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THE ROLE OF CHIRALITY IN THE ORIGIN OF LIFE

Abdus Salam



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International Atomic Energy Agency and United Nations Educational Scientific and Cultural Organization INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

THE ROLE OF CHIRALITY IN THE ORIGIN OF LIFE *)

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ABSTRACT

"Any man who, upon looking down at his bare feet, doesn't laugh, has either no sense of symmetry or no sense of humour" (Descartes) $^{1)}$.

We reemphasize the role of chirality in the theories which determine the origin of life – in particular the fact that almost all amino acids, utilized in living systems, are of L-type. Starting from Z^0 -interactions, we speculate on an explanation of the above fact in terms of quantum mechanical cooperative and condensation phenomena (possibly in terms of an *e-n* condensate where the *e-n* system has the same status as Cooper-pairing) which could give rise to second order phase transitions (including D to L transformations) below a critical temperature T_c . As a general rule, T_c is a low temperature. From this, it is conceivable that the earth provided too small a location for the production of L-amino acids. We suggest *laboratory testing* of these ideas by looking for the appropriate phase transitions.

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1. One may summarize *) the presently accepted view of the origin of life as falling into three stages: the cosmic stage; the prebiotic chemical stage; and the biological stage.

1) The cosmic stage concerns itself with the early history of the universe where the electroweak made a phase transition into two forces, electromagnetic and weak, 10^{-12} secs after the universe was born. The temperature was then 250 GeV and the carriers of the neutral weak force – the Z_0 particle – acquired mass.

2) Chemistry became important after the planets were formed (some 10 billion years later) though it may have played a role in the *presolar epochs* as well, (long after the quarks of the early cosmic era had condensed into protons and neutrons and much after the recombination with electrons which took place some 10^5 years following the Big Bang). Molecules of future life could thus have formed even before the origin of the Earth itself²).

3) The biological era which concerns itself with the replication of nucleic acid polymers and protein synthesis. The biological stage may have started some 3.8 billion years ago.

2. Classically, a chiral molecule and its mirror image (defined by left (L) or right (D) optical/rotatory dispersion)³⁾ have been considered energetically equivalent. However, the parity-violating weak interactions give rise to L and D configurations ³⁾ and ensure that this equivalence is no longer exact – one of the two molecules, L or D, being energetically stabilized, with energy differences of the order of 3×10^{-19} eV.

In living systems, protein molecules are composed of twenty *L*-amino acids (though some amino acids of the opposite *D*-type do occur in cell walls of certain bacteria) $^{**)}$. The polynucleotides contain sugars in *D*-configurations only. Clearly, once living processes had selected handedness, the complex machinery of protein synthesis and stereoselectivity of enzymes could have assured that such handedness is perpetuated.

^{*)} Units $h = c = k_B = 1(1 \text{ °K} = 10^{-4} \text{ eV}).$

^{*)} Of the 74 amino acids, for example, found in samples of the Murchison meteorite, only 8 are present in proteins, 11 have other biological roles, and the remaining 55 have been found only in extraterrestrial samples ^{4),5)}).

3. The most significant of parity violating weak interactions are the weak-neutral, these being mediated by the Z^0 bosons ⁶). These interactions are of exceptionally short range by atomic and strong nuclear physics standards, and to a very good approximation may be taken as contact phenomena. Recent calculations by Mason, Tranter and MacDermott ^{3),7)}, indicate that four of the amino acids in aqueous zweitterionic conformation – (essentially all the ones for which these calculations are available – alanine, valine, serine and aspartic acid) – are *L*-stabilized relative to their 'unnatural' *D*-mirrors for configurations in *aqueous* media. (A minor triumph, for the sugars – particularly for *D*-glyceraldehyde – the calculations show that the right-handed variety is the more stable).

This stability affects 1 out of 10^{17} molecules at room temperatures (since $10^{-17} \approx \frac{3 \times 10^{-19} ev}{300^{\circ} K}$). It is the smallness of this figure which has prompted many chemists to wonder if this mechanism could indeed be responsible for the ultimate optical asymmetry.

The crucial problem is that of amplification of this electroweak advantage over the course of time so that, for example, the 20 amino acids (which make up the proteins) convert almost entirely from D into L types. This problem has been considered by K.D. Kondepudi and C.W. Nelson⁸⁾ following the seminal ideas of F.C. Franck.

Consider, for example, quartz crystals which may be taken as *non-equilibrium* statistical mechanical systems at ambient temperatures of the order of T = 300 °K. Using an autocatalytic mechanism and theory of delayed bifurcations, one can show that a lake 1 km sq. and four metres deep would need 10^4 years to produce the necessary electroweak advantage so far as quartz is concerned. Kondepudi and Nelson give a general theory of spontaneous chiral symmetry-breaking in *nonequilibrium* chemical systems and the possible influence of weak-neutral currents in such a process. They conclude that on a long time scale (10^4 years), for reactions occurring in large volumes, such as the oceans, the effects of parity violations due to weak-neutral currents cannot be considered small.

