Society 1.2
The physics of complex systems
(Revised)
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The fundamental principle that makes physics the first and only science is and remains this: the field process of atomistic interactions in any physical field can only involve pair by pair conservations. In our previous essays, we looked at where the conservations of motion and change come from. We started with the simplest kinds of atomisms colliding -- a pair of "balls" banging into each other. These could be, for example, molecular or atomic "balls." As well, they could be baseballs, billiard balls, golf balls, ping-pong balls, gum balls, sand particles, or dust particles. We then discussed what happens in terms of mass, momentum, and energy conservations from the pair by pair collisions. However, there is a problem, in that we have to face the fact that there are different kinds of pair by pair interactions.

In a simple exercise, we are going to tell you about eight different kinds of "balls" bouncing into each other, and give you each time an atomistic case, simple or complex, in which the physical process can be seen.

Case 1: Symmetrically Conservative Interactions

A ball bounces and hits something, for example, a wall. It then bounces back as high or as fast as it was thrown.

This example, called a "symmetrically conservative" interaction, follows the common idea that most people have regarding collisions, in that you can't tell the difference if the collision took place "backward" or "forward"; namely, A bounces into B, and they bounce out in different states of motion A' and B', or whether the reverse takes place, where A' and B' bounce into each other, producing states A and B.

We see this in bouncing balls, projectiles hurled through space, planetary “balls” moving around each other attracted by gravitational force.

The word “conservative” here means that the interaction is ***conservative and reversibly mechanical***. This is in distinction to the rest of the cases which we will see will be irreversibly thermodynamic (see below).

Can you see such continuing motion as reversible conservative interactions seem to imply? Certainly. As we saw in the earlier lesson, fill up a glass of water, blow up a balloon, or put rocks in a tub. What happens among them? The balls, atomic or molecular balls, are indefinitely bouncing on each other. Put them in a container with a certain temperature and they keep bouncing indefinitely. And, as you now know, they also will create the return momentum of pressure as they bounce against any or all confining walls

To discuss this issue, Maxwell introduced the physical study of a kinetic theory of matter, a statistical mechanics of matter. Writing an article in 1860, he said: "So many of the properties of matter, especially when in gaseous form, can be deduced from the hypothesis that their minute [very small] parts are in rapid motion ... that the precise nature of their motion becomes a subject of rational curiosity."

Case 2: Interactions involving Frictional Loss of Energy

A ball bounces, but it does not bounce as high or as fast as from whence it was started or dropped*. The energy is not conserved at the bouncing level; thus, the motion is not reversible. We say that there was **a frictional loss of energy**. That "lost" energy went into heat: the ball or what it bounced against got a little warmer. You can try it by dropping a real ball on any good hard surface and you will see such loss of height and energy.

This interaction is not reversibly mechanical. Thus. it is ***irreversibly thermodynamic***. Irreversibly thermodynamic means that energy will persist but not at the same level as in the simpler mechanically interacting balls; it will go out to other lower levels of organization. You should note that our first law of thermodynamics, which we got from pure mechanics, states that regardless of how the balls bounce, energy cannot be lost, only transformed into other forms or levels. According to the second law, the subject which is so important for irreversible thermodynamics, energy will be transformed into lower levels of organization as a result of natural processes.

Let us talk about how this second case is different, yet also the same, as the first case. Can you do this process with a bunch of balls? Certainly. Put a bunch of fine particles - sand, pills, Wheaties, or diatomaceous earth - in a box and shake it. You can even see or hear the particles bouncing around on each other. But, differing from the first case, in time they stop. Why? Because of friction in their encounters. Due to the thermodynamics of their motion rather than the mechanics of bouncing, they lose energy into heat on each bounce and ultimately stop bouncing. If you want to see these particles exhibit indefinite motion as in the first case, put vibrators or buzzers on the walls of the container. That vibration will restore movement to the ensemble. Particles resting at the walls will be impulsed into motion.

Think of this as baseball. The “batters” at the wall will keep making “base hits.” Once out in the field, they share their motion via impulses, and the batters at the wall soon get all the players out in the field back into motion. In time, all that vibrational energy imparted at the walls gets shared or partitioned out in the field. This is called "equipartitioning of the energy".

