

THE MECHANISM OF ICE CRYSTAL GROWTH AND THE THEORY OF EVOLUTION

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ABSTRACT

Ice crystal growth has been cited as an example of how evolution creates greater order. The modern explanation of ice crystal shape is described. The *second law of thermodynamics* is developed in terms of entropy change and applied to ice crystal growth. The difference between the *operation* of thermodynamic systems and their *origin* is discussed. It is concluded that ice crystal growth is similar to the *operation* of life processes but does not support the *origin* of life as described by the theory of evolution.

INTRODUCTION

Johannes Kepler, the yet-to-be famous astronomer, presented a unique New Year's gift to his patron in the winter of 1611. The scientist gave his benefactor a witty, reasoned discussion on why snowflakes (more precisely, ice crystals) have six corners. Since microscopes and diffraction instruments had not yet been invented, no one really knew why crystals took the shapes they did. Kepler [1] argued for the development of external shapes in crystals by the filling of three-dimensional space with atoms in various packing arrangements. He used analogies such as stacked cannon balls, bee hives, and packing of other geometric shapes. Since he was unable to convince himself that the internal structure produced the external shapes, Kepler concluded that there is a *formative faculty* which maintains six-cornered shapes. For his efforts to understand the cause of crystal shapes and his arguments which almost resulted in an explanation of crystalline shapes, he has been called by some "the father of crystallography".

Ice crystals are still being studied today. It is not completely clear, even now, why crystals grow into some of the beautiful shapes like that shown in Figure 1. Since the growth of ice crystals results in greater order, or a decrease in entropy, some have attempted to justify the theory of evolution by an analogy to crystal growth. This paper will discuss ice crystal growth, the *second law of thermodynamics*, and why neither support the theory of evolution. This work is supportive of the creation model because it refutes the concept that there is a self-organizing principle in matter which moves from molecules to man. Rather, the organization in form and process we observe all around us is due to the design of the Creator and the operation of the *second law of thermodynamics* instituted by the Creator.

THE MODERN EXPLANATION OF CRYSTAL SHAPE

The hexagonal symmetry of an ice crystal is an outward manifestation of an internal arrangement of the atoms in the ice. Each water molecule is V-shaped with an oxygen atom at the vertex and a hydrogen atom at the two extremities. An angle of 105 degrees separates the legs. Ice molecules are bound together in an open lattice and form puckered layers with hexagonal symmetry, as seen in Figure 2 and described by Fletcher [2]. Each molecule is surrounded by four nearest neighbors, so that each group has one molecule at the center and the other four at the corners of a tetrahedron, all the same distance away. The molecules are held in place mainly by electrostatic attraction between the positive charge of the hydrogen atom and the negative electrons of the neighboring oxygen atom. This is called a hydrogen bond.

Ice crystals grow as thin hexagonal plates or long hexagonal columns, depending on temperature. Two faces can be defined for ice crystals - the basal face and the prism face. The basal face is typically the surface which shows hexagonal symmetry. For example, the basal face in Figure 1 is the surface facing the reader. Both the upper and lower surfaces are basal faces. The prism face is perpendicular to the basal face. It faces outward from an arm or portion of an arm. This face does not exhibit hexagonal symmetry. For some temperatures, the basal face grows faster than the prism face, resulting in long hexagonal columns or needles. At other temperatures, the prism face grows faster, resulting in thin hexagonal plates, starlike stellar crystals, and fern-like dendrites. The shape(habit) of ice crystals as a function of temperature found by Magono and Lee [3] is shown in Figure 3. The fern-like dendritic nature of crystals is caused by the humidity. The greater the humidity, the more feathery the crystals will appear.

Hallet and Mason [4] have explored the reasons the basal and prism faces grow at different rates as a function of temperature. They have discovered that water vapor molecules collect on the ice and migrate across the surface to their final lattice positions. The rate at which the molecules migrate across the surface varies with temperature, and is different for the basal and prism faces. For some temperature ranges there is a net surface migration from the basal to the prism faces, resulting in a plate-like shape or habit. For other temperature ranges the situation is reversed, resulting in a net flux of molecules from the prism to the basal faces and the formation of columns or needles.

Figure 4 is a result of the work of Mason et. al. [5] which shows the mean migration distance of water molecules on the basal surface of ice as a function of temperature. It shows a complex relationship with two maxima at 0°C and -10°C. If a similar relationship is assumed for the prism face but shifted about 5°C to warmer temperatures, the ice crystal habits in Figure 3 can be explained.