Objections to this work have been voiced by Goldanski⁹⁾ and following him by Avetisov, Kuz'min and Anikin¹⁰⁾. For one thing, these authors¹⁰⁾ (as well as L. Orgel, private communication) maintain that the electroweak advantage takes place by repetitive steps in these calculations and that there are $N = 10^{17}$ steps involved. The earth must therefore have contained $N^2 \approx (10^{17})^2 \approx 10^{34}$ chiral molecules to take proper account of the resulting fluctuations. This, these authors ⁹⁾ find difficult to credit and conclude that "the role of weak neutral currents in the origination of the biomolecular chirality should not be considered essential". Kondepudi (private communication) agrees with this estimate (10^{34}) but maintains that "this number of molecules need not all be reacting at the same time. This is the total number that is *fluxed* through the nonequilibrium flow system in 1.5×10^4 years".

Without necessarily disagreeing with the work of Kondepudi and Nelson (particularly at high temperatures where the equations they use may be considered part of the renormalization group), we *speculate* on an alternative mechanism. The discussion in this note is mainly physical in character. We discuss the enhancement due to phase transitions in Appendices A, B and C.

We would like to treat this as an equilibrium problem quantum mechanically. The quantum mechanical formalism treats the phenomenon as a cooperative one where condensation aspects are emphasized and the transitions D to L are accomplished below a critical temperature T_c .

In general, when global cooperative and condensation phenomena do take place, low temperatures (or high densities, as for example for neutron stars) are necessary. If T_c for the amino acids turns out to be very small, then it would be plausible that the origin-space in which production of chiral amino acids takes place, was larger than the earth. We discuss this problem in Sec.8.

4. A modern version of the phenomenon of condensation has been described by A. Leggett ¹¹) who gives a uniform treatment of a superfluid (like liquid helium II), where T_0 – the so-called degeneracy temperature – is ≈ 3 °K, as well as of *metallic superconductivity* for Cooper-paired electrons below a transition temperature T_c . The latter is more relevant for our purposes as we shall see.

What is "condensation"?

"Imagine that you are on a mountain-top looking down at a distant city square. The crowd is milling around at random, and each individual is doing something different: Now suppose,

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however, that it is not market day but the day of a military parade, and the crowd is replaced by a battalion of well drilled soldiers. Every soldier is doing the same thing at the same time, and it is very much easier to see (or hear) from a distance what that is. The physics analogy is that a normal system is like the market day crowd – every atom is doing something different – whereas in a Bose condensed system the atoms (or, more accurately, the fraction of them which is condensed at the temperature in question) are all forced to be in the same quantum state, and therefore resemble the well drilled soldiers: "every atom must do exactly the same thing at the same time" ¹¹.

The analogy of the behaviour of the crowd with racemicity and of the well-drilled soldiers with L-amino acids is apt. The number of particles in any given energy level is fixed as a function of temperature, and as a result the total number of particles occupying the levels cannot be greater than some number $N_{max}(T)$ (which decreases along with T). At some temperature T_0 the quantity N_{max} becomes equal to the total number of particles in the system N, while below T_0 we have $N_{max} < N$. At such temperatures there are simply not enough quantum states available to accommodate all the particles. "The resolution of the problem is remarkably simple: below T_0 the system adjusts by taking all the particles which cannot be accommodated by the distribution formula and putting them in the single quantum state which has the lowest energy (the "ground state".) Since these surplus particles are a finite fraction of the whole (in fact, at zero temperature all of them), we reach the remarkable result that a *macroscopic* number of particles (of order N, which typically is of order say 10^{23}) occupy a *single* quantum state. This phenomenon is known as *) "Bose condensation" ¹¹.

^{*)} After this paper was completed, Dr. J. Chela-Flores gave us the following quotation to insert into the text. We gladly do so: "Perhaps the earliest suggestion of the possible occurrence of condensation in biology was made almost three decades ago by Delbrück, who was concerned as to "whether or not something very peculiar from the quantum mechanical point of view, like superconductivity or superfluid helium, will come up. If strange cooperative phenomena can happen at room temperature in very special molecules. . ., then certainly life will have discovered this"¹². Within the context of the origin of life, condensation was conjectured to occur in the earliest riboorganism¹³ under the effect of low temperatures estimated to be approximately 160° K."

5. The necessary conditions for condensation have been studied by L. Landau ¹⁴). Landau distinguished between Bose superfluids and Fermi superfluids (even for Fermi superfluids like superconductors the "superfluidity" is produced by bosonic *condensates* *) like those for Cooper pairs).

"A Fermi gas with attraction between the particles must have the property of superfluidity"; "howsoever weak the attraction **) is". (Ref.15, p.153).

6. For $T = T_c$ we have the phase transition with all its aspects of suddenness. For $T < T_c$ the superfluid persists reaching its climax at T = 0. The question arises as to what happens when $T > T_c$. To answer this question, we consider cooperative phenomena. The main features of a cooperative phenomena can be illustrated by considering with Atkins ¹⁷⁾ the semi-classical treatment of ferromagnetism. At 0°K the electron spins are aligned parallel to one another to give a resultant magnetization even in the absence of an external magnetic field. However at a finite temperature thermal agitation is able to turn over some of the spins and the average magnetic moment in the direction of magnetization is thereby decreased. "As soon as this process starts, an electron chosen at random is likely to have neighbours pointing against the direction of magnetization as well as with it and this reduces the energy needed to reverse the spin of the electron, so that, as the temperature increases and more spins are turned over, it becomes increasingly easier to turn over the remaining spins and the disordering process develops with ever increasing rapidity. At the Curie point the disordering is eventually complete and the spins point equally in both directions" so that only a 50-50 racemic state survives.