In the first case, the molecules have "sustained motion." While not immediately obvious, their energy came from the sustained temperature of the walls. Something was maintaining the wall temperature. To put this another way, vibrational energy was put into the molecules in the wall which happen to be bound together into a solid form. (We have been only looking at fluid motions in the ensemble, but let us mention that these

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* This is looking at the problem as half a system. We can imagine one ball bouncing against another identical ball. One ball bouncing against an impervious immovable wall makes up a half system

molecules in the solid state are bound together physically-chemically as or by springs. Think of a solid form like the application of a solid bat, which brooks no nonsense from a ball pitched at it.) In baseball terms, think of the wall as being many batters. One or more of the batters in the wall will always make a hit. Imagine a poor pitcher, faced not by one batter, but by a dense myriad of batters, all swinging away or even picking balls off the ground, tossing them up and hitting them into play. Vibrating the walls by putting an electric buzzer on them simulates temperature. The sand or dust particles will move and sustain the play.

To see why this second case simulates the first case, let’s take the first container of gas molecules outside into the cold. The wall temperature will lower. We’ll find that the molecules do not possess as much motional energy as before. Their temperature -- meaning their energetic motion governed by the walls -- is less. The two cases are almost the same.

If you tried the second case experiment with very fine dust particles, you would find that the particles stay in sustained motion a very long time, if not indefinitely. By looking under a microscope, you can even see the motion. This type of motion was noted in 1827 by Robert Brown, a Scottish botanist who observed under a microscope the movement of plant spores floating in water. Albert Einstein proved that the motion of those fine particles – which are very much larger than atoms and molecules -- have their motion supported, as Brownian motion, from the impulses of the very much smaller molecules and their molecular motions. Think of them as very small impulsing batters. Their motion is also supported by impulses from the vibrating energy of the walls. Brownian motion is directly supported by molecular motion coming from the walls.

In actuality, this is not quite true. If we reduce the wall temperature to lower and lower temperatures, toward what is called the absolute zero of temperature, we find that all motion does not cease. Ways to get toward that temperature are using: a water ice bath (0°C), a solid carbon dioxide bath (-79°C), a liquid nitrogen bath (- 196°C), or a liquid helium bath (-268°C). A theory says you cannot get lower than -272.15°C which is very near 0°K. People have produced baths within 0.001°C of absolute zero of absolute temperature and are moving toward one millionth of a °C of it. This concept of absolute zero temperature is actually more than a concept, it is a very real number and state. For example, the average temperature throughout the reach of the universe, away from hot stars and gases, is about -268°C, near liquid helium temperature.

As you go down in wall temperature, you might expect all molecular motion to cease. But physicists discovered a newer branch of mechanics, more elaborate than Newtonian mechanics, called ***quantum mechanics***. There is a small measure, known as ***Planck's constant h,*** which can serve to do what temperature does at very small motional energy levels. The constant *h* can substitute as a source of action, thus producing the equivalent of a small temperature motion. In order to look at how much motion, we need to discuss how much equivalent temperature can be produced by h. This formula will help:

$h/t = hf = kT$

where:

kT is the motional energy associated with temperature T
f = frequency
t = period of vibration ($t = 1/f$)

The formula tells us how much equivalent temperature T can be produced by *h* if the effect of *h* is to create a process cycle, or a vibration, with the period of vibration t (or of the frequency f, so many jitters per second). If *h* were zero, then we would be in a Newtonian world. But since it is not, we are in a mixed Newtonian-quantum mechanical world. The part that Newton did not explore was that part which becomes involved in the connections between quantum mechanics and thermodynamics. You cannot get ignore all quantum theory when you want to manage real systems.

In the end, it is quantum effects at the level of *h* which relate and sustain the bottom motion of small fundamental entities and their essential interactions with the physical vacuum. This is why, when not in an arena of very small size or very low temperature where quantum effects must be accounted for, the two cases of motion - conservative and frictional - are very much alike.

The Brownian motion example permits us to bridge the micro-macro gap. When you go out into the sunlight, not only do you get the thermal motion of all the atoms, molecules, and photons[*], but you get the energy of all Brownian particles among these particles. You also get the energy that other Brownian particles are able to extract both physically and chemically from those particles. These latter could include, for example, small living cells. That process works its way through all levels up to the point even when you reach into your cupboard and take out some bagels and lox, and eat them. You also are a Brownian creature, even though you're big. The whole process is a Great Chain of Being (and Becoming, and, eventually, Unbecoming).

Case 3: Interactions involving Stickiness

A ball bounces on another ball or hard surface and it sticks. You can try this with putty or asphalt in order to see the process. (You can also get married.)