THERMODYNAMICS AND ENTROPY

The *second law of thermodynamics* states that for all real processes the entropy of the universe always increases. The change in entropy can be defined in terms such as heat flow, volume change, pressure change, energy available to do work, or order and disorder. All but the last of these quantities are called macroscopic variables, i.e., they are large-scale quantities representing large numbers of molecules. For example, the differential change in entropy may be defined as:

$$dS = \frac{dQ}{T} \tag{1}$$

where dS is the change in entropy, dQ is the quantity of heat removed from or added to a system, and T is the absolute temperature. We can demonstrate how entropy changes according to the second law by considering a simple, everyday experience. Assume two blocks of equal mass, initially at 20°C and 0°C, are placed in thermal contact and allowed to come to thermal equilibrium. The blocks, shown in Figure 5, will come to a final temperature of 10°C. If the total system is expressed as a subsystem (1,2), a medium (3), and the rest of the universe (4); then equation 1 becomes:

$$dS = \frac{dQ_1}{T_1} + \frac{dQ_2}{T_2} + \frac{dQ_3}{T_3} + \frac{dQ_4}{T_4} \tag{2}$$

Assuming in this case the heat transfer only occurs from the hot block to the cold block within the subsystem, not to the medium ($dQ_3 = 0$) and the rest of the universe surrounding the two blocks ($dQ_4 = 0$), then:

$$dQ_1 = m_1c_1dT_1 \tag{3}$$

and:

$$dQ_2 = m_2c_2dT_2 \tag{4}$$

where m_1 and m_2 are the masses of the hot and cold blocks, respectively, c_1 and c_2 are the specific heats, and dT_1 and dT_2 are the changes in temperature. Substituting dQ_1 , dQ_2 , dQ_3 , and dQ_4 back into equation 2:

$$dS = m_1 c_1 \frac{dT_1}{T_1} + m_2 c_2 \frac{dT_2}{T_2} \tag{5}$$

Integrating both sides of equation 5 results in:

$$\Delta S = \int_{S_o}^{S_f} dS = \int_{T_1}^{T_f} m_1 c_1 \frac{dT_1}{T_1} + \int_{T_2}^{T_f} m_2 c_2 \frac{dT_2}{T_2} \tag{6}$$

where ΔS is the total change in entropy; S_o and S_f are the initial and final entropy states, respectively; T_1 and T_2 are the initial temperatures of the hot and cold blocks, respectively; and T_f is the final temperature of the two blocks in contact.

Then:

$$\Delta S = m_1 c_1 \ln \frac{T_f}{T_1} + m_2 c_2 \ln \frac{T_f}{T_2} \tag{7}$$

For the purpose of this exercise, we have assumed that the masses of the two blocks are equal to 1 kg each and the specific heat is 1000 J/kgK. This is not necessary to demonstrate the general result, but permits a simpler illustration. Substituting the assumed values for mass, specific heat, and temperature results in:

$$\Delta S = (1kg)(1000 \frac{J}{kgK}) \ln \frac{283K}{293K} + (1kg)(1000 \frac{J}{kgK}) \ln \frac{283K}{273K} \tag{8}$$

or:

$$\Delta S = -34.73 \frac{J}{K} + 35.98 \frac{J}{K} \tag{9}$$

or:

$$\Delta S = +1.25 \frac{J}{K} \tag{10}$$

The entropy change for this simple illustration is positive, in agreement with the *second law of thermodynamics*. However, it is important to note that the entropy of a portion of the system, the hot block in this case, actually decreased. Because heat was removed from the hot block, dQ_1 was negative, and its entropy decreased. When this heat was transferred to the cold block, dQ_2 was positive and the entropy increased for this block. Since the change in entropy is defined as the heat transferred divided by the temperature of the block, the same quantity of heat transferred from the hot block will result in a smaller change of entropy than for the cold block. Consequently, the net change in entropy for the universe was positive. This will always be the case for all real processes for heat transfer or any other real process no matter how entropy is defined.

ORDER AND ENTROPY

We have seen how a change in entropy can be calculated from macroscale quantities like heat flow. However, we have yet to understand what entropy actually is. It turns out that entropy is a measure of how mass and energy are distributed in the universe. The more heterogeneous the distribution of mass in space and the greater the difference in levels of energy, the more ordered the universe. Part of the difficulty with understanding entropy is that it actually measures the *disorder* of things. When we say that the entropy of the universe always increases,

we are actually saying that total mass and energy of the universe tend in the direction of less order. This does not mean that mass and energy can not become more ordered at some location in the universe, but only that the total universe becomes less ordered with time.

