Snowflakes, snow crystals, hail and rain
Nanoparticles in the atmosphere

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1. Introduction

There would appear to be an infinite variety of snow crystals, no two are alike it would seem. Careful examination, however, shows that, like human beings, they can be classified. Snowflakes are groups of snow crystals all of a similar pattern.

Snowflakes indicate the size of the multimer[1] particles in the clouds that are turning to snow. We have, as far as I can tell, no other means of knowing the size of the multimer particles in a cloud.

Snow crystals from a cloud indicate the type of cloud. Some clouds produce spiky snow crystals, other clouds produce plate-like snow crystals, yet others produce snow crystals with seven hexagonal plates (one at the centre and the other six hexagonal plates surrounding it).

Snowflakes can change into rain. At one time many meteorologists thought that most rain came from snowflakes melting rather than directly from cloud particles, which they considered to be superfine drops of liquid water. This view is not generally supported by observations, though it is known that clouds can have snow within them on a summer's day. Thunderclouds are very cold but they generally produce hail as well as rain rather than snow. Hail is frozen rain (liquid water) whereas snow is frozen from multimer particles in a cloud.

Snow crystals are actually centrosymmetrical resonators[2] so that when they melt, they do so in pulsating jerks, initially at 24 points all at once, and then when these have vanished 12 points all at once, to leave a simple hexagonal plate, which then, with enough energy, changes into a raindrop. This melting in quantized jerks could indicate that the growth of the snow crystal resonator is also a jerky centro-controlled action with constant reorganization of the numerous nendorec units that make up the individual snow crystal. Consider it like a pile of bricks organized by different bricklayers to make different structures according to the individual bricklayer—organized but not chaotic. A snow crystal can almost be considered as a living organism!

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[1] See Meditation 5, *Nanotechnol. Perceptions* **7** (2011) pp. 103–104 for a definition of multimer.

[2] All snow crystals have either a hexagonal or a trigonal symmetry. Most snow crystals are centrosymmetrical, the exceptions being the rodlike and trigonal crystals.

Nanotechnology Perceptions **10** (2014) 164–172
Received 20 November 2014

Cirrus clouds, being very cold, may be made of multimer/solid phase matter, which we have been unable to study precisely in our laboratories.

2. Clouds to rain—how does it happen? Clouds to hail—how does it happen? Clouds to snow—how does it happen?

The answer to the above questions is, at present, "We simply do not know the precise mechanism." What we do know is:

1. Clouds belongs to the *multimer phase*. The particles of a multimer phase float in air and are absorbers and radiators of electromagnetic waves. They exist at all levels in the troposphere. There are hundreds or thousands of multimer phase allotropes with a wide range of densities from almost liquid density to almost gas density. There is fog at sea level, orographic clouds on the hills, altostratus and nimbostratus clouds just above the tops of the hills and cirrus clouds at the highest levels. Cumulonimbus clouds extend from sea level to the tropopause. There may be some multimers in the noctilucent clouds and in the aurora borealis (we have not analysed these stratospheric phenomena).
2. Rain belongs to the *liquid phase*. The drops of rain are a thousandfold denser than air at sea level. Air decreases in density from sea level to the tropopause but raindrops do not decrease in density with altitude. There is little rain in cirrus clouds and probably no rain at all above the tropopause and in the stratosphere.
3. Hail belongs to the *solid phase*. Hail is formed when liquid water drops freeze. Hail is granular in structure and large hailstones usually show an onion type structure: layers of ice that can be distinguished.
4. Snowflakes are aggregates of snow crystals in the *solid phase*. There is a large number of different snow crystals, perhaps no two are the same, just as we know no two human beings are the same, even identical twins are not truly identical. Each snow crystal is unique, each snow crystal is quantized (the scientific word for unique!).

We know that liquid water is, like all other liquids, a mixture (or an alloy); water is an alloy of $(H_2O)_2$, $(H_2O)_4$ and $(H_2O)_6$. The dimer is mainly associated with steam and is present in the atmosphere. $(H_2O)_4$ is present as the predominant allotrope in liquid water on Earth with some $(H_2O)_6$ and some $(H_2O)_2$ also present in liquid water between 0 °C and 100 °C at sea level.

