July, 1877) I have proved from geological evidence that the antiquity of our habitable globe must be at least three times greater than it could possibly be had the sun derived its heat simply from the condensation of its mass. This proves that the gravitation theory of the origin of the sun's heat is as irreconcilable with geological facts as it is, according to Haeckel, with those of evolution, and that there must have been some other source, in addition, at least, to gravity, from which the sun derived his store of energy.

That other source is not so inconceivable as has been assumed, for it is quite conceivable that the nebulous mass from which the sun was formed by condensation might have been possessed of an original store of heat previous to condensation. And this excessive temperature may be the reason why the mass existed in a nebulous or rarefied condition. Now if the mass were originally in a heated condition then in condensing it would have to part not merely with the heat of condensation, but also with the heat it originally possessed.

The question then arises—By what means could the nebulous mass have become incandescent? From what source could the heat have been obtained? The dynamical theory of heat affords, as was shown several years ago (*Phil. Mag.* for May, 1868), an easy answer to this question. The answer is that the energy in the form of heat possessed by the mass may have been derived from *motion in space*. Two bodies, each one-half the mass of the sun, moving directly towards each other with a velocity of 476 miles per second, would, by their concussion, generate in a *single moment* 50,000,000 years' heat. For two bodies of that mass, moving with a velocity of 476 miles per second, would possess $4,149 \times 10^{38}$ foot-pounds of kinetic energy, and this, converted into heat by the stoppage of their motion, would give out an amount of heat which would cover the present rate of the sun's radiation for a period of 50,000,000 years.

There is nothing very extraordinary in the velocity which we have found would be required to generate the 50,000,000 years' heat in the case of the two supposed bodies. A comet having an orbit extending to the path of the planet Neptune, approaching so near the sun as to almost graze his surface in passing, would have a velocity of about 390 miles per second, which is within eighty-six miles of that required.

It must be borne in mind, however, that the 476 miles per second is the velocity at the moment of collision. But more than one-half of this velocity, or 274 miles per second, would be derived from their mutual attraction as they approached each other. We have consequently to assume an original or projected velocity of only 202 miles per second. If the original velocity was 678 per second, this, with the 274 derived from gravity, would generate an amount of heat which would suffice for 200,000,000 years. And if we assume the original velocity to have been 1,700 miles per second, an amount of heat would be generated in a single moment which would suffice for no less than 800,000,000 years.

It will be asked, Where did the two bodies get their motion? It may as well, however, be asked, Where did they get their existence? It is just as easy to conceive that they always existed in motion as that they always existed at rest. In fact, this is the only way in which energy could remain in a body without dissipation into space. Under other forms a certain amount of it is constantly being transformed into heat which never can be retransformed back again, but is dissipated into space as radiant heat. But a body moving in void stellar space will retain its energy in the form of motion undiminished and untransformed for ever, unless a collision takes place.

The theory that the sun's heat was originally derived from motion in space is, therefore, for this reason, also more in harmony with evolution than the gravitation theory, because it explains how the enormous amount of energy which is being dissipated into stellar space may have existed in the matter composing the sun untransformed during bygone ages. Or in fact for as far back as the matter itself existed.

In conclusion there are only two sources conceivable from which the sun could have derived his heat. The one is *gravitation*, the other *motion in space*. The former could have afforded only about 20,000,000 or 30,000,000 years' heat, but there is in reality no absolute limit to the amount which may have been derived from the latter source, for the amount generated would depend on the velocity of motion. And when we take into consideration the magnitude of the stellar universe, the difference between a motion of 202 miles per second, and one of 1,700 miles to a great extent disappears, and the one velocity becomes about as probable as the other.

It may be urged as an objection to the theory that we have no experience of bodies moving in space with such enormous velocities as the above. This objection, for the following reason, is of no weight.

No body moving with a velocity exceeding 400 miles per second could remain a member of our solar system; and beyond our system there is nothing visible but the stars and nebulæ. These stars, however, are suns like our own, and visible because, like the sun, they have lost their motion—the lost motion being the origin of their light and heat. Bodies moving in stellar space with these enormous velocities can have neither light nor heat, and, of course, must be invisible to us. They must first lose their motion before the kinetic energy in the form of motion can be transformed into light and heat, so as to constitute visible suns.