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^{*)} A condensate is the constant part of a spin zero field ⟨φ⟩ which can arise for some theories (provided the potential for φ is like an inverted mexican hat). This is achievable for fields which carry zero frequency (zero energy and zero momentum).
**) "Imagine two people on an old sagging, nonlinear mattress. They tend to roll toward the middle, even if they don't like each other. That is, there is an attractive interaction. The cause of this interaction is that the people create distortions in the mattress, and the distortions try to merge. The electrons in the metal do not stand still but rather zip through the lattice at something like the Fermi velocity. The ions are attracted to the electron is long gone, but it has, in effect, left behind a trail of positive charge, which is the lattice distortion we mentioned above. Another electron, transversing the same path, would find that its way has been prepared with the positive charge that it finds so attractive. We can imagine that the first electron created a phonon, which the second happily absorbs. Notice that the interaction is strongest if the two electrons traverse exactly the same path — that is, if they have, say, equal and opposite momenta" ¹⁶.

We shall use the results of this section in the footnote to Appendix B to obtain one estimate of T_c for most amino acids.

7. How important are the effects of the parity violating weak interacitons for specific amino acids? This question may be answered by setting ⁶⁾ $1-4 \sin^2 \theta \approx 0^{*}$; the resulting elegant expression for the Hamiltonian has led to *molecular-conformation-dependent values* for parity violation which for Ala, Val, Ser and Asp have been calculated to give ^{3),7)} -3.0, -6.2, -2.3 and -4.8, in units of 10^{-19} eV.

The authors of Refs.3 and 7 express the energy values in atomic units (1 atomic unit = 1 Hartree = 27.2 eV) corresponding to the *L*-configuration of the *aqueous zwetterionic* amino acids. (The simplest amino acid, glycine (residue R = H) is not resolvable into optical isomers. On account of the further symmetry implied by R = H, parity violation when averaged over a complete rotation of the carboxylate group through all configuration angles, turns out to be zero, in agreement with experiment. For the sugar glyceraldehyde the value is $+1.8 \times 10^{-19}$ eV corresponding to its *D*-configuration ^{3),7)}).

The classical chemist has hitherto used the electromagnetic force as the only fundamental force which can produce chemical effects. He has not considered the electroweak force, and in particular its Z^0 component, since the effects due to Z^0 are supposedly very small at low temperatures.

^{*)} It may be noted in passing that if $(1 - 4 \sin^2 \theta) \approx 0$ uniformly, one is taking the contribution of the neutrons inside the nuclei into account, but not of the protons, except when deuterons substitute for protons. Also note that the isotope C^{13} should give a different contribution than C^{12} . This is the peculiar hallmark of Z^0 interactions. Such behaviour has been attributed in the past to pre-solar cosmic abundance. For example, "the discovery that amino acids from the Murchison meteorite are as a group highly enriched in deuterium ($\delta D = 1370\%$) strongly suggests that the amino acids or their percursors were formed at low temperatures in interstellar clouds" ¹⁸. This pathway reportedly supports the hypothesis of a direct relationship between organic rich interstellar grains, comets, dark asteroids, and carbonaceous chondrites ¹⁹. It is clearly important to get the precise ratios of D/H, tritium/hydrogen as well as for C^{13}/C^{12} among the L and D amino acids separately (in order to distinguish the effects of Z_0 from the contributions due to abundances in the early universe). This has been done for the Murchison meteorite by Engel, Macko and Silfer ²⁰ who conclude that optically active materials were present in the early Solar System before life began.

We shall now show that the electroweak interactions (for which there is nothing comparable in classical chemistry) can give rise to a phase transition *).

Like all phase transitions, this one will have a behaviour like $(T_c - T)^{\alpha}$, $T \to T_c$. This makes the amplitude (or derivatives thereof) an infinite quantity.

To compute T_c exactly is difficult (for one thing, on account of the incompleteness of the standard model of elementary particles), but we can without difficulty measure T_c (Appendix C). In the sequel we shall assume T_c does exist and that it has been measured for each amino acid.

8. Since the ambient temperature of the Earth's surface is ≈ 300 °K (the maximum temperature on the surface being ≈ 350 °K), if $T_c \ll 300$ °K, the present formalism may not apply to the Earth. (The fact that the prebiotic temperatures may be less than 300 °K was the content of a 1966 work by Sanchez, Ferris and Orgel ²²⁾.) **)

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^{*)} The superconductivity phase transition can be attributed to the attractive force due to the parity non-conserving effective interaction produced by the spin-0 part of Z^0 which is itself caused by spontaneous symmetry breaking associated with the condensate $\langle \varphi \rangle \neq 0$ (see Sakita ²¹).