Case 4: Interactions involving Deformation

A ball bounces on another ball or hard surface, and one or the other deform. Try dropping a piece of fruit, or any other squishy thing, even, say, a block of wood and watch it dent.

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[*] Photons have no mass, they only have hf where f is their vibratory frequency; they can collide and share and equipartition energy. They also can show a similar equation of state, including temperature and pressure. It is easy to show that photons – in effect, light beams - exert pressure. Why else do you think that those little particles stay floating around indefinitely where ever you look?

Case 5: Interactions involving Breaking

A ball bounces on another ball and one or the other crack, or splinter into pieces. Try a glass ball on a hard metal surface.

Case 6: Interactions involving Exchanging of Bonds

A ball (particle, atomism) bounces on another ball (particle, atomism). One or both break up and some or all of the pieces rejoin. This is the process of ***chemistry*** - the making, breaking, and exchanging of bonds. It takes place in your stomach when you eat a cookie. It takes place in a glass of water when you put an Alka Seltzer init and watch a fizzing chemical reaction. Put some yeast in dough and watch a reaction take place as the dough rises. Or breathe in and out - in comes the good air (oxygen), out goes the bad (carbon dioxide). Or burn a piece of paper, or gasoline, or gas. You've conducted a chemical reaction.

Just to give you a flavor of writing a chemical reaction, namely identifying what all the atoms and molecules are doing, we will write verbally the oxidative reaction that supplies energy to our bodies. It is one of a number of thermodynamic processes that make life possible:

- fuel + oxygen ∅ carbon dioxide + water + byproducts.

  ∅ is a symbol that means goes to form

Or, since we use a variety of fuels:

- simple carbohydrate + oxygen ∅ carbon dioxide + water
- protein + oxygen ∅ carbon dioxide + water + byproducts (among the byproducts, for example, are urea which appears in our urine).
- oils or fats + oxygen ∅ carbon dioxide + water + byproducts (among those byproducts are acetone, which at times can be smelled on your breath).

The oxygen on the left-hand side of the equation comes in through your lungs when you breathe, or comes in through your gills from the surrounding water if you are a fish. The carbon dioxide and water on the right-hand side may go out through your breath or your urine.

From this beginning at the notions of chemistry, note that the social machinery within you or that you manage has to deal with both sides of the reaction -- both for providing supplies for intake and the management of outgoes, whether directly useful to your system or not. If you don't manage both sides, the system can easily come to a halt.

Of course, you should understand that your body is also working on other reactions, for example, anabolic reactions -- ones that build up your tissue:

- carbohydrate + fats + some proteins + oxygen ∅ your proteins + carbon dioxide + water + byproducts

There is also a large family of cells that are not aerobic, that do not use oxygen in their metabolism. They are generally considered to be primitive but they are perfectly competent in their capability to persist and coexist with you oxygenators.

Case 7: Interactions involving Pair Annihilation and Pair Production

Two bodies collide and they both disappear, producing only an equivalent remnant energy of photons. Equally astounding, a bolt of photonic energy strikes a point and out comes two bodies! This process is known as ***pair annihilation*** and ***pair production***. It only happens with elementary particles -- electrons, protons, neutrons, and many other fundamental particles (which, ultimately, are all elementary combinations of a few leptons and quarks). Briefly, they require a rather complete quantum theory, involving that little number *h*, the minimum quantum of action, and also Einstein's derivation from special relativity, $E_o = mC^2$. Physics also has a big number C -- the velocity of light. It turns out that mass m can be converted into energy E_o (from that mass at rest) according to this measure C, but that can only take place with very small particles when they are moving very fast. It is that kind of nuclear reaction that makes stars burn and give off energy, as well as make atom bombs and nuclear reactors work. It was that energy from the Sun that made planetary processes possible, including the process of life. These processes in the stars also made all the matter we deal with, except for some more primordial matter like hydrogen and helium. Knowing these elaborate processes will help one manage whole Earth systems if that is one’s desire. Life comes as the result of very energetic collision of particles. It emerges both as an evolutionary and a developmental process.

Case 8: Interactions involving More Particles

One last interaction: two particles collide and after some delay, a bunch of little particles come out from the collision. This is the process of sexual intercourse and reproduction.

From these examples, you see the physics of pair interaction is very rich. It is worthwhile to carry that rich picture with you every time to want to start in on the management of a different physical system. Each time, you will be dealing with the pair by pair collisions and their conservations.