The basic concept of the *second law of thermodynamics* is in agreement with the Biblical statements of the creation account and the subsequent initiation of death and decay. During the six days of creation God ordered the universe by creating mass, space, and time; energizing the mass; and arranging the mass and energy in specific ways. On the seventh day God rested. The *second law of thermodynamics* was probably instituted at the time of Adam's sin in the garden of Eden. It is in operation today and will be so until God intervenes at the end of the ages. He also intervenes intermittently in the form of miracles from time to time. The disorder of the universe normally increases with time under God's oversight. A reasonable analog to the action of the second law is the winding down of a clock. The mass and energy of a clock is ordered by design and its initial winding. When released, the clock slowly winds down, decreasing its order with time. The clock will always wind down - never wind up by itself.

For us to reach a better understanding of entropy, we will need to study a second illustration, this time on the microscale. Consider a box with a barrier in the middle, as seen in Figure 6. On one side are black marbles and on the other side white marbles. Now we take out the barrier and let them mix. How has the entropy changed? Is the trend toward an increase or a decrease in entropy? To more easily quantify this example, we will assume originally 3 black marbles on one side of the partition, 2 white marbles on the other side, and 6 possible energy states available to the marbles on each side. The marbles are allowed to move around and randomly assume six possible energy states. Only one marble can occupy a given energy state at a time. Although the marbles are in random motion, the total number of possible configurations is determined by the original design of the system. We will define Ω to be the number of possible energy configurations in which the system may be arranged. This variable is called the thermodynamic probability by Zemansky and Dittman [6]. Considering the black side first, the number of possible energy configurations is given by:

$$\Omega_B = \frac{6!}{(6-3)!3!} = \frac{6 \cdot 5 \cdot 4 \cdot 3 \cdot 2 \cdot 1}{(3 \cdot 2 \cdot 1)(3 \cdot 2 \cdot 1)} = 20 \quad (11)$$

where Ω_B is the number of energy configurations on the black side of the partition. This result is due to the number of possible combinations and permutations of 6 energy states taken 3 at a time. Since the 3 marbles are indistinguishable, the result must be corrected by 3! in the denominator, resulting in 20 possible ways the 3 black marbles may be arranged with the partition in place. Considering next the white side, we find the number of possible energy configurations to be:

$$\Omega_W = \frac{6!}{(6-2)!(2!)} = \frac{6 \cdot 5 \cdot 4 \cdot 3 \cdot 2 \cdot 1}{(4 \cdot 3 \cdot 2 \cdot 1)(2 \cdot 1)} = 15 \quad (12)$$

where Ω_W is the number of energy configurations on the white side of the partition. Here 6 energy states were taken 2 at a time. The result was corrected by 2! to account for the 2 marbles being indistinguishable.

A definition of entropy in terms of microscale quantities is:

$$S = k \ln \Omega \quad (13)$$

where S is the entropy of a given system, k is the Boltzman constant equal to 1.38×10^{-23} J/Kg, and Ω is the number of possible energy configurations of the system. With this definition, the entropy, S_P , of the box of black and white marbles in the box with the partition is:

$$S_P = S_B + S_W \quad (14)$$

where S_P is the total entropy of the box of black and white marbles, S_B is the entropy of the black side and S_W is the entropy of the white side. Substituting equation 11 and equation 12 into equation 13 separately and then both into equation 14 results in:

$$S_P = k \ln \Omega_B + k \ln \Omega_W \quad (15)$$

or:

$$S_P = k \ln(\Omega_B \Omega_W) \quad (16)$$

When values for the variables are substituted:

$$S_P = (1.38 \times 10^{-23} \frac{J}{K}) \ln(20 \cdot 15) \quad (17)$$

or:

$$S_P = 7.87 \times 10^{-23} \frac{J}{K} \quad (18)$$

This is the configurational entropy of the box of marbles with a partition dividing the black marbles from the white marbles. If the partition is now removed, the total number of available energy states is 12. The 5 marbles are free to arrange themselves throughout the entire box, not just to the original 6 energy states on one side of the partition. The number of possible configurations of energy with no partition, Ω_{NP} , is:

$$\Omega_{NP} = \frac{12!}{(12-5)!2!3!} = \frac{12 \cdot 11 \cdot 10 \cdot 9 \cdot 8 \cdot 7 \cdot 6 \cdot 5 \cdot 4 \cdot 3 \cdot 2 \cdot 1}{(7 \cdot 6 \cdot 5 \cdot 4 \cdot 3 \cdot 2 \cdot 1)(2 \cdot 1)(3 \cdot 2 \cdot 1)} \quad (19)$$

or:

$$\Omega_{NP} = 7,920 \quad (20)$$

The entropy of the box without the partition, S_{NP} , is:

$$S_{NP} = k \ln \Omega_{NP} = 12.39 \times 10^{-23} \frac{J}{K} \quad (21)$$

The change in entropy by removing the partition is then:

$$\Delta S = S_{NP} - S_P = +4.52 \times 10^{-23} \frac{J}{K} \quad (22)$$

By removing the partition we have caused the entropy to increase. The reason for this increase is the greater number of ways in which the marbles can be distributed. Feynman [7] in discussing this example concludes that entropy is greater when the marbles have fewer restrictions on their distribution. He goes on to show that a box originally containing all black marbles on one end and white marbles on the other will become mixed with time such that the black and white marbles will become evenly distributed throughout the box. The probability is so low that an original mixture of a large number of black and white marbles will separate with time into all black marbles at one end and white marbles at the other, that one never observes such an event. The diffusion of smoke from a source throughout a room is always the normal sequence of events, never the concentration of smoke into a small volume from an original wide dispersion.

Entropy is then a measure of how energy and mass are distributed in the universe. It can be calculated from macroscopic quantities like heat transfer, but is also quantifiable at the molecular scale by knowing the distribution of individual molecules. In fact, entropy calculated

from macroscale quantities should be identical to the summation of the contributions of the entropy from molecular-scale configurations. Unfortunately, it is often difficult to account for all the degrees of freedom and sources of order when considering large numbers of molecules and possible energy states. Approximations are often made which need to be validated. Fortunately, the macroscopic-scale entropy should be an upper limit to entropy calculations. Therefore, if we are dealing with a change in configurational entropy on the microscale, like the formation of an ice crystal, we can measure the upper limit of entropy change on the macroscale by the amount of latent heat removed because of the phase change.

ICE CRYSTAL GROWTH AND ENTROPY

Let's take these principles we've reviewed and apply them to the growth of an ice crystal. We will first calculate the macroscale entropy change in growing an ice crystal and then find the equivalent microscale entropy change. Assume a subsystem contains 1 m^3 of air saturated with water vapor at 0°C and a pressure of 1 atmosphere, as shown in Figure 7. This volume will contain approximately 2.67×10^{25} air molecules and about 1.62×10^{23} water vapor molecules. If heat is now removed from this subsystem, the air and water vapor will cool, the air will become supersaturated, and cloud droplets will form, if normal concentrations of condensation nuclei are present. These cloud droplets will release latent heat of condensation as they form. As more heat is removed the temperature of the air, water vapor, and cloud droplets will cool until ice crystals are nucleated and begin to grow by vapor-to-solid deposition. Latent heat of deposition is also released by the growing ice crystals. By the removal of heat, water vapor molecules originally in completely random motion of the vapor state, are incorporated into more ordered liquid and solid states of cloud droplets and ice crystals. The removal of heat from the subsystem is defined as a negative quantity, so the macroscopic change in entropy of the subsystem is negative. This decrease in entropy is what would be expected for an increasingly ordered arrangement of molecules on the microscale.

The heat extracted from the subsystem must be accounted for somewhere else, however. We will assume that the heat will be distributed into the medium surrounding the subsystem, as shown in Figure 7. Furthermore, we will assume that the medium is sufficiently massive that the quantity of heat removed from the subsystem will not change its temperature nor affect the rest of the universe. These assumptions are common practice both theoretically and experimentally. For example, it is typical to immerse an experimental apparatus in a water bath to maintain a constant temperature. The water bath absorbs or gives up small quantities of heat but maintains isothermal conditions if it is sufficiently massive. This is convenient theoretically because entropy changes are easy to calculate under isothermal conditions and the entropy changes can be restricted to a limited volume in space. One important feature of such a system is that the boundary between the subsystem and the medium allows heat but not mass to flow through, permitting the subsystem to be defined as a "closed system". On the other hand, since we have contained all the heat changes to the subsystem and the medium, the boundary between the medium and the universe will not permit heat to flow through. This boundary defines the total medium and subsystem as an "isolated system". A third type of boundary often referred to in thermodynamic discussions is the "open system". A boundary enclosing such a system will permit both mass and heat to flow. Such boundaries and definitions may be conveniently placed as desired around a system or process but care must be taken to properly treat where the sources and sinks of mass and heat occur.

