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The Role of Chirality in the Origin of Life

Chirality, Phase Transitions and their Induction in Aminoacids

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"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, cf. Walker 1979)

Summary. The role of chirality in the theories that determine the origin of life are reemphasized—in particular the fact that almost all amino acids utilized in living systems are of the L type. Starting from Z^0 interactions, I 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 hot a location for the production of L amino acids. I suggest laboratory testing of these ideas by looking for the appropriate phase transitions.

Key words: Prebiotic chirality — Origin of life — Condensation

Section 1

One may summarize the presently accepted view of the origin of life as occurring in 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 electroweak forces made a phase transition into two forces, electromagnetic and weak, 10^{-12} s 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 itself (Orò et al. 1990a).

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

Section 2

Classically, a chiral molecule and its mirror image [defined by left (L) or right (D) optical/rotatory dispersion] have been considered energetically equivalent. However, the parity-violating weak interactions give rise to L and D configurations (Mason and Tranter 1984), and ensure that this equivalence is no longer exact—one of the two molecules, L or D, being energetically stabilized, with energy differences on the order of 3×10^{-19} eV.

In living systems, protein molecules are composed of 20 L amino acids (although some amino acids of the opposite D type do occur in cell walls of certain bacteria). 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 (Knervolden et al. 1971; Cronin 1989).

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 was perpetuated.

Section 3

The most significant of the parity-violating weak interactions are the weak–neutral, these being mediated by the Z^0 bosons (Harris et al. 1978). 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 (Mason and Tranter 1984; Tranter and MacDermott 1989) indicate that four of the amino acids in aqueous zwitterionic 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 $10^{-17} \approx (3 \times 10^{-19}\ \text{eV})/300°\text{K})k_B$. It is the smallness of this figure that 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 Kondepudi and Nelson (1985) following the seminal ideas of F.C. Franck.

Consider, for example, quartz crystals that may be taken as nonequilibrium statistical mechanical systems at ambient temperatures on the order of $T = 300°\text{K}$. Using an autocatalytic mechanism and theory of delayed bifurcations, one can show that a lake 1 km^2 and 4 m 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 (Goldanski *in* Avetisov et al. 1987). For one thing, these authors (as well as L. Orgel, personal 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 (Goldanski *in* Avetisov et al. 1987) 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 (personal 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. The enhancement due to phase transitions is discussed in Appendices A–E.

I would like to treat this quantum mechanically as an equilibrium problem. 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, e.g., as for neutron stars) are necessary; now if T_c for the amino acid 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. This problem is discussed below.

Section 4

A modern version of the phenomenon of condensation has been described by Leggett (1990) giving a uniform treatment of a superfluid (like liquid helium II), where T_0—the so-called degeneracy temperature—is $\approx 3°\text{K}$, 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 below.

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, 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 (Leggett 1990).

The analogy of the behavior 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, whereas 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" (Leggett 1990). Because 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 10^{23}) occupy a single quantum state. This phenomenon is known as Bose condensation.

Section 5

The necessary conditions for condensation have been studied by L. Landau (Landau et al. 1980). 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 condensate is the constant part of a spin zero field $\langle\varphi\rangle$ that can arise for some theories (provided the potential for φ is like an inverted Mexican hat). This is achievable for parts of fields that carry zero frequency (zero energy and zero momentum).]

"A Fermi gas with attraction between the particles must have the property of superfluidity . . . howsoever weak the attraction is" (Abrikosov 1987). To clarify this point further, consider the following situation (Goodstein 1985):

> 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 electrons but, owing to their large mass, move very slowly compared to the much lighter electrons. By the time the ions respond 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.

Section 6

For $T = T_c$ the phase transition is present with all its aspects of suddenness. For $T < T_c$ the "superfluidity" persists, reaching its climax at $T = 0$. The question arises as to what happens when $T > T_c$. To answer this question, let us consider cooperative phenomena. The main features of cooperative phenomena can be illustrated by considering with Atkins (1959), the semiclassical 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 neighbors 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.

The results of this section will be used in Appendix B to obtain one estimate of T_c for most amino acids.

Section 7

How important are the effects of the parity-violating weak interactions for specific amino acids? This question may be answered by setting $(1 - 4 \sin^2\theta) \approx 0$; 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 (Mason and Tranter 1984; Tranter and MacDermott 1989) -3.0, -6.2, -2.3, and -4.8, in units of 10^{-19} eV. These authors express the energy values in atomic units (1 atomic unit = 1 Hartree = 27.2 eV) corresponding to the L configuration of the aqueous

zwitterionic 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 experimental results. For the sugar glyceraldehyde the value is $+1.8 \times 10^{-19}$ eV corresponding to its D configuration [see section 1, Appendix E].

The classical chemist has hitherto used the electromagnetic force as the only fundamental force that can produce chemical effects. He has not considered the electroweak force, and in particular its Z^0 component, because the effects due to Z^0 are supposedly very small at low temperatures. I shall now show that the electroweak interactions (for which there is nothing comparable in classical chemistry) can give rise to phase transitions.

The superconductivity phase transition can be attributed to the attractive force due to the parity nonconserving effective interaction produced by the spin-0 part of Z^0, which is itself caused by spontaneous symmetry breaking associated with the condensate $\langle \varphi \rangle \neq 0$.

Like all phase transitions, this one will have a behavior like $(T_c - T)$, $T \to T_c$. 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 T_c can be measured without much difficulty. In the sequel it is assumed that T_c does exist and that it has been measured for each amino acid.

Section 8

Because 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 indeed be less than 300°K was the content of a paper by Sanchez et al. (1966); these authors claim 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 prebiotic medium with one more cold and much more concentrated at least for some syntheses." Thus in the language of the present note, the data of Sanchez et al. may perhaps be interpreted as advocating $T_c \lesssim 250$°K. On the other hand, K.D. Kondepudi (personal communication) has suggested that unless $T_c \lesssim 2.7$°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:

1) Presolar contributions may be necessary to get low enough temperatures.