Internal Characteristics of the Atomisms in Simple Systems

Atomisms, whether simple or complex, sustain their motion by interacting with walls and other depots that supply their fundamental conservations. All such depots are called ***potentials*** or ***potential stores***. Thus, like simple atomistic systems, complex atomisms may get:

- temperature or energy of motion from the walls,
- momentum - either as a diffusive influx or convectively as from a stream - from or through the walls,
- chemical potentials (storage of various mass species) from or through the walls or in depots distributed throughout the field space

Still only viewing them as simple systems, we turn to some of the ***internal characteristics of the atomisms*** (or molecularities). A ***molecularity*** is a bound form of a number of atomisms, for example, the binding of two people in a partnership or a number of people in a company.

When we spoke of the energy of motion of a particle -- its kinetic energy -- we did not indicate that such a characterization meant that our particle was likely a rigid solid-like particle. The six degrees of motional freedom were motions of translation (side to side movements) in three spatial directions -- such as N-S, E-W, and up-down -- and motions of rotation in three directions of spin. These did not exhaust all possible degrees of freedom and we even named where some of the others might come from. But we didn't indicate that those six degrees were "external" degrees of freedom. Now we have to clarify "internal" degrees of freedom (ones inside the atomisms).

1. We can store energy internally as springy motion. At the same period of time that Newton laid down the laws of motion and talked about the universal law of gravity[*], another physicist, Sir Robert Hooke, discovered another basis for mechanical force. That force on matter, he said, measured by the push or pull on any chunk of matter, causes a "movement" or "displacement" in the direction of the force which is proportional to the force. Hooke had discovered a source for an internalized process in matter -- the ***elastic*** or ***spring force***[*].

Blow gas into a balloon. Feel the elasticity of the gas (but separate this from that of the balloon; the balloon has its own elasticity which can be tested by blowing up a paper bag or sack instead). Stretch a rubber band or bend a steel rod; you can feel their elasticity. Press on water (by doing a belly flop into a pool); you can feel its elasticity. The water's elasticity is better seen if you press on it with a heavy duty hydraulic pump. Freeze a bottle of water or wine in your refrigerator, and see the water or wine expand and push as it freezes. You will see that each phase of matter has a different measure of elasticity: solids are stiffest, liquids next, and gases the least stiff (or, conversely, gases are the most compressible, and solids the least).

Exerting a force through a distance changes the energy in the system and does work. This new form of energy is referred to as the ***internal potential energy***. It lies within the atomism either in interior motions of part of the atomism or else it lies in the field. For the former, it can be, for example, vibrations or rotations of parts. For the latter, we will show it to you in a couple of ways.

When you lift up a body in the Earth's gravitational field – pick up a stone, for example -- you become aware that a force is required on your part to overcome the force of the gravity by

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[*] Gravitational force is a mechanical force system whereby all particles of matter attract or tend to move in toward each other in proportion to their respective masses.

[*] The elastic force is not a primary force. Each of the primary forces, such as gravity or the electric force, can produce spring force.

which a very big Earth attracts that stone. (If you try lifting a stone on the Moon, you would find it required a much smaller force. This is because the mass of the Moon, which is doing the attraction, is so much less than the Earth's.) You did work in lifting that stone. Does that increase of energy remain in the system? Certainly. Drop the stone to the level from which you lifted it or onto your foot and see how that recovered energy -- now an energy of motion -- can do work, for example, in crushing your foot. Where was that energy when you lifted the stone? It is in the field. (Einstein elaborated that into a very strange and marvelous descriptive form of physics: general relativity.)

2. Electrical charge is another *internalized property of matter that "creates" a force in a sense similar to gravity*. Electrical charge can develop either a push or a pull. There are so-called "plus" or "minus" charges. Like electrical charges, such as two “plus” charges, push apart. Unlike charges, such as a plus and minus pair, pull together. This process allows an electrical force to conduct through rods, wires, even through the muscle fibers in our bodies. In fact, what we ordinarily call pushes and pulls is most commonly due to very close, very intimate electrical forces even if it doesn't seem so and the process appears hidden from us. It is hidden because the electrical charges reside in the very small atoms.

3. ***Nuclear forces are a few even more intimate forces***. However, these are beyond the scope of this work and needed for discussion, because they are just another example.