Going back to the water vapor being cooled and converted into ice, let's assume that we only remove the heat necessary for one ice crystal to form at 0°C . This would require slow extraction of heat so that cloud droplets would not form and the suspension of an ice embryo in the volume of the subsystem at 0°C . Although these conditions are uncommon for clouds, it would be possible to do this experimentally if care were taken. Theoretically, this has the benefit of ignoring all other sources of heat such as latent heat of condensation and the heat capacity of air and cloud droplets. This is no different than partitioning the energy by type of process - in this case the latent heat of deposition. The amount of heat released by forming a single hexagonal plate 1 millimeter in diameter and 100 micrometers thick is:

$$dQ = -mL = -\rho VL \tag{23}$$

or:

$$dQ = -(.9164 \frac{gm}{cm^3})(6.50 \times 10^{-5} cm^3)(2834 \frac{J}{gm}) \quad (24)$$

or:

$$dQ = -1.69 \times 10^{-1} J \quad (25)$$

where dQ is the amount of latent heat released by deposition, m is the mass of the crystal, ρ is the density of ice, and L is the latent heat of deposition (sublimation), and V is the volume of a 1-millimeter diameter, hexagonal plate 100 micrometers thick. During the growth of the ice crystal its temperature will remain at 0°C, as observed during phase changes at a pressure of 1 atmosphere. The temperature of the air and water vapor will also remain at 0°C if the heat is removed slowly enough. The change of entropy by the removal of the latent heat of deposition for the mass of this ice crystal at 0°C is then:

$$\Delta S = \frac{dQ}{T} = \frac{-1.69 \times 10^{-1} J}{273K} \quad (26)$$

$$\Delta S = -6.18 \times 10^{-4} \frac{J}{K} \quad (27)$$

This change in entropy on the macroscale should be the upper limit to estimates of entropy change on the microscale.

Now, let's consider the entropy change on the microscale by the reconfiguration of the molecules from the vapor state to the solid state of a hexagonal plate. First, we need to know the entropy of the water vapor in its initial state. A mixture of air and water vapor obeys the ideal gas law very closely, even when near the condensation point for water vapor. Consequently, the derivation for the entropy of an ideal gas will be followed. The full treatment of the ideal gas statistics may be found in Goodstein [8]. The final result of this derivation for the entropy of an ideal gas is:

$$S = -Nk \ln \frac{N}{V} + \frac{3}{2} Nk \ln kT + Nk \left(\frac{5}{2} + \frac{3}{2} \ln \frac{2\pi m}{h^2} \right) \quad (28)$$

where S is entropy, N is the number of molecules in the gas, V is the volume, k is the Boltzman constant, m is the mass of a molecule of water vapor, and h is the Planck constant. Since only the water vapor molecules change phase, we will ignore the entropy of the air molecules. They have the same entropy before and after the formation of an ice crystal because the volume and temperature are held constant. The air molecules are present to facilitate the transfer of latent heat released at the crystal to the boundary of the subsystem. Substituting the values of N , V , and T specified earlier into equation 28 results in:

$$S = +49.89501 \frac{J}{K} \quad (29)$$

where S_N is the entropy of the water vapor in the gaseous state before the ice crystal has been grown. Of the 1.62×10^{23} molecules in the initial volume, 1.98×10^{18} of these molecules will be incorporated into the lattice of the ice crystal. The entropy of the water molecules in the volume remaining after the ice crystal is grown may be found by substituting the same V and T but a new N (equal to $1.62 \times 10^{23} - 1.98 \times 10^{18}$ molecules) into 28, giving:

$$S_{N-\Delta N} = +49.89441 \frac{J}{K} \quad (30)$$

where $S_{N-\Delta N}$ is the entropy of the water vapor after the crystal is grown. The original entropy of the ΔN molecules which are incorporated into the ice crystal is then:

$$S_{\Delta N} = S_N - S_{N-\Delta N} = +6.03 \times 10^{-4} \frac{J}{K} \quad (31)$$

This procedure for finding the entropy of the water molecules which are incorporated into the ice crystal is a close approximation. It did not consider the affect of the air molecules on entropy. Because the number of molecules is so large, however, the error is small. Now, let the number of water molecules incorporated into the ice crystal, in general, be given by n and the number of positions available to these molecules in the crystal be given by n' . In the case where a perfect crystal is formed with no vacancies and no dislocations, the number of positions, n' , will be the same as the number of molecules, n . Since all n molecules are indistinguishable, the number of ways in which the molecules may be arranged must be corrected by a factor, $n!$ Therefore, the number of configurations in an ice crystal, Ω_s , is given by:

$$\Omega_s = \frac{n!}{(n-n)!n!} = 1 \quad (32)$$

This results in the configurational entropy of an ice crystal, S_s , being:

$$S_s = k \ln \Omega_s = 0 \quad (33)$$

The change in entropy of water vapor molecules in the subsystem, ΔS_{Sub} , in going from the vapor state to the solid state is then:

$$\Delta S_{Sub} = S_s - S_{\Delta N} = -6.03 \times 10^{-4} \frac{J}{K} \quad (34)$$