The $(H_2O)_6$ allotrope of solid water is in common ice. It is less dense than normal liquid water because the latter is mainly the $(H_2O)_4$ allotrope with only a little $(H_2O)_6$ present. Living matter is mainly eutectic water, which has an even greater proportion of the $(H_2O)_4$ allotrope than in common liquid water and consequently less $(H_2O)_6$. Because every living creature is different these ratios are different for different animals and plants and, hence, some can withstand colder conditions than others. Because we have not developed methods to determine the different ratios of $(H_2O)_2$:$(H_2O)_4$:$(H_2O)_6$ in any sample, studies are restricted to qualitative work rather than quantitative statements.

According to the nendorec hypothesis, phase changes are always predicted to be in the following order, without exception:

$$\text{Solid} \rightarrow \text{(smectic)} \rightarrow \text{(nematic)} \rightarrow \text{(eutectic)} \rightarrow \text{liquid} \rightarrow \text{multimer} \rightarrow \text{gas}.$$

This is best seen in the sublimation of solid carbon dioxide, which *appears* to be solid to gas without the liquid phase but careful study shows that there is a nanometric liquid layer on the surface of the solid carbon dioxide solid as it is subliming. Likewise, although boiling *appears* to be liquid to gas without the multimer phase, a careful study of the supercritical boilers reveals the presence of the multimer phase in boiling in a way relatively easy to understand: if there were no multimer phase, boiling would not occur as huge bubbles rising from the heated surface. Also likewise, melting of solid to liquid always proceeds via the eutectic phase. This is best observed in freezing where globules of eutectic form on the surface of a solid and jiggle about as they change into the solid phase as grains in a metal. The smectic phase is called erroneously a liquid crystal whereas it is really a powder of monomolecularly thick particles of finite size (similar to the platelets of snow crystals but these are only one molecule thick, so the individual platelets cannot be seen). Smectic *is fluid but not liquid*. The nematic phase is also erroneously called a liquid crystal but it is a powder of monomolecular thick threads (or tapes) of finite length. The tapes are shorter at low temperatures just after the phase has changed from the smectic (or solid) phase. They are longer at higher temperatures just before it changes into a globule of eutectic phase. The nematic phase is fluid but not a liquid.

Hence, when a cloud changes from a multimer phase to a liquid phase, that is raindrops, the process is simple. The multimer particles change phase and release latent heat. The raindrop is the same weight as the multimer particle. Some clouds give fine raindrops and others give large raindrops. The old concept of a million minute particles of liquid water drops in clouds suddenly joining together to form one raindrop that can fall to the earth below is quite unlikely to be correct even though it is found in many meteorological textbooks.

The conversion of rain to hail via the eutectic phase is relatively simple because that phase is so similar to finite drops of liquid. What happens is the liquid phase splits into many eutectic droplets that stick together and then these change into the solid phase of the hexagonal $(H_2O)_6$ ice allotrope. Hence, although a cloud (multimer phase) is a mixture (or alloy) of $(H_2O)_2 + (H_2O)_4 + (H_2O)_6$ and this changes into a liquid phase which is also a mixture of $(H_2O)_2 + (H_2O)_4 + (H_2O)_6$ as raindrops, when these change to hail the $(H_2O)_4$ are changed into $(H_2O)_6$ via the reaction $(H_2O)_2 + (H_2O)_4 \rightarrow (H_2O)_6$. So, the multimer phase is a mixture, the liquid phase is a mixture, and the eutectic phase is a mixture but the solid phase is not a mixture, it is a particle (of many nendorecs) of pure $(H_2O)_6$ solid and a hailstone is millions of these nendorec particles from one drop (one nendorec) of liquid water.

A raindrop or a snowflake indicate the weight of the multimer phase particle in a cloud. However, the density of the multimer particle is only 0.001 of that of the raindrop so the volumetric size of the cloud particle is 1000 times greater than the liquid particle of raindrop. This would make it 10 times bigger in the x,y,z axes if the multimer particle were spherical, but if the multimer particle in a cloud was like a piece of paper then its size in the x,y plane would be much greater and the z axis would be very small. It would also be very flexible, hence we have never seen the individual particles of a cloud, just as we have never seen the individual particles of solid helium in superfluid helium, but the individual particles in a cloud will be quite large!