2) 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 at 135°K for Jupiter, 120°K for Saturn, 85°K for Uranus, 55°K for Neptune, and 20°K for Pluto (see section 2, Appendix E).

3) If T_c is considerably less than 300°K, then one 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 mentioned in Section 2 to be implemented.

In order for the biotic alternative to prevail, it is necessary to invent a mechanism to deliver organic molecules to the Earth from the cooler locations mentioned above. This was considered by Orò (Orò 1961; Orò et al. 1990a), and in greater detail recently by Chyba et al. (1990). 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 the Earth was accreting intact cometary organics at a rate of at least $\approx 10^6$ to 10^7 kg per year—a flux that thereafter declined with a half-life of $\sim 10^8$ years. These results may be placed in context by comparison with terrestrial oceanic and total biomasses, $\sim 3 \times 10^{12}$ kg and $\sim 6 \times 10^{14}$ kg, respectively.

3) Contrary to the general impression, alanine molecules could withstand temperatures as high as ≈700°K for 1 s whereas other amino acids could withstand temperatures in the range of 600–800°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 kg) 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 mentioned in Section 2.

Section 9

Is the laboratory testing of the central hypothesis of this note feasible? This can be tested by taking a racemic mixture of crystalline L and D amino acids.

The crystalline conformations of L and D amino acids do not differ much from the zwitterionic 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 that 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 that 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 one should be able to compute the values of T_c when electroweak 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 the dissociation temperatures.

One could contemplate reaching 0°K, but this would have to be strictly local. The best way to determine T_c for a given amino acid is at present by experimentation. 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 (see section 3, Appendix E).

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 optical activity when polarized light is shined upon a racemic mixture of 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) for circular dichroism (CD) (see section 4, Appendix E). An alternative means of detecting the process may be by measuring differences of specific heats and looking for anomalies in the curve $C = \gamma T + \beta T^3 + \ldots$ like what has been done (see Appendix D) for [illegible] amino acids like melanins and tumor melanosomes (Mitzutani et al. 1976).

Section 10

I 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 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" (Pasteur 1860).

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Appendix A

Section A.1

To implement these ideas for L amino acids we start with the Z^0 interaction

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

(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., $T_{3L} = \bar{\psi}\gamma_\mu\left(\frac{1+\gamma^5}{2}\right)\tau_3\psi$ 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). Proton and neutron (composite) fields have been used in preference to the elementary quarks, as this illustrates the point that for our present calculations (up to certain energies and temperatures), it is not important to know the elementary entities themselves. In addition there is the Higgs field φ, with a known nonzero expectation value $\langle\varphi\rangle$, which is needed to give masses to the protons, neutrons, and electrons as well as the Z^0 particle. Choosing the value of $\langle\varphi\rangle \neq 0$ is the same as spontaneous symmetry breaking. The Higgs particles on account of their nonzero 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 ($\approx 2 \times 10^{-6} \times \langle\varphi\rangle$). [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 that give this, look like $b\bar{\varphi}t\bar{t}$ where $b \geq \frac{1}{3}$. 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.]

Let $(1 - 4\sin^2\theta) \approx \frac{1}{13}$ with the present empirical value of the parameter $\sin^2\theta \approx 0.231$. Unlike some authors (Harris et al. 1978; Mason and Tranter 1984; Tranter and MacDermott 1989) let us not assume 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

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

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)

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

Section 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 center for the mirror transformations), oxygen (2), nitrogen (1) and hydrogen (4), plus a residue that 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 (Mason and Tranter 1984).

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

Appendix B

Section B.1

Consider the pseudoscalar terms in the effective interactions, which, after integrating out the Z^0 field, is proportional to $V_\mu \times A_\mu + A_\mu \times V_\mu \approx \bar{\psi}\gamma_\mu\psi\bar{\psi}\gamma_\mu\gamma_5\psi + \ldots$. A part of these terms is proportional to $(1 - 4\sin^2\theta)$. Such terms have been set equal to zero by some authors (Harris et al. 1978; Mason and Tranter 1984; Tranter and MacDermott 1989). I shall not make this approximation. These terms contain 4-Fermi interaction of electrons that are proportional to the pseudoscalar quantity $\sigma\cdot p$ in the nonrelativistic approximation, where only large components are kept. Such terms are proportional to $(1 - 4\sin^2\theta)[(e^+e \times e^+\frac{\sigma\cdot p}{m_e}e) + (e^+e \times n^+\frac{\sigma\cdot p}{m_n}n)] + n^+n \times e^+\frac{\sigma\cdot p}{m_e}e$. The important point for our purposes is that this part of the parity-violating sector of e–e coupling is negative for half the states of the system, i.e., for states that have the opposite eigenvalue for the operator $\sigma\cdot p$ before and after the interaction—and positive for the remaining half of the states.

I concentrate on the attractive set among the 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 within 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" (Abrikosov 1987).

Section B.2

The ideas and results from BCS theory, which may be of interest to us in developing our analogy, are next emphasized.

The condensate wave function for a metallic superconductor is the "gap" function $\Delta(0) = \omega_D\exp\left(\frac{-2}{gv}\right)$. Here ω_D is the Debye cutoff $\approx 10^2K$ for most metals, p_f stands for the Fermi momentum, ω_f is the corrresponding Fermi energy, and g is the effective 4-Fermi coupling parameter for electrons, which in general is given by $v = \frac{p_f m}{\pi^2}$, whereas $gv \approx 1$ represents an approximation. Thus the expression for the exponent may be taken to be of order unity (as $gv \approx 1$). I shall continue to make this approximation. Empirically, one finds that $\omega_D \approx (10^{-1}\text{–}10^{-4})\omega_f$. ["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 $\Delta t \approx (\Delta\omega_D)^{-1}$" (Abrikosov 1987). This implies that for the electron–phonon interaction, the time interval is given by approximately 10^{-13} s for $T_c = 10$°K for the case of niobium (superconductivity) and 10^3 s for the case of amino acids if $\omega_D \approx 3 \times 10^{-19}$ eV.]