To summarize, we can see energy stored in kinetic forms of motion – either external or internal -- and in potential forms internal to the field. (There is the third way of converting mass into energy, such as between photons and fundamental matter particles, but that only takes place under very very strong forces, so we can ordinarily neglect those processes. We see them, as we said, in how our Sun and other stars generate energy, and we see it in certain atoms that are radioactive and unstable, such as radium and uranium).

4. A simple mass particle might have up to 12 degrees of freedom into which it could store energy. It may store kinetic energy of motion stored in each of its 3 degrees of "translational" freedom or 3 degrees of "rotational" freedom. It might have spring or potential storage stored in them. That would be the specific heat (or energy) you could find in an elastic ball-like atomism or molecularity. Each degree of temperature that you heat up such a ball -- transferring energy into the ball -- requires that you put energy into those 12 modes of motion.

5. Energy can be associated with fragments of a molecularity. This occurs in chemical change. If you put enough heat energy into a molecularity, it may break an elastic bond and you would see fragmented particles. Or, conversely, particles may join up and give up a binding energy and stay tied by a spring-like bond. For example, to get married -- to come together in the partnership bonds of matrimony -- means to give up an energy given to the act of bonding.

In simple atomic chemistry, we will not be concerned with annihilation and pair production of matter. We will have to be concerned with the additional conservation of electrical charges - of their plus and minus forms and of their total or net amounts, but we are not going to provide a great deal of detail about the electrical processes except to point out that they exist. We will also point out that the two force systems - the gravity force and the electrical force - are effectively the two forces that we see acting to organize things around us. The other two forces (strong and weak nuclear forces) tend to act intimately at the very very small size of things within us and all around us, but that is all bottom line physics.

To summarize, with simple systems:

- We see the pair by pair conservations of a) mass, b) momentum, and c) energy; there is also the other conservation of d) electrical charge to consider.
- If our field systems are made up of atomisms whose electrical charges are paired up, plus and minus -- then we consider them electrically neutral molecularities. Metaphorically speaking, they have gotten married and finished "sparking", so that they do not play electrical games anymore (at least not in public!).
- Simple system equations of state will be in terms of these three or four physical conservations. Also, corresponding to each conservation, there will be an equation of change for the dynamic field.

In addition, if the banging particles bang together sufficiently energetically to break up the plus-minus electrical bonds, then the fragments may continue to form and to rejoin up in combinations until only certain pairings will continue to persist. Such a conglomerate field is known as a field in ***chemical or near chemical equilibrium***: as many players are transforming in one direction as in the other direction. Such kinds of processes are viewed as ***dynamic equilibria***. If the processes of change continue, you can have a mixture of atoms, molecules (which are combinations of atoms), and ions[*]. The latter are electrically charged fragments, made by uneven separation of plus-minus particles. If this pairing, breaking, and bonding (i.e., chemistry) occurs -- a result of the particles electrical nature -- there will be equations of state for each mass species that continue to exist.

Internal Interactions of Complex Atomisms

We saw that in simple systems, when the atomisms bang into each other, their internal interactions are like those of simple springs. In a few interactive collisions, they are brought to equilibrium. When complex atomisms (or molecularities) bang into each other, their internal interactions are different. Instead, their internal movements are never brought to a simple state of completion within one or a few interactive collisions. Their

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[*] Atoms consist of electrically charged electrons (minus charge) circling a nucleus with plus charge, where the two sets of charge are equal in number. Ions are atoms that are unbalanced so that the two sets of charge are no longer the same: they may have too many or too few electrons. Think of it as humans trying to find opposite electrical partners to marry. This continuing motion of chemical bonding represents an additional diffusive transport. That transport into specific atoms and molecules is called the **chemical reaction rate**.

interior movements are organized into very very long time delayed patterns as countable by external bangings. We have estimated that in complex field systems, the time for internal patterns to settle down is of the order of 10,000 bangings minimally, and in the cases that really are going to interest us, in the order of millions, billions, or trillions of bangings. This by itself may help you will understand that the physics of complex atomisms is quite different from the physics of simple atomisms. There is a lot of internal ‘hanky-panky’ going on.

Complex systems still involve movement and change. The atoms and molecules still remain the same kind of ball players. But what is different is the ***long time delayed internal processes*** that are taking place. What are they? They comprise a factory of processes which are, for the most part, long drawn out flow processes. The players are the same kind as before but they are involved also in much slower play. Most commonly, this is due to very long and large associations between the players. ***They play weaker or slower games on top of their fast games.*** They involve remnant weak components of strong forces. We say that they are involved in a complex "cascade" of energetic processes pouring into and through the field system at very many time and process scales.

