COMMITTEE I
The Unity of the Universe

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ENERGY AND THE UNITY OF THE UNIVERSE

by

Marcelo Alonso
Executive Director
Florida Institute of Technology, Research and Engineering, Inc.
Melbourne, Florida

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Marcelo Alonso

Florida Institute of Technology

I. Introduction

This paper explores how in our efforts to understand the universe two concepts, mass and energy, have evolved from a limited mechanical role until they have merged into one entity, mass-energy, and have become the most fundamental parameters for describing most natural phenomena over extremely large range of orders of magnitude. This fusion of the concepts of mass and energy, a consequence of Einstein's Theory of Relativity and Planck's Quantum Theory, has been one of the most revolutionary ideas of contemporary science.

In describing the universe our senses function as transducers that receive a variety of external inputs and transform them into codified electric signals carried by different mechanisms to the brain where they are decodified and stored (memory). As a next step, these signals are structured as "knowledge," that is organized information (concepts and ideas), which can be combined or interrelated in the processes called "reasoning" and "analysis." The whole process can be reversed with the brain sending codified signals back to the pertinent organs for proper action.

When this is applied to what is called "science," i.e. knowledge related to the structure and functioning of the universe, we note that it reaches in humans an extraordinary level of sophistication and abstraction. The scientists invent concepts that allow to simplify and systematize the observed phenomena and to reduce our understanding of the functioning of the universe to a few relations among those concepts, which are designated "physical laws."

Since our perception of the universe is highly restricted because the limitations of our transducers (the senses) and of our signals processor (the brain), the physical concepts and their relations are continuously modified as our "knowledge" and the brain's reference basis broaden. This evolutionary epistemological process has been accelerated in a dramatic way by the development of "instruments" and "tools" which are extensions of our sensorial organs and which allow us to gather "knowledge" well beyond our natural capabilities.

2. Mass

Perhaps the two "scientific" concepts that most clearly exemplify this extremely successful evolutionary epistemological process are those of "mass" and "energy." Let us begin first with the concept of mass.

"Weight" is a natural concept that arises from the simple experience of lifting and moving bodies. Also "matter" is a primary concept, that can be defined somewhat loosely as "the stuff" of which bodies are made. A first scientific step might have been the statement that "weight is an attribute of all matter," as a sort of primitive physical law.

Thus it seemed reasonable to assume that there was some relation between the "amount" of matter in a body and its weight, a statement rather imprecise from the point of view of science since the term "amount of matter" requires an operational definition.

A tremendous leap forward to conceptual advancement were Newton's laws of motion and his theory of gravitation formulated in 1666. His second law of motion contains a fundamental generalization by the introduction of the concept of "force" beyond the notions of weight and of push and pull and related to the rate of change of velocity (i.e. acceleration) of a body (Note 1). But this required the introduction of an abstract concept, "inertial mass", for which no direct sensorial experience exists. In fact it took more than a century to fully clarify and appreciate the meaning of mass and to define it operationally, independently of force, an effort in which E. Mach played a leading role in the late 19th century. But the astonishing result is that the notion of mass has been found to be correct well beyond the scope of the forces of which Newton was aware.

In fact, through his theory of gravitation Newton introduced the first fundamental force of nature to be recognized; gravitation ($F = Gm_1m_2/r^2$), to which he applied his law of motion, ($\vec{F} = md\vec{v}/dt$) assuming implicitly the equivalence of inertial and gravitational mass, an assumption that is still considered valid. A natural consequence of combining the two laws was that weight is reduced to the gravitational force exerted by the Earth on all bodies near its surface ($\vec{W} = m\vec{g}$) becoming a strictly terrestrial concept, while mass is a universal property of matter. Once this was recognized, weight became a secondary concept and its primary place in a conceptual hierarchy was occupied by mass (a fact not yet well recognized by many engineers, chemists, and even physicists: Table of Atomic Weights, instead of Table of Atomic Masses; weight of elementary particles instead of mass of elementary particles).

But when electric and magnetic forces were discovered, which required the introduction of the concept of electric "charge" (another conceptual abstraction) it was found that to describe the motion of charged bodies it was not necessary to introduce "electric" or "magnetic" masses, but that Newton's inertial mass was still valid for describing motion under such forces, a most outstanding fact that reveals a unique, though unintended, foresight on the part of Newton. Or put in other words inertial mass is the first example of our ability to invent concepts that transcend the circumstances under which they were invented and which might suggest that scientific knowledge may correspond to a sort of objective understanding of reality.

The concept of mass has acquired an even more transcendental relevance and abstraction through its role, coupled with gravitation, in determining the space-time metric ($ds^2 = \sum g_{\mu\nu}\, dx_\mu dx_\nu$, $\mu, \nu = 1, --, 4$; the coefficients $g_{\mu\nu}$ are related to the distribution of mass in the universe) according to Einstein's theory of general relativity, and therefore determining the motions of all matter in the universe as well as other relevant phenomena. This again is a development well beyond the frame under which the concept of mass was first introduced. We shall not elaborate on this aspect in this paper.

3. Energy

Let us go next to the concept of energy, which had a modest and largely algebraic beginning. As it is well known, the precursor to energy was the concept of "vis viva", mv^2, introduced empirically by G.W. Leibnitz, contemporary of Newton, to calculate the final velocities in two body collisions when combined with the conservation of momentum $\vec{p} = m\vec{v}$ (Note 1). This way of analyzing collisions brought empirically into physics another role for the notion of mass not directly related to Newton's second law of motion.

The concept of "<u>kinetic</u>" energy ($E_k = 1/2\ mv^2$) was then introduced by Kelvin in 1856 as a direct algebraic result emerging from a first space integration of Newton's second law and associated with a very practical concept, "work" ($W = \int_{P_0}^{P} Fds = E_k - E_{k,o}$). This allowed to carry out important calculations in which it was not necessary to know the details of the motion, but it was enough just to relate a final state to an initial state. It is well known the practical importance of the concept of "work," which can be easily calculated in many instances, and whose usefulness has transcended the scope of science.