We have deduced that particles of multimer phase in clouds change into solid snow crystals and they *must* do so via both the liquid and the eutectic phases both of which are mixtures of $(H_2O)_2 + (H_2O)_4 + (H_2O)_6$. This would seem to be impossible but we know that it must happen so here is a suggestion because nobody has produced centro-symmetrical snow crystals in the laboratory, though many have tried to do so. Snow crystals are a distinct part of snowflakes and we know that they come from clouds.

When liquid *ortho*-nitrochlorobenzene (melting point 32 °C) is supercooled it is quite stable until a seed crystal is added, whereupon it rapidly crystallizes but the process via the eutectic phase and the release of latent heat produces an amazing, unexpected result: the drop of liquid does not become a solid lump but it produces dendrites that grow upwards against gravity (Figure 1), this uses some of the latent heat of fusion released in the phase change. Observation shows that the liquid or eutectic flows over the surface of the solid crystallites, the dendrites increase in height as they rise upwards (Figure 1). This is a very rapid process and one wonders whether the beautiful quartz crystals found by geologists were actually formed very quickly in conditions that are not fully understood by humans at present.

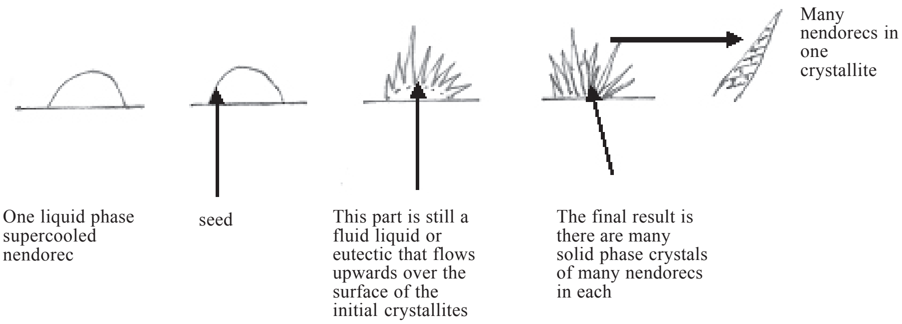

Figure 1. Observations made when crystallizing a supercooled globule of *o*-chloronitrobenzene.

This flowing of the liquid or eutectic phase over the surface of the crystallites gives us a good indication why we find onion type hailstones from large thunderclouds. Initially small hailstones are formed from some raindrops, but these come into contact with some drops of supercooled liquid raindrops and they amalgamate and spread over the surface of the solid before they themselves solidify and finally we have the onion-type large hailstone that does so much damage when it impacts with objects on earth (Figure 2).

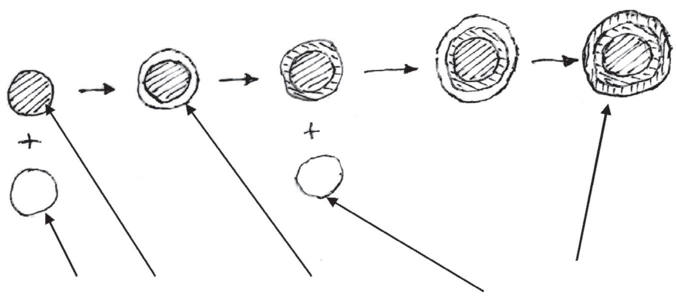

Figure 2. A diagram of the crystallizing of a drop of rain in a thundercloud to form a hailstone with an onion-type structure.

We are using the principles of amalgamation, splitting and spherodization.[3] Phase changes release energy to power a process, and this is the way in which multimers in clouds can change into snowflakes made of many snow crystals.

[3] See part II of Meditation 20, *Nanotechnol. Perceptions* **9** (2013) pp. 30–33.

The first stage is that the multimer particle is planar rather than spherical (Figure 3). It contains a mixture of $(H_2O)_2 + (H_2O)_4 + (H_2O)_6$ and it is supercooled. A seed touches part of the boundary as in our example of *o*-nitrochlorobenzene and this starts the crystallization process within the multimer particle. Various sites change first to the liquid phase and then to the eutectic phase and then they change to the solid phase where dendrites often appear. Finally, when all the material that was originally in the multimer particle has been used up in the manufacture of snow crystallites they fall to the ground as snowflakes (Figure 5).

