XX. Microscopic observations on hail

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diluted state, and to dispense with the dipping in water altogether.

The diluting is a very much simpler and more economical method, and it is evidently a more certain one.

If the gallo-nitrate be diluted not more than ten times, it imparts a high degree of sensibility, but in that case the paper must be used immediately. It may be diluted as much as forty times, and in favourable circumstances will still give an intense picture. In diluting to that extent the paper becomes less sensitive, but it is less subject to the spontaneous change, and preserves its useful properties much longer.

To develop an impression, the gallo-nitrate ought to be of the full strength, particularly in gallic acid, upon which the depth and intensity of the picture chiefly depend, and which in a saturated solution will be present in greater or less quantity, according to the temperature of the air, by which the general chemical action is also affected.

London, July 7, 1846.

XX. *Microscopic Observations on Hail*.

By A. WALLER, M.D.*

IN a paper read before the Royal Society, June 18, 1846, I have presented some observations on the microscopic examination of globules of water, as they exist in fumes of steam, fogs, clouds, and mists. I found that they consist of particles of water perfectly spherical, without the least appearance of a vesicular structure, as is generally taught. I now proceed to examine, in a similar manner, water in some of the other forms in which it presents itself in meteorology, and commence with hail.

Some confusion seems to exist between different authors respecting the distinction between hail and sleet, which it is very desirable to avoid. Kaemtz, in his *Manual of Meteorology*, states that "very small hailstones are termed sleet." Pouillet, *Elémens de Physique*, who is generally very precise in his terms, gives the following definition: "Le gresil [sleet], which we have the opportunity of observing in our climates almost every year during the months of March and April, has doubtless an origin similar to that of snow. It is also congealed water, or rather small needles of ice pressed and interlaced together, forming a kind of ball of rather a compact nature, and sometimes surrounded with a real coating of transparent ice." In one dictionary I find sleet termed "a fall of rain and snow together," and in another, "a kind of

* Communicated by the Author.

smooth small hail or snow not falling in flakes, but single particles." The cause of this confusion arises from our inability to give any character visible to the naked eye, applicable on all occasions, for distinguishing hailstones, sleet, and globular masses of snow from each other. In ordinary cases, particularly in the summer months, no difficulty is found in the use of the term hailstones. We might then define them as consisting generally of fragments of ice, hard, nearly opaque, and producing various physical effects in proportion to their velocity; but a more minute examination soon shows, that they are generally accompanied with some sufficiently small to deserve the name of sleet according to Kaemtz, and others with no more consistency than flakes of moistened snow; and if we were to accept the definition of sleet by M. Pouillet, in this country, where hail is generally much smaller than in warmer climates, hail storms would be of comparatively very rare occurrence. In showers of sleet and snow the same difficulties are sometimes experienced; if particles of sleet invariably presented themselves under the form of transparent globules or particles of ice, no possibility of confusion would exist between them and the other two, but we also find them sometimes mingled with some that are more or less opaque and possessing a greater size. This uncertainty respecting the precise meaning attached to the words hail and sleet, is found in the accounts of many meteorological phenomena; and it would be desirable, in order to avoid it, to define the exact sense in which they are employed, or what would be still preferable, to describe with more precision the principal physical characters presented by the particles themselves. I fear it will be impossible at present to propose any set of terms which in every case would be free from objection, any more than with regard to the different forms of clouds or other meteorological phenomena, which pass with gradual transition from one form to another; but I would propose to confine the term sleet to all particles of water which are transparent throughout, whatever may be their size, and that of hail to those which are merely semi-transparent throughout, or possess at any part the power of irregularly dispersing light, which, as we shall see hereafter, arises from their being composed of minute globules. The term snow will be applied to all those particles of water in the atmosphere in which we can detect a crystalline appearance by aid of the microscope. With regard to hail, which possesses no cohesion and loses its form when it comes in contact with any solid body, I term it amorphous hail, from its having no definite form; and the snow, whose crystalline forms have

been altered by moisture or by caloric, I call on the same principle amorphous snow.

I will now proceed to mention the results of a few observations I have made upon hail.

