The Entropy - Syntropy Inversion in Water
Part I
Fantappiè's Vision and Living Systems

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1. Some Historical Background

Many thinkers, whether educated in the sciences or not, have been puzzled by the dictates of the Second Law of Thermodynamics with its march towards disorder, on the one hand, and the result of biological evolution with its march towards purposeful diversification and organization, on the other. Darwin himself was drawn into the controversy by claims made by several British physicists, especially Kelvin, and felt the need to respond (Barrow and Tipler, 1986). Discussion continued during the last century with perhaps the best known contribution published by Schroedinger in his influential book "What is Life", in which he proposed an equal input of randomness (entropy) and order (negentropy) from the environment into life forms to explain their origin and evolution. However, following the success of the field of statistical mechanics in the 1930s and 40s, modern physical scientist have embraced the strict thermodynamic concept, that all natural processes, both living and non-living, are the result of random events. And because of their subordinate position in the scientific hierarchy, biologists, in general, also accept this view.

As a consequence, today's mainstream theory is that life sprang into existence with the spontaneous appearance of a self-replicating chain molecule (protein, DNA, RNA, . . .) in the chemical chaos of the Earth's primordial seas. At the present time, the favoured species is a molecule of RNA – the unstable sister molecule of the better known, DNA. Many authors have estimated the probability of this event happening, and although this is a technical biochemical question, it is sufficient for us to report that the number of molecules that can be made by joining four different nucleotides into a chain molecule 100 nucleotides long (a string of 100 beads made of four different coloured beads simulating that RNA molecule) exceeds the number of particles in the visible universe. Even though this calculation gives a result of astronomic dimensions for the number of such chain molecules, physicists claim that thermodynamics proves that, though the probability may be infinitesimally small, the possibility still exists of a chain spontaneously appearing with the required unique properties. Little wonder that so many authors describe this event as a "miracle" (see my forthcoming book "The Living Pixel", available free to interested readers by writing to jgwatterson@gmail.com).

However, miracle or not, this first step is a mere triviality. The physicochemical conditions that must now follow its creation before any biological material can appear, bring even more astronomic uncertainties. This molecule and its descendants must encounter the right environment prevailing in the vast expanse of ocean, including the right materials, energy supplies, structural information, . . ., and all in the correct historical sequence. We are reminded of Hoyle's colourful epithet of a whirlwind sweeping through a junkyard and producing a fully functional jumbo jet! Over the

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billion years or so from the appearance of this molecule to the first biological cell, the miracles continue to pile up, multiplying the probabilities yielding even more vanishingly small values. We now have not just a collection of miracles, but the miracle of the miracles!

Why do so many scientists align themselves with such an unreasonable account of events? It is possible, I suppose, to understand why classically trained physicists would do so. The dictates of the Second Law does not rule out improbabilities, however small. But in my opinion, this contorted argument is a misuse of mathematical practice. A result showing a vanishingly small probability indicates a zero possibility – or to put it another way – to claim a non-zero probability is, in the end, to disregard the point of the calculation! So next: why do so many biologists believe it? In my experience, the reason seems to be to avoid a clash with the traditional scientific establishment. If you say life is not an accident, then the implication is there must be a hidden underlying cause – in a word, you imply a creator, or worse, vitalism!

In the same decade as Schroedinger's book appeared, Luigi Fantappiè was developing his concept of syntropy in Italy. In 1941 he realized that his new idea was able to explain the evolutionary development shown by living systems, especially the phenomenon of differentiation (Di Corpo, 2013). Unfortunately, his work has not yet been published in English, so that reference to it is lacking in scientific literature, at least in the anglosaxon world. For example, as a student in the 1960s, I learnt of Schroedinger, Heisenberg, Bohr, Fermi, . . . , but Fantappiè's work remained unknown to me until 2016!

Because he lived and worked in the heady days of quantum physics, I guess Fantappiè was not aware of the fear of vitalism that has ruled over the biological world since the time of Darwin. In any case, as far as I know, he saw his concept of syntropy applying to Nature in general. This overriding view had cemented in his mind before he encountered the puzzles of differentiation and increasing diversity inherent in biological evolution, but he later realized that his new world-view could explain them.

