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THE ANTHROPIC PRINCIPLE AND THE ARROW OF TIME

by

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DISCUSSION PAPER

on

Roman U. Sexl's

ON THE ORIGIN OF ORDER IN THE UNIVERSE

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It is certainly a good time and a rewarding task to discuss this paper of Roman Sexl "On the Origin of Order in the Universe." I accept, of course, the overall picture which Dr. Sexl has presented, and I also agree with most of his more detailed statements. What I especially like in his presentation is his explanation of the universal mass-volume diagram in logarithmic scales with their vastly varying orders of magnitude. But let me, for the sake of discussion, concentrate on our minor differences of opinion and on some points which I should like to amend or simply add.

First of all, we may inquire more closely into the primordial origin of all of these physical magnitudes, which means to ask for the numerical values of the fundamental constants of nature. Some of these numbers are codetermined by conventions like the definition of pound or kilogram, but others are really natural in the sense of being independent of our accidental choices of metrological units. A typical example is Sommerfeld's fine structure constant $\alpha = 2\pi e^2/ch \approx 1/137$. More recent measurements[1] yielded an admirably precise value, $1/\alpha = 137.0359(6)$, its being less than one par per million. This is an absolute value which seems to hint to some hidden unity of the physical forces. Most physicists hope that science will be able, sooner or later, to calculate such a natural number from new principles which we are eagerly looking for. But there are some colleagues who guess that α might be somehow an accidental number, a result of God's playing dice (so to say, with Einstein). In any case it is a thought provoking and illuminating endeavor to imagine how the universal order would look like if $1/\alpha$ had another value, say 200 instead of the 137 which it happens to have in our universe.[2] In Sexl's paper, α occurs implicitly in the first line of page 20 as the ratio of the first to the second term on the right-hand side of that equation. Sexl goes on to neglect the second term in comparison with the first one, as

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[1] The most accurately ones use the quantised Hall effect, which was discovered by von Klitzing a few years ago and awarded a Nobel prize a few weeks ago.

[2] There is an old jocular equation, $2 \cdot 137 = 1 + 273$, allegedly and funnily connecting Sommerfeld's constant with Kelvin's value in centigrades.

being about 137 times smaller, and so this middle term does no longer show up in the final expression of the energy E, later in the page. This is quite right, but in other circumstances α cannot be neglected; its order of magnitude determines, for example, the size a of the hydrogen atom which lays at the very bottom of Sexl's diagram. The pertinent formula is $a = \alpha\, h/2\pi c\, m$ where m is the mass of the electron and, as before, c the volicity of light and h Planck's quantum of action. A change of α would affect the temporal and energetic scales as well as the spatial ones. The whole microscopic structure of the universe including the laws of organic chemistry and physiology may change quite sensitively.

Another fundamental constant of this kind is the ratio M/m between the mass of the proton and that of the electron. It happens to be about 1850, and we do not know whether or not a different value would violate some fundamental principles. It is not clear to me either how deeply the fabric of our universe would be affected by a change of this number—be it real in time, or in our imagination only.

Yet there is no doubt about the importance of the gravitational attraction between an electron and a proton in relation to their electrical attraction. This coefficient $\varepsilon = \gamma\, mM/e^2$, a natural measure of Newton's gravitational constant γ, has the extremely small value of $\approx 10^{-40} \approx 2^{-130} \approx e^{-92}$. About fifty years ago Dirac proposed that this number might decrease during the cosmic evolution. This interesting idea seems to conflict with the more recent observations and estimations. A similar (and probably related) fate had Heisenberg's vision that at the Compton length of the proton, which is about 10^{-15} m, our continuous space notions should be replaced by some kind of geometrical atomism. Now we are pretty sure that Minkowski's smooth space-time structure stays valid until at least 10^{-17} m, which is a hundred times smaller than Heisenberg's value. Nowadays we usually guess that a discrete structure of space and time should obtain at a much smaller scale, as an effect of Einstein's gravitational force combined with quantum theory. This amounts to the Planck length $l = \sqrt{\gamma\, h/2\pi\, c^3}$ of about $3 \cdot 10^{-36}$ m, and the corresponding Planck time $\tau = l/c \approx 10^{-44}$ s.

These considerations stress the deep importance of that mysterious number, 10^{-40}. How likely is this tiny ε the unique solution of some

fundamental (eigenvalue) equation? Be that as it may, had ε a different numerical value (which is, to be sure, independent of any metrological conventions), that universe would not equal our universe. Recent studies seem to indicate a surpringly narrow margin to be observed in order to avoid drastic changes. Imagine, for example, a decrease of ε by one decadic order of magnitude, from 10^{-40} to 10^{-41}. If we view this on a logarithmic scale, which seems to be the appropriate thing to do in this case, what we see is a relatively small change only, namely from -40 to -41. Nevertheless, the physical conditions in the possible planetary systems would have to undergo dramatic changes. These would probably suffice to destroy the probability of any organic life, or the like, in the universe.