Shortly after a new abstraction, again of mathematical nature, emerged in physics, that of "potential" energy (introduced by L.N.M. Carnot late in the 17th century) which could be expressed by certain functional relations in terms of the coordinates of the particles on which the forces act. When the force satisfies $\nabla \times \vec{F} = 0$, which in turn implies $\vec{F} = \nabla f$, where f is a function of the coordinates, it is possible to calculate the work without knowing the path of the particles, i.e. work can be calculated as a definite path integral that depends only on the initial and final states ($W = \int_A^B Fds = f(B) - f(A)$). The first and for some time only force satisfying this mathematical requirement was the gravitational force. By a strike of genius Rankine suggested to use the negative of the function f(x) resulting from the path integration of the force and called it "potential" energy $E_p(x) = -f(x)$; then the force is related to the potential energy by $\vec{F} = -\nabla Ep$. In the case of gravitational forces $E_p = - G m_1 m_2/r$. One immediate consequence of this definitional change was that for this kind of forces the sum of the kinetic and potential energies (otherwise it would have been the difference) remains constant during the motion ($E_k + E_p = \text{const.}$) and this sum was called the "total" energy of the particle. It is important to recognize that this result, while revealing some peculiar physical properties of the systems considered, was of restricted applicability, limited to the so-called "conservative" forces, and traditionally referred to as "conservation of mechanical energy."

So far one could say that the conservation of energy of a particle was a useful mathematical result derived from the nature of the forces and Newton's second law without major universal or cosmological implications. When dealing with a system of particles considered as structureless mass-points subject only to mutual (or internal) conservative forces the conservation of the total energy of the system was a simple mathematical extension of the case of one particle. And by assuming that the universe is an isolated system in which only conservative forces act between the different particles, the law or principle of conservation of energy of the universe was a straightforward conclusion. This we could call the "Newtonian vision" of the universe; it was a universe dominated by gravitation and in which all bodies were in well defined motions but nothing else changed. But this vision proved to be an oversimplication as seen below.

The development of thermodynamics in the late 19th century and its subsequent evolution into statistical mechanics, allowed to understand heat as a process of energy transfer by molecular collisions between two systems or two parts of a system having different average molecular energies, and to identify temperature with the average energy of the molecules, thus reducing heat and temperature to mechanical concepts . However, these two crucial conceptual steps served only to emphasize the work-energy relation of mechanics as applied to systems of many partcicles, for which the internal forces were not expressed explicitly, but did not require broadening the concept of energy, except perhaps for the introduction of the concept of internal energy, which however, can also be introduced independently of thermodynamics.

4. Electromagnetic Energy

Another conservative force recognized late in the 18 th century was that of the Coulomb-interaction ($F = kqq'/r^2$) between two electrically charged particles, resulting in a potential energy $E_p = kqq'/r$ very similar to the gravitational potential energy from the formal point of view. That meant that the motion under electric forces could be described in the same way as under gravitational forces, satisfying the conservation of energy. However, the "magnetic" force on a particle ($\vec{F} = q\vec{v}x\vec{B}$), which is velocity dependent, could not be associated with a potential energy and the notion of "total energy" did not seem to be fully applicable. (However a vector potential $\vec{A}$ can be introduced so that $\vec{B} = \nabla \times \vec{A}$).

The situation could be worked around by using Lagrange and Hamilton formulations of the equations of motion (Note 3) which implied a broader definition of momentum $\{\vec{p} \to \vec{p} - (q/c)\vec{A}\}$. The kinetic energy had then to incorporate the effect of the magnetic field through the vector potential so that a modified constant total energy resulted ($E_k + E_p = \text{const}$, with $E_k = [\vec{p} - (q/c)\vec{A}]^2/2m$). However an expression for the energy of a system of several moving charges has not yet been formulated in a satisfactory form.

The first truly revolutionary extension of the concept of energy came, in the last part of the 19th century, with the formulation by J.C. Maxwell, of the equations for time dependent electromagnetic fields (Maxwell's equations), relating the fields to their sources (charges and currents). To maintain the work-energy relation inherited from Newtonian mechanics (in which particles play a passive role) two new ideas had to be introduced. The first was to ascribe energy to the electromagnetic field (energy density $\sim E^2 + B^2$) which implied that the field associated with charges and currents was not just a useful mathematical tool but a real physical entity. This clearly was a monumental conceptual abstraction, way beyond the original concept of kinetic energy. The second new idea was that the electromagnetic energy associated with the motion of charged particles can be transferred from one place to another with the velocity of light c. (Poynting vector $\vec{S} \sim \vec{E} \times \vec{B}$.) This is what we currently call electromagnetic radiation. That meant that energy can be transferred by electromagnetic fields without the intervention of matter, thus even in a vacuum. But the sources of the electrogmagnetic radiation were moving charged particles.

Inasmuch as matter in the universe is mostly composed of charged particles the energy of the universe according to Maxewell's theory, is not just the kinetic energy of the particles and their gravitational potential energy, but is mostly electromagnetic energy. In this way we recognize that the existence of electromagnetic forces requires the extension of the concept of energy to include electromagnetic energy in order to preserve the conservation of energy in the universe. This extension is not just a mathematical artifice but it has a profound physical meaning. We can visualize all matter in the universe composed of charged and neutral particles immersed in maxwellian electromagnetic radiation which, as we shall see later on, might require a consideration of the concept of "vacuum." We could call it the "Maxwellian vision" of the universe.

Thus, like in the case of mass, a concept originally of limited scope, kinetic energy or energy of motion, has acquired a new dimension in our conceptual framework by virtue of the existence of gravitational and electromagnetic forces.

5. Energy and Mass

A new profound evolution of the concepts of mass and energy took place with the advent in 1905 of A. Einstein's Theory of Relativity, based on the assumption that all inertial observers in uniform relative motion are equivalent and therefore the physical laws appear in the same form to all of them, (Principle of Relativity). A subsidiary assumption, well supported experimentally, is that all such observers measure the same velocity for the propagation of electromagnetic radiation (speed of light, c). Inertial observers compare their observations using the well known Lorentz transformation which couples space and time coordinates (Note 4). One consequence is that the momentum of a particle is no longer $\vec{p} = m\vec{v}$ but rather $\vec{p} = \gamma m\vec{v}$, where $\gamma = (1-v^2/c^2)^{-1/2}$, in order to maintain the law of motion in the general Newtonian form ($\vec{F} = d\vec{p}/dt$). This in turn implies that to preserve the kinetic energy-work relation ($E_k - E_{k,o} = W$), the kinetic energy must be expressed in the form $E_k = mc^2 (\gamma -1)$. Recalling the definition of γ , this expression reduces to the newtonian expression ($E_k = 1/2\ mv^2$) for $v \ll c$, i.e. in the non-relativistic (N.R.) limit.

