most powerful constructive agent in producing the many marvels which the monster tubes of the great astronomers have shown to exist in such endless variety in the heavens.