Using the methods of Gorkov and Sakita for the nonrelativistic electron case, an equivalent Landau–Ginzburg 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 approximately given by $\Delta(T) \approx \pi\left(\frac{8}{7\zeta(3)}\right)^{\frac{1}{2}}[T_c(T_c - T)]^{\frac{1}{2}} = 3.06[T_c(T_c - T)]^{\frac{1}{2}}$ 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 $T \approx T_c$ (Abrikosov 1987).

3) $C_s(T_c) = C_n(T_c) + \frac{4}{7\zeta(3)}\frac{p_f m}{\hbar^3}T_c$. Here C_s corresponds to specific heat for the superconducting phase, whereas C_n denotes the corresponding quantity for the normal case. From this, the result that $[C_s(T_c) - C_n(T_c)]$ is proportional to T_c is obtained. The same formula seems to apply for some of the organic materials as shown by Mizutani et al. (1976).

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

One consequence of scaling laws of physics is that $\gamma = \gamma'$ (Goodstein 1985, p. 481).

If these results can be carried 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 $(f_+ + f_-)T_c$. Because the melting point (m.p.) represents the dissociation limit for the amino acids, one expects that $(f_+ + f_-)T_c$ is less than $T_{m.p.}$. Mr. P. Agbedjro, to whom thanks are due, has compiled from the 1988–1989 "Handbook of Chemistry and Physics," the following table of the melting points of the amino acids: Ala 568°K, Arg 537°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, and Val 571°K. These numbers uniformly lie between 500°K and 600°K except for Tyr, which is ≈615°K.

This could give 250–300°K if $f_+ = f_- = 1$ [compare the work of Sanchez et al. (1966), cf. Section 8] for one estimate of T_c. However this estimate could vary between a very wide range of values if $f_+ \neq f_- \neq 1$.

5) The present BCS theory applies to the low temperature case. How are the ideas of this theory utilized for the case of high T_c? Our interest is in the critical temperatures for amino acids that 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 take T_c to values as high as 125°K. There is, as yet, no accepted theory (Randjbar-Daemi et al. 1990) 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 that 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 that are retained in the lattice ions. ω_D could be as high as ≈10^{14}K; and (2) an attempt to find a transmitting system of electrons with high polarizability: molecular organic crystals, polymers, for example C_x (where C stands for carbon and x represents a multiple repetition of the group). Unfortunately, as far as high T_c superconductivity is concerned, neither

of these two suggestions have proven very effective in increasing T_c to higher values.

Appendix C

To proceed for the case of amino acids from these expressions is not that easy: the difficulties in carrying this program through are recounted below.

Section C.1

For the amino acids, let us take an expression for T_c that is similar in form to the expression for superconductivity $T_c = \Delta E \exp(-1/\lambda)$. "$\Delta E$ 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, and ΔE is related to ω_D, and $\lambda \propto gv$. Let us designate $\exp(-1/\lambda)$ as the probability factor for the transition A to A^* to take place. The major problem will be to secure $gv \approx 1$ so that this probability factor is not too small.

1) A nonperturbative calculation like the one used by Sakita (1985) is needed for the case of superconductivity but for attractive parity-violating interactions. The difficulty in this case lies in choosing what the analogy is for the Fermi energy.

2) The electrons in the inner shells of atoms are probing much more deeply into the quark structure of the nucleon. In Appendix B such electrons were observed to give rise to 10^{20}°K in the superconductivity case. Chemical phenomena are probing deeply into the centers of nucleons (and the quarks within them), the energies involved being much higher than one is used to.

3) $gv \approx 1$ may be difficult to achieve. Because $\lambda \propto gv$ the fact that $gv \neq 1$, in general, may mean a diminution of probability represented by $\exp(-1/\lambda)$.

Section C.2

There is another possibility, that is, to consider the relativistic term $\bar{n}\gamma_\mu n \times \bar{e}\gamma_\mu\gamma_5 e$. This term does not have the factor $(1 - 4 \sin^2\theta)$ in front of it.

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 a field φ' can be invented that could have the effective coupling $[\varphi' \times (\bar{n}e + \bar{e}\gamma_5 n)]$. From the calculations previously made (Mason and Tranter 1984; Tranter and MacDermott 1989), for this particular case if $T_c \approx \omega_D \exp(-2/g'v')$ and if $g'v' \approx 1$, ω_D can be taken as 3×10^{-18} eV.

What field does φ correspond to? Clearly an $\bar{e}$–n pairing (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 off by a grand unification mass $\approx 10^{14}$–10^{15}GeV or does it rely upon the work of Rubakov and his collaborators (Kuzmin et al. 1985; Arnold and McLerran 1987; Ringwald 1990), which ascribes baryon violation to the standard model with $\langle\varphi\rangle = 250$ GeV? In other words is $\langle\varphi\rangle = \langle\varphi\rangle'$? I would tend to favor this, but this does bring us to the modern unresolved controversies that are the substance of present-day theoretical particle physics.

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

Section 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, $T_c \geq 350$°K. This would mean that the Earth suffices for the production site of amino acids, in general. This is a possibility that should not be ignored if laboratory tests are made for amino acids in accordance with what is suggested in Section 9.]

All that may reasonably be inferred at this stage is the existence of a nonzero T_c due to the attractive forces mentioned before.