Contemplations of this kind have been summarized by some authors under the heading of a new approach to natural philosophy, called the anthropic principle. Roughly speaking, it proposes to look at that conditions which the so called laws of nature must meet in order that the existence of humans or other intelligent populations is not legally prohibited (or, which is the same thing here, physically prevented). The main obstable in this field is, of course, our lack of phantasy or, which is almost the same, our poor mathematical craft or power together with our less than perfect experimental and observational experience. All this notwithstanding, the field is not so dark as one could all too easily surmise. As a typical example, let me mention the chemical basis of organic life. (By the way: the preorganic level of order is not dead, but alive on a lower level, which I like to call the dynamical level of life, followed by the vegatative, the animal, and the intellectual level.) As you know, organic chemistry is centered around carbon, which is just one of the chemical elements chosen out of one hundred others. For a long time many people talked about an analogue of organic chemistry based on silicon, a chemical element whose atoms exert, like those of carbon, for valency bonds. But now we are rather sure that there can be no organic life (no self reproduction by means of digital information processes) centered around silicon. (The artificial life, or even intelligence, based on the chips from the Silicon Valley are quite another thing: It is artificial, man made, and not spontaneously grown). That kind of order which is called organic life

depends on the well balanced electronic shell structure of the carbon atom. This electron configuration $(1s)^2\ (2s)(2p)^3$ of the carbon shell must be fine tuned in a very fortunate way. Distort it slightly, and all the wonders of the long molecular chains and reactions are gone. Such are the structural origins of order in the universe.

Its temporal origins are, of course, also of the utmost importance. In our days the sciences find them, as Sexl explains, in the original cosmological singularity and during the ensuing spatial expansion which gave rise to atoms, galaxies, stars, planets, rivers, plants, animals, and humans. This cosmic process with emerging order structures is quite consistent with an overall increase of entropy, which can be regarded as a measure of disorder. Organic beings are able to eat negative entropy and store part of it within their own architectures. Negative entropy may be interpreted as the information (the built in formation) that is contained in the thermodynamic state (as opposed to the dynamic state which has always a vanishing entropy). There is thus no contradiction between the emergence or transvolution (the so called evolution) of higher and higher structures, and the second law of thermodynamics.

The other, atomistic dilemma of the entropy concept is much more serious: According to the second law of thermodynamics the entropy of a thermally isolated system has to increase irreversibly in time[3]. How can this phenomenon be made consistent with the well proven reversibility and quasi-periodicity of the atomic motions? Boltzmann's proposal, so nicely explained by Sexl, is not convincing, as von Weizsäcker has pointed out many years ago: By believing in Darwinism, Boltzmann contradicted himself with an overwhelming probability, because we can imagine a vast majority of cosmic fluctuation which are much smaller than the Darwinian ones, and are consistent with all our experiences, and are much more probable. Weizsäcker then arrived at a phenomenological philosophy of time, close to that of Husserl, Bergson, or Heidegger. But I agree with Sexl that we should look

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[3]This is not only a definition of the time direction, but a substantial proposition, because the orientation of time may be defined otherwise, e.g. by the outgoing waves of any radiation.

for a cosmological solution of the thermostatistical problem, which is based on a more realistic cosmology than that which prevailed between Laplace and Boltzmann. An important point here is that our dynamical universe may no longer be treated as an isolated system not even with respect to energy and much less so with respect to entropy. Since about 1970, I have argued that an increasing cosmic volume could very well be a strong cause of entropy production. Sexl's piston picture is a nice illustration of this kind of argument.

What I do not understand in Sexl's work and what seems to me rather unlikely, is the model of an oscillating universe with an ever increasing entropy (on the pages 14 to 16 of his paper). In a cyclic or almost cyclic universe one should expect an infinity of cycles before that one which we are living in. Then there is no reason to assume that the entropy content of the universe should steadily increase from left to right, that is, from what we humans call past to what we call future. Any argument in favor of one direction of time would as well or as badly favor the opposite direction.

In this context Sexl's piston picture becomes convincing only if it is supplemented by an atomistic or microscopic model analogue to that given by Boltzmann in his famous "Gastheorie", where he used his statistical collision equation based on what he called "molecular chaos". A better name would be "semi-chaos" instead of "chaos", because his assumption is, as the Ehrenfests have made clear, asymmetric with respect to (what we call) past and future. As I have pointed out in my contribution "Irreversibility and Quantum Theory" to ICUS X in Seoul 1981, the temporal asymmetry of Boltzmann's statistical equation can be understood only by an appeal to the cosmological arrow of time, as evidenced by the galactic space expansion and the cosmothermal background radiation. An intermediate step in this chain of reasoning is the electromagnetic time arrow of the Sommerfeld causality. According to this empirical law, which is an asymmetric strenghtening of the better known Einstein causality, an (electromagnetic) effect cannot temporarily precede its (electromagnetic) cause. Now it is essential to realize that this chain of reasoning applies to the final big bang as well as to the original one. This means that the time flow should gradually die out when the universe approaches its maximum volume and that "after" that it should continuously build up in the opposite direction. Next assume that there are (or will be, if we stick to our provincial language) some intelligent creatures in the other hemicosmos, which is by no means sure according to the anthropic

principle with its small probabilities. But if we make that assumption, than these very strange colleagues of ours would experience a time arrow that is in the opposite direction, according to our temporal concepts, which become rather abstract anyway if expanded to the whole universe. But this difficulty of our subjective intuition is not much harder than for example Einstein's twin paradox which has been understood and experimentally confirmed long ago. When the Phoenicians sailed around Africa they were surprised to find the sun in the north, and their contemparies (including Herodotus) laughed at their report—quite wrongly as was realized soon after in Alexandria. In a similar way the direction of time may very well be different in various parts of the universe.