So far nothing very fundamental seems to have changed except perhaps for the coupling of space and time, which of course is in serious discrepancy with our sensorial experience (we shall elaborate on this point later on), and the well known consequences derived from that coupling (length contraction, time dilation, etc.) However, for our purpose there is a more important development. The expression for the kinetic energy can be written as $E_k = \gamma mc^2 - mc^2$ and we may interpret this algebraic relation as follows. The first term, $E = \gamma mc^2$, can be considered as the energy of a particle in <u>motion</u> (relative to the observer) and the second term, $E_0 = mc^2$, as the energy of the particle at rest (also relative to the observer); the difference $E-E_0$ is thus the energy added to set the particle in motion, i.e. the kinetic energy. It may seem that this is only a matter of terminology without adding any new physics to the analysis.

But at this point Einstein made one of his boldest assumptions. After applying his theory to relate the energy of a light ray as measured by two observers in relative motion ($\epsilon'/\epsilon = \gamma\{1 - (v/c) \cos\phi\}$), he proceeded to calculate the change in energy of a particle emitting light (radiation) and concluded that if a body emits (absorbs) energy in the amount ΔE its mass diminishes (increases) in the amount Δm so that $\Delta E = \Delta m . c^2$. This led him to the conclusion that "the mass of a body is a measure of its energy content" ($E = mc^2$), which he supplemented with another extraordinary statement: "If the theory corresponds to the facts, radiation conveys inertia (mass) between the emitting and absorbing bodies." With those two statements Einstein changed for ever the way we look at physical phenomena and energy became the primary concept used to describe in a beautifully simple and unified way the processes in the universe.

The universe is composed only of energy which manifests itself as mass ($E=mc^2$) or as radiation ($E=h\nu$, a relation also established by Einstein). All processes in the universe correspond to exchanges of energy (and momentum) in terms of mass and/or radiation, or rather field energy, between interacting systems. This we might call "Einstein's vision" of the Universe. This is a long way from the simple notion of kinetic energy resulting from the integration of Newton's equation of motion. Also this shows dramatically once more how concepts introduced in a rather restricted sense have been extended and generalized to successfully explain entirely and unforeseeable new situations, and this is one of the most astonishing results of human thinking.

But, of course, no matter how beautiful Einstein's theory of relativity might be, it is of little value if it is not corroborated by the experiments. To begin with, Einstein's theory of relativity is beyond our sensorial and intuitive experience. For us, humans, space and time are two different unrelated notions, and the same applies to energy and mass. The reason for this distinction is very simple: life phenomena are extremely N.R. comprising energy exchanges minuscule (no more than a few eV) compared with the rest energies of the particles involved (electrons, protons, nuclei, etc.). We have to examine phenomena in which the energies are comparable to the rest energies of the particles involved (0.5 MeV for electrons, 900 MeV for protons) to be able to test Einstein's theory, as he himself pointed out. And so far it has been found that the theory is correct in all cases it has been tested (fine structure of H spectrum, Compton effect, radioactive decay, nuclear binding energy, nuclear fission and fusion, etc.).

The most direct experimental proof of the mass-energy relation $E=mc^2$ is the photon production of electron-positron pairs and the annihilation of electron-positron pairs into photons, but many other processes involving elementary particles testify the correctness of Einstein's theory. Perhaps the two most spectacular applications of Einstein theory have been to nuclear power and nuclear weapons, and to explain the generation of energy in the sun and in all stars through the fusion of hydrogen nuclei (protons) into helium nuclei (helion) with the mass that is lost being transformed into other forms of energy (electrons, neutrinos, photons) (Note 5). Besides the importance of being able to explain the source of the vast amounts of energy radiated by the Sun, of which the Earth receives a small fraction, the applicability of the mass-energy relation, developed for terrestrial physics, to extraterrestrial systems gives us confidence that our mind is capable of understanding the universe in spite of having direct access to only a tiny part of it. (A previous example of extraterrestrial extrapolation was the discovery of the chemical composition of the stars by comparing their spectra with those observed on Earth, and the calculation of the expansion of the universe by measuring the Doppler effect (red shift) of the radiation received from other galaxies. Of course Newton was the first one to extrapolate terrestrial science to explain planetary motion using his law of "universal" gravitation).

As a parenthetical, but nevertheless extremely important, remark we should note that inasmuch as life on Earth depends critically on the radiation energy from the Sun, we may conclude that life on Earth, and probably elsewhere in the universe, is a consequence of Einstein's mass-energy relation ($E=mc^2$). In other words, life is a relativistic effect albeit of second or higher order, but it functions at a nonrelativistic level.

6. Energy in Quantum Theory

Parallel to the development of the theory of relativity, another crucial revolution, the emergence of Quantum Theory, took place in Physics which gave even more importance to the notion of energy. It all began in an unexpected empirical way when in 1900 M. Planck proposed the radically new idea of the quantization of the energy of a harmonic oscillator ($E=nh\nu$) to successfully explain quantitavely the energy distribution in black-body radiation. (Interestingly enough although Planck's results were correct his mathematical derivation was not). Shortly after, Einstein introduced in 1905 the notion of a quantum of electromagnetic radiation or photon ($\epsilon = h\nu$) to explain the photoelectric effect and through the concept of transition probabilities that he also introduced, he correctly derived the black-body energy distribution. The photon as a quantum of EM energy was further corroborated in 1923 by the analysis of the Compton effect. N. Bohr extended in 1913 the notion of energy quantization to the motion of electrons in atoms by introducing some adhoc hypothesis, and correctly explained the hydrogen spectrum.

It was not until the second half of the 1920's that Quantum Mechanics became a formal structure similar to Newton's mechanics, thanks to the work of de Broglie, Schrödinger, Heisenberg, Dirac and others. Among the many novel ideas of Q.M. two are of particular interest for our purpose in this review. In the first place Q.M. established a close relationship between particles and fields: particles were described by fields (the wave function) and fields could be described by particles (photons in the case of the EM field). This was referred to in the early days of Q.M. as the wave-particle duality. And in the second place Q.M. established on a firm basis the rationale for the quantization of energy (and other physical quantities such as angular momentum) and provided a well defined formalism or methodology to deal with energy exchanges at the molecular, atomic and subatomic levels (Note 6). Or put in another form, quantization became the rule at the fundamental level. Therefore, while the theory of relativity put energy as the central concept for analyzing processes in the universe, Q.M. provided the rules that govern energy exchanges. Note that we cannot obtain information about the energy states of a system unless we subject it to energy exchanges. In atoms and molecules these exchanges occur through collisions or the absorption or emission of EM radiation, which can easily be observed in the laboratory.

Like in the case of the theory of relativity, Q.M. deals with concepts and abstractions that are beyond our direct sensorial experience and that explains why Q.M. could not be developed until we improved substantially our methods of observation and the precision of our measurements. Our sensorial experience involves large numbers of atoms and the effects of quantization become smoothed out and imperceptible. However, each of the atomic or molecular processes in living systems occurs strictly in accordance to the rules of Q.M. Life operates quantum-mechanically at the fundamental level. One of the most interesting examples is photosynthessis, the absorption of photons by plants to synthesize carbohydrates out of CO_2 and H_2O (Note 7).