JAMES CROLL

ON THE FORMATION OF HAILSTONES, RAINDROPS, AND SNOWFLAKES[1]

THE author commences by recapitulating some of the leading points in a paper which he read before the same Society on October 31, 1876, "On the Manner in which Raindrops and Hailstones are Formed." In this paper, which was published in NATURE (vol. xvi. p. 163), he had shown that the aggregation of the small cloud particles into raindrops or hailstones is sufficiently accounted for by the fact that the larger particles descend faster than the others, and consequently overtake those immediately beneath them, and, combining with these, form still larger particles, which move with greater velocity, and more quickly overtaking the particles in front of them, add to their size at an increasing rate. He also showed that the shape and structure of ordinary hailstones was exactly such as would result from this manner of formation. For he had observed that the shape of hailstones was not as it at first sight appeared, that of more or less imperfect spheres, but that of more or less imperfect cones or pyramids with rounded bases, the conical surfaces being striated, the striæ radiating from the vertex; the texture being that of an aggregation of a number of small ice particles without crystalline form, being packed more closely together toward the base or rounded face of the stone. In this paper the author had reverted to the possibility of making *artificial hailstones* by blowing a stream of frozen fog against a small object, making, as it were, the cloud to rise up and meet the stone, instead of the stone falling through the cloud.

He had not, however, then overcome the difficulty of obtaining such a stream of frozen fog, but gave two sketches of plaster stones, which, as far as their shape and the striated appearance of their surface were concerned, closely resembled hailstones, and which plaster stones had been obtained by blowing some finely-divided

[1] Abstract of paper by Prof. Osborne Reynolds, F.R.S., read at the Manchester Literary and Philosophical Society.

plaster of Paris against small splinters of wood by means of a jet of steam.

In the discussion which followed the reading of that paper Dr. Crompton suggested the ether spray, such as is used in surgery, as a means of obtaining a frozen fog, and Prof. Reynolds explains how after various attempts he had succeeded in combining a spray of ether and water so as to form artificial stones. He then proceeds as follows :—

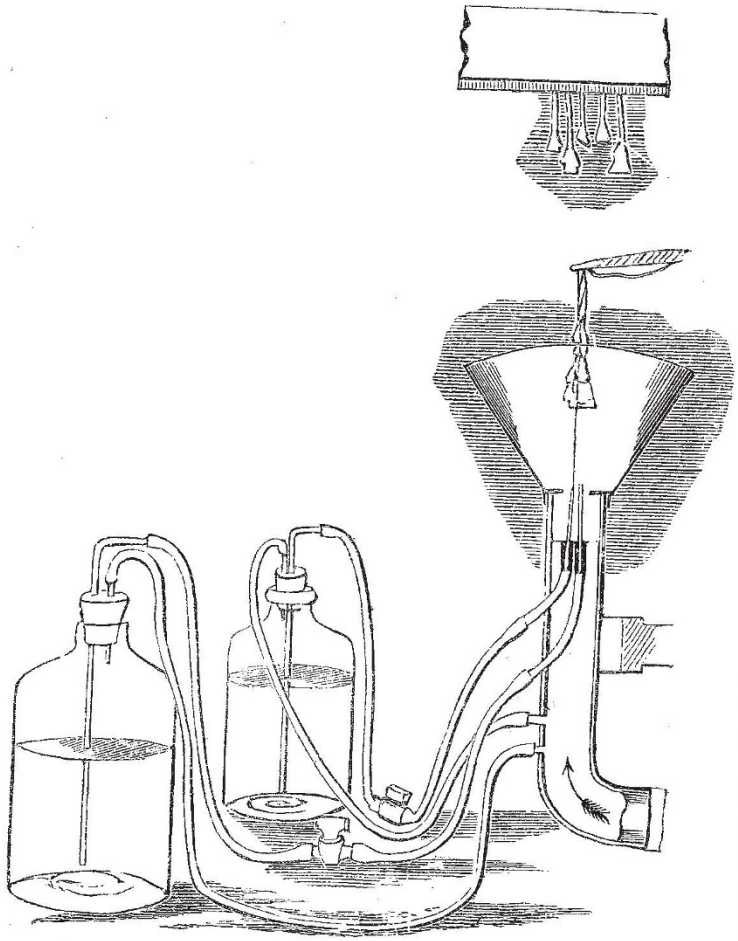

FIG. 1.