Let’s state this another way. The processes of change they engage in internally are so slow that it looks as if they had a memory. No "story" of what a complex system is engaged in can be described from the outside in a completed form in one or a few interactions. It goes on through an interminable number of external interactions before even the simplest of their "stories" are complete. The great mathematician-physicist, John von Neumann, grasped this idea when he provided the modern digital computer with a temporary memory storage in the form of a standing wave on a liquid. He possibly got the clue for this from a dear friend, the neurophysiologist Warren McCulloch. This is not different from you tying a knot on your finger where the persistent wave of excitation of your nervous system continues to remind you of something that you want to remember.

Let us imagine wandering around inside a big molecule, a cell, your body, a city, a civilization, or a galaxy. It will always look like a giant busy play. All you will see are pieces moving in and out of a great number of stations; activities and processes are continually going on. It isn't until a great number of steps have taken place at some or all stations that what is going to emerge becomes apparent as a "product" or a "message"; i.e., that you know that Act I of the play has taken place, or that an inning has been played. What emerges from the material-energetic transformations are only such higher ordered "products" or "messages" made up of the same kind of material-energetic processes we see in the simplest of systems. We add one more transporting diffusion: a diffusion into internal action. That diffusion measure is called the ***associational viscosity***. Here is where the long time delay lies which makes for complexity.

We can answer briefly two questions: why can we call it "physics"; and what does that get us? It is physics because, once again, we can identify new conservations and how the processes of association take place and what they represent. That gives us the chance to use the same science we used before for the simpler systems. Why is that good or necessary?

Because, as we said, there is only one science (or to put it more precisely, there is either only one science or there are no sciences).

We are fortunate that the physical game played by nature is and has to be indefinitely repetitious. It is only because of that that we can deal with the many forms of those games by attempting to recognize the repetitions. We can deal with the physics of complex systems because we can recognize their conservations. Otherwise, we could not deal with them scientifically. The thing that makes our game not a tautology is that complex systems exist, and we can find their conservations by the rules of physics. They arise from the forces that nature exhibits and uses. The physics we are describing is only possible for games that persist in nature. Other, non-persistent, systems may pass before our eyes. Perhaps we can talk about their kinetics. We cannot fully talk about them as field systems. It is only a complex system if the complex patterns it displays repeat again and again and again. It is like a play that repeats again and again with only moderate changes in its patterns. It is baseball played in myriads of ball parks for interminable innings.

The Factory Day of Complex Systems

If, as we perhaps might or might not suspect, we are in one universe, we cannot be certain of what came before all the yesterdays of time before "today" and we cannot be certain of what will be all of the tomorrows. So we are not yet fully certain about the entire system of our universe. Since the messages or products are not complete in one particle or atomism interaction, what do we do about conservations? Where are they?

They emerge from the "***factory day.***" This is a much longer period of time over which all of the internal associations take place within the complex atoms. And then that day is repeated. How do we know that such a factory day exists? <u>We only know when we can see it and find it</u>.

If you have billions of billions of billions of stars and you look at them and you see a pattern of stages -- of birth, middle age, and death among them -- and you figure out such is the process that is going on among them, then you can grasp the factory day of their performance. Their factory day may be a million to a hundred billions of years. Astronomers studying stars over many, many nights get a notion of the physical processes by which stars sustain their field existence. Biologists can do the same for millions of living organisms today; archeologists for millions of species of organisms in the past.

Physicists have begun to do that analysis for galaxies, stars, planetary and planetesimal bodies, living organisms, for chemical, geochemical, biochemical, and nuclear chemical processes, and for atoms, ions, and molecules. My colleagues and I have begun to indicate what such "star charts" would show for living societies. The theme and its variations are not new. Using these laws of physics, it is possible to figure out the factory day for most systems. Let us explore in the next sections what such a factory day is like for a human organism.

Factory Day for the Human Organism

At a first rudimentary level, one takes a breath. Then one takes another breath, and so on and on. As long as breath follows breath, and heart beat follows heart beat, some of the fundamental internal machinery is working. Note that the process starts out of the momentum and the movements of the heart, the lungs, and the other organs. At the bottom of this, there still remains only momentum, energy, matter, and electric charge.