The merging of Q.M. with the theory of relativity was accomplished by P.A.M. Dirac in 1932 with his formulation of the theory of the electron, which explained some peculiarities of the electron such as its spin and its magnetic moment. Curiously enough it is possible to have particles with no rest mass, but with energy and momentum ($E = cp$). These particles can never be at rest and must move always with the velocity of light. The photon is one case, and until recently it was assumed that the neutrino was another, but some new theories seem to demand that the neutrino have some mass, although much smaller than that of the electron, perhaps only a few eV. This means that a particle cannot have mass without having energy but that some particles can have energy without mass.(Recent observation of neutrinos from the supernova 1987A suggests that their mass cannot exceed 11eV).

Another peculiarity of Q.M. is that to each particle there is an <u>anti</u> - particle with the same mass and opposite charge (if the particle is charged); other properties are also supposed to be opposite . In some cases, like the π^0 and the γ , a particle and its antiparticle might be indistinguishable. When a particle and an anti-particle collide they disappear and new particles are created; their mass-energy comes from the mass-energy and the kinetic energy of the colliding particles. One could say that through collisions the initial mass-energy can be reorganized in new forms, but the creation of new particles is not restricted to particle-antiparticle collisions. In any collision new particles can be created provided that enough energy is available relative to the C.M. of the colliding particles to be transformed into the mass-energy of the new particles (other selection or conservation rules must also be fulfilled but we do not need to be concerned with them now).

Thus we can visualize the universe at the fundamental level as a very dynamic system similar to a boiling soup in which instead of steam bubbles particles are continuously created and annihilated depending on the energy available. In the same way that as a soup cools down the bubbles disappear, as the energy available in collisions decreases with a general cooling trend in the Universe, certain particles are no longer created because there is not enough energy for their creation. This fact has important cosmological implications as we shall see later. Many high-energy particle processes that no longer occur naturally in our small part of the universe can be produced in small scale using powerful particle accelerators.

To finalize this review of how energy is used in quantum theory we shall consider briefly how interaction processes are analyzed. Over-simplifying the theory we may say that in an interaction process (scattering, radiation, decay, etc.) certain initial particles p_1, p_2,--- disappear and new ones p'_1,p'_2 -- appear and that this occurs through the mediation of a field F. The field itself is quantized and expressed in terms of units or particles of definite energy (and momentum), such as the photons in the case of the electromagnetic field constituting what is called quantum electro-dynamics (Q.E.D.) The probability of occurrence of the event $p_1,p_2,\text{---} \longrightarrow p'_1,p'_2$ ---through the intervention of the quantized field F is expressed by means of a probability amplitude A_{if} whose basic form is $A_{if} = \langle \psi_i(p_1,p_2,\text{--}) \mid F\ (q) \mid \psi_f\ (p'_1, p'_2, \text{---}\rangle$, , where F(q) is the field with quanta q, and ψ_i and ψ_f describe the initial and final states. All these are not ordinary functions, but rather contain operators that create the final and annihilate the initial particles involved in the process.

Without entering into the mathematical details, which are rather complex, there are two aspects that we should consider for our purpose:

1. The probability amplitude for any process is zero unless the total energy (and momentum) is conserved. It is possible that at some intermediate steps energy (and momentum) is not conserved, but these are very short lived situations that are quickly corrected and energy conservation is restored in the end. Thus energy is conserved at the very foundation of physical processes.

2. Interactions of particles through a field are considered as taking place through the exchange of particles associated with the interaction field that act as carriers of energy (and momentum). In the case of Q.E.D. the carriers are the photons. Other interactions need other carriers (as we shall see later on). This way of thinking can be represented in a simple form by the Feynman diagrams, some of which are shown in Fig. 1 for electrons and positrons (Note 8). Each one is associated with a particular probability amplitude that can be calculated according to well prescribed rules.

Q.E.D. is a most successful theory which gives results with extreme accuracy over a wide range of processes due to the electromagnetic interaction. It seems reasonable to believe that the same formalism can be applied to describe the processes due to the other known interactions: weak (responsible for β-decay), strong (responsible for the nuclear forces), and presumably gravitation (responsible for the large [illegible] structure in the universe). This is the area in which research is currently concentrated. But we emphasize that energy plays the key role in this formalism.

It appears that all particles in the universe fall into two groups: <u>fermions</u>, with half-integerspin and obeying Pauli exclusion principle and Fermi-Dirac statistics, and <u>bosons</u>, with integral spin and obeying Bose-Einstein statistics (but not Pauli exclusion principle). A system of identical fermions must be described by an antisymmetric state function, while for a system of identical bosons the state function is symmetric. The particles or quanta associated with the interactions are all bosons since they do not obey the exclusion principle because many quanta can exist in the same state, depending on the strength of the field. But the particles involved in a process can be either fermions (leptons, nucleons, etc) or bosons (mesons, etc.) Thus we refine the vision of the universe as a soup of fermions and bosons in constant mutual interaction and transforming among themselves through the action of field-bosons that jump from one particle to another carrying energy and momentum according to certain rules (conservation laws and symmetry restrictions). This we may call the "quantum field-theoretic vision" of the universe, in which energy is the leading unifying concept, and matter corresponds to highly concentrated energy of quantized fields.

3. Energy and the Standard Model

In the last decades considerable progress has been made toward a unified approach to the four fundamental interactions (Table 1) First at energies higher than 100 GeV the EM and weak interactions merge into one, the electro-weak, (as the work of A. Salam, S. Weinberg, and others has shown) resulting in the introduction of three new field-bosons: W^+, W^- and Z^0. Next the strong interaction is now relatively well understood thanks to the quark theory first advanced independently by M. Gell-Mann and G. Zweig in 1964. The new theory, patterned after the Q.E.D. is called quantum chromodynamics (Q.C.D.) and has required the introduction of eight field-bosons called "gluons." The merging at energies of the order of 10^{15} GeV of the electro -weak and QCD theories into one, the grand unified theory (G.U.T.) is still in the making. (The quantization of the gravitational field, i.e. quantum gravity, with a field-boson called "graviton" is in its early stages and will not be considered here). This is not the place to elaborate on these new theories and we will limit ourselves to illustrate how energy exchanges through the intervention of field-bosons provide a satisfactory and unified framework for the understanding of the universe.