Curious minds, like those of Schroedinger and Fantappiè, sensed that the appearance of molecules (protein, DNA, RNA) does not explain the origin of living, compared to non-living, activity. Just like other molecules, biological molecules are hard, solid, dead particulate matter. I use the term "molecular machines" for these objects in my writing, however, I am aware that many readers find this idea unsympathetic, or even antithetic, to life. So let's ignore my "mechanical" terminology for the moment as we proceed. What curious minds sense is, that biological activity needs a special type of energy.

This proposal contrasts starkly with the standpoint of physicists, since they claim there is no need for energy at all. Every system in liquid water is supplied with unlimited energy, because they exist in a "heat bath" at a certain temperature, say 20 degrees. Their temperature gives all the molecules of the system "thermal motion", and that's why the proposal that life is about energy immediately invites the heretical label of "vitalism". Consequently, according to thermodynamics, it is thermal motion that supplies all the energy needed for cellular activity. This is accepted dogma, in spite of the fact that, according to the Second Law, thermal motion is also claimed to be responsible for the contrary effect of the randomization of energy in general, not only in biology – it is the overriding inescapable entropic energy. Or expressed in a different way: a contradiction lies at the heart of this dogma. As I've made clear in my contribution to the recent controversy about magnetic biosensing (https://elifesciences.org/articles/17210#comments), it does not, and cannot, explain the experimental fact that the contents of the living cell are never observed to be in random motion – they avoid it!

In living systems, energy moves through structures which determine the pathway of its flow. For example, the photons of sunlight caught by chloroplasts are destined to become stored in the chemical bonds of sugars. Speaking in shorthand, we might say: life is energy management. It uses natural energy flows available in the environment as the driver of this activity. And because this natural flow of sunlight pre-existed in non-living matter, then the label of "vitalism" can no longer be applied as though it is a peculiarity of the ideas of heretical biologists. This argument is illustrated by the waterwheel shown in Fig 1. The waterwheel has been used since ancient times and has caught the attention of thinkers throughout its history. Its fascination stems from the elusive nature of its power source – could it even be modified by clever engineering to produce a perpetuum mobile? Ironically, its image stands as a symbol for the origin of the study of thermodynamics, and was an inspiration for the engineers of the industrial revolution, such as Carnot. In this example, we see gravitational energy pass through the machine as it becomes converted into the motion of the wheel. This is in no way dependent on passive randomizing forces, it is movement powered by syntropic flux in the gravitational field. There is no magic vitalist force here – the drive is external, independent and natural.

As Fantappiè explained, Nature's two fundamental drives surround us. Indeed, this circumstance is everybody's daily experience – scientist or not – we are simply not aware of it. On one hand, we live in an expanding universe. On the grand scale, cosmologists tell us that the galaxies are speeding away from one another at an ever accelerating rate. On the small scale of our world, we also notice things disperse. Our energy and resources supplies are being spread out and wasted. In popular science TV shows, physicists remind us that we are caught in the unidirectional march of Nature towards the inevitable Heat Death of the Universe, when the totality of its energy has thinned out to nothingness.

On the other hand, we also live in a contracting world. Earth's gravity is forever acting on us and our actions. It is all-pervading, we cannot shield our activities from it. Rain falls from above. Great cities fall in rubble onto the ground. All matter moves as close to the Earth's centre as possible. On the grand scale also, black holes in the centres of galaxies pull their vast collections of stars ever inwards in unified formation as they spin.

These twin natural tendencies are driven by spontaneous flows of matter and energy, one outwards and the other inwards. I'll call them, the entropic flux and the syntropic flux, respectively. These terms refer to basic phenomena best described as movements, of either escaping away into larger environments, or of concentration into smaller regions of space. As the example of the waterwheel demonstrates, structures that are compatible with fluxes can capture some of the available motion and divert it to other "unnatural" pathways. As I mentioned above, I call these intervening structures "machines". I now hope that this very broad picture of the concept softens its meaning for those readers concerned by its dry mechanical connotation.

