COMMITTEE I
Unifying Principles in Science

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Session III Discussant Remarks

ENERGY: THE ESSENCE OF THE UNIVERSE

by

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ENERGY: THE ESSENCE OF THE UNIVERSE

(Comments on the invited papers by M. Bauer-preliminary version)

Scientific research is a lot like mountain climbing. Many ways are explored, many dead ends. At some time even, the idea that reaching the summit is imposible blocks further progress. Then someone gets through. Minds are unblocked and others follow by the same road, but with more ease. Other roads are found and the peak is reached from all sides. Finally, looking down and around from the top, an integral picture of the mountain emerges and it is realized that there is an easy way up. Sunday picnics follow. (Then, on to the next and higher peak...)

Unifying principles in science are akin to the view from the top. The mountain was always there, but one grasps its wholeness only when the last ascent is completed.

Energy is a modern concept, slowly taking form during the last century, until Einstein's summit of thought displayed the equivalence of energy and matter. And matter is ancient history. Should we retrace to earlier times the history of energy under the guise of matter? Is it fair play second-guessing the thinkers that have given us the modern concept of energy? Perhaps not, but it is certainly interesting from the point of view of exhibiting a certain unity of thought in our centuries old quest to understand nature. We'll come back to this later.

Professor Elbek's view from the top results in a concise and agile picture of the progressive penetration of the energy concept in the different arenas of our scientific endavour to comprehend the physical world. In doing so he succeds in showing how it brings a unity to all branches of physics, to begin with. Actually, the acting principle in this unifying process is the concept of conservation of energy, even if energy itself is not clearly defined. This is the road along which one finds, inter alia, the mechanical equivalent of heat, the prediction of the neutrino and above all the equivalence of matter and energy, and thus of matter and interaction fields.

As Einstein and Infeld put it in their book, "The evolution of physics", before relativity "... matter has mass, whereas field has not. Field represents energy, matter represents mass". But, "From the relativity theory we know that matter represents vast stores of energy and that energy represents matter... We could therefore say: Matter is where the concentration of energy is great, field where the concentration of energy is small. There is no sense in regarding matter and field as two qualities quite different from each other". And further along, "There would be no place, in our new physics, for both field and matter, field being the only reality"

As we know, such a program has advanced quite a lot along the lines of quantum, not classical, gauge field theory, but with a twist. More on this below.

At this stage one can bring forth the only attempt to define energy itself (that is, without any qualifyers like kinetic, chemical, nuclear, etc.) known to the present writer. It is due to Planck in his Treatise on Thermodynamics (page 41, Dover english edition). To quote:

> "The energy of a body, or system of bodies, is a magnitude depending on the momentary condition of the system..... The energy of the system in a given state, refered to the arbitrarily selected normal state, is then equal to the algebraic sum of all the effects produced outside the system when it passes in any way from the normal state. **The energy of a system is, therefore, sometimes briefly denoted as the faculty to produce external effects."**

We find the last sentence, underlined by us, the most significative as a unifyng conceptual definition, even if a litle abstract.

For one thing, the elements of the physical description that contribute to this faculty can now be listed and accounted. Thus we have contributions from the motion of the system as a whole (kinetic energy), from its location and coupling to external fields (potential energy), and finally from its mass (proper energy), which includes the rest mass of the elementary constituents as well as their internal motion and interaction fields (internal energy, heat content, etc.). The faculty of producing external effects lies in the possibility of exchanging energy with the environment (rest of the universe) through physical processes that transform one form of energy into another, including the creation and anihilation of mass.

A final remark is to stress the word "faculty". One is really talking of the capability of a system of affecting its environment, independently of whether or when it is exerted *.

Energy is a measure of the presence of a system in the universe.

The above proposed definition seems to run into trouble if the system considered is the whole universe. For then, what is external to the system?. Although Planck's definitions did not originate from the consideration of nature at a cosmological level, one could go back to the assertion that energy is a characteristic of the state of the system **referred** to an arbitrarity selected normal state. Then we could, following Professor Fritzsch's provocative paper, select the normal state as the **nothingness** from which the universe -that is, energy- is created.

The original unknown amount of energy is not conserved due to the expansion of the universe. Energy is lost systematically. However, two very distinct stages occur. The initial one is extremly short lived and turbulent: dramatic drop in temperature

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* A housewife, remarking to a neighbour on how much energy her little boy has, and thus on the need to keep on eye on him, is really thinking of his capacity for doing mischief.

(energy), symmetry breaking(s) and inflation period(s), energy density fluctuations. The second is the universe as we know it today, cold, almost flat, still expandind and loosing energy except that "... this loss is relatively modest since the energy density is dominated by ordinary matter (e.g. galaxies), and not by the radiation field" (H. Fritzsch).

This stage is more likely to underlie the concept of the reference normal state of Planck. It accounts for the practical homogeneity of space and time at a local level and thus explains the gestation and acceptance of the energy conservation principle.

After setting forth the limitation on this principle, arising from Einstein's theory of General Relativity, Professor Fritzsch's paper produces a lively snapshot of one of the most exciting arenas of modern physics: the bringing together of cosmology and elementary particle physics, that is, of the macrocosm and the microcosm.

Modern quantum field theory seems to be yielding a unified description of the physical world, present, past and future. Throughout this description energy (temperature) is the ordering parameter, both for the type of process and for the time of ocurrence.

The unified picture of quantum gauge field theory differs from Einstein and Infeld's expectation, quoted previously. One is certainly considering that the physical reality corresponds exclusively to energy fields. But the energy is quantized, basically in the form of mass for most of the fields. In our present cold stage, the distinction between "clasical matter" and "classical fields" obeys to statistics, being associated respectively with Fermi-Dirac fields (neutrons, protons, electrons,...) and Bose-Einstein fields (photons, gravitons, mesons,...). The massless bosons can and do give rise to macroscopic fields of comparatively low energy density, precisely because of their statistics and their lack of mass.

The picture is however different when massive bosons are exchanged, as in the nuclear interaction. There can be (momentarily) more energy in the interaction field than the energy represented by the nucleon masses and in the whole system considered, e.g. the nucleus. Seemingly energy conservation may be grossly violated at the microscopic level also, -but for very short times-, under the "cover" of the uncertainty relations of quantum mechanics. We know however that such "virtual processes" cannot be dismissed and also how present quantum gauge field theories are handling them.

It is not our purpose to discuss this in detail. We rather want to bring into the discussion the very intimate connection between energy and "time", which surfaces both at the cosmological and the microscopic level. This connection, and even the proper meaning of time, is to our mind, one of the fundamental open problems in our understanding of nature. What is the distinction or the link between time as an element of the space-time manifold and time as a generator of energy displacements, that is, as a dynamical variable cannonically conjugate to energy?. Can we fully comprehend the meaning of energy and its role as a unifying concept without first understanding its complementarity relation with time?

Is energy the essence of the universe?. This is really a very old question, raised to begin with in the speculations about matter. To quote: "What is matter? Is the world all made of **one** stuff, as the Ionian philosophers of 2500 years ago thought, or are there **several** basic substances that are not reducible to each other?" (M.P. Crosland, "The science of matter" Penguin Books Inc, 1971). Energy seems to fill quite well that **one stuff** role, unless time reveals itself as the other substance to which energy is irreducible.