^{**)} The Sanchez-Ferris-Orgel paper ²²⁾ says that tetramer formation in 0.01 *M* HCN is accelerated by lowering the temperature from 300°K to 250°K. The authors conclude that "we may have to replace the usual picture of a warm dilute pre-biotic medium with one more cold and much more concentrated at least for some syntheses". Thus in the language of the present note, the above paper ²²⁾ may perhaps be interpreted as advocating $T_c \leq 250$ °K. On the other hand, K.D. Kondepudi (private communication) has suggested that unless $T_c \leq 2.7$ °K – the ambient universal temperature – the entire interstellar space could be optically active provided, of course, the density of amino acids is not too dilute over most of space.

In this case, there could be several possible scenarios:

a) Pre-solar contributions may be necessary to get low enough temperatures;

b) Or major contributions come from the more distant and the cooler parts of the solar system with ambient temperatures less than T_c . In this context it is good to remember that the *maximum* surface temperatures have been estimated as 135°K for Jupiter, 120°K for Saturn, 85°K for Uranus, 55°K for Neptune, and 20°K for Pluto *).

c) If T_c is considerably less than 300 °K, we could entertain the (somewhat odd) notion that the Earth only acted as a junction place where *L*-amino acids came together with *D*-sugars and nucleotides for the replication phenomena to get started for the biotic stage of Sec.2 to be implemented.

In order for the biotic alternative of Sec.2 to prevail, it is necessary to invent a mechanism to deliver organic molecules to the Earth from the cooler locations a) or b). This was first considered by Orò ²³⁾, and in greater detail recently by Chyba, Thomas, Brookshaw and Sagan ¹⁸⁾. The latter authors conclude that:

1) "The Earth did accrete prebiotic organic molecules important for the origins of life from impacts of carbonaceous *asteroids and comets* during the period of heavy bombardment 4.5×10^9 to 3.8×10^9 years ago" (cf. the Chiron comet?).

2) For plausibly dense (10-bar carbon dioxide) early atmospheres, these authors find that 4.5×10^9 years ago Earth was accreting intact *cometary* organics at a rate of at least $\approx 10^6$ to 10^7 kilograms per year – (a flux that thereafter declined with a half-life of $\sim 10^8$ years). These results

^{*)} Such extraterrestriality had been anticipated on different grounds. Some forty years ago, Stanley Miller performed fundamental experiments demonstrating that the action of electrical discharges on a mixture of water vapour, methane and ammonia could produce reasonable yields of simple amino acids (glycine and alanine). Subsequent experiments along the same lines by Orgel, Ponnamperuma and others have confirmed Miller's findings. The Miller-Orgel-Ponnamperuma "experiments simulated an environment rather similar to the lower atmospheric regions of Jupiter, where it is known that there are violent thunderstorms. Jupiter (or one of its satellites like Europa) may well be the best candidate in the Solar System for rudimentary extraterrestrial life!" ²³⁾⁻²⁷⁾

It is also conceivable that chemical evolution and synthesis of biochemical compounds have occurred and are occurring *now* in Titan – the largest satellite of Saturn. Titan has a reducing atmosphere – a desirable feature. This may explain in part, "some of the darker spots observed in Europa's outer surface and more recently in Triton, the remarkable satellite of Neptune"²⁾. (Triton's surface temperature apparently is $\approx 38 \pm 4^{\circ}$ K.)²⁸⁾

may be placed in context by comparison with terrestrial oceanic and total biomasses, $\sim 3 \times 10^{12}$ kilograms and $\sim 6 \times 10^{14}$ kilograms, respectively.

3) (Contrary to the general impression) the alanine molecules could withstand temperatures as high as ≈ 700 °K for one second whereas other amino acids could withstand temperatures in the range of 600° to 800°K for a like period of time and remain stable and intact upon impact with the Earth.

It is tempting to assume further that this material ($\approx 10^6$ to 10^7 kilograms) maintained its chirality at delivery (particularly if T_c had a small value near zero). This follows from the formula $-\frac{\partial \Delta}{\partial T} \approx \frac{3.06}{2} \times \sqrt{\frac{T_c}{T_c-T}}$ (see Appendix B.2) if the formula applies to the case of amino acids. At this juncture life could have started and the chirality perpetuated in accordance with the biotic picture in Sec.2.

9. We wonder if the laboratory testing of the central hypothesis of this note is feasible. This can be tested by taking a 50–50 racemic mixture of *crystalline* L and D-amino acids and lowering the temperature.

The crystalline conformations of L and D amino acids do not differ much from the zweitterionic forms except for the absence of water molecules inside the lattice cell. Barring for alanine, there are no definite calculations which show that it is indeed the L-configuration which prevails for these crystals. However this may not affect the laboratory testing of the hypothesis of this paper because lowering of the temperature below the transition temperature would eventually convert all amino acids into that particular configuration which only partially predominated before. Conversely, a raising of temperature through T_c would show that a pure configuration below T_c can be converted into a racemic mixture for $T > T_c$.