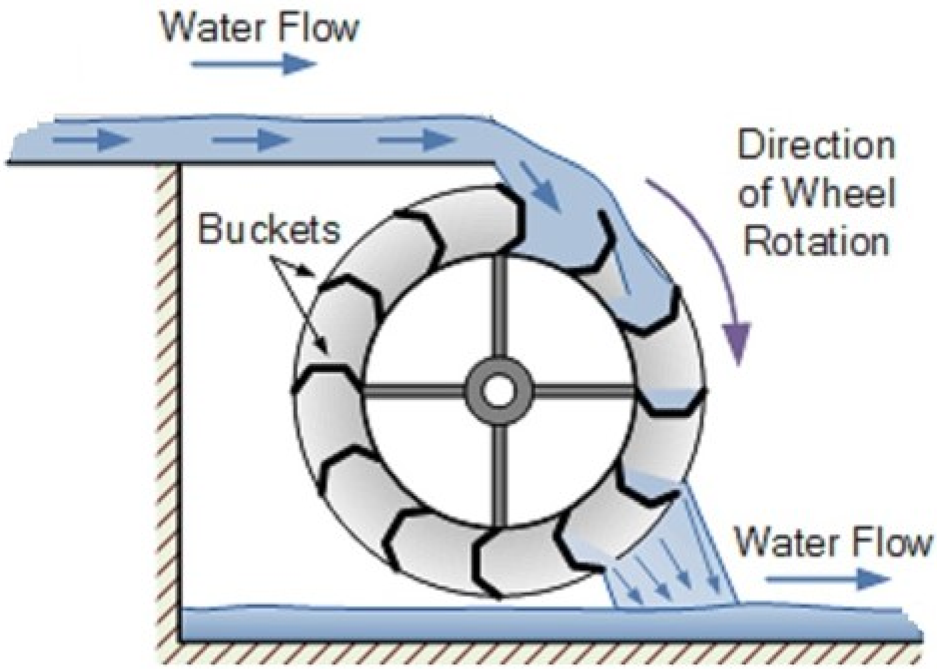

Figure 1. The Waterwheel
The waterwheel is one of the earliest versions of a man-made machine. The question of how and why it functions fascinated engineers long before the concept of energy was developed by science. Briefly, gravitational energy (falling water) is converted into mechanical energy (grinding grain). The universal drive of gravity is external to, and independent of, the waterwheel itself. This mechanism is clearly not the result of the randomizing chaotic motion, that physicists claim explains all natural phenomena including life.

2. Four Machines

To help us in our understanding of life and its origins, it is convenient to divide machines into two major classes – mechanical and chemical. The basic notion of "mechanical" refers to machines that function to move ponderous matter using those parts of their structure that are designed to exert an obvious force. The vast majority of man-made machines belong to this category, whereby energy derived from fuel, say petroleum, is converted into a macro level energy, say a spinning axle. This familiar type of machine therefore diverts energy upwards to a higher hierarchical level of scale. The mechanism of expanding hot gas pushing a piston is the very foundation of the study of thermodynamics. From this picture of outward energy flow, Clausius derived the concept of entropy. We can thus describe this mechanism as operating with up-out action illustrated in Fig 2.

On the other hand, consider the mode of action of the waterwheel. Again its function is mechanical: grinding grain, crushing stone or turning the looms of the Yorkshire mills. Yet in this case, now the power is derived from a syntropic flux, whereby gravity pulls the driving water supply inwards towards the Earth's centre. So here we have an example of up-in action, although this type is no longer common. The vast majority of actions today use the expansion of hot gases as the drive. But here, because gases cannot pull on solid structures to make the machine parts move, a different material must be employed in up-in machines to transfer energy from level to level.

To paint a clearer picture, let's discuss a couple of other familiar examples. A rocket engine is a very crude up-out machine – impressive but crude. Its structure is a rigid, confined space with an opening on one side only to control the direction of the expanding gas, so that the outward force is exerted on the solid walls. The energy of the gas molecules is collected and transferred up to the macro level to move objects in our anthropocentric world. By comparison, a gymnast's move is a sophisticated up-in action. Muscle is a highly structured machine, whereby the pulling force of contraction of microscopic muscle cells is collected and diverted upwards via a lever system up to the gymnast's skeleton. In this case, energies that move naturally inwards are transferred up to the scale of our human world.

The second major class of machine is labelled "chemical". In these machines, the energy derived from the natural flux is directed downwards. As Fig 2 indicates, their mode of action does not require rigid moving parts such as pistons, cams, wheels or skeletal levers, which exert forces onto bodies in our world. On the contrary, their structures are internal and usually invisible to us. They cause changes on the molecular level, so we say they produce chemical work. Scientific and industrial engineering have not produced many examples of this type of action to date, but rapid progress in the high-tech fields is accelerating. In Part II, the work cycle of this type of machine action that produces energized chemical bonds will be analyzed.