This agrees within about 3% of the result from the macroscopic calculation of entropy change in equation 27. This slight difference is due to the lack of consideration of other sources of entropy change, such as the orientation of the water molecules in space, the vibrational contributions, and the electronic contributions. A water molecule is not simply a spherical ping-pong ball-like object in the vapor which is stacked like cannon balls in the lattice, but rather, has smaller-scale features which contribute to energy and entropy calculations. In calculating the latent heat removed, all these characteristics were integrated into the latent heat, but were not considered in the microscale calculations of configurational entropy change. If they had been, the microscale entropy change would be identical to the macroscale value of entropy change. The fact that the microscale entropy change is close to and slightly smaller than the macroscale entropy change, validates the fact that our procedures are correct. Further consideration of the other sources of entropy change would likely bring the microscale calculations into full agreement with the macroscale.

In order to decrease the entropy in the subsystem by growing an ice crystal heat had to be pumped from the subsystem into the medium, which has the same temperature as the subsystem. The heat pumped into the medium is positive and equal to $1.69 \times 10^{-1} J$ from equation 25. If no other sources of heat were involved, the change in entropy for the medium, ΔS_{Med} would be:

$$\Delta S_{Med} = \frac{dQ}{T} = \frac{+1.69 \times 10^{-1} J}{273K} = +6.18 \times 10^{-4} \frac{J}{K} \quad (35)$$

This means that the net change in entropy, ΔS , considering only the subsystem and medium, will be zero.

$$\Delta S = \Delta S_{Sub} + \Delta S_{Med} = 0 \quad (36)$$

However, the work necessary to pump the heat from the subsystem to the medium was generated at the expense of an increase in entropy somewhere else in the universe. The total change in entropy, ΔS , for all components of this process over the entire universe will be greater than zero, once more agreeing with the *second law of thermodynamics*.

The extraction of heat from the vapor results in more order in the subsystem as the water molecules form hexagonal patterns and collapse into lower energy states. The hexagonal structure the molecules assume and the manner in which they migrate to assume these patterns is circumscribed by the original design imposed on the water molecules. If the environmental conditions are slightly different, e.g. the temperature varies slightly, the shape of the crystals will change somewhat but always in a pre-determined response to the environmental conditions. If we were working with the vapor of some other chemical material, the crystals could form shapes according to cubic, monoclinic, or other crystal systems. The shapes and patterns will form according to the design built into the molecules of the material. We could continue to explore to deeper and deeper levels as to why the atoms combine into molecules as they do, why the protons, neutrons, and electrons combine into atoms as they do, etc. However, we will continue to come to the same conclusion as that of Kepler [1] at his level of observation when he stated that a *formative faculty* exists in nature which causes the six-sided shape of snowflakes. He attributed this *formative faculty* to the Creator's design which is preserved from the origin of the universe until now. Such design could not have originated by chance because the order of the universe as a whole does not increase, but decreases. Ice crystal growth then is in full agreement with the *second law of thermodynamics* and exhibits original design by the Creator.

EVOLUTION AND THE SNOWFLAKE

It is my belief that biological life processes *operate* in a very similar manner to ice crystals. Work is extracted from higher energy states to drive the metabolism and other processes of plants and animals. Order can be increased in a local subsystem by a decrease in order of the universe as a whole. These complex processes are proscribed by the original design built into them which does not change with time. See Thaxton et. al. [9] for a discussion of the difference between order and complexity. Like ice crystals, design is evident in the operation of biological processes.

Evolutionists would extrapolate this description of the *operation* of biological systems to the *origin* of life processes. The generation of order is given free reign and not restricted by design constraints. The earth's biosphere is visualized to be an "open system" which energizes biochemical processes to organize simple inorganic molecules into complex macromolecules. However, we have shown that the growth of ice crystals is a result of extracting heat from water vapor. It completely obeys the second law of thermodynamics. The shapes ice crystals assume is proscribed by the environmental conditions and the original design of water molecules by the Creator. Ice crystal shapes have not "evolved" over time as evolutionists would suggest for life processes. The same ice crystal shapes are observed today as reported by Han Ying [10] over two thousand years ago.

Even if plants and animals were not bound by original design and could evolve, the information necessary for life processes to operate today would have taken longer to develop than the 20 billion years or so our universe has assumed to have existed by evolutionists. Even Crick [11] and Hoyle [12] have recently recognized this problem. Crick [11] has resorted to *panspermia* to explain the formation of life on the earth. *Panspermia* is the concept that life did not succeed in starting on earth by itself, but was seeded by microorganisms wafted in from space. This is a tacit admission that life is so complex that random processes could not possibly have formed macromolecules containing this information without design. The basic error that evolutionists have made is to explain the *origin* of life in terms of processes by which life *operates*. The information evident in the existence and complexity of life demands a Creator. Even the growth of an ice crystal demands a Creator.