To conclude, note that ideally we should be able to compute the values of T_c when electroweak interaction theory is fully worked out. The numerical value of this quantity could lie anywhere, around 2.7°K^{*)} (the ambient temperature of outer space) or beyond 350°K (but below

^{*)} Although we could contemplate reaching $0^{\circ}K$, this would have to be strictly local.

the dissociation temperatures). However, the best way to determine T_c for a given amino acid is at present experiment. The analogy of the "superfluidity" exhibited by amino acids and sugars is to "superfluidity" in superconductors and not to the liquid helium. In the case of superconductivity, one has to apply an external magnetic field and look for the Meissner effect to determine T_c . Likewise, the "superfluidity" of amino acids (or sugars) is measured by shining on these external light sources. *)

One direct way to test for evidence of the hypothesis (regarding the existence of such a phase transition), is to lower the temperature while measuring the optical activity when polarized light is shone upon a particular amino-acid. If the polarization vector gets rotated, one may be sure that the appropriate phase transition has taken place. **)

The process ***) itself could perhaps be detected by optical ****) rotatory dispersion (ORD) or circular dichroism (CD). An alternative means of detecting the process may be by measuring differences of specific heats and looking for anomalies in the curve $C = \gamma T + \beta T^3 + ...$ like what has been recently done for the non-amino acids like melanins and tumour melanosomes ³⁰.

10. We have shown that chirality may provide a boundary condition for theories of the origin of life and that Z^0 interactions – as well as what comes beyond the standard model of fundamental interactions (CP violation, for example) – ought to play a central role in this story. In

^{*)} The difference between superconductivity and Bose superfluidity for He⁴ lies in the fact that the Cooper pairs (which are bosons) are rather large objects ($\sim 10^{-4} cm$) compared with the inter-particle distance ($\sim 10^{-6} cm$), i.e. there is a significant overlap between Cooper pairs.

^{**)} If this analogy is correct for the amino acid case, then the Meissner effect should have a parallel in the polarization vector undergoing a phase change at $T = T_c$.

^{***)} I would like to thank Dr. A.J. MacDermott for sharpening the suggestion regarding the polarization measurements, and Dr. J. Chela-Flores for the suggestion regarding the use of specific heats.

^{****)} It is conceivable that the experiments are best done where a heavy atom substitutes for one of the light atoms. The analogy could be with the Patterson phases in normal x-ray diffraction analyses where one uses atoms of gold, platinum or mercury. We have been able to discover that amino acid crystals have been made with nickel, iron or copper, for example, crystals of silver glycine AgOOC-CH₂-NH₂ or copper DL- α -aminobutyrate Cu(OOC·C₂H₆NH₂)²⁹.

this context, the following quotation from L. Pasteur (who did not even know of Z^0 particles) is perhaps prophetic: "Life as manifested to us is a function of the asymmetry of the Universe and of the consequences of this fact. The Universe is asymmetrical. Life is dominated by asymmetrical actions. I can even imagine that all living species are primordially in their structure, in their external forms a function of cosmic asymmetry." ³¹

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Appendix A

A.1) To implement these ideas for L-amino acids we start with the Z^0 interaction:

$$L_{int} = \frac{e}{\sin\theta\cos\theta} \left[(T_{3L} - \sin^2\theta J_{em})_{\mu} Z_{\mu}^0 \right] . \qquad (A.1)$$

(units $\hbar = c = 1$). Here J_{em} is the electromagnetic current, T_{3L} is the left-handed third component of the weak isospin consisting of the (anomaly-free) combination of the proton-neutron (p, n)and neutrino-electron (ν_e, e) left-handed doublets (of weak isospin) i.e. $T_{3L} = \overline{\psi}\gamma_{\mu} \left(\frac{1+r\gamma^5}{2}\right) \tau_3 \psi$ where $\tau_3 = \frac{1}{2}(1, -1)$ where ψ stands either for the doublet of protons (p) and neutrons (n), or for the doublet of neutrinos (ν_e) and electrons (e) (Protons and neutrons (composite) fields have been used in preference to the elementary quarks, since this illustrates *the point that for our present calculations (up to certain energies and temperatures)*, it is not important that we know *the* elementary entities themselves). In addition there is the Higgs field φ with known non-zero expectation value $\langle \varphi \rangle$ which is needed to give masses to the protons, neutrons and electrons as well as to the Z^0 particles on account of their non-zero expectation value ($\langle \varphi \rangle \neq 0$) can act as perfect condensates at zero temperatures. In terms of this quantity ($\langle \varphi \rangle = 250 \, GeV$) the electron mass m_e turns out to be a very tiny

number *) $\approx 2 \times 10^{-6} \times \langle \varphi \rangle$.