The apparatus is shown in Fig. 1. It consists of a brass tube half an inch in diameter, one end of which is connected with bellows capable of maintaining a constant pressure of about 18 inches of water, on the other end of the tube is a cap over the end of which is a flat plate or diaphragm having a central opening $\frac{1}{8}$ of an inch in diameter which forms the aperture for the blast. Entering through the sides of the main brass tube are two small brass tubes which reach to within $\frac{1}{2}$ an inch of the plate and into the ends of which are sealed fine glass capillary tubes, the glass being very thin ; these protrude just through the middle of the aperture, the one about $\frac{1}{16}$ of an inch and the other $\frac{1}{32}$. Through these tubes the water and ether are separately introduced into the blast to form the spray, and it is mainly on the adjustment of these tubes that the efficiency of the apparatus depends. It is essential that the ether tube should be slightly the longest, otherwise the ends become stopped with ice, and I find it better that the ether tube should be somewhat larger than the water tube. The bore of the tubes must be very small, but this is not sufficient, for unless the glass is very thin the spray will not be finely divided. Both the ether and water are forced through the tubes from bottles by connecting the interiors of these bottles with the bellows, and the quantities of ether and water are regulated either by raising and lowering the bottles or by means of the cocks in the pipes.

The tube is fixed in an ordinary retort-stand, so that the blast is vertical. If then a small splinter of wood is held pointing downwards into the spray, a lump of ice forms on the end of the splinter, and this lump has all the appearance of the hail-stones. It is quite white and opaque, it is conical in form and has a rounded base and striated surface.

In this way I have formed stones from half to three-quarters of an inch in diameter. When, however, the stones are growing large it is necessary to move this splinter so as to expose in succession all parts of the face of the stone to the more direct action of the spray.

When using this apparatus in a warm room I have found it best to fix a pad of blotting paper over the jet at a height of 10 or 12 inches. The surface of this pad is cooled by the spray and prevents radiation from the ceiling, which otherwise tends to melt the top of the stone. For a similar reason I have found it well to surround the blast with a wide cylinder or inverted cone of paper, which keeps off radiation without interfering with the action of the jet.

By sticking several pieces of wood into the pad, pointing downwards, a number of stones may be made at once.

In Fig. 2 a medium-sized stone as well as one of the largest stones are shown attached to the splinters of wood. The surface of the cone, where continuous, is truly conical, or rather pyramidal, but this surface is broken, as it were by steps, and a very marked fact is that all the continuous surfaces have the same vertex, and hence the different conical surfaces to which they belong, have not the same vertical angle, the surface being exactly such as would be acquired by the fragments of a sphere so constituted that the fracture tended to follow radial lines.

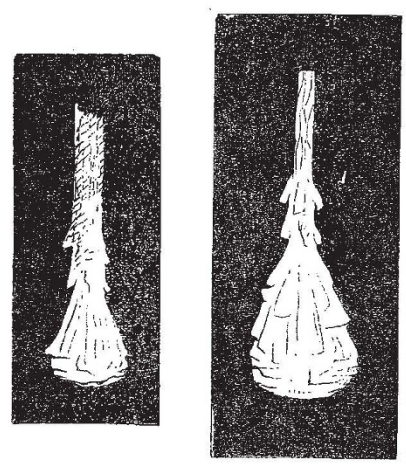

FIG. 2.

Owing to the radiation of the surfaces from a common vertex and the steps which occur between the vertex and the base, the angle of the conical surface of the stone is greater near the vertex than near the base. Thus the smaller stones appear less elongated than those which are larger.

The fact that in the sketches of actual stones, which I gave in my last paper, I showed the steps as less pronounced and the angles larger than they are in the artificial stones, is probably owing in some measure to my having formed my ideas from the observation of favourable specimens chosen from amongst those which fell. The larger angles were probably also, in part, owing to the smaller size of the actual hailstones, which were not much more than one-fourth of an inch across. But I think that it is important to notice that the somewhat imperfect way in which the outside layers in the surface of the artificial stones are continued, may be owing to the narrowness of the jet of air which, on striking the stone, tends to diverge laterally rather than to flow upwards past the sides of the stone, as it would do if the jet were broader, or as the air must do when the stone is falling through it.

The rate at which stones can be formed depends on the amount of water which can be introduced into the spray, the larger stones taking from one to two minutes. At first sight this may seem to be somewhat slow, but the following estimate tends to show that the artificial are probably formed quicker than the actual stones.

The speed of the jet of air at the point at which the stones are formed is nearly equal to that at which the larger stones would fall through the air. This is shown by the fact that if a large stone becomes accidentally detached from its splinter of wood it rather falls than rises, but when this happens with smaller stones they are driven up by the force of the blast.