But let us jump to a more integrative level. There is more to see over the day. Besides keeping its heart beating and lungs breathing, the organism has searched for and acquired food, slept, moved, drunk fluids, voided, and had interpersonally interacted with its fellow organisms. There is much more machinery involved at this level. But notice, more or less, one day is like another.

This is still not quite integrative enough. There are other machinery processes, such as water balance over three days and the female menstruation cycle which involves the chemical apparatus associated with sex and reproduction. But engraved within the body's machinery there is more nearly a yearly scaling of processes. That may be seen in the reproductive balance, in dealing with the seasons by the body machinery. The factory day for us as individuals is one or a few days, or hardly more than one year.

Factory Days for Species and Life

There is also the striking balances with other species making up the trophic web of life. The squirrel eats and stores nuts; we eat the squirrel; the worms eat us; the bacteria eat the worms; they put the matter stuff back into the rivers and oceans and earth and atmosphere; and the plant eats from these and grows the nuts seasonally or longer. All this goes on, with many threads in process, in space, in time.

At a still more integrative level, sexual organisms reproduce themselves, roughly in a generation time, many in even longer periods. Our human generation time is approximately 20-30 years; we live perhaps close to three generations. This becomes developmental. It becomes the factory day for our species. In comparison to the factory day of the stars, the one for our species is hardly longer than the one for us as individuals.

Beyond that lie longer scales even more integrative, with a factory day for life as a whole – for all species -- beginning perhaps 3.8 billion years ago, not too long after the birth of our planet. This scale is evolutionary.

You now can see many factory days, each one or level has to be attended to by its physics, by its conservations. In toto, as one runs through the entire gamut of such factory days, one finds an entire cascade spectrum of energetic processes. Energy flows through, transforms level to level.

Conservations of Complex Systems

Energy. The conversations of complex systems remain the simple conservations, but transformed a bit. Energy and flow of energy through the atomistic states remains energy and the flow of energy. But we have discussed that there are internal ways to store that energy. In particular, in complex systems, there is a characteristic energy which is stored in the atomism and there is a characteristic factory day flow of energy passing through the atomistic system. For example, in the human organism, the characteristic energy stored in that organism is about 600,000 kilocalories, or kcal, of energy, the amount of energy that you might find stored and available to burn in about 300 lbs. of sugar. (The Nazi experiments performed on people "proved" that that is what you could get out of a person by working him or her to death). We can see it when we put on or take off pounds at a caloric cost of about 3,500 kcal per pound. The characteristic factory day energy when the earth day is taken to be the factory day, is about 2,000 kcal per Earth day (perhaps 1,800 for adult females, 2,400 for adult males).

Mass. There is a characteristic mass and distribution of mass species, and a characteristic flow of a variety of mass species per factory day in the organism. In simple systems, it was perhaps one or a few mass species. In living organisms, those mass species are carbohydrates, oils or fats, proteins, water, some ions, some salts and minerals, modest amounts or traces of some heavy metals, e.g. iron, magnesium, selenium, molybdenum. The chemistry in the human corresponds as a rough average to 130 lbs. of ingredients and to the factory day flow of those ingredients which will burn (oxidize) in net and produce 2,000 kcal. each factory day. What is that material flow? A little more than 1/2 lb. of carbohydrate, 2 oz. of fat, 2 oz. of protein, a quart or two of water, and a pound of oxygen each day. The byproducts emerge as carbon dioxide, urine (some water and byproducts like urea) and feces (with a considerable fraction of undigested materials and dead bacteria who lived high off "the hog" in passage through your GI tract).

Momentum. Momentum -- the result of the pair by pair collisions representing forces which change momentum -- is transformed in complex systems into ***action*** that emerge from the complex factory day of the rapidly colliding atomisms. Action is the energy-time product. What emerges is their organized actions rather than the itsy-bitsy changes in momentum from collisions at simpler levels. From cells banging into cells, we see their complex slower biochemistry emerging; from that system level, we see organized actions throughout the organs; from thence we see the organized actions of the organism; from them we see the organized actions of the social group. We should recognize most of these actions as trans-actions. Each level is made up of the organized momentum-like characteristics of lower atomistic processes. That is all there is.

If you want a physics statement we could say: The sum of all of the small momentum changes taking place at every level throughout the organism over the factory day represents a ***characteristic daily action*** H_O which itself is the summation of a spectrum or matrix of daily actions.