We shall take $(1 - 4 \sin^2 \theta) \approx \frac{1}{13}$ with the present *empirical value* of the parameter $\sin^2 \theta \approx .231$. Unlike the authors of Refs. 3, 6 and 7, we shall not take this quantity to equal zero. Neglecting neutrinos (and Higgs), the right-hand side of (A.1) can be written in the form:

$$\frac{e}{4\sin\theta\cos\theta}(V_{\mu}-a_{\mu})Z_{\mu}. \qquad (A.2)$$

Here

$$V_{\mu} = (1 - 4 \sin^2 \theta) J_{em\mu} + (-\bar{n}\gamma_{\mu}n)$$
 (A.3)

^{*)} It is perhaps worth remarking that this number is very large for the top quark if its mass is in excess of 100 GeV. Thus the terms which give this, look like $b\varphi t\bar{t}$ where $b \ge \frac{2}{5}$. Some physicists ,like Y. Nambu, take this as the defining property of the field φ , i.e. φ is considered as a $t\bar{t}$ composite.

and

$$-a_{\mu} = (\bar{p}\gamma_{\mu}\gamma_{5}p - \bar{n}\gamma_{\mu}\gamma_{5}n) - (\bar{e}\gamma_{\mu}\gamma_{5}e) \qquad (A.4)$$

To this must be added the purely electromagnetic terms (which are parity conserving)

$$eJ_{em\mu} \times A_{\mu}$$
 (A.5)

A.2) In order to address the question of the existence of a finite critical temperature T_c for the phase transition into a condensed mode, we recall that our picture of amino acids is as follows:

Amino acids consist of a backbone made up of atoms of carbon (2 in number, one of which C_{α} acts as the centre for the mirror transformations), oxygen (2), nitrogen (1) and hydrogen (4), plus a residue which may consist of hydrogens (up to 15), carbons (up to 8), nitrogens (up to 3), oxygens (up to 2) and sulfur (up to 1). The electrons interact with protons and neutrons essentially (in fact with the quarks contained inside the nucleons) at the location of these objects; they in particular interact with neutrons.

The amino acid gets its L or D configurations through mirror arrangements of the atoms contained in the backbone structure. It has been shown that L or D configurations are correlated with left or right chirality ³⁾.

In the sequel we shall represent the state of a given amino acid as composite of p, n and e. It must be remembered that the amino acids are not metallic compounds. Thus there is no concept of Fermi energy nor of wandering electrons. The electrons from the *inner shells* interact with the nucleons, in particular, with the neutrons and quarks inside them.

Appendix B

B.1) Consider the pseudoscalar terms in the effective interactions which, after integrating out the Z^0 field is proportional to $V_{\mu} \times A_{\mu} + A_{\mu} \times V_{\mu} \approx \bar{\psi} \gamma_{\mu} \psi \bar{\psi}' \gamma_{\mu} \gamma_5 \psi' + \dots$ {A part of these terms is proportional to $(1 - 4 \sin^2 \theta)$. (Such terms have been set equal to zero by the authors of Refs. 3, 6 and 7). These terms contain four Fermi interaction of electrons which are proportional to the pseudoscalar quantity $\sigma \cdot p$ in the non relativistic approximation, where only large components are kept plus other terms. Such terms are proportional to $(1 - 4 \sin^2 \theta)[(e^+e \times e^+\frac{\sigma \cdot p}{m}e) + (e^+e \times n^+\frac{\sigma \cdot p}{m}n)] + n^+n \times e^+\frac{\sigma \cdot p}{m}e$.} The important point for our purposes is that this part of the parity violating sector is negative for half the states of the system, i.e., for states which have the opposite eigenvalue for the operator $\sigma \cdot p$ before and after the interaction - and positive for the remaining half of the states.

We concentrate on the *attractive* set of these parity violating terms. Because of the absence of such terms in the parity conserving (in fact repulsive) Coulomb force, this would allow us to develop the analogy for metals with the theory of superconductivity. The situation is analogous to that of BCS theory where the 4-Fermi effective interaction of the electrons is attractive. According to Landau's criterion, the electron fluid must therefore exhibit "superfluidity" ¹⁵.

B.2) We now emphasize in 1) to 4) the ideas and results from BCS theory which may be of interest to us in developing our analogy.

The condensate wave function for a *metallic* superconductor is the "gap" function $\Delta(0) = \omega_D \exp(\frac{-2}{g\nu})$. Here ω_D is the Debye cutoff $\approx 10^2 K$ for most metals, p_F stands for the Fermi momentum, ω_F is the corresponding Fermi energy, while g is the effective 4-Fermi coupling parameter for electrons and ν in general is given by $\nu = \frac{p_F m}{\pi^2}$, *), while $g\nu \approx 1$ represents an approximation. Thus the expression for the exponent may be taken as of order unity (since $g\nu \approx 1$). (We shall continue to make this approximation.) Empirically, one finds that $\omega_D \approx (10^{-3} - 10^{-4})\omega_F$.

^{*) &}quot;The fact that the interaction spreads over an energy interval $\Delta \omega_D$ implies, according to quantum mechanics, that it is retarded, or in other words, it operates during a finite time interval $\Delta t \approx (\Delta \omega_D)^{-1}$ " (Ref.15, p.361). This implies that for the electron-phonon interaction, the time interval is given by approximately 10^{-13} secs for $T_c = 10^{\circ}$ K for the case of niobium (superconductivity) and 10^3 secs for the case of amino acids if $\omega_D \approx 3 \times 10^{-19}$ eV.