I find that the speed of the blast varies from 150 to 200 feet per second, *i.e.*, from one-and-a-half to two miles a minute. The larger stones, therefore, traverse from one to four miles of frozen spray. So that if we imagine a cloud as dense as the spray it would have to be from one to four miles thick in order that the stones might, in falling through it, attain the size of the artificial stones ; and considering that the stones would only gradually acquire a speed equal to that of the blast, the time occupied in falling through the cloud would in all probability be very considerable, at least from five to ten minutes after the stone had acquired a sensible size.

As regards the proportion which the density of spray bears to that of a cloud, a comparison may be made from the fact that when working in saturated air at a temperature of 60° or 70° F., the condensation of vapour supplied sufficient ice to form the spray ; and since it is probable that the dense summer clouds, from which hail is formed, result from the cooling of air from temperatures nearly, if not quite, equal to this, there is probably no great difference in the density of the clouds and the spray.

I have not yet had an opportunity of examining the texture of these stones under the microscope, but to all appearance they consist of an aggregation of small spherical particles of ice ; and it seems worthy of notice that while nothing like a snow crystal ever appears to be produced in the ether spray, the moment the blast is stopped the end of the ether tube becomes covered with ice, which often assumes the form of snow crystals.

This appears to indicate the character of the difference between those conditions which result in snow and those which result in hail.

When the cloud-particles are formed at or above the temperature of 32°, and then freeze, owing to cooling by expansion or otherwise, the particles as they freeze retain their spherical form. This is what happens in the spray.

On the other hand, when saturated air at a temperature below 32° is still further cooled, the deposition of the vapour will be upon ice, and will take the form of snow crystals.

The aggregation of the snow crystals into flakes is, as I pointed out in my previous paper, accounted for by the larger crystals overtaking the smaller crystals in their descent, and the still more rapid descent of the flakes as they increase in size.

As regards the formation of rain-drops, I have nothing to add to what was contained in my last paper. The same explanation obviously applies to both hail and rain, and any doubt which may have been left by the less direct arguments in my former paper will, I venture to think, have been removed by the verification of my predictions in the production of artificial hailstones so closely resembling in all particulars those formed by nature. And, in conclusion, I would thank Dr. Crompton for the suggestion of the means by which I have been able to produce these stones.

OUR ASTRONOMICAL COLUMN

THE SOUTH POLAR SPOT OF MARS.—Prof. Asaph Hall has instituted a series of measures of the position of the south polar spot of Mars, with the Washington refractor during the late favourable opposition of the planet, having been led thereto by the great discordances in the positions of the spot, as determined so far. He adopts Oudeman's node and inclination of the equator of Mars, which, for the epoch taken, viz., 1877, September, 17·0, G.M.T. give $N = 47° 56'$, $I = 39° 14'$, and the angle of position of the south pole 162° 6′, and assumes the time of rotation of the planet 24h. 37m. 22·73s., as found by Mr. Proctor. The observations were made with a power of 400, and on thirty-two nights, from August 10 to October 24, during the whole of which period the spot was always seen with great distinctness, and little change in its appearance noted except what might be accounted for by change of distance. From thirty-four equations of condition treated on the method of least squares, Prof. Hall finds for the angle of position of the south pole of Mars at the above-mentioned epoch 166° 22′, for the radius of the small circle described by the spot 5° 11′, and for the angle of position of the spot at the epoch, with respect to the rotation-axis of the planet, 311° 24′. The various determinations of the south polar distance of this spot are as follow :—

	° ′		° ′
Herschel, 1783 ...	8 8	Linsser, 1862	20 0
Bessel, 1830	8 6	Kaiser, 1862	4 16
Mädler, 1837	12 0	Hall, 1877	5 11
Secchi, 1857	17 42		

On several of the finer nights, when the markings on the edge of the spot were very distinct, it appeared as "a depression in the surface of the planet."

PROF. NEWCOMB'S LUNAR RESEARCHES.—It is understood that if no unforeseen delay occurs in the printing, Part I. of "Researches on the Motion of the Moon," upon which Prof. Newcomb has been engaged for six years past, will be ready for publication in the course of next month. It is devoted to the discussion of eclipses and occultations previous to 1750. An abstract appeared in *Silliman's Journal* for November last.

THE CORDOBA OBSERVATORY.—In an address delivered on November 4, on the occasion of receiving from the Governor of the province of Cordoba the premiums awarded at the Centennial Exhibition in Philadelphia to the Argentine National Observatory and to himself for Lunar and Stellar Photographs, Dr. B. A. Gould gave a brief outline of the successive applications of photography to astronomical purposes since Mr. Bond's experiments with the 15-inch refractor of Harvard Observatory in 1850, with more particular reference to work executed at Cordoba of late in this direction. Dr. Gould expresses