For the sake of completeness we shall briefly review first the current status of particle physics from the point of view of the interactions to which they are coupled. Leaving aside the gravitational force, that affects all known particles, it is possible to classify the particles in two major groups. The leptons (Table 2) are fermions coupled to the EM and weak interactions, but not to the strong interaction, all have spin 1/2 and either they have charge or are neutral. As far as it is known today they seem to be truly "elementary," that is they can be considered as point sources. The hadrons are subject to all three forces. They are more massive than leptons and can be grouped into baryons (Table 3) and mesons (Table 4), Baryons are fermions with spin 1/2, 3/2. The two lighter baryons are the proton and the neutron, which for many years were the only ones known. Mesons are bosons with integer spin (0,1,2). The first meson to be discovered was the pion. But in the decade of the 60's, as more powerful accelerating machines were put into operation, a large number of baryons and mesons were discovered, most of them short lived, which were called "resonances."

In order to make some sense of this proliferation of particles, M. Gell-Mann and G. Zweig independently proposed in 1964 the quark model of hadrons, which now is accepted as the correct one. This model assumes that the hadrons are not "elementary" particles, but composites of quarks. The notion that protons and neutrons have an internal structure was confirmed in 1968 by analyzing the scattering of high energy electrons by protons or neutrons, which indicated that small electric charges existed within the protons and neutrons. Current theories assume that there are six types or "flavors" of quarks, with properties shown in Table 5. Quarks are fermions, with spin 1/2 and fractional charge (2/3 e or -1/3 e). They also seem to be structureless or elementary like the leptons. It is customary to group the quarks and leptons in three families or "generations,"

$$\begin{pmatrix} u & \nu_e \\ d & e \end{pmatrix}, \quad \begin{pmatrix} c & \nu_\mu \\ s & \mu \end{pmatrix}, \quad \begin{pmatrix} t & \nu_\tau \\ b & \tau \end{pmatrix},$$

each representing a different level of elementarity. The existence of the t quark is still hypothetical.

Baryons are supposed to be composed of three quarks according to the schemes shown in Figs. 2 and 3 while mesons are composed of a quark and an antiquark, as shown in Fig. 4. Quark masses are not well known since no free quarks have been observed and the effective mass of a bound quark might be quite different. Evidence points out that the wave functions of baryons are symmetric in the space, spin, and flavor of the three quarks; this is clear, for example, from $\Delta^{++} = (uuu)(\uparrow\uparrow\uparrow)$, which also has L=0 in the ground state . Since the wave function of a system of quarks must be antisymmetric (they are fermions) the natural conclusion is that quarks must have another poperty or attribute with three possible values. This new property has been designated "color" (no relation with sensorial colors) with its values called r (red), g (green) and b (blue). Accordingly we should group the fundamental fermions as follows:

$$\begin{pmatrix} u_r & u_g & u_b & \nu_e \\ d_r & d_g & d_b & e \end{pmatrix}, \begin{pmatrix} c_r & c_g & c_b & \nu_\mu \\ s_r & s_g & s_b & \mu \end{pmatrix}, \begin{pmatrix} t_r & t_g & t_b & \nu_\tau \\ b_r & b_g & b_b & \tau \end{pmatrix},$$

The idea of color was proposed in 1964 by O. Greenberg in connection to the structure of the Ω^- particle which has the same configuration as the Δ^{++} and Δ^-. The state function of a system of quarks is then symmetric in space, spin and flavor, and antisymmetric in color. For three quarks q_1, q_2, q_3, the singlet color state function is

$$\frac{1}{\sqrt{6}}(r_1g_2b_3 + g_1b_2r_3 + b_1r_2g_3 - g_1r_2b_3 - r_1b_2g_3 - b_1g_2r_3)$$

The color antisymmetry indicates that the total color of a baryon is zero: baryons are colorless. This problem does not arise with mesons, composed of quarks and antiquarks, for which the Pauli principle does not impose that restriction. Even so mesons are also colorless, and the color state function of the system $q\bar{q}$ is:

$$\frac{1}{\sqrt{3}}(r_qr_{\bar{q}} + g_qg_{\bar{q}} + b_qb_{\bar{q}})$$

The field bosons mediating the strong interaction between hadrons are called "gluons", which are supposed to be massless and have spin 0, besides possessing color. It appears to be very difficult (requir~~es~~ing a very large energy) to excite a qqq-system above the color singlet state and therefore the strong interaction must produce a very strong bond in color singlets. This points toward a "color invariance" of the strong interaction which in turn implies that the field-bosons must carry color. Thus gluons must exist in the color combinations $r\bar{r}$, $r\bar{g}$, $r\bar{b}$, $g\bar{r}$,--. Only eight different gluons exist because of the invariance of the combination $r\bar{r}+g\bar{g}\ b\bar{b}$.

The theory dealing with color-carrying particles is called Quantum Chromodynamics (Q.C.D.). It is a non-linear theory because the gluons are also endowed ~~of~~ with color. Therefore gluons can interact with gluons through the exchange of gluons. (In contrast photons do not interact with each other since they are chargeless, i.e. EM interaction is charge preserving.) One consequence is that neither quarks nor gluons can exist in isolation, a property called "confinement", because the strong interaction must grow dramatically with distance, becoming almost infinite at about 10^{-12}cm.

In processes involving gluons, the quarks can change color but cannot change flavor. According to Q.C.D. processes due to the strong interaction can be calculated in a fashion similar to Q.E.D. and represented by Feynman diagrams, with gluons carrying energy, momentum and color (Figs. 5 and 6). Obviously since quarks are electrically charged there are processes involving hadrons that are described by Q.E.D., (recall Note 8), such as the electron-positron annihilation into mesons, or pion decay (which amounts to quark-antiquark annililation) into two photons (Fig. 7).

It might be recalled that although the nuclear force , i.e. the nucleon-nucleon force (pn, pp, nn) had been well known experimentally for long it had defied consistently a theoretical approach like the electromagnetic forces. A first attempt was made in 1935 by H. Yukawa who proposed the meson as the carrier of the nuclear force. In fact according to the quark model the nuclear force is a sort of residual strong interaction between two quark systems (nucleons), each colorless, in the same way than the

Van der Waals intermolecular forces are residual electric interactions between molecules, each dynamically electrically neutral. The quark model nicely explains the nuclear force between two nucleons (Fig. 8), and, alas, it appears as if a meson has been exchanged in the interaction. This is another example of how the insight of scientists may produce the right answer in the wrong way.