March 22, 1846.—There was a fall of hail which lasted several minutes. The hailstones were generally of a lenticular shape, about half the size of a French bean, of a dull white colour, and semi-transparent. As they fell they were received in a blanket on this and on the following occasions, as when folded up in it, they might be preserved much longer from melting. One of them placed under the microscope was found to disengage bubbles of air in great abundance; its surface presented several irregular fissures by reflexion. After liquefaction, the drop of water resulting was found to contain numerous particles of various forms. Some of these were perfectly spherical, transparent, and agglomerated together in groups. Some were single, with a central nucleus,

Fig. 1.

others were completely opaque, black, and globular. Other hailstones contained, besides particles similar to the above-described, some of a siliceous appearance, causing a gritty feel when compressed between surfaces of glass. Shortly after the hail there followed a fall of rain: some drops of it being examined in the same way, were found to contain numerous irregular particles, some of which were apparently particles of soot, but I could detect no globular particles, nor any resembling sand.

March 23.—There occurred a fall of hail more considerable than the former, but the hailstones were smaller, though of similar shape. At the commencement of the fall, the hailstones, as soon as they struck the earth, split into numerous fragments, which remained loosely adhering together, much like wet sand

or the ices of pastry-cooks. The others which fell after did not break up in this way. Several of them, examined as before, disengaged, as they melted, bubbles of air in abundance. When the stone was reduced to a thin disc of ice, it became sufficiently transparent to be viewed by transmitted light. It was then perceived to consist of numerous particles of either a globular or ovular shape, closely adhering together, and presenting, on what appeared their surface, numerous very minute black points. The drop of water which resulted con-

Fig. 2.

tained very slight traces of foreign matter of the most minute dimensions. In a few instances I perceived a collection of spherical globules of a green colour about $0^{\text{mm}}\cdot005$. One or two deposited a particle apparently siliceous, which appeared to be in the centre of the hailstone.

April 3, 2 P.M.—There fell some hail for about five minutes. The weather warm, sun strong, occasional showers during the day. About half an hour previously I observed brilliant, thin, white cirro-strati at various points of the sky: before the hail fell, there appeared a second cloud over head, apparently much lower than the former, very dense and extending rapidly. The first hailstones so completely lost their cohesion and liquefied so quickly, even as they fell on my coat, that I at first took them for drops of rain, with which they were accompanied. Those which I collected resembled a grain of rice in size and colour. The dark cloud quickly disappeared after the fall of hail; the upper ones still remained about the same. I had not an opportunity of using the microscope.

April 6, 5 P.M.—A heavy fall of rain with hailstones about the size of a sweet pea. Under the microscope, the hailstones, when sufficiently thin, appeared to consist of spherical globules of various sizes, as in fig. 1, mixed with others of an angular outline. Air-bubbles as usual.

The foreign matter was found to consist of particles like sand, and others resembling microscopic lichens.

May 10, 3 P.M.—Wind N.W. an hour or two previous, bringing numerous masses of clouds, detached portions of which rapidly disappeared under the action of the sun's rays. Temperature warm; shortly before the fall of hail, the wind blew violently in the most opposite directions. A few hailstones fell of nearly a globular form. Under the microscope they gave off air-bubbles as usual, and all contained minute amorphous particles, some of an organic appearance, as in fig. 2. The thin disc of ice, besides the globular particles, presented many minute circular spots of different sizes, which as the ice melted, appeared to form the air-bubbles. These presented a different appearance from the globular particles before mentioned; they were much less defined and more irregular in their size. In some instances I could detect what appeared to be globular particles imbedded in a matrix of ice.

Air contained within Hailstones.

It is remarkable that, in all the accounts of hailstones which I have met with, I have not found any mention of the quantity of air which is contained in their interior. Under the microscope, the rapid formation of air-bubbles is the first point which attracts the attention, giving rise to the idea that a chemical action disengaging a gaseous body must be taking place. As I have invariably observed this in all the numerous hailstones which I have examined, I regard it as intimately connected with all those which, like those I have met with, are composed of separate globules, and have a semi-transparent aspect. Although the greater part of this air is disengaged during the process of liquefaction, some part of it remains in the state of small air-bubbles, on the surface of the drop of water resulting from the fusion of the ice, and may be perfectly distinguished by the unassisted eye. Hitherto I have not been able to determine the amount of air which a hailstone is capable of containing, but as far as I have been able to judge, it is more than the volume of the hailstone itself. We must furthermore bear in mind, that as the density of the atmosphere is less as we ascend, the original volume of the air, supposing it to have been confined at the moment the hail was formed, must have been much more considerable than at