This paper is intended to be expanded in future research to show how entropy changes in biologic processes and how much information content macromolecules contain. It is intended that the calculations of Hoyle [12] will be repeated and used to quantify the statements made about biological processes in this paper.

CONCLUSIONS

Ice crystal growth is consistent with the *second law of thermodynamics*. It is a consequence of the removal of heat from water vapor and the inherent design of water molecules to form an orderly crystal lattice. The growth of ice crystals is similar to the *operation* of life processes, but does not support the *origin* of life as described by the theory of evolution. Even the growth of an ice crystal demands a Creator.

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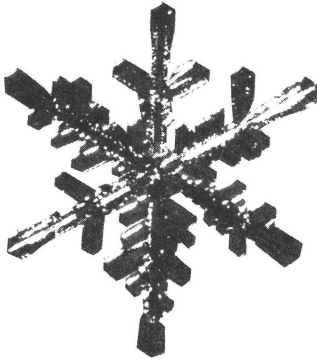


Figure 1. A plane dendritic ice crystal approximately 5mm in diameter.

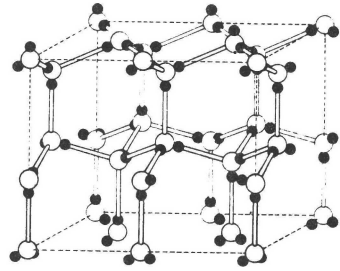


Figure 2. A three-dimensional lattice of water molecules in an ice crystal. The white balls are oxygen atoms and the black balls are hydrogen. After Fletcher [2].

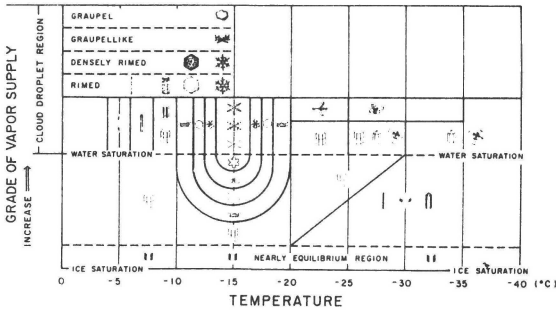


Figure 3. Temperature and humidity conditions for the growth of ice crystals. After Magono and Lee [3].

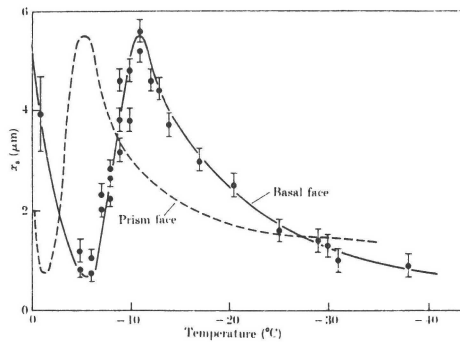


Figure 4. The mean surface migration distance x_s as a function of temperature. After Mason et. al. [5].

$m_1 = 1\text{ kg}$
$T_1 = 20^\circ\text{C}$
$T_1 = 293\text{K}$

BLOCK 1

$m_2 = 1\text{ kg}$
$T_2 = 0^\circ\text{C}$
$T_2 = 273\text{K}$

BLOCK 2

$m_f =$	2 kg
$T_f =$	10°C
$T_f =$	283K

COMBINED BLOCKS

Figure 5. Two blocks originally separated at different temperatures, then placed in contact and allowed to come to thermal equilibrium.

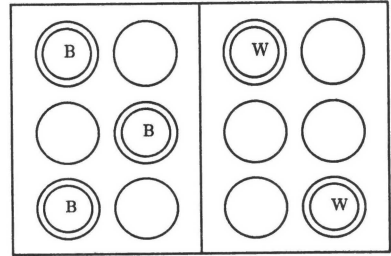


Figure 6. Black and white marbles in a partitioned box. B are black marbles, W are white marbles, and blank circles are empty positions.