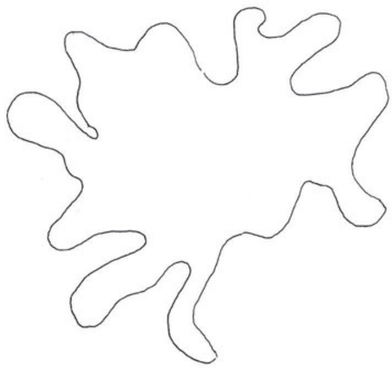

Figure 3. A planar, amoeba-like multimer particle of one type of cloud. The particles will likely be different for different types of cloud and, hence, all snowstorms can be quite different in the type of snow that falls (Figure 4). One may recall the excuse given by railway officials who were unable to run their trains because "The wrong type of snow was on the tracks".

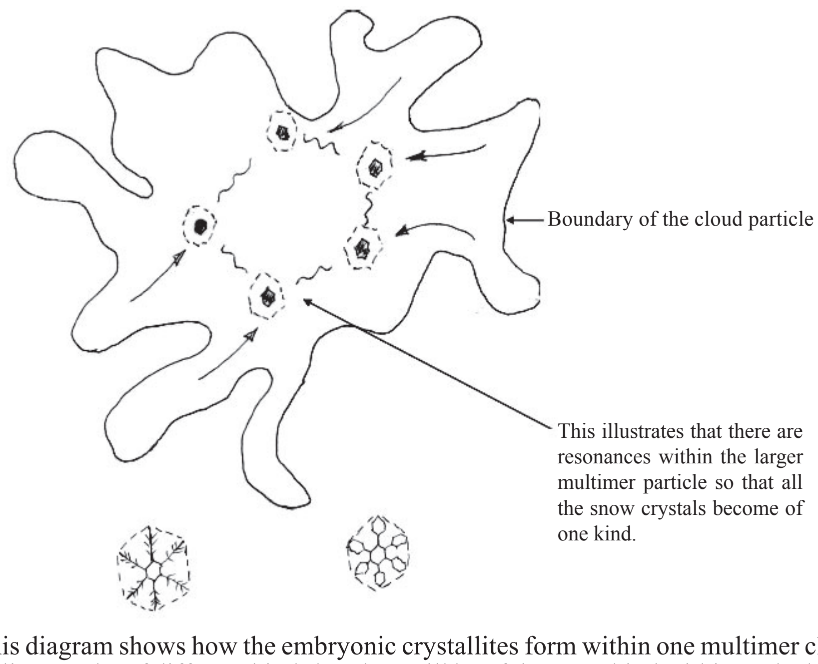

Figure 4. This diagram shows how the embryonic crystallites form within one multimer cloud particle; the crystallites can be of different kinds but they will be of the same kind within each cloud particle and for each type of cloud.

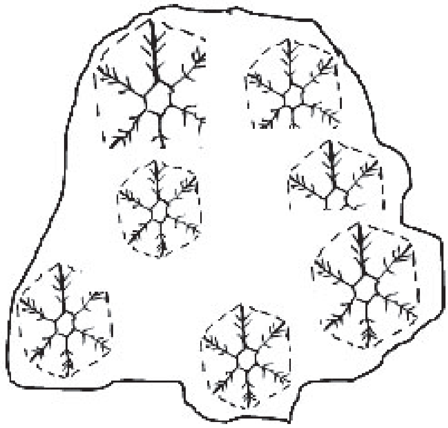

Figure 5. This illustration shows how the crystallites that have all been within one cloud particle just stick together to form a snowflake. It is really remarkable that within each multimer particle of a cloud nanosized droplets of liquid form and these easily change into the eutectic droplets, which droplets lose heat and with a temperature drop become crystallites of $(H_2O)_6$ solid phase. These tiny hexagonal crystallites within the multimer particle of cloud are rather like the tiny urea crystals found in a living amoeba (a form of eutectic water).

All studies reveal that even these multimer phase particles changing into solid phase snow crystals do so in the following sequence:

$$\text{Multimer} \rightarrow \text{Liquid} \rightarrow \text{Eutectic} \rightarrow \text{Solid.}$$

This is the way one would expect from a nendorec hypothesis and it is pleasing that snow crystals and snowflakes illustrate it so well.

3. Summary

Clouds are made up of many low density multimer phase particles. Different clouds have different allotropes of the multimer phase. There are many more allotropes of the multimer phase than there are different types of cloud.