3. Biological Machinery

In their study of energy transduction, thermodynamicists have relied almost exclusively on analyzing the up-out action of our man-made machine – the steam engine. Although this field has proven to be very fruitful, our methods of using this energy source pales into insignificance compared to the biological world. Cells use all four types of machine action – consider for example, cell division. This common event happens over a time span of a few minutes. The cell performs trillions upon trillions of coordinated physicochemical reactions in strict temporal and spatial order to synthesize and transport the required building blocks and finished products. There is no mix-up of the replicated chromosomes to be shared between the daughter cells, even though the copies of the metre-long DNA chains must be packed and transported to opposite poles of the mother cell. This work is achieved by a motile apparatus, which must itself be synthesized, assembled and finally disassembled during the time of the event. The level of organization here eclipses the impressive international effort which was required for the assembly and operation of the large hadron collider over the past 10 years.

Another enlightening comparison is the difference in energy usage. Enormous power is supplied to our machines, like the particle colliders, to produce collisions between sub-atomic particles, while Nature's collisions are delicate and run on low levels of power. This huge difference parallels the difference in physical sizes of the machines. And while the single up-out event in the collider produces a chaotic entropic explosion of atomic nuclear fragments, the multitude of precise steps involved in cell division produce coherent syntropic structures that control energy flows up and down through multiple levels of scale. While the steel cylinders of motors withstand the high temperatures of uncontrolled fuel combustion, biological machines operate within the soft gelled environment of living cytoplasm, efficiently burning their fuel without damaging their internal structures. How do these watery machines play the roles of chemical converters, on the one hand, and yet survive their roles of being mechanical force transducers, on the other? Or putting the contrast in a nutshell: our machines are much less complex in organization, but much more wasteful in consumption, than Nature's.

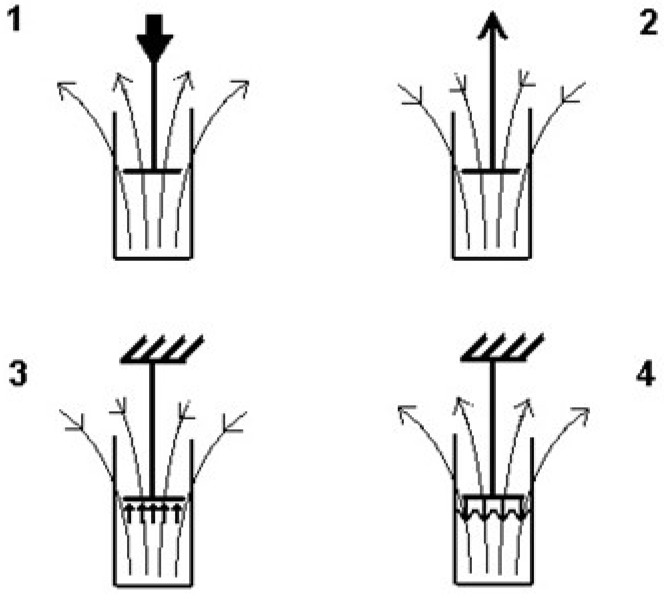

Figure 2. Four Machines
The two basic fluxes, each one powers two types of energy transfer. The machines consist of a cylinder containing a medium which is either expanding = outwards-directed, or contracting = inwards-directed. The cylinders are fitted with a piston, which gets (1) pushed outwards for up-out (steam engine), or (2) pulled inwards for up-in (muscle contraction), mechanical action. If the piston cannot move, then the drives produce changes in the internal structures of the medium, producing pressure for down-in (3), or tension for down-out (4), chemical action. The four types of action are fully described in "The Pixel Machine", available free to interested readers on writing to jgwatterson@gmail.com.

thick arrows = pressure
thin arrows = tension
thin curved arrows = entropy and syntropy fluxes

4. The Structural Inversion in Water

To understand the central role of water in biological machinery, we need first examine the intriguing properties of liquids. The obvious distinction between solids and gases does not apply to liquids, but it does reveal the apparently opposing tendencies shown by liquids. Solids are held together by strong chemical bonds so that they maintain their size and shape. Gases on the other hand, must be contained so that they are prevented from escaping and losing their size and shape. So liquids exhibit the puzzling behaviour of both – they have the potential for both syntropic and entropic behaviour. Like gases, they flow and so can change their shape, yet like solids, they remain connected internally and so keep their size. On Earth, a layer of liquid lies between the syntropic environment of solid ground below and the entropic environment of gaseous atmosphere above, as illustrated figuratively in Fig 3. It interacts with both, because it shares some of the properties of both. The flexibility of these opposing energy fluxes within the liquid gave rise to life and fuelled the evolution of the biosphere, which eventually came to occupy this entire layer.