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

$$T_c \approx \frac{\langle\varphi\rangle}{10^3} \exp[-2/gv(1 - 4 \sin^2\theta)] \approx 2.5 \times 10^{20}\text{K} \qquad \text{(C.1)}$$

Here ΔE is taken to be $\approx\langle\varphi\rangle$ multiplied by the old familiar factor of 10^{-3}, while gv is still taken ≈ 1. The exponential factor gives $\exp -26 \approx 10^{-10}$, so that altogether one has $10^{-13} \times \langle\varphi\rangle$.*

Because the only quantity that 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 that have been set up.

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 one takes $\omega_D \approx m_e \approx 2 \times \frac{\langle\varphi\rangle}{10^6}$.

Appendix D

After this paper was completed, Dr. J. Chela-Flores provided the following quotation to be inserted into the text. I 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 (Delbrück 1963). Within the context of the origin of life, condensation was conjectured to occur in the earliest riboorganism (Chela-Flores 1985)

* This is such an important point that I shall discuss it further in a separate note to be published in a physics journal. The top quark is necessary to get $gv = 1$. The reason for this is that g contains m_t^2, which is of the order of m_w^2.

under the effect of low temperatures estimated to be approximately 160°K.

Regarding the laboratory tests mentioned in the text, I 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.

Appendix E consists of four clarifications that occur in places in the text.

Appendix E

1) 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 behavior has been attributed in the past to presolar cosmic abundances. 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" (Chyba et al. 1990). This pathway reportedly supports the hypothesis of a direct relationship between organic-rich interstellar grains, comets, dark asteroids, and carbonaceous chondrites (Cruikshank 1989). It is clearly important to get the precise ratios of D/H, tritium/hydrogen, as well as C^{13}/C^{12} 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 (Engel et al. 1990); these authors conclude that optically active materials were present in the early solar system before life began.

2) Such extraterrestriality had been anticipated on different grounds. Some 40 years ago, Stanley Miller performed fundamental experiments demonstrating that the action of electrical discharges on a mixture of water vapor, 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!" (Orò 1961; Ponnamperuma and Molten 1973; Mitton 1977; Hanel et al. 1979a; Orò and Mills 1989; Orò et al. 1990b). 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" (Orò et al. 1990b). [Triton's surface temperature apparently is $\approx 38 \pm 4$°K (Soderblom et al. 1990).]

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

4) 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. I find that amino acid crystals have been made with nickel, iron, or copper, for example, crystals of silver glycine $AgOOC\text{-}CH_2\text{-}NH_2$ or copper DL-α-aminobutyrate $Cu(OOC \cdot C_2H_4NH_2)_2$ (Wyckoff 1966).

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PHYSICS LETTERS B

Chirality, phase transitions and their induction in amino acids

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"Atoms such as carbon, oxygen, nitrogen and hydrogen, the major constituents of biological molecules, are less than 0.4 nm in diameter.... The behaviour of small molecules is a reflection of the intrinsic properties of the constituent atoms. Hence it might be expected that the behaviour of large macromolecules can be explained by a knowledge of atomic properties. Since organelles, whole cells and organisms are essentially macromolecular assemblies, it may be possible in time to derive an atomic theory of life" [A.R. Rees and M.J.E. Sternberg, From cells to atoms – An illustrated introduction to molecular biology (Blackwell, Oxford, 1984) p. 3]. It has been suggested that chirality among the twenty amino acids which make up the proteins may be a consequence of a phase transition which is analogous to that due to BCS superconductivity [A. Salam, J. Mol. Evol. 33 (1991) 105]. We explore these ideas in this paper and show, following Lee and Drell [I.H. Lee and S.D. Drell, in: Fermion masses in the standard model, M.A.B. Bég Memorial Volume, eds. A. Ali and P. Hoodbhoy (World Scientific, Singapore, 1991) p. 13], that a crucial form for the transition temperature T_c involves dynamical symmetry breaking. The t-quarks or supersymmetry (or something similar which ensures a heavy mass) appear to be essential if such mechanisms are to hold.

1. The T_c for BCS superconductivity for metals is of the form $\omega \exp[-2/g_{\rm eff}\sigma(0)]$. We conjectured that a similar formula may hold for the case of amino acids chains. In the present paper we shall explore this further.

First, let us review the subject of BCS superconductivity. The best treatment, which I know of has been given by Sakita [1], following on the work of Ginsberg and Landau [2] and of Gorkov [3].

The idea is to start from the Feynman lagrangian methodology of writing down the BCS theory for the superconducting electronic system. One tries to write down the equivalent Ginzburg–Landau equation. From this equation is deduced the value of temperature T_c.

2. The BCS hamiltonian is given by

$$H = H_0 + H_1 ,$$

$$H_0 = \sum_{s=\uparrow\downarrow} \int \mathrm{d}x\, \psi_s^+(x) \left(\frac{2}{2m}(-\nabla) - \mu \right) \psi_s(x),$$

$$H_1 = -g_{\rm eff} \int \mathrm{d}x\, \psi_\uparrow^+(x) \psi_\downarrow^+(x) \psi_\downarrow(x) \psi_\uparrow(x) , \tag{2.1}$$

where $g_{\rm eff}$ is an attractive coupling constant between spin up ($\uparrow$) and spin down ($\downarrow$) electrons and antielectrons is the chemical potential. *The sign of $g_{\rm eff}$ is part of the assumption* of the hamiltonian which signifies an attractive force between Cooper-paired systems of electrons consist of one of the particles being replaced by its antiparticle with a factor of two which appears in the mass term.

