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I. ATOMIC POLARIZATIONS

A+B. ORIGINS: FROM SYMMETRY TO SYMMETRY-BREAKING (ASYMMETRY)

Even though the ultimate goal of physics is a "theory of everything" that could explain all the forces of Nature, two basic partial theories have as yet attempted to describe the Universe: the Einstein's general theory of relativity explaining gravity as a function of curves in space and time, and quantum mechanics developed from Planck's quantum principle and Heisenberg's uncertainty principle. The grand unified theory (GUT) is a not too satisfactory attempt to incorporate the uncertainty principle into general relativity of quantum mechanics which implies that all particles don't have well-defined position and velocities but are represented by a wave. This wave/particle duality implies that particles have a property called spin and that there are two groups of particles, the matter particles with 1/2 spin such as the electron, and the force particles with integer spin 0, 1 and 2 such as the photon. Contrarily to the matter particles which have a different antiparticle, in the case of the force-carrying ones, the antiparticles are the same as the particles themselves (see Hawking, 1990).

In the speculative search of unification schemes involving higher dimensions, the key is now recognized as being the concept of *symmetry* (see also **III**, p. 400). There are various types of symmetry, from the simple rotational symmetry, through two-dimensional translational symmetry to the three separate symmetries known up to 1956 called C which means that the laws are the same for particles and antiparticles, the symmetry P which means that the laws are the same for any situation and its mirror image and the symmetry T which means the reversion of the direction of motion of all particles and antiparticles in time (see Hawking, 1990). It is classically known since A.E. Noether's work in 1918 that every symmetry of physical interactions implies a conservation law to which it corresponds. Among such conserved quantities in Nature, there is the electric charge to which and others can be attributed a symmetry (see Nambu, 1992 and chapter I.C.1).

As mentioned in Addenda **III**, according to Hunter (1991), "the final crack in the edifice of perfect symmetry was Lee and Yang suggestion (1956) that the charge-parity (CP) symmetry might be violated in the weak interactions". This mechanism has further been extended in 1967 by Sakharov to explain skewing the universe toward matter (**III**, p. 400 and **IV**.I.C.1). Recent scenarios for the origin of this matter asymmetry have been proposed by M. Dine and L. MacLerran which rely on a version of the inflationary model of cosmology (see Freedman, 1991). Otherwise, parity is known to be involved in two types of vectors: *axial* vectors (surface + sense of rotation) such as spin which are unchanged by reflection and therefore have even parity; *polar* vectors (length + direction) such as momentum which change sign on reflection and therefore have an odd parity. The product of a polar vector and an axial vector is called a pseudoscalar and the processes involving it will not obey the law of parity (Ulbricht, 1959). Since, experimental results have been contradictory (Garay and Ahlgren-Beckendorf, 1990).

In the inflationary expansion of the post Big Bang cooling universe, the symmetry between strong and weak-electromagnetic forces would have be broken, quickly in the "old" (Guth), slowly in the "new" (Linde and others) chaotic inflationary models (see Hawking, 1990). *Symmetry-breaking* phase transitions early after the Big Bang could have led the Higgs field (see below) to multidirectionality in the universe.

When a quantum version of gravity will finally arise from the merger of Einstein's theory of relativity and quantum theory, it will prove to be asymmetrical (Penrose, 1989). If the Big Bang was itself a time asymmetric phenomenon, then we have further reason to consider polarity as the time-space evolutionary arrow (arrows of time see Hawking p. 152). Furthermore it has been proposed by Coweney and Highfield (1990 see **III**) that the theory of chaotic evolution (chaos, see chapter II) blows apart time-symmetric determinism.

Within the limits set by the incertainty principle, minimal nonuniformities would have then been amplified to progressively originate the ordered - and polarized - structures. Liquid crystals have recently been proposed by Yurke and Turok (see Flam, 1991) as providing such a real cosmic model of symmetry-breaking. The defects produced in liquid crystals are found to be closely analogous to those that may have arisen in the early universe and they appear where regions of differing molecular orientation meet (Spergel and Turok, 1992). The Higgs field is one of the possible processes that could break the symmetry between forces and particles. It indicates a direction in a comparable but more abstract sense than a magnetic field breaking the symmetry of space (see Spergel and Turok, 1992).