Using the methods of Gorkov and Sakita for the non-relativistic electron case, an equivalent Landau-Ginzberg equation for the BCS theory is written down. This gives the following results for the superconductivity case:

1) T_c , the critical temperature is given by $T_c \approx (1.76)^{-1} \times \Delta(0)$;

2) The dependence of $\Delta(T)$ on temperature is given by $\Delta(T) \approx \pi (\frac{8}{7\zeta(3)})^{1/2}$ $[T_c(T_c - T)]^{1/2} = 3.06[T_c(T_c - T)]^{1/2}$ for $T < T_c$; (here $\zeta(x)$ is the Riemann zeta function: $\zeta(x) = \sum_{n=1}^{\infty} n^{-x}$). $\Delta(T)$ decreases with increasing temperature. Its derivative with respect to T becomes infinite at $T \approx T_c^{-15}$;

3) $C_s(T_c) = C_n(T_c) + \frac{4}{7\zeta(3)} \frac{p_P m}{h^3} T_c$. Here C_s corresponds to specific heat for the superconducting phase, while C_n denotes the corresponding quantity for the normal case. We obtain from this, the result that $(C_s(T_c) - C_n(T_c))$ is proportional to T_c . (The same formula seems to apply for some of the organic materials as shown by Mizutani et al.³⁰.)

4) The expression 2) above, for $\Delta(T)$, holds for $T < T_c$. What happens in general for $T > T_c$? Goodstein ¹⁶⁾ states that for the (analogous) case of magnetic susceptibility, this expression is of the form, $f_+ \times \varepsilon^{-\gamma}$ for $T > T_c$, provided the susceptibility for $T < T_c$ has the form $f_-(-\varepsilon)^{-\gamma'}$, where $\varepsilon = \frac{T-T_c}{T_c}$.

One consequence of the working of scaling laws of physics is that $\gamma = \gamma'$ (Ref.16, p. 481) with the predilection towards $f_+ = f_-$.

If we can carry these results over to the amino acid case, a racemic mixture starts forming for $T > T_c$ completing, *in general*, the process to a 50-50 mixture for $(f_+ + f_-)T_c$. Since the melting point (m.p.) represents the dissociation limit for the amino acids, one expects that $(f_+ + f_-)T_c$ is less than $T_{m.p.}$. This could give 250°K to 300°K if $f_+ = f_- = 1$ (compare the work of Sanchez et al. ²²) (cf. Sec.8) as an estimate of T_c^{*} . However this estimate could vary between very wide

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^{*)} Mr. P. Agbedjro, to whom our thanks are due, has compiled for us from the 1988-89 Handbook of Chemistry and Physics, the following table of the melting points of the amino acids: Ala 568°K, Arg 537°K, Asp 597°K, Cys 533°K, Glu 497°K, Gly 535°K, His 560°K, Pro 511°K, Ile 557°K, Leu 566°K, Lys 497°K, Met 554°K, Phe 557°K, Pro 493°K, Ser 519°K, Try 563°K, Tyr 615°K, Val 571°K. These numbers uniformly lie between 500°K and 600°K except for Tyr which is ≈ 615°K.

range of values if $f_+ \neq f_- \neq 1$.

5) The present BCS theory applies to the low temperature case. How do we utilize the ideas of this theory for the case of high- T_c ? We are interested in the critical temperatures for amino acids which may well be in excess of 350 °K. Such a model beyond BCS might, for example, follow more the analogy of high T_c -superconductivity where present experiments takes T_c to values as high as 125 °K. There is, as yet, no accepted theory ³²⁾ of these high T_c -superconductors and it is not clear what, if anything, is the analogue of Cooper pairs.

Two of the mechanisms suggested for high T_c superconductivity may possibly be of relevance to the case of "superfluidity" for amino acids. These are: 1) The use of the electrons of inner shells of atoms which are retained in the lattice ions. ω_D could be as high as $\approx 10^5$ K; 2) An attempt to find a transmitting system of electrons with high polarizability: Molecular organic crystals, polymers, for example C_{xs} (where C stands for carbon while x represents a multiple repetition of the group). Unfortunately, as far as a high- T_c superconductivity is concerned, neither of these two suggestions have proven very effective in increasing T_c to higher values.

Appendix C

From these expressions to proceed for the case of amino acids is not that easy: We shall recount here the difficulties in carrying this programme through.

C.1) For the amino acids, we shall take an expression for T_c which is similar in form to the expression for superconductivity $T_c = \Delta E \exp(-\frac{1}{\lambda})$. " ΔE is the energy difference between the states A and A^{*}. A is the ground state, A^{*} is the excited state of the ... system (it can easily be shown that such an interaction is necessarily an attraction if it is not strong"). λ depends on the interaction of electrons for the case of superconductivity, while ΔE is related to ω_D , and $\lambda \propto g\nu$. We shall designate $\exp(-\frac{1}{\lambda})$ as the probability factor for the transition A to A^{*} to take place. Our major problem will be to secure $g\nu \approx 1$ so that this probability factor is not too small.

a) We need a non-perturbative calculation like the one used by Sakita (1985) for the case of superconductivity but here for attractive parity violating interactions. (The difficulty in this case lies in choosing what the analogy for the Fermi energy is.)

b) The electrons in the inner shells of atoms are probing much more deeply into the quark structure of the nucleon. We saw before in Appendix B that such electrons give rise to 10^5 °K in the superconductivity case. Chemical phenomena for the amino acid case are probing deeply into the centers of nucleons (and the quarks within them), the energies involved being much higher than one is used to.

c) $g\nu \approx 1$ may present difficulties to achieve. Since $\lambda \propto g\nu$ the fact that $g\nu \neq 1$, in general, may mean a strong diminution of probability represented by exp $\left(-\frac{1}{\lambda}\right)$.