the time we examine it. Hail, as we know, is abundantly formed at the elevation of Mont Blanc, and probably much higher. Supposing the air in our observations had been confined at that height, its volume would have been about double that which it presented at the time it was liberated, supposing the temperature on both occasions to be the same. The influence of temperature would no doubt operate in a different direction, as hailstones must be considered to take their origin at a temperature below zero; and when examined, even after their fall, they have been found generally, by M. Pouillet, -3° or -4° below 0° Cent., whereas when the air escapes, they may be considered exactly at 0° Cent. But admitting the temperature to have been -10° Cent. when they were formed, the dilatation of the air would be about $\frac{1}{28}$ th of the volume, which is far from compensating for the decreased pressure. By subjecting hailstones while kept several degrees below the freezing-point to a decreased pressure or a vacuum in the air-pump, we might decide whether the air has any communication with the external atmosphere, and with what force it is retained.

In observation May 10, the air appeared to be fixed within the hailstone, under the form of globules, very distinct in their appearance from the solid spherules. Their diameters varied from the one-fifth of a millimetre to sizes considerably smaller. As they disappeared they seemed to form the air-bubbles, which are invariably to be seen escaping. In the other cases I could only detect, under the highest power, minute dark points at most of the size of $0^{\text{mm}}\cdot005$, which appeared to be on the surface of the spherules. I can only conjecture them to consist of air, because after fusion I could perceive nothing like them in the drop of water. If it should result from future observation with the air-pump, as I have suggested, that the particles of ice merely retain air from the same cause as other porous bodies, the transparent condition of ice may enable us to form some idea of the manner in which porous bodies, such as charcoal, act in fixing gaseous substances within them; and whether the gases are reduced to a state of liquid by their molecular attraction with the solid.

Solid Globular Particles.

In the observations given above, it is found that, with the exception of the first, all the hailstones have been seen under the microscope to be composed entirely of minute spherules of ice agglutinated together; and even the discrepancy in that instance may be accounted for, from my attention having been principally engaged with the numerous air-bubbles that were

escaping. At the time I commenced these observations I was not aware that this structure of the hailstone had ever been ascertained before, but I now find that it has been already stated by several authors. Descartes, who admitted the existence of clouds composed of solid globules, explained the formation of hailstones by some of these globules being detached, and I believe agglomerated together. Berzelius, who gives in his *Treatise on Chemistry* a succinct and excellent account of hail, attributes it to the "agglomération de plusieurs grains," "arrondis et non en cristaux comme la neige." In the *Encyclopædia Britannica*, art. Hail, we find also that hail is formed "by many little spherules of ice agglutinated together." It appears surprising, that with such correct descriptions of hail there should still exist in works of a more ambitious character, others so much more imperfect and erroneous. In fig. 1, I have traced the forms of these globules: some of them appear more ovular than globular, and I believe that such is the real shape of some; although at the same time we must bear in mind, that a transparent globule of the high refractive powers of water will appear much distorted if part is seen through others before it, while the rest of it is perfectly exposed. The average size of those I have represented is about one-third of a millimetre; they do not vary greatly from this standard, and I have found them generally the same on other occasions.

It is evident that these globules must have existed in a solid state previous to their agglomeration to form hail, and therefore their maximum temperature at that time must have been below the freezing-point.

In what manner are we to account for the formation of these globules previous to their agglomeration?

In the experiments on congelation under the microscope, the account of which has been given in the paper before referred to, we have already seen with what facility these globular forms of ice are produced by the condensation of the moisture from the atmosphere on a surface of glass or Canada balsam. A curious and unforeseen analogy was found between their appearance in my experiments and their formation in nature. In winter a refrigerating mixture causes a deposit from the air, in which crystalline forms, frequently of a very regular appearance, were generally perceived. Only at a few points were discovered globular forms of ice, and these were generally surrounded on their surface with minute pyramidal crystals, giving them a mace-like appearance.