Supersymmetry posits an underlying symmetry - and thus interchangeability between particles that constitute matter and those that transmit force. A predicted consequence of supersymmetry is that all known elementary particles have unseen supersymmetric twins, sometimes called sparticles. This would unify the matter particles (spin 1/2 and 3/2) with the force carrying ones (spin 0, 1 and 2-graviton). Such concepts help to "discern deep communalities underlying nature's forces" (Witten in Horgan, 1991). Supersymmetry has been invoked (see **II**) as one of GUTs attempting to unit the three fundamental forces of nature that govern particle physics (Ross, 1984): quantum chromodynamics (QCD), the theory of the strong force that binds quarks together, and electroweak unification, "partial unification" of electromagnetism and the weak force. Such GUTs are not very satisfactory because they do not include gravity. "The main difficulty in finding a theory that unifies gravity with the other forces is that general relativity does not incorporate the uncertainty principle of quantum mechanics" (Hawking, 1990). A possible solution to this unification problem was the so-called "supergravity" which unifies the matter particles (spin 1/2 and 3/2) with the force-carrying particles (spin 0, 1 and 2 = graviton) into "superparticles" (Hawking, 1990). A set of "superparticles" might make the coupling constants converge at extremely high energies (Amaldi's current researches, see Hamilton, 1991). A window is expected to be opened on the new supersymmetric world with the new accelerators and, indirectly, on the ultimate "theory of everything" to possibly unite the fundamental forces including gravity (Ross, 1991).

Complete unification scheme would thus require a reconciliation of the quantum theories and general relativity, the theory of gravity. However, as supersymmetry did not meet this goal, attempts were made to combine it with the newly developed *string* concept proposed to explain the strong force (see C) rather than by that of quantum chromodynamics (see above). A string is a one-dimensional vibrating loop which might be an electron if it vibrates at one frequency or a quark if it vibrates at another (see C.1). From that combination of concepts, Schwarz and others proposed in the 1970's the more ambitious *superstring* theory according to which just as stringlike particles could give rise to the strong force, so could "the vibrations of superstrings give rise to the mass-carrying particles and to all the forces acting on them - including gravity" (see Horgan, 1991). Thereby, the superstring theory necessarily involves gravity while holding according to one of his brilliant proponents, Edward Witten cited by Horgan (1991), that all physical phenomena - from quarks to quasars - would arise from multidimensionally wriggling strings.

C. Electric bipolarization

1) *Electric charges*

We have seen that a local symmetry is intimately connected with the basic forces of Nature (see A+B) and that electrically charged particles generate around themselves a field of force. In its turn, the electromagnetic field also exerts a force on the original charged particle (Newton's law of action-reaction). Consequently, the electric charge associated with a local symmetry (the electromagnetic force) is "both the source and the receiver of a field of force" (see Nambu, 1992).

The initial plasma of unbound quarks and gluons or "quark soup" (Fukugita and Hogan, 1991) cooling immediately after the Big Bang has preceded the transition to matter resulting from the containment of light quarks (up and down) into protons (+) attracting electrons (-) to build the first atom H and neutrons. Adjustment between both charges must have been extremely precise to meet the evolutionary constraints. Would the charges on the electron and proton have been a factor of three higher, the periodic table would end at the element boron! In other respects, would the charge on the electron have exceeded that on the proton by one part in 10^{18}, the overall electrical repulsion between a human and earth would equal the gravitational attraction and we would float off into space!... according to the dazzling statement of Wilkinson (1991).

The electromagnetic *attraction* between negatively charged electrons and positively charged protons has been pictured as being caused by the exchange of large numbers of virtual massless particles of spin 1, the photons. By contrast, the *repulsion* between two electrons would be due to the exchange of force-carrying photons (see Hawking, 1990).

In its attempts to solve the strong force, the original string theory regarded particles like the protons and the neutrons as waves on a string rather than only particulate quarks and gluons. The recently revised heterotic string theory proposes that the two charges +1 or -1 would result from a string deformation into knots, one (+) being perpendicular (up) to the string axis and the other (-) parallel (down) to it. It is the primordial positively charged knot which was baptised quark by Murray Gell-Mann in 1963 (see Hawking, 1990). As suggested by Bounias (1990), interactions between two differently or similarly oriented and electrically charged knots would thus prefigure respectively the *attractive* and *repulsive* phenomena described above.

2) *Electric dipoles*

Under the influence of an electric field, positive and negative charges will move in opposite directions. This asymmetric distribution of charges is said to have a dipole moment. Such electric dipole moment is the product of the charge and the resulting separation. It can also be induced by an alternating electric field with a local maximum produced by a focused laser beam (Chu, 1992). This dipole-force optical trapping of atoms complements those exerted by magnetic and electric fields.

Polarizability is then the constant of proportionality between this induced moment and the applied electric field. According to the simple, symmetric quark model, the neutron and proton electric polarizabilities would be equal. However, such a prediction could be contradicted by recent measurements revealing that the electric polarizability of the neutron to be larger than that of the proton (Holstein, 1991).

Charge density describes the distribution of electrons in a molecule. When partitioned among atoms and by numerical integration it permits to obtain atomic charges, dipoles, etc. (Wiberg *et al.*, 1991).