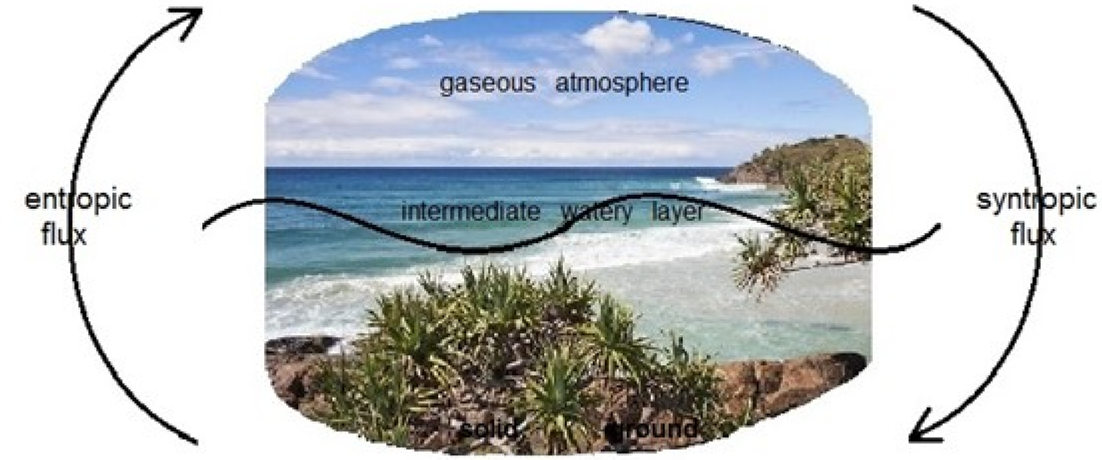

Figure 3. Earth, Sea and Sky
The triple-layered surface of our planet provides the environmental conditions for the overall cycle of outward and inward energy flows. Solar radiation produces the entropic drive by evaporation from the oceans (lifting water), while condensation provides the environment for the opposite syntropic (falling water) drive, as we saw in the waterwheel. Evolution of living forms has produced much more highly refined machines able to capture energy from both halves of the cycle.