In summer the deposit was more confusedly crystalline, liable to liquefy from various external causes, and then to re-

turn again to a solid condition. The globular forms of solid particles were in consequence very numerous. The cause of this difference was, that in one case the quantity of moisture in the air was small, the deposition gradual, and the transitions of temperature from one extreme to the other very small; in the other, the moisture was abundant, the temperature of the air greatly lowered, and the crystalline action rapid. We find the same difference between the crystals obtained from a concentrated solution in a liquid exposed to a rapid decrease of temperature, and those which are formed in a solution less concentrated and progressing more gently. A still greater analogy is found in the crystals of naphthaline, iodine, camphor, and other substances volatile at the common temperature, when allowed to crystallize in empty bottles without the application of artificial heat. When either of these bodies is driven off in a state of vapour, the fumes that are formed when condensed on glass, present the form of either minute globules or of crystals, according to the temperature in which they are exposed. When the fumes are given off from either of these substances in a state of ebullition, it is found that the globules are of much larger dimensions than any which are formed at a temperature below the boiling-point. On a former occasion I have fully demonstrated that such is likewise the case with regard to the fumes of water. I will not attempt at present to offer any explanation of this fact, which is so invariably the case, that at any time, by the microscopic inspection of the globules, it is easy to decide whether they are formed from boiling water or at a temperature below.

The above observations confirm what we might have already anticipated, that the production of solid globular particles arises from the same cause as that which produces confused crystallization; and that in fact it is simply confused crystallization of separate particles. The most efficient cause of this is rapid congelation, which apparently does not allow the constituent particles sufficient time to group themselves in geometrical forms, but obliges them to assume that which their molecular attraction tends to give them. Between the two extremes, of a globular form and a perfect hexagonal prism, frequent shapes which the crystals assume in frost, we have various intermediate forms which may be considered as the resultants of the crystalline and molecular powers. Although by our experiments we may observe the circumstances in which these globules are formed, it would be impossible to ascertain by their means, with any precision, the condition of temperature requisite in one instance to form small crystals, and in the other minute globules. But in

nature we not unfrequently meet with experiments performed for us, which if examined with care would, I believe, furnish us with the desired information.

In the winter months, during a hoar frost, we sometimes find, adhering to minute filaments on the hedges, such as those of the spider's web, very minute globules of transparent ice, such as exist in hail and sleet. On other occasions, instead of globular forms, we find others of crystalline shapes. Careful observations made as they are in process of formation, with the instruments we possess for examining the state of temperature and the movements of the atmosphere, would no doubt give us the formula of these two deposits. The same observations would likewise enable us to determine, whether the temperature of the air around is such that any existing mist or fog must contain its globules in a solid state, according to the hypothesis advanced by Descartes. I am inclined to believe that such is not unfrequently the case.

It is evident that these globules, with the exception of their being formed on the surface of bodies which are stationary, are in all respects exactly similar to the particles of sleet. Frost, which forms in the same way, presents under the microscope crystalline forms, which are so much like those of snow that I have scarcely been able to distinguish one from the other. But if such deposits formed on the surface of the earth present analogies so great to those formed in the atmosphere, that they almost deserve the names of "ground sleet" and "ground snow," it naturally suggests that something like hail may also occasionally be produced in the same way, or in other words, the globules of ice may be found in a state of agglomeration. I have seen somewhere a definition of hoar frost, which describes it as a collection of spherules of ice; and according to the view I take, I believe that such is sometimes the case, although the observations I have hitherto made, I must confess, have not yet enabled me to detect this structure in hoar frost*.

Kensington, June 1846.

* Since making the foregoing observations, I have had an opportunity of witnessing another storm, which occurred on June 23, 1846, when a violent shower of rain fell, and having continued for about a quarter of an hour, it became mixed with hail, which had been preceded for a few minutes by thunder. The largest hailstones attained the size of a French bean, and were accompanied by others of all sizes down to that of a pea. Their shape was generally biconical; colour, a dull, without any external envelope of transparent ice, resembling in all respects those I had previously examined on other occasions, with the exception of one, *which was*