3) *Polarized conductivity*

Superconductivity is a striking macroscopic property that arises from the quantum nature of electrons (see **I-III**). A number of properties of the supraconductors cuprates and bismuthates have been precisely predicted from the local-density band theory. Thus, the so-called Fermi surfaces crossed by four low energy excitations or "quasiparticle" bands have been pictured with electron-like (-) and hole-like (+) charge carriers (Pickett *et al.*, 1992). Superconductivity has also been found in calcium-doped, symmetrical, so-called buckyballs of the C_{60} fullerene family (at 18 K in K_xC_{60}, Hebard *et al.*, 1991). This family has recently been expanded to include asymmetrical forms (see Koshland Jr., 1991).

Semiconductors are of direct concern for problems of bipolarity and modern computers with their electronic memories built from semiconductors such as silicon or germanium directly draw on that principle. The silicon is a *p*-type semiconductor which ordinarily does not harbor free electrons; the bit line is *n*-type silicon, a semiconductor that does harbor free electrons. In the alternative of a bit ("binary digit") or information unit, the 0 corresponds to a charge by the electrons while the 1 is represented by the absence of electrons and therefore stored as the absence of charge. The 0's and 1's stored in a memory chip are therefore represented by the presence or absence of negative electric charge at sites in the silicon crystal.

In the crystalline lattice of the semiconductor, atoms are held together by electrons called valence electrons. These electrical properties of the 4-valence electrons silicon atom can be controlled by dopants such as the 5-valence electrons arsenic and phosphorus atoms providing an extra electron and therefore giving an *n*-type semiconductor. The 3-valence boron as impurity increases the conductivity by the introduction of "holes" - vacant sites into which electrons can move - thereby providing a *p*-type semiconductor by negative charge deficit. The electric charge in the chip can thus be conveyed by carriers of negative (electrons) or positive ("holes") charges (Meindl, 1987).

In *bipolar* transistors, contrarily to unipolar devices, both electrons and holes play an essential part. As part of modern electronic circuits, rectifiers are *p*- and *n*-types semiconductors in contact with one another and two such junctions placed back to back produce a bipolar transistor. First known to possess a rectifying action were copper in contact with cuprous oxide and selenium in contact with aluminium. When the transistor was invented in 1948 by Shockley, Bardeen and Brattain (see in **I**, I.C.3 and in Sze, 1991), the semiconductor insulating layer became known as the metal-oxide-silicon field-effect transistor, or MOSFET for short.

By contrast with the above electronic devices, the magnetic storage of binary data such as in floppy disks relies on a pattern of current reversals, reversing themselves the pattern of magnetization corresponding to a succession of 0's and 1's that constitute the individual bits of data (see Kryder, 1987 in **I** D.2).

D. Magnetic polarization

1) *Cosmological level*

The earth's magnetic field is reenforced by a self-perpetuating geodynamo process produced by a magnetic field itself induced by the electric current generated by the interaction of the earth's magnetic field with the conducting molten iron propelled through the earth's outer core. Every million years or so, the magnetic field reverses polarity (see Hoffman, 1988). The magnetic field at the core might be a simple dipole aligned with the earth's rotational axis, as suggested by the mostly blue color in the Northern and red in the Southern hemisphere of the earth's core-surface map (see Bloxham and Gubbins, 1989).

Among the alternative explanations proposed about the geomagnetic reversals of the poles there is the suggestion that the geodynamo generates less secular variations and nondipole field (Runcorn, 1992). An axial multipolar field could predominate rather than the classical dipolar pattern during the transitional interval (Bogue, 1991).

2) *Magnetic fields*

In the first computer memories, the "information-storage unit" was recorded as patterns of charge ("dots" or "dashes") produced by an electron beam at spots on the screen of the first televisions (Ridenour, 1955).

In the magnetic type of artificial memory system the units are tiny rings of ferrite magnetic materials called "cores". Like such magnetic cores which remember their magnetic history, a ferroelectric material such as barium titanate "remembers" the direction of an electric field applied to it. Ferromagnetic materials thus become polarized near magnetic fields while ferroelectrics become spontaneously polarized when exposed to an external electric field. Ferroelectrics remain polarized even when a field is removed. They can thus provide "the makings of nonvolatile computer memories, chalking up either a "1" or a "0", depending on how electric charges are distributed in the ferroelectric". The contents of such a ferroelectric memory can be switched by exposing the material to another electric field of the opposite polarity (Corcoran, 1991).

3. *Magnetic monopoles*

Following Cabrera's discard of his 1982 results (see **III**), a new monopole detection trap should soon be ready in a renewed attempt to get an unequivocal sighting of a solitary magnetic pole - a "north" without a "south" (Stone, 1991).

E. Light polarization

Sensitivity of vision to the polarization of light is widely spread among invertebrates and vertebrates. The double cone mosaic generates a "polarization contrast" neural image and a model referring to birefringence has been proposed (Cameron and Pugh, 1991 and ref. herein).