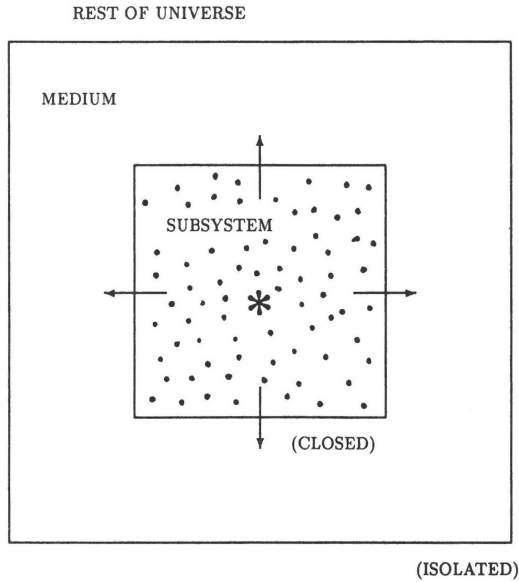


Figure 7. Ice crystal and vapor in a closed subsystem which is free to exchange heat with the surrounding medium. The subsystem and medium constitute an isolated system which can not exchange either mass or heat with the rest of the universe.

DISCUSSION

Entropy can be a hard concept to grasp. This paper is useful in providing several simple illustrations by which to calculate entropy change. A "simple" water vapor-to-ice phase change is a good place to begin before tackling the more complicated organics.

On page 2, paragraph 5, the two blocks of equal mass must be assumed to be of the same specific heat as well. "Of the same substance" would satisfy the requirement.

Edmond W. Holroyd III, Ph.D.
Arvada, Colorado

This paper highlights one of the more serious flaws in the atheistic views on the creation of the universe, namely the absence of reason and understanding in basic physics, for when the reasoning process operates and fundamental laws of physics are considered the conclusions do not support the "chance" theory of creation of matter and life. Such unreasoned approaches to explaining the universe actually take more "belief" or "faith" than does accepting the existence of a Creator! Consider, for instance, the probability of the molecules arranging themselves in the shape of the ice crystals shown in Figure 1 or in the very precise structure of the lattice in Figure 2. Its kind of like the probability that a book could be reformed into its original form after running it through a paper shredder, then thoroughly stirring up the millions of pieces of paper with their fragments of ink on them! This paper underscores the importance in the education process of teaching children (and older students, too) how to think (judging from the abstract, Hettke's paper addresses this issue).

I do have two questions, however. Regarding the microscale entropy change discussed following Eq. 34, is it possible to calculate the contributions of orientation, and of the vibrational and electronic states? And, is it possible that when these are considered the difference between the macroscale and microscale could be larger than 3%, i.e. that the entropy change could be even larger than the macroscale? In the same paragraph, you state in one place that the microscale entropy change "would be identical to the macroscale" if these other factors were considered, then later on (in the last sentence) you state the change "would likely" be the same as the macroscale. Which do you mean and if it is the former, on what basis can you be so definite that the results on the two scales would be identical?

The second general question deals with your statement in the section on "Order and Entropy" where you state that the second law was probably instituted at the time of Adam's sin in the garden. Please elaborate. Why couldn't the second law have been instituted on the fourth day of the creation when the stars were created, or on the sixth day after everything was created?

Laurence D. Mendenhall, Ph.D.
Placentia, California

CLOSURE

Response to Dr. Holroyd:

In the example of entropy change when two blocks come to thermal equilibrium, I did not specify "of the same substance" or "of the same mass" until equation (8). At this point, I made these assumptions to show that entropy increases, without complicating the example. However, entropy will increase even if both the masses and specific heats are assumed to be different for the two blocks.

Reponse to Dr. Mendenhall:

I believe it is possible to calculate the entropy explicitly considering the contribution of orientation, vibrational, and electronic states of the water molecules. In fact, to accomplish my long-term goal of entropy calculations on the DNA molecule, this must be done. I would not expect this contribution to be larger than the 3% because the total entropy change is bounded by the macroscopic changes.

The use of the phrase "would be identical to the macroscale" incorporates qualifying clauses from the previous sentences. If "smaller-scale features which contribute to energy and entropy" had been fully considered in the microscale calculations of configurational entropy change, the microscale and macroscale would be "identical". The phrase "would likely" later in the paragraph following equation (34) refers to the expectation to when this is actually attempted.

The macroscale entropy change is simply the summation of microscale entropy change. If we are aware of all microscale effects and adequately treat them, they should add up to the macroscale estimate of entropy change calculated by energy flow and temperature effects.

The time at which the second law was instituted is a controversial issue. Some have stated that the curse upon creation after Adam's sin was actually the institution of the second law because "death" is the essence of the second law. However, others have questioned how the creation could have operated from creation to Adam's sin without the second law. It is a fundamental law which is basic to all physical and biological processes such as heat exchange or digestion. My preference for institution of the second law after Adam's sin is to explain the operation of physical processes before Adam's sin by a different set of basic laws.

We are told this will also be true in the New Heavens and New Earth after the end of time. God apparently causes the world to operate in accordance with different principles in different ages.

Larry Vardiman, Ph.D.