Next let us consider briefly the weak interaction that involves both quarks and leptons, limiting ourselves to examine how the associated processes can be explained in terms of energy (and momentum) carried by a new type of (massive) field-bosons. As it is well known the weak interaction was first introduced by Fermi in 1932 in connection with his theory of β-decay in nuclei of which the two processes known at his time were $n \rightarrow pe\bar{\nu}_e$ and $p \rightarrow n\bar{e}\nu_e$. (Only the first one occurs with free nucleons because energy consideration but both can occur with bound nucleons depending on the energies of the nuclei involved). According to the quark model the β-decay of a neutron (udd) can be attributed to the process $d \rightarrow ue\bar{\nu}_e$, and the β^+-decay of a proton (uud) to the process $u \rightarrow d\bar{e}\nu_e$. Many more processes have been observed in the last two decades that can be ascribed to the weak interaction, and that can be interpreted as involving quarks and leptons. Examples of such processes are $\Sigma^0 \rightarrow \Lambda^0 e \bar{\nu}_e$, $\pi^- \rightarrow \pi^0 e \bar{\nu}_e$, $K^- \rightarrow \pi^0 \mu^- \bar{\nu}_\mu$.

A careful analysis of the weak processes in which electric charge is exchanged prompted O. Klein in 1938, long before the quark theory, to introduce two weak bosons, W^+ and W^-, to carry the weak field, in the same way that the photon carries the EM field (with no change in charge) (Fig. 9). The $W^\pm$, like the photon, have spin 1. From the value of the transition amplitudes for weak processes it has been estimated that the mass of the W^+ is of the order of 83 GeV, or about 90 times the mass of a proton. This is the energy that is required to create a free W^+. However, when they serve as intermediaries (as in Fig. 9) they can exist for a certain time Δt with violation of energy conservation as long as energy is conserved in the overall process. Using the uncertainty relation $\Delta E \, \Delta t \sim \hbar$, with $\Delta E \sim m_w c^2 \sim 80\,GeV$, one gets $\Delta t \sim 10^{-26}\,s$. During this time the W^+ can travel the distance $\Delta x \sim c\Delta t \sim 10^{-16}\,cm \sim 10^{-3}\,fm$, or a small fraction of the hadron sizes. Thus the weak interaction is of extremely short range, almost impossible to detect.

The analysis of several other processes such as $K^+ \to \pi^+\pi^-$ and $\Lambda^0 \to n\pi^0$, has pointed out the existence of charge-preserving weak processes involving a neutral weak boson (or neutral current) also with spin 1, and now designated Z^0 (Fig. 10). The mass of the Z^0 is estimated to be about 94 GeV. The experimental verification in 1983 of the existence of the $W^\pm$ and Z^0 bosons has not only been a further proof of the model of energy exchanges through field bosons to explain fundamental processes, but a monument to the ingenuity of the human mind.

According to the electro-weak (E-W) theory developed by A. Salam and S. Weinberg in 1967, at particle energies above 100 GeV the EM and weak interactions merge into one E-W interaction, with the four bosons $W^\pm, Z^0$ and γ as the field energy carriers. However, at particle energies below 100 GeV the weak bosons $W^\pm$, Z^0

cannot be created as free particles and the two interactions separate (i.e. a symmetry breaking takes place) and become different, which is the way we now observe them. Only by using accelerators of sufficient energy can the EW processes be produced in the laboratory (Note 9).

Since our purpose is not to review the current status of particle physics, but only to explore how energy plays a unifying role in the analysis of fundamental processes, we will not pursue further with the current research in particle physics. Summarizing what is designated as the "standard model" of particle physics, it is based on the assumption that there are three families or generations of fermions, each with two quarks and two leptons, but each quark can appear in one of three colors. That gives a total of 24 fundamental fermions. To this we must add 12 field bosons associated with the interactions: eight gluons, carriers of the strong interaction, and four bosons ($W^{\pm}$, Z^0, γ), carriers of the electro-weak interaction. To these 36 "particles" it has been proposed to add another one, the Higgs boson, with a mass somewhere between the $W^{\pm}$ and Z^0 and the photon, . This large number of fundamental particles may not be aesthetically satisying, but the unifying methodology for describing their interactions is of extraordinary simplicity.

One sore point still exists. Gravitation has not yet been successfully expressed in the formalism of quantum field theory, i.e. quantum gravity, although several theories have been proposed. If success is achieved a completely unified picture of all interactions through energy exchanges by field-bosons will have been reached. However, it may occur that gravitation is an entirely different kind of interaction directly related to the structure of space-time determined by the mass (energy) density and thus not amenable to this kind of field theoretic treatment. (For a critique see R.M. Wald, General Relativity, Oxford Univ. Press, 1984, Ch. 14).

8. Energy and Cosmology

We shall now consider briefly the role that energy (and particle physics) play in current cosmological theories. By necessity our review will be very restricted in scope and we will not even touch upon many important cosmological considerations. According to current thinking based on an idea first proposed in 1948 by Alpher, Gamow and Herman, the universe begain in space and time about 15 x 10^9 years ago (15 Gyr.) in what is loosely designated as the Big Bang (B.B.) This term was coined by F. Hoyle to describe graphically the magnitude and speed of the early events. The B.B. is supposed to have been a state of extremely large energy density, with all the energy concentrated in a very small region. Right after the initial state the universe began an expansion process, going first through a rapid inflationary process and afterwards expanding more or less at a steady rate, currently estimated to be 22 km/s per million light years of separation (Hubble constant). The expansion was accompanied by a gradual decrease in the average energy per particle (Doppler effect) and a corresponding decrease in the "temperature" of the Universe. As the average energy decreased several phenomena occurred, which can be called phase transitions or symmetry breakings, which resulted in important changes in the composition and structure of the universe until about 10^6 years after the B.B., when it finally reached a structure not very different from its present form.

Before proceeding to review the successive phases in the evolution of the universe some words of caution are necessary. Any theory about the very early stages of the universe ($< 10^{-2}$s) is not subject to direct experimental verification because of the high energies involved, except that some assumptions can be verified in a much smaller scale in the laboratory by using high energy accelerators. Second the concepts of time and energy are extrapolated back to extremely small and extremely large values respectively; whether that extrapolation is completely valid or not is not very relevant as long as it provides an appropriate frame of reference. And third the conditions of the universe before the B.B. are impossible to ascertain and they probably will remain unknown to us because it is assumed that the inflationary process erased all vestiges of the initial conditions.