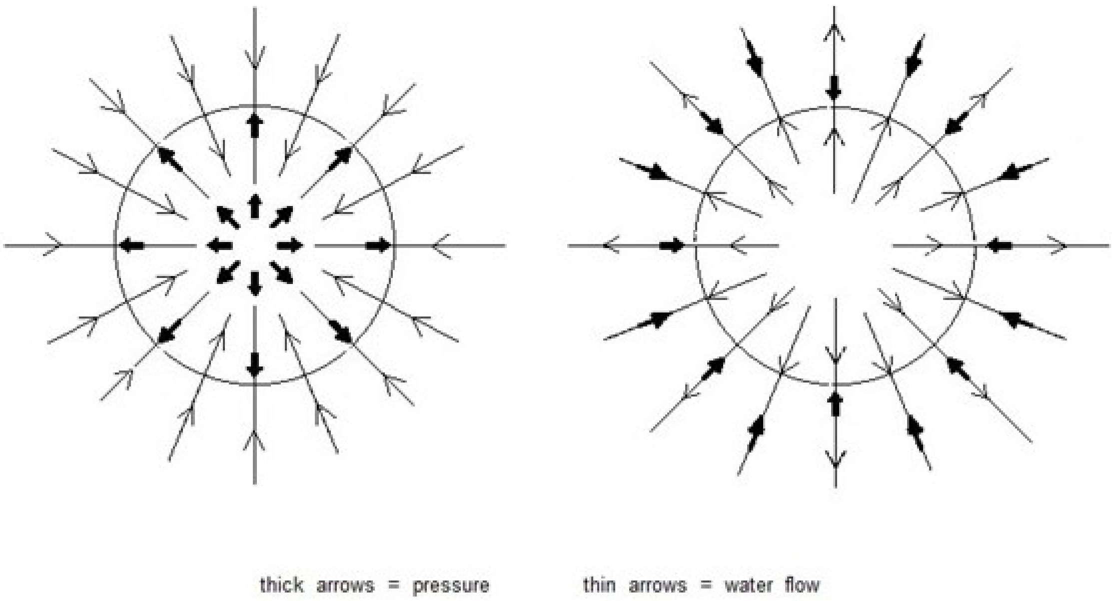

Figure 4. Schematic Representation of the Puzzle of Osmosis
Circles illustrate cross sectional area of our imaginary sausage. In the left panel, water flows into the circle even when the pressure inside exceeds that outside, clearly indicating that water is not being pushed in. In the right panel, water flows out of the circle even when the pressure outside exceeds that inside, indicating here again that water must be flowing against its own pressure. In the left panel the flow is syntropic. In the right panel it is entropic.

thick arrows = direction of pressure forces
thin arrows = unexpected direction of water flow

Water, and liquids in general, generate osmotic forces – here we have the hint of another natural drive. The underlying cause of osmotic phenomena is always present, even in undisturbed water where it remains unnoticed, but manifests itself most clearly when two solutions of different concentrations make contact. A truly surprising property of osmotic systems is how simple they are. They need just two components, say salt and water, to make solutions, yet even though it has been studied since ancient times its mechanism remains a mystery still today (osmosis is a Greek word meaning "push"). To remind readers of how osmosis happens, we need only recall the ordinary experience of watching a frankfurter sausage warming in a pot of water. Usually it swells as water is drawn inwards through pores in its skin, and even bursts if the pressure inside rises too high. On the other hand, if there is too much salt in the surrounding water, it will shrink as water flows out through its porous skin.

The difficulty that osmosis poses for us in trying to understand how it happens, is that the force acting on the water opposes its movement, inwards to swell and outwards to shrink, as illustrated in Fig 4. Or to put the problem in question form:

- why does the water flow inwards through pores in the sausage skin when the pressure inside is higher than that outside in the pot (one atmosphere), and thus opposes this flow?
- and in the second case of surrounding salty water, why does water continue to flow outwards when the pressure inside drops below one atmosphere, so that the higher outside pressure now opposes this flow?

I say "opposes this flow", however this opposition can only be apparent, because such flows defy Newton's Second Law of Motion, which states that matter is accelerated in the direction of the force acting on it – or to rephrase in simpler language, matter always moves with the force, according to the most famous equation in science, $F = ma$. The answer to these paradoxical movements of matter lies in the fact that the forces we see on the macro level are not the forces acting on the water molecules at the micro level. All liquids are kept in their condensed connected state by syntropic forces pulling their molecules together and forming clusters.

Clusters are short-lived islands of order in their random environment – constantly forming and breaking apart – but at any instant there is tension holding them together, just as there is inside the stable smaller molecules that chemists are familiar with, like the hydrogen and oxygen atoms within the water molecule itself, H_2O. So here we see the result of the duel nature of liquids outlined above – like gases, they exert entropic pressure on the macro level caused by chaotic collisions of clusters with one another, but like solids, they exert syntropic tension on the micro level caused by the attraction operating between the molecules inside the clusters maintaining their temporary form. Clusters are entities which lie on the intermediate hierarchical level where they play the role of linking the entropic drive above to the syntropic drive below. They are the agents of the activity in the liquid layer on our planet we call "the biosphere" depicted in Fig 3.

Thus it is the force on the micro level that acts on the individual water molecules. This binding attraction is called the hydrogen bond by chemists, or simply H-bond, and it acts mutually on all molecules linking them momentarily together, so that large clusters of up to thousands of molecules exist at any given time. Hence molecules can be pulled through the membrane separating the solutions, even though there is the macro force of pressure, observable in our world, being exerted on the solution they enter. So it is the bonding force linking molecules together that explains the puzzling phenomenon of flow against pressure (Watterson, 1997).