We can introduce electro-magnetic interaction in a gauge-invariant way by the minimal substitution

$$\nabla \to \nabla - \mathrm{i}eA ,$$

and treat the vector potential $A(x)$ as an external source. Then, in general, the hamiltonian equals

$$H=\sum_{s=\uparrow,\downarrow}\int \mathrm{d}\boldsymbol{x}\,\psi_s^+(\boldsymbol{x})\left(-\frac{1}{2m}(\nabla-\mathrm{i}e\boldsymbol{A})^2-\mu\right)\psi_s(\boldsymbol{x})-g_{\mathrm{eff}}\int \mathrm{d}\boldsymbol{x}\,\psi_\uparrow^+(\boldsymbol{x})\psi_\downarrow^+(\boldsymbol{x})\psi_\downarrow(\boldsymbol{x})\psi_\uparrow(\boldsymbol{x})\,, \tag{2.2}$$

which is invariant under gauge transformations:

$$\psi_s(\boldsymbol{x})\to\exp[\mathrm{i}e\Lambda(\boldsymbol{x})]\psi_s(\boldsymbol{x}),\quad \boldsymbol{A}(\boldsymbol{x})\to\boldsymbol{A}(\boldsymbol{x})+\nabla\Lambda(\boldsymbol{x})\,. \tag{2.3}$$

The partition function based on the appropriate lagrangian corresponding to the above hamiltonian is given by

$$Z=\int \mathrm{D}\psi\,\mathrm{D}\bar{\psi}\exp\left[-\int_0^\beta \mathrm{d}\tau\int_V \mathrm{d}\boldsymbol{x}\,\bar{\psi}_s\left(\frac{\partial}{\partial\tau}-\frac{1}{2m}(\nabla-\mathrm{i}e\boldsymbol{A})^2-\mu\right)\psi_s\right],$$

where we have written a non-relativistic equation for the fermion (electron) ψ in the theory:

$$\exp\left(g_{\mathrm{eff}}\int_0^\beta \mathrm{d}\tau\int_V \mathrm{d}\boldsymbol{x}\,\bar{\psi}_\uparrow(\boldsymbol{x})\bar{\psi}_\downarrow(\boldsymbol{x})\psi_\downarrow(\boldsymbol{x})\psi_\uparrow(\boldsymbol{x})\right). \tag{2.4}$$

Note that the sign before g_{eff} has changed to plus g_{eff} instead of minus g_{eff} in the hamiltonian formulation. This is because $\Delta H=-\Delta L$ for the case of potentials which do not contain time derivatives of the fields themselves. The four-fermion interaction can be expressed in terms of a complex auxiliary Higgs scalar field ϕ:

$$\frac{1}{C}\int \mathrm{D}\phi\,\mathrm{D}\phi^*\exp\left(+\kappa^2\int \mathrm{d}^4x\,\phi^*\phi+g_{\mathrm{eff}}^{1/2}\kappa\int \mathrm{d}^4x(\bar{\psi}_\uparrow\bar{\psi}_\downarrow\phi+\psi_\downarrow\psi_\uparrow\phi^*)\right), \tag{2.5}$$

where we have used the notation

$$\int \mathrm{d}^4x\equiv\int_0^\beta \mathrm{d}\tau\int_V \mathrm{d}^3\boldsymbol{x}\,. \tag{2.6}$$

The constant C is given by

$$C=\int \mathrm{D}\phi\,\mathrm{D}\phi^*\exp\left(+\kappa^2\int \mathrm{d}^4x\,\phi^*\phi\right), \tag{2.7}$$

where κ is a constant with dimension of mass. We shall introduce a source for the ϕ field in the form

$$Z[j,j^*]=\frac{1}{C}\int \mathrm{D}\psi\,\mathrm{d}\bar{\psi}\,\mathrm{D}\phi\,\mathrm{D}\phi^*\exp\left[-\int \mathrm{d}^4x\,\bar{\psi}_s\left(\frac{\partial}{\partial\tau}-\frac{(\nabla-\mathrm{i}e\boldsymbol{A})^2}{2m}-\mu\right)\psi_s\right]$$

$$\times\exp\left(+\kappa^2\int \phi^*\phi\,\mathrm{d}^4x+g_{\mathrm{eff}}^{1/2}\kappa\int \mathrm{d}^4x(\bar{\psi}_\uparrow\bar{\psi}_\downarrow\phi+\psi_\downarrow\psi_\uparrow\phi^*+j^*\phi+\phi^*j)\right). \tag{2.8}$$

The partition function is given by

$$Z=Z[j,j^*]|_{j=j^*=0}\,. \tag{2.9}$$

The action which has appeared in (2.8) is $L\,\mathrm{d}\tau$ where

$$L=L_0+L_1\,, \tag{2.10}$$

$$L_0=\int \mathrm{d}\boldsymbol{x}\left[\bar{\psi}_s\left(\frac{\partial}{\partial\tau}-\frac{\nabla^2}{2m}-\mu\right)\psi_s+\kappa^2\phi^*\phi\right], \tag{2.11}$$

$$L_1 = \int \mathrm{d}\boldsymbol{x}\left(-\frac{\mathrm{i}e}{2m}\left[\bar{\psi}_s \nabla\psi_s - (\nabla\bar{\psi}_s)\psi_s\right]\boldsymbol{A} + \frac{e^2}{2m}\bar{\psi}_s\psi_s\boldsymbol{A}^2 + g_{\mathrm{eff}}^{1/2}\kappa(\bar{\psi}_\uparrow\bar{\psi}_\downarrow\phi + \psi_\downarrow\psi_\uparrow\phi^*)\right). \tag{2.12}$$

Using the temperature dependent Fourier decomposition

$$\psi_s(\boldsymbol{x}, \tau) = (\beta V)^{-1/2}\sum_{\boldsymbol{k}} \psi_s(\boldsymbol{k}, n)\exp[\mathrm{i}(\boldsymbol{k}\cdot\boldsymbol{x} - \xi_n\tau)]\,, \tag{2.13}$$

we obtain the free action

$$\int_0^\beta \mathrm{d}\tau\, L_0 = \sum_{\boldsymbol{k},n}\left[\bar{\psi}_s(\boldsymbol{k}, n)(-\mathrm{i}\xi_n + \omega_k)\bar{\psi}_s(\boldsymbol{k}, n) + \kappa^2\bar{\phi}^*(\boldsymbol{k}, n)\bar{\phi}(\boldsymbol{k}, n)\right]. \tag{2.14}$$