In dealing with the evolution of the universe there are three quantities that are useful. They are Planck's distance, time and mass:

$$d_p = \left(\frac{\hbar G}{c^3}\right)^{1/2} = 2\times 10^{-33}\,\mathrm{cm},\quad t_p = \left(\frac{\hbar G}{c^5}\right)^{1/2} = 9\times 10^{-42}\,\mathrm{s},\quad m_p = \left(\frac{\hbar c}{G}\right)^{1/2} = 10^{19}\,\mathrm{GeV},$$

Also time (measured in s), average energy (measured in eV), and temperature (measured in K) are related by

$$tE^2 \sim 2.5\times 10^{11},\quad tT^2 \sim 10^{20},\quad T \sim 10^4 E$$

The evolution of the universe from the point of view of the energy can then be summarized as follows (Table 8 and Fig. 11).

a. Before Planck's time, 10^{-42}s, we cannot guess how the universe looked like except that the temperature was of the order of 10^{19} GeV or higher. Under those conditions gravity was very strong and probably the dominant interaction, but a quantum theory of gravitation is still lacking (and perhaps it will never exist). It is assumed that, shortly after, the universe went through a rapid inflationary process by which its size probably increased by a factor as large as 10^{20} and conditions were established for the further"normal" expansion which allowed it to reach its present state. Gravitation became completely separated from the other interactions.

b. Up to about 10^{-33}s, or for temperatures above 10^{15} GeV the particles' energy was so high that all particles appeared as masslesss and there was no difference between quarks and leptons as well as among the strong and electroweak interactions. This is the period of the Grand Unification Theory (GUT). But the GUT requires the intervention of 12 supermassive bosons designated X (three colors r,g,b, and four charges ± 4/3 and ± 1/3) with rest energy of about 10^{15} GeV. These bosons are the carriers of the interaction (energy) responsible for transitions between quarks and leptons. One interesting feature is the possibility of proton decay via X-bosons: $p \rightarrow \pi^0 e^+$, or $p \rightarrow \pi^+ \bar{\nu}$, $T_{1/2} \sim 10^{30}$ yr (Fig. 12). During the GUT era we may visualize the universe as a mixture of fermions and bosons, without differences among each group, and subject to two fundamental interactions.

c. At the temperature of about 10^{15} GeV, a phase transition or symmetry breaking occurs: X-bosons can no longer be created in free states and therefore the strong (color sensitive) force separates from the electro-weak (color insensitive) force. Quarks and leptons become then different fermions.

d. Up to the time 10^{-10}s, when the temperature dropped down to 10^2 GeV, the universe was a mixture of quarks and leptons in interaction through the exchange of gluons and electroweak bosons ($W^{\pm}$, Z^0, γ) which at those energies appeared as massless. That means that the only forces in operation a gravitation, strong (or color) and electroweak. Early during this era the predominance of matter over antimatter was established. (Note 10).

e. At a temperature of about 10^2 GeV a new phase transition or symmetry breaking occurs. Below that temperature the more massive electroweak bosons ($W^{\pm}$, Z^0) cannot be created in free states in electroweak processes and begin to disappear from the universe. The result is a separation of the electric and weak interactions. The universe then reduces to a mixture of quarks, leptons, gluons and photons.

f. Between 10^{-8}s and 10^{-2}s, or a temperature range from 10 GeV down to 1 GeV, the strong (color) forces cluster quarks and gluons into colorless nucleons (protons and neutrons). Due to the nature of the strong interaction all quarks and gluons disappear because they are confined to nucleons (protons and neutrons). Actually they are initially confined to hadrons, but since most hadrons have a very short life they quickly decay and only nucleons are left. In the subsequent period up to 10^2s (or temperatures down to about 0.1 MeV) most heavy leptons decay and the universe becomes essentially a mixture (plasma) of nucleons, electrons, neutrinos and photons. all interacting among themselves.

g. As it is well known neutrons are unstable and decay with a half life of about 900s. Thus the number of neutrons decreases rapidly in comparison to that of protons. However, at about 10^2s or temperatures of 0.1 MeV a new process is possible: nucleosysthesis. At that energy the residual strong interaction is sufficient to bind nucleons into stable structures, (the binding energy of the deuteron is 2.2 MeV)and the first light nuclei began to form (${}^2_1H$, ${}^3_1H$, ${}^3_2He$, ${}^4_2He$).Nucleosynthesis froze the number of neutrons in the universe to about 15% of that of protons. (Eventually all other nuclei were formed in processes that still occur in the stars including our Sun.)

h. Between 10^4s and 10^6yr when the temperature dropped from 0.1 MeV down to about 10eV, it was possible for the electric force exerted by nuclei to bind the electrons into stable structures called atoms, mostly hydrogen. At that stage most of the charged particles disappeared as free particles. The universe became a mixture of atoms (mostly hydrogen), neutrinos and photons. The interaction of photons with matter was then greatly reduced. It is said that the photons decoupled from matter. This might have been the origin of the background EM radiation, which currently correspond to a temperature of 2.7 K (or 10^{-3}eV).

i. From 10^6 yr up to the present (about 1.5×10^{10} yr) the large structures (galaxies, stars, etc.) appear under the action of gravitation, which became by default, the dominant long range interaction involving all matter, in spite of being the weakest of all forces. Nuclear processes continue to occur in stars.

A relatively recent development in the evolution of the universe is the emergence of life, that is self-replicating system whose functioning depends critically on energy exchanges, of the order of 1eV, between rather complex molecules. (this process began on Earth about 3.5×10^9 years ago).

We shall not discuss how energy is processed in living systems but shall only point out how important is energy for life. The sun, whose mass is 2×10^{30} kg, emits energy at the rate of 3.8×10^{26} J/s or 16 J/kg/day. By contrast a human turns over about 7×10^4 J/kg/day or 4000 times more per unit mass than the sun. The explanation is very simple: most of the mass in the sun is energetically inert, while our whole bodies participate actively in the energy transfers. Living beings are energy processing systems. An even more recent development has been the appearance of intelligent systems, capable of manipulating information and therefore of affecting natural energy process, at least on a local scale (on Earth they appeared about 10^9 yr. ago).

9. Energy and The Cosmological Fate

In the previous section we have examined how, based on energy considerations, we can arrive at a reasonable answer to the problem of the origin and evolution of the universe. Can also the physical laws and our understanding of energy exchanges provide a clue about the future? For those who believe that we have been able to understand the rules under which the universe operates and that these rules do not change in time the answer is a cautious "yes". The answer has to be cautious because we will never be able to verify experimentally the validity of our conclusions due to the extremely long periods of time involved.

The whole issue boils down to three questions:

1. Is the universe closed, flat or open?
2. If the universe is not closed, how will it evolve?
3. Can intelligent life affect the course of cosmological evolution?