As the pressure on a liquid is reduced, clusters increase in size (and so decrease in number) until at zero pressure they have grown to such a size that there is just one single cluster in the container that holds them. At this point, tension, rather than pressure, begins to be exerted on the macro level, as an unbroken connection of linked molecules begins to build, that stretches from boundary to boundary and pulls on the container walls. Now the medium cannot flow – it has become a gel. In this solid state, the regions of broken links are isolated within the body of the liquid medium. I call these regions "anticlusters", to indicate the structural inversion in the arrangement of the water molecules throughout the medium depicted in Fig 5.

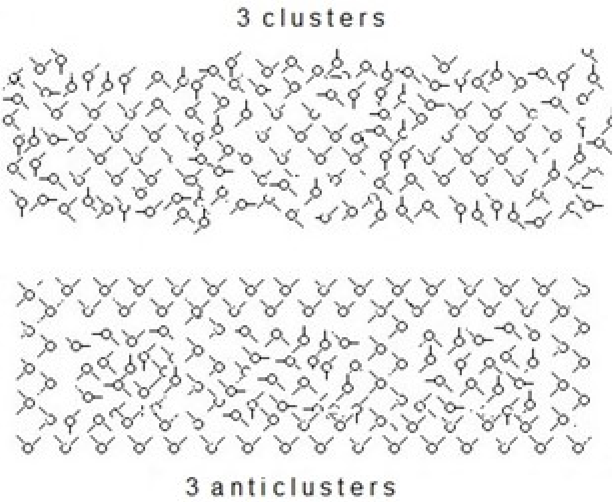

Figure 5. The Cluster – Anticluster Structural Inversion
Pictorial representation of clusters showing structured regions of water molecules separated by and surrounded by randomly orientated fluid molecules, and anticlusters showing random regions isolated within the bulk phase of ordered gelled molecules. In our ordinary experience of fluid water in a glass, the liquid is under pressure illustrated in the upper panel – the atmospheric pressure in our macro world. But in the living cell, the cytoplasm is a gel which is held solid by macro tension illustrated in the lower panel. In regions of the cytoplasm which must begin to flow, as for example during cell division, the switch from anticlusters to clusters causes the gel to become fluid. The inversion, known to cell biologists as the "gel-sol transition", has been studied by colloidal scientists for decades.
(For a thorough overview see https://elifesciences.org/articles/17210#comments).

To us, the watery medium that is a gel appears to be stationary because it is solid, but on the molecular level movement continues within the anticlusters. In the cell, the solid cytoplasm prevents macro level movement, that is, the pushes and pulls we experience in our world have disappeared. In this state, energy is being transferred between anticlusters and the chemical bonds on the level below. On the other hand, in those regions where macro movement of cell contents is needed, the cytoplasm starts to flow, as the mechanical forces we are familiar with become active. For example, every muscle cell, from the tiniest insect wing to the strongest weight-lifter's biceps, contracts as it develops active tension. Gels are the living medium, able to generate forces observable on our macro level. This model explains how the two classes of machines, mechanical and chemical, are coordinated, since they interact at the junction of the hierarchical levels of scale. We might say, that clusters are both physical and chemical objects, and their coordination across the macro-micro divide is necessary for the function of living matter.

To see this argument in simple terms, consider the overall scheme of energy management in the biosphere. As with many of our man-made machines, the energy source for performing work resides in chemical bonds of, for example petroleum, in motors, and sugars, in cells. But sugars must themselves first be synthesized in the leaves of plants (photosynthesis). Today, we know of course, that these coupled processes of producing fuel on one hand, and work, on the other, are achieved by different machines – synthesis in chloroplasts and respiration in muscles. First, the capture and storage steps is downward-directed, carried out by cellular complexes possessing internal structures on the molecular level – sunlight in the external flux being injected into chemical bonds of sugar. Then second, the upward-directed steps are carried out by skeletal machines in our muscle cells – sugar being converted into carbon dioxide fuelling contraction. That both upwards and downwards transfers are possible is due to the switch that occurs naturally in the structure of water – the cluster-anticluster inversion.

In Part II, a deeper analysis of the four machines will be presented by describing their work cycles following in the footsteps of the young French engineer, Sadi Carnot. In his ground-breaking publication of 1824, Carnot attempted to solve the puzzle of heat-into-work conversion, and in doing so began the study of energy transformations in general – an unfinished study which, by extending to biology, continues still today.

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