Now if human organisms were simple fundamental particles, their simple "factory day" of interaction (their collision scale) would be *h* or a few times that number. That was the marvel of quantum mechanics. But humans have H_O which is characteristic of the species. The daily action of a human is the same 2,000 kcal of energy expended during the factory day, but also 2,000 kcal-days of <u>action</u>. That is what you, as the organism, ate and ingested material and energy for, so that you could perform that characteristic action. And what characteristic daily actions did you do with that characteristic daily energy? You ate, slept, worked, voided, got mad, made love, attended to people, got envious, got anxious, escaped, played, etc. We can begin to recognize the human drama. How do you know a person, or any other living creature? By observing them and noting their characteristic spectrum or stream of action, the transactions they engage in. In fact, you can furnish a list and know that, somewhere on Earth, anything you put down on the list someone is doing -- today, and yesterday, and tomorrow. It is both a glorious, an objective, and a disgusting thought, but that's it.

In summary, the conservational transactions are for complex atomisms are:

- factory day fluxes or streams of characteristic energy,
- characteristic mass species, and
- a spectrum of characteristic actions that make up the equation of state and equations of change of the species ensemble and their play.

The Other Measures in Complex Systems

Let us look at what happens in complex systems regarding mass density, temperature, and pressure.

Mass density. Mass density, still an overall simple concept, now has all of its component specific mass or number densities of each independent or chemically transforming atomism.

Temperature. Temperature, still measurable as kinetic energy of motion in any external motional degree of freedom (for example how much energy or action that you expend in eating), is elaborated into the specific energy via all of the channels into which energy can be stored -- all the other motions and potentials stored in the field space.

Pressure. Pressure, deriving from momentum, itself can no longer be perceived as a simple measure. As we went from a simple gas phase with momentum representing the changes in motion for sharply distinguishable collisions, we reached the still relatively simple liquid phase with momentum now also representing the associated state of many close neighbors hammering (and yammering) at each other. We begin to notice that the pressure now is elaborated by the close field forces of attraction and repulsion between the players (where these forces are most commonly electrical). But when we come to complex atomisms, their associations display a resulting new transport from their interiors -- their associational viscosity. As well, their internal actions, the form of the energies that pour out from their interiors, affect the partitioning of the external momentum. And so we see a new process in the pressure. We see the ***social pressure*** of the associated complex ensemble.

We will give you a metaphor, what the music sounds like when you strike a note in a complex system. If you are a simple system and we give you a push, you bounce away. If you are a complex atomism, you may still bounce away but three weeks later you continue to wonder why we did it! The melody lingers on. And for all we know, you may then hit us. In another example, if you see two players join in a simple system, you know a simple chemical bond formed. In a complex ensemble, you do not know whether they conspired to kill the king, decided to form a company, make love, or were just trying to find directions to a restroom or the First National Bank. That complex of internal associations and its externalization defines the social pressure. Where does it come from? Still from the simple internal forces and processes, electrical and chemical flow, say at the brain organ, but it is hierarchical chemistry now, it is a complex of processes and internal flows.

Language as Catalyst in Complex Systems

One last property of that transformed action complex that emerged from simple momentum and forces is the transport of action and the switching of actions associated with "information" and "language". In fact, we define ***language*** as the small matter-energy catalysts that switch or evoke states of action.

Language is physical. Whether we whisper to someone using an acoustic signal or an electrical signal, or wave using a chemical signal such as a perfume or pheromones, or make a mechanical signal, we are using a small matter-energy complex. Language is a catalyst because its action is only to amplify and change some other system's motion without itself being affected. And its effect, as that kind of amplifier, is to get your action attention and/or to evoke in you a new action state. All this is the real working part of the social pressure in complex system. Someone can say "Conquer the enemy for God and country!" and use that language to convince others to hurl themselves into action. Or someone can say "Lets loot" or "Let's lynch", and civil unrest occurs. Or "Let's stay home, its raining" can be equally compelling. (Think how small the energy is that is represented by the putting of this writing in ink on the paper as compared to what that energy might release in action if you take us seriously.)

A memory function of a physical-chemical nature makes possible the use of language to make possible the long time delay in action in the factory day of a complex atomism.

And we need only add one idea to the prescription of equations of state and change. We have to continue to identify the potentials that drive such a field system or ensemble of players. Those potentials still arise from the walls or distributed depots. The potentials themselves may either be simple or complex systems. But they still provide energy, matter densities, momenta or sources that supply, govern, or evoke action. That we will talk about in the next chapter.