A low density multimer particle in a cloud can lose latent heat and become single raindrop. The size of the raindrop indicates the weight of the multimer particle but the latter is a thousand times greater in volume than the raindrop. Although we have seen raindrops these giant multimer particles appear to be invisible!

A low density sheet-like multimer particle in a cloud can lose latent heat and split into embryonic snow crystals that combine together to make a snowflake that has a greater volume than its equivalent raindrop though it is smaller than the multimer phase particle from which it was formed. The weight of the raindrop, the snowflake and the multimer will be similar.

This study of nanoparticles in the atmosphere reveals that although we can see and photograph the liquid and the solid phases of water as raindrops, hail, snowflakes and snow crystals, we cannot see or photograph any individual and much larger particle of the multimer phase that forms the basis of the many and varied types of cloud.

Appendix A: Remarks on snowflakes by Kenneth Libbrecht of the California Institute of Technology.[4]

The particular path that a crystal follows through the turbulent atmosphere determines its final form, so no two crystals end up exactly alike. However, the six arms of a single crystal all travel together, so they all grow in synchrony (Figure A1).

Figure A1. Nothing synchronizes the growth of the six arms of a snow crystal. They all grow independently. But since they grow under the same randomly changing conditions, all six end up with similar shapes. The vast majority of snow crystals are not very symmetrical; irregular crystals are by far the most common type. Near-"perfect", symmetrical snow crystals are not common.

The lattice has molecular dimensions, and it is not trivial how this nanoscale symmetry is transferred to the structure of a large snow crystal. The snowflake is, in fact, a simple example of self-assembly.[5] There is no blueprint or genetic code that guides the growth of a snowflake, yet marvellously complex structures appear.

The overall snowflake morphology behaves peculiarly as a function of temperature, whereby it changes from platelike to columnar and back again as the temperature is lowered. This behaviour has proven particularly difficult to explain, even at a qualitative level. Although the phenomenon was described over 75 years ago we still cannot explain why snow crystals grow so differently when the temperature changes by just a few degrees. In fact, our understanding of crystal growth in general is remarkably primitive compared with our knowledge of crystal structure.

For now at least, we are left with the unsettling fact that we still cannot explain, even at a qualitative level, some of the most basic characteristics of snowflakes. This question is vital because the varying growth rates of the basal and prism surfaces are what ultimately determine the temperature dependence. Unfortunately, so far no-one has been able to measure these growth rates with sufficient accuracy, nor do we have a model of the ice surface that allows us to calculate condensation rates.

The lowly but lovely snowflake exhibits an impressive phenomenology that stems from the subtle interactions between seemingly simple physical processes. There may be no direct industrial applications for snow crystals, but understanding them requires us to explore fundamental questions about how solids form and how structures arise during crystal growth. This basic research could lead to new discoveries in metallurgy, nano-scale self-assembly and other areas.

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4 www.its.caltech.edu/~atomic/snowcrystals

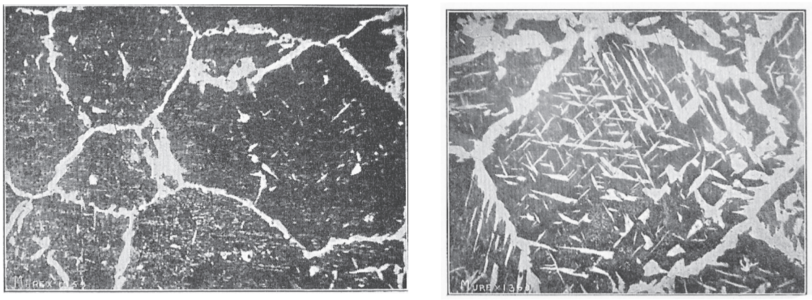
5 Biological self-assembly is an extremely complex process, and we do not understand much about how it works at a fundamental level.

This problem has received considerable attention from metallurgists, since freezing a metal from its melt often produces micro- or even nano-scale dendritic structures that can profoundly affect the strength, ductility and other properties of the final material.

Appendix B: Metallurgy

This growth of snow crystals within the multimer phase particle of a cloud, which particle has turned out to be rather larger than one expects from conventional meteorology books (where the particles are liquid drops about 200 μm in diameter, thus needing one million of these droplets to make just one raindrop), is really the same as the growth of inclusions within grains as they cool down in metals and ceramics.