Therefore, the propagator of the electron with four momentum $(\boldsymbol{k}, n)$ is given by

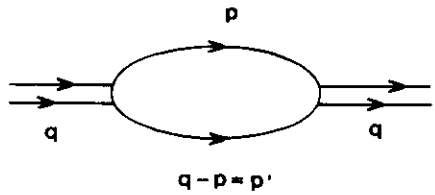
$$\frac{1}{\omega_k - \mathrm{i}\xi_n}, \quad \omega_k = \frac{\boldsymbol{k}^2}{2m} - \mu, \quad \xi_n = \frac{\pi}{\beta}(2n+1)\,, \tag{2.15}$$

and the propagator of ϕ by

$$\frac{1}{\kappa^2}\,. \tag{2.16}$$

Notice that the propagator of ϕ to this order does not depend on four momentum, because the lagrangian (2.11) does not contain the kinetic energy term.

3. *Calculation of the loop diagram.* We shall compute one-loop diagram with two external ϕ-lines. The (temperature dependent) leading terms are



$$\mathbf{q}_0 = 0 \quad = \frac{g_{\mathrm{eff}}\kappa^2}{\beta V}\sum_{n,\boldsymbol{p}}\frac{1}{(\mathrm{i}\xi_n - \omega_p)(-\mathrm{i}\xi_n - \omega_{p'})} = A + B\boldsymbol{q}^2 + \ldots\,, \tag{3.1}$$

where

$$A = \frac{g_{\mathrm{eff}}\kappa^2}{\beta V}\sum_{n,\boldsymbol{p}}\frac{1}{\xi_n^2 + \omega_p^2} = \sum_n \frac{g_{\mathrm{eff}}\kappa^2}{\beta}\frac{1}{(2\pi)^3}\int \mathrm{d}^3\boldsymbol{p}\,\frac{1}{\xi_n^2 + \omega_p^2}\,. \tag{3.2}$$

Introducing density of states $\sigma(\omega)$ from the ansatz

$$\frac{1}{(2\pi)^3}\int \mathrm{d}^3\boldsymbol{p} \equiv \int \mathrm{d}\omega_p\,\sigma(\omega_p)\,, \tag{3.3}$$

we get

$$A = \sum_n \frac{g_{\mathrm{eff}}\kappa^2}{\beta}\int_{-\infty}^{\infty}\frac{\mathrm{d}\omega\,\sigma(\omega)}{\xi_n^2 + \omega^2} \approx \sum_n \frac{g_{\mathrm{eff}}\kappa^2}{\beta}\sigma(0)\int_{-\infty}^{\infty}\frac{\mathrm{d}\omega}{\xi_n^2 + \omega^2}\,, \tag{3.4}$$

where $\omega_p = p^2/2m - \mu = 0$ is the Fermi surface and we have approximated by using density of states at the Fermi surface by putting a cut-off $n_{\max}$

$$\omega_{\mathrm{D}} = k_{\mathrm{B}}\,T\pi(2n_{\max} + 1)\,. \tag{3.5}$$

Thus

$$A = g_{\text{eff}}\kappa^2\sigma(0)\ln\frac{4\gamma\omega_D}{\pi k_B T}, \quad \gamma = \text{the Euler constant}. \tag{3.6}$$

The coefficient of $|\phi_c|^2$ terms $\Gamma[\phi_c, \phi_c^*]$ is then

$$\kappa^2\left(1 - g_{\text{eff}}\sigma(0)\ln\frac{4\gamma\omega_D}{\pi k_B T}\right)\phi_c^*\phi_c . \tag{3.7}$$

The expression within the brackets gives the critical temperature as

$$T_c = \frac{4\gamma\omega_D}{\pi k_B}\exp\left(-\frac{1}{g_{\text{eff}}\sigma(0)}\right). \tag{3.8}$$

Note that the terms appearing before the logarithm in (3.7) appear in the exponent while terms which are arguments for the log appear as $A_D\omega$ in the formula for T_c.

Since the Higgs mechanism is the relativistic version of the above, one may write the entire calculation of one-loop diagrams as well as the calculation of T_c in the form of corrections to the calculation of mass of the Higgs field. We shall adopt this procedure with slight variations.

4. The point we wish to make is summarized by (3.8) which has the form $A\omega_D \exp[-2/g_{\text{eff}}\sigma(0)]$. In order that the exponential factor does not present too much of a restriction $1/g_{\text{eff}}\sigma(0)$ should be of the order of unity. This gives $T_c \approx (\gamma\omega_D/\pi k_B)\exp(-2)$.

Before proceeding, we shall make some remarks about the amino acids. The crystalline structure of amino acids is characterized by the graph shown in fig. 1.

Apart from the N terms, here R_1 to R_4 are the residues which specify the amino acid concerned. The peptide bond which gives rise to proteins is formed, for example, where the molecules of water are consistently expelled and the lattice structure is reduced to the simple form