C.2) There is another possibility, that is, to consider the relativistic term $\bar{n}\gamma_{\mu}n \times \bar{e}\gamma_{\mu}\gamma_{5}e$.

Could we utilize this term to invent a condensate model of \bar{e} -n pairing like the Cooper pairing? The answer is clearly *yes*, as can be seen by the fact that an interchange of particles 2 and 4 by a Fierz reshuffle can be made, so that the term reads $\bar{n}e \cdot \bar{e}\gamma_5 n$. Both factors contained here are scalars and we can invent a field φ' which could have the effective coupling ($\varphi' \times (\bar{n}e + \bar{e}\gamma_5 n)$). From the calculations previously made ^{3),7)}, if $T_c \approx \omega_D \exp(-2/g'\nu')$ and if $g'\nu' \approx 1, \omega_D$ can be

taken as 3×10^{-18} eV.

What field does φ' correspond to? An \bar{e} -*n* pairing condensate (with $\Delta B \neq 0, \Delta L \neq 0$) brings back the memories of proton decays and baryon number violation. The question would then be, is this triggered by a grand unification mass $\approx 10^{14} \cdot 10^{15}$ GeV or can it rely upon the work of Rubakov and his collaborators ³³ which ascribes baryon violation to the standard model with $\langle \varphi \rangle = 250$ GeV? In other words is $\langle \varphi \rangle = \langle \varphi \rangle'$? We would tend to favour this but this does bring us to the modern unresolved controversies which are the substance of present day theoretical particle physics.

There is a further uncertainty which comes about because of the uncertainty in physics of the standard model. This theory (with Z^0 particles) violates parity P and charge conjugation C but conserves CP. If parity violation P is accompanied by CP (\approx T) violation (and this seems to be the case from the K° system), this is usually accomplished by writing down a mass matrix of Cabibbo-Kobayashi-Maskawa type. Such a mass matrix has been shown to involve necessarily a phase factor if there are 3 generations. A different procedure would be to build this violation as a consequence of extra terms like in Weinberg's new theory which uses gluons. It could also be built in by postulating the existence of invisible axions, where the associated mass term may lie between 10^{12} GeV, or by enhancing the symmetry of the theory to left-right symmetry, or of the idea above of considering the condensate $\langle \varphi' \rangle \neq 0$ of the spin-0 field φ' which has interactions with $\bar{n}e$ and $\bar{e}\gamma_5 n$ or . . . This may mean the addition of extra terms to the standard model and more terms for T_c .

C.3 The value 250 °K obtained in Appendix B.4, if correct, could provide one of the better possibilities physically. It would mean that the Earth had a reasonable chance of being the site of prebiotic *L*-amino acid production. [The very best possibility is, of course, $T_c \ge 350$ °K. This would mean that the Earth suffices for the production site of amino acids, in general. This is a possibility which should not be ignored if laboratory tests are made for amino acids in accordance with Sec.9.]

All that may reasonably be inferred at this stage is the existence of a non-zero T_c due to

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the attractive forces we have mentioned before.

Be that as it may, consider the case of four-Fermi interactions with electrons. Since this term comes together with the factor $(1 - 4 \sin^2 \theta)$, the form to be expected is of the type

$$T_c \approx \frac{\langle \varphi \rangle}{10^3} \exp(-2/g\nu(1-4\sin^2\theta)) \approx 2.5 \times 10^2 \,^{\circ}K \tag{C.1}$$

Here we have taken ΔE to be $\approx \langle \varphi \rangle$ multiplied by the old familiar factor of 10^{-3} , while $g\nu$ is still taken ≈ 1 . The exponential factor gives $\exp -26 \approx 10^{-10}$, so that altogether we have *) $10^{-13} \times \langle \varphi \rangle = 2.5 \times 10^2 \, {}^{\circ}K$.

Since the only quantity which has the right transformation character (for such parity violating interactions) is Z^0_{μ} , or its longitudinal part where $\partial Z_{\mu}/\partial x_{\mu} \approx M\varphi$, therefore 250 GeV must somehow play a role of in the formulae we have set up.

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^{*)} To emphasize the arbitrariness in the calculation so far shown, it is worth remarking that T_c comes out to be $T_c = \omega_D(\exp -2/1 - 4 \sin^2 \theta) = 5$ °K if we plausibly take the cutoff $\omega_D \approx m_e \approx (2 \times \frac{\langle \varphi \rangle}{10^6})$. This is such an important point that we shall discuss it further in a separate note to be published elsewhere.

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