When a metal cools the rate of cooling frequently determines the type of grain structure that is produced and, hence, the properties of the resultant metal piece. Some of the best examples are those of eutectic grains (Figure B1).



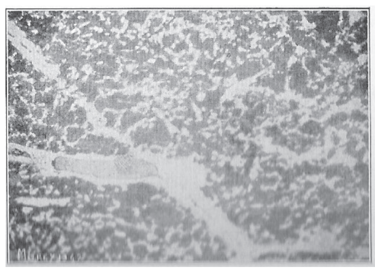


Figure B1. 0.5% carbon steels. Clockwise from upper left: slow cooled, showing network of ferrite; slow cooled from 1450 °C, showing Widmanstätten structure (ferrite precipitated at boundaries and on the planes of an austerite grain); showing ferrite formed around an inclusion of manganese sulfide even after annealing. After E.C. Rollason, *Metallurgy for Engineers*. London: Edward Arnold (1961).

Another good example is martensite in iron alloys (Figure B2).

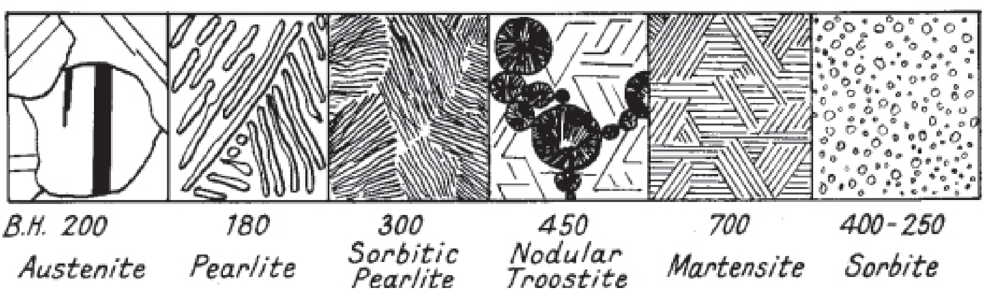


Figure B2. Forms of carbide in micro-constituents in steel (after Rollason, *loc. cit.*).

The authors' own experience was in uranium oxides, where the U_4O_9 needles grew within the UO_2 larger grains.

Hence the growth of snow crystals, dendrites and hexagonal symmetry, is really quite normal. According to the Principle of General Relativity all these processes are of the same type of order that has been observed in nendorecs; they are nuclei [the $(H_2O)_6$ units] with order, resonating within a boundary. The randomness and chaos so often associated with these beautiful snow crystals is really only within the human mind when it fails to understand something in the world around us. Careful observation shows "order without chaos".

Appendix C: Some other evidence supporting the concept of platelets of multimer phase particles forming clouds in our atmosphere

1. Flat thin plates cannot produce a rainbow. Quite small droplets of 0.01 mm suggested by Geoff Jenkins of the Met Office are 10^5 Å in size; this is 25 wavelengths of violet light or 15 wavelengths of red light, it is quite possible that if clouds were made of droplets of water then clouds would give rainbows.
2. Flat thin sheets can float better than spheres, especially as the multimer phase density is less than the liquid phase density. So clouds of these particles float very easily.
3. Flat thin platelets given energy from the Sun could move air very readily (like shaking a piece of paper easily produces a draught) whereas droplets cannot produce a wind (like shaking a hammer does not produce a draught).
4. Flat thin platelets can cohere together and then these can form mamma or tubes. The power to drive these tubes can come from the multimer phase changing into the liquid phase and releasing energy as latent heat. This provides the horizontal power for turning a tornado tube, and that energy can do a lot of damage.
5. Flat thin platelets of multimer phase in the form of a mist can absorb heat (radiation) from the Sun and turn into invisible and transparent multimers; this burning off of the morning mist is a very common event.
6. Contrails from aircraft at high altitudes could not be droplets of liquid water because they would not be seen, whereas if they are multimer phase they could be seen because they are so voluminous and low density so that they continue to float in the sky for a long time after the aircraft has passed out of sight.
7. The colour (or shades of grey) of clouds may come from the different particles reflecting the sunshine or moonshine in different ways due to the characteristics of the surface of the particles (rather like the wings of some butterflies have no pigments to give them their beautiful colours).
8. These multimer particles are diaphanous, one could say they each constitute a natural bit of a negligée, but together they make a cloud!