The answer to the first question depends critically on the mass-energy density throughout the universe since the bulk of energy is presently in the form of mass and the force dominating the dynamics of the universe is gravitation. It has been estimated that if mass is distributed in the universe with a density larger than 2×10^{-26} kg/m^3 (critical density), or about 12 nucleons per m^3, the universe is closed (Note 11). That means that the kinetic energy of expansion will eventually be transformed into gravitational potential energy. After that stage the universe will begin to contract with a reversal of the events that occurred during the expansion. First the potential gravitational energy will go back into kinetic energy; as the matter-energy density increases all other forces begin to enter into play. Even so two alternatives are possible. One is that after some time, the universe ends in a Big Crunch, which most probably will be followed by a new Big Bang. We have then an oscillating universe (fig. 13) Chances are however that the contraction might be stopped at a certain intermediate stage and an expansion starts over again. Then we have a fluctuating but ever expanding universe. This might be a more interesting universe since every renewed expansion begins under new conditions.

However, if the mass-energy density in the universe is equal to or less than the critical density the universe is either flat or open and it will continue expanding forever with new events occurying as conditions change. Current evidence, based on estimates of luminous matter in galaxies and on the process of nucleosynthesis, indicates that the present average mass-energy density in the universe is of the order of 10^{-27} kg/m^3, supporting the idea that the universe is open. However, there is still great uncertainty about how much mass-energy exists in the universe and several considerations, which we cannot elaborate here, suggest the existence of considerable amount of "dark" matter, i.e. of matter not coupled to the EM field, that can make the universe flat.[*] The questions are how much dark matter exists, how it is distributed and what it is made of. None of these questions have received yet a definitive answer. Concerning the last one, a strong candidate are the neutrinos. However, for neutrinos to be able to

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[*] B. Schwarzschild, Physics Today, May 1987, p. 17

aggregate in lumps to exert a gravitational action they can not be relativistic. And in order for the neutrinos to slow down well below the relativistic energies they must have mass. From the analysis of β-decay and other neutrino processes, and more recently those received from Super Nova 1987 A, the mass of the ν_e should not exceed 30eV. (L.N. Bahcall & S.I. Glashow, Nature, 326, 476 (1987)).This mass, though small, might be large enough in a neutrino-dominated universe to contribute in an appreciable amount to the gravitational energy and even result in a flat universe. Other candidates are more esoteric and hypothetical (axions, photinos, strings, etc.).(L.M. Kraus, Sci. Am., December 1986, p. 58) For our purpose it is enough to conclude that depending on the amount of dark matter, The estimated average mattter-energy density points to an open or at most flat universe.

The answer to the second question posed at the beginning of this section has been explored in detail by F. J. Dyson (Fig. 14). (Rev. Mod. Phys. 51, 447 (1979)).The future of an open universe is basically dominated by the gravitational energy with an appreciable contribution from nuclear energy. According to Dyson after 10^{14} yr. most of the stars will have exhausted the hydrogen fusion process and depending on their size and other factors will have become white dwarfs, neutron stars, or black holes. By that time all life will have disappeared from the universe because lack of photons of adequate energy to sustain life. This means that life can be possible in the universe during the span of 10^{10} yr - 10^{14} yr.

A process that might occur shortly after at about 10^{15} years is the disturbances of planetary systems as they move through their respective galaxies. (Note 12) The next process in time should be the loss of stars by galaxies or intergalactic encounters with times of the order of 10^{19} yr. Gravitational radiation resulting in a collapse of planetary orbits into their suns or of stars toward the center of their galaxies is a much slower process with a time scale of 10^{20} yr. to 10^{24} yr. After 10^{30} yr. proton decay will have contributed appreciably to the disappearance of nucleons. During all this time a substantial amount of matter will have concentrated in black holes releasing considerable amounts of gravitational radiation. But at about 10^{64} yr. to 10^{100} yr., depending on their size, black holes will collapse and decay into EM radiation emitting at the end a big burst of radiation with a power which might reach 10^{24}W. Other processes may occur at still later times but it might seem a bit futile for our purpose to look that far into the future.

Will there be an end for things to happen? According to Dyson the answer should be in the negative. But one thing seems to be certain. As the universe expands the mass-energy density continues decreasing and the cooling of the universe proceeds steadily. The universe is gradually reduced to a cold mix of electrons, positrons, neutrinos and photons, and perhaps will eventually reach a stable cold configuration.

And this brings us to the third question: can intelligent structures, capable of handling information, i.e. codified energy, alter the course of the universe? In the first place intelligent systems are a relatively recent event in the universe as indicated at the end of the previous section, but in addition these systems require special environmental conditions that probably are found only in a relatively small number of places in the universe. On the other hand intelligence has evolved on Earth in a dramatic way. Only about 10^6 years ago the highest level of intelligence known to us, the humanoids (Genus Homo) emerged, and Homo Sapiens has existed only for about 10^5 years. But even the intelligence of Homo Sapiens has evolved dramatically in the last 10^4 years. Is there a limit to the development of intelligence on Earth? It seems reasonable to assume that intelligence will continue to grow beyond whatever we can imagine today; the major limiting factor will probably be how future intelligent societies can use energy under the conditions available to them.

It is conceivable that in other parts of the universe intelligence has already developed way beyond the levels found on Earth. Can we find about those super intelligent systems and communicate with them? Unfortunately we only know how to transmit information by using EM energy, and this energy is transmitted with a finite velocity, that of light ($c = 3 \times 10^8$ m/s). Given the interstellar distances, it appears very difficult to establish useful communication with other intelligent societies. Intelligence on Earth will remain isolated, and the same may apply to intelligence in other parts of the universe, because the inherent limitation of the propagation of EM energy. The conclusion then might be that intelligence, being a sparsely localized phenomenon in the universe will not be able to alter the course of evolution of the universe. But intelligence can change the local conditions where it exists as humans are doing with the planet Earth, and not necessarily for the better, especially because ~~a~~ of misuse of the energy resources.

9. Conclusion

This brief overview of the role of energy in the universe has left out many important considerations such as: what is the origin of energy (and mass)? What is the origin of the fields? Was energy (and mass) created out of nothing? Why do only particles with certain masses (rest energy) exist? How much energy (or matter) exist in the universe (the problem of dark matter)? What will be the fate of the energy (and mass) of the universe? (Depends on whether the universe is closed or open) Is energy conserved in the universe as a whole? (Apparently not) And above all, what is energy? Nobody knows but energy is everywhere in the universe and the universe changes because energy is exchanged among its components. We might say that energy is the essence of the universe.

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APPENDIX WITH MATHEMATICAL CALCULATIONS IS AVAILABLE UPON REQUEST.