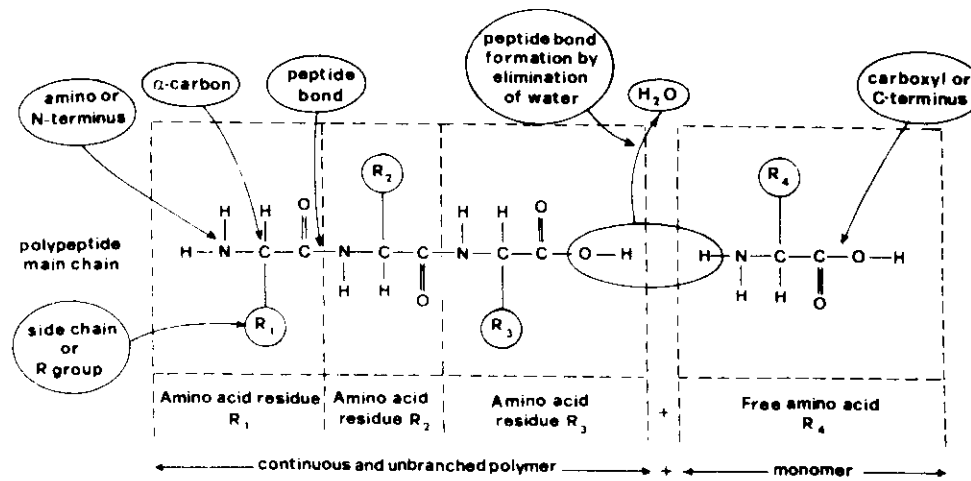
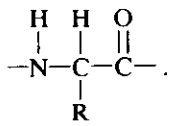


Fig. 1. This diagram is taken from ref. [4].



The hydrogens give up their loose electrons and act as metallic hydrogens. (Superconductivity has been established for a similar case by Carr [5].)

5. *Helicity and chirality of the matter fields* [#1]. Let us review the definition of chirality, which is the eigenvalue of γ_5, with $\gamma_5 = +1$ corresponding to right-handedness, and $\gamma_5 = -1$ to left-handedness:

$$\gamma_5 R = R, \quad \bar{R}\gamma_5 = -\bar{R}, \qquad \gamma_5 L = -L, \quad \bar{L}\gamma_5 = \bar{L}, \tag{5.1}$$

where R, L are Dirac spinors with only two independent components. They may be obtained from a four-component Dirac spinor ψ by the following projections:

$$R = \tfrac{1}{2}(1+\gamma_5)\psi, \quad \bar{R} = \tfrac{1}{2}\bar{\psi}(1-\gamma_5), \qquad L = \tfrac{1}{2}(1-\gamma_5)\psi, \quad \bar{L} = \tfrac{1}{2}\bar{\psi}(1+\gamma_5)\,. \tag{5.2}$$

For later applications, it is important to note that

$$\bar{\psi}\psi = \bar{L}R + \bar{R}L, \quad \bar{\psi}\gamma^\mu\psi = \bar{L}\gamma^\mu L + \bar{R}\gamma^\mu R\,, \tag{5.3}$$

written as

$$(\alpha\cdot\boldsymbol{p} + \beta m)\psi = E\psi, \quad E = (p^2 + m^2)^{1/2}\,. \tag{5.4}$$

Using the identity $\alpha = \gamma_5\sigma$, and the fact that γ_5 and σ commute, we can rewrite this in the form

$$\sigma\cdot\hat{\boldsymbol{p}}R = \frac{E}{p}R - \frac{m}{p}\beta L, \quad p = |\boldsymbol{p}|, \qquad \sigma\cdot\hat{\boldsymbol{p}}L = -\frac{E}{p}L - \frac{m}{p}\beta R\,. \tag{5.5}$$

These equations become decoupled if $m = 0$:

$$\sigma\cdot\hat{\boldsymbol{p}}R = R, \quad \sigma\cdot\hat{\boldsymbol{p}}L = -L\,. \tag{5.6}$$

Therefore, for massless Dirac particles, chirality is the same as helicity, for antiparticles, chirality is the opposite of helicity. [An antiparticle has the same chirality as the particle, by definition; but it has the opposite helicity due to a change in the sign of E in (5.4).]

A conventional mechanical mass term in the lagrangian density cannot be invariant under SU(2), because it is proportional to $\bar{\psi}\psi = \bar{L}R + \bar{R}L$. Therefore, in this theory the electron mass can arise only by virtue of a spontaneous breakdown of SU(2). A convenient way to implement this is to introduce a doublet Higgs field

$$\phi = \begin{pmatrix} \phi_+ \\ \phi_0 \end{pmatrix}, \tag{5.7}$$

where the subscripts refer to the electric charges. The mass term is

$$\mathcal{L}^{\text{mass}} = \vartheta\left(\bar{L}\phi R + \bar{R}\phi^\dagger L\,\frac{\rho}{\rho_0}\right), \tag{5.8}$$

where $\bar{L}\phi$ is an SU(2) singlet, and a Dirac spinor. If ϕ has non-zero vacuum value, then for low excitations and $\rho = \rho_0$, (5.8) is indistinguishable from a conventional mass term.

The Weinberg–Salam model is obtained by gauging SU(2)×U(1), generated by weak hypercharge.

[#1] This chapter is taken essentially from the book of Huang [6].

With these, the covariant derivative can be written in the form

$$D^{\mu}=\partial^{\mu}+ig(W_1^{\mu}t_1+W_2^{\mu}t_2)+ieQA^{\mu}+ieQ'Z_{\mu}\,. \tag{5.9}$$

Electric charge $=eQ$, $Q=\tau_3+\tau_0$ where the neutral charge matrix Q' is defined by

$$eQ'=\tau_3\cot\theta_w-\tau_0\tan\theta_w\,. \tag{5.10}$$

Here τ_0 is the singlet matrix among τ_0, τ_1, τ_2, τ_3, while $Q=\tau_3+\tau_0$.

To study the masses of the gauge fields, it is convenient to go to unitary gauge [#2], in which

$$\phi=\begin{pmatrix}0\\ \rho/\rho_0\end{pmatrix}, \tag{5.11}$$

where ρ/ρ_0 is a real field.

In terms of fields in the unitary gauge, the lagrangian density is

$$\mathscr{L}=-\tfrac{1}{4}(\boldsymbol{G}\cdot\boldsymbol{G}+\boldsymbol{H}\cdot\boldsymbol{H})+\tfrac{1}{4}g^2\rho^2\left(W_1^2+W_2^2+\frac{Z^2}{\cos^2\theta_w}\right)+\partial\rho\cdot\partial\rho-\lambda(\rho^2-\rho_0^2)^2\,. \tag{5.12}$$

Rewrite in the unitary gauge, where η is the real Higgs field in unitary gauge, in which $\phi(x)$ has the form (5.12) and

$$\rho(x)=\rho_0+\eta(x)\,. \tag{5.13}$$

6. To compute any further, we must guarantee the g_{eff} in the effective lagrangian is a positive number corresponding to attraction. Further, the proton left behind migrates to the nitrogen so that the Z^0 meson before being annihilated gives rise to an interaction between the quarks contained inside the proton and inside the nitrogen. (That it has to be nitrogen rather than the carbon (next door) is empirically guaranteed by the "right" configuration which is imparted to the corresponding molecule which contains sugars [#3] and no nitrogens [#4].)

To consider Z^0 containing part of the lagrangian, write it as

[#2] We should in fact have a triplet of fields

$$\begin{pmatrix}W^+\\ Z^0\\ W^-\end{pmatrix}\qquad W^+=W_1-\frac{iW_2}{\sqrt{2}}\,,$$

likewise $W^-=W_1+iW_2/\sqrt{2}$ belonging to a vector representation of the internal group SU(2), while the Higgs particles are a complex $\frac{1}{2}$ representation of the same group SU(2). We have neglected W^+ and W^- throughout this paper because their contribution is small at low momenta.

[#3] We may consider 2, 8, 20, 28, 50, 82 and 126 as "magic numbers" for nuclei, provided spin–orbit coupling is taken into account. (See ref. [7].) Nuclei containing 2, 8, 20, 28, 50, 82 or 126 neutrons or protons are particularly stable. The detailed evidence supporting this point of view is discussed in ref. [8] with the fact of 20 coming out naturally. Goeppert Mayer goes on to consider in detail the protons and neutrons and the spin–orbit couplings in terms of a potential energy which has a shape somewhat between that of a square well and a three-dimensional isotropic oscillator. (See table 1.)

[#4] The discussion from now on is not exclusively relevant to the rest of this paper. The problem for the usual quark model is to see if the Pauli principle holds for quark assignments. This means that in the final analysis the quark model which substitutes quarks for nucleons will have quark spheres of influence reduced depending on the number of colours. This implies that certain discrepancies in the nucleon model are removed when quarks are taken into account. These discrepancies, for example, concern the spin of ${}_{11}Na^{12}$. The magnetic moment of this nucleus would indicate $p_{3/2}$ rather than $d_{3/2}$ orbit. That these considerations have something new to tell us is an important point in its favour. (We would urge very strongly that parity violation among the proteins used by this mechanism should be further examined in order that the Z^0 and its decay are properly considered.)

Table 1

Oscillator number	Square well	Spectral term	Spin term	Number of states	Shells	Total number
0	1s	1s	$1s_{1/2}$	2	2	2
			$1p_{1/2}$	4		
1	1p	2p	$1p_{3/2}$	2	6	8
	1d	3d	$1d_{3/2}$	6		
2			$1d_{3/2}$	4	12	
	2s	2s	$2s_{1/2}$	2		20

$$L_{\rm int}(Z^0)=\frac{eZ^0}{\sin\theta\cos\theta}\left[\left(T_{3\rm L}-\sin^2\theta J_{\rm em\,L+R}\right)\right]. \tag{6.1}$$

Here $J_{\rm em}$ is the electromagnetic current, $T_{3\rm L}$ is the left-handed third component of the weak isospin consisting of the (anomaly-free) combination of the proton and neutron (p, n), (or the quarks inside the proton or the neutron). Z^0 here requires a mass because of the spontaneous symmetry breaking implied by the last equation.

$$L^{\rm mass}=g_{\rm eff}\left[T_{\rm L}^3-(4\sin^2\theta J_{\rm em\,L+R})\right]L_{\rm int}\frac{\rho}{\rho_0}. \tag{6.2}$$

Here $g_{\rm eff}$ is proportional to $(e^2/16\sin^2\theta\cos^2\theta)\eta_{\mu\nu}/(k^2-m_Z^2)$ where $\eta_{\mu\nu}=1,-1,-1,-1$. This is positive provided $m_Z^2\gg k^2$ and we consider the three space-rotation invariant part of the expression above.

We shall take $(1-4\sin^2\theta)\approx\frac{1}{13}$ with the present *empirical value* of the parameter $\sin^2\theta\approx 0.231$. We shall not take this quantity to equal zero as has been done by authors of refs. [8,9] in the hope that the renormalization group will give the "exact" value as $\frac{1}{4}$ (personal communication). We do not believe this will ever happen.

For the mass term we take the ansatz, as the symmetry breaking which is given by eq. (2.4), which follows on from (2.5) and (2.7) where κ is a constant with dimension of mass. We shall introduce a source for the ϕ field in the form of eq. (2.8). In terms of the quantity ($\langle\varphi\rangle^0=250$ GeV) the electron mass $M_{\rm e}$ turns out to be a very tiny number $\approx 2\times 10^{-6}$. Such a number is large only for the top quark if its mass is in excess of 100 GeV. Thus the term which gives rise to this, looks like $f\varphi\bar{t}_{\rm L}t_{\rm R}$ where $f\geq\frac{2}{5}$. Some physicists (like Y. Nambu) take this as the defining property of the field φ, i.e. φ is considered as a $\bar{\rm t}$t composite.

According to Lee and Drell, a proposal is considered according to which the masses of the fermions in the standard model are determined by dynamical symmetry breaking rather than being introduced as arbitrary parameters in the lagrangian, they are determined self-consistently by the requirement that the proper self-energy vanish the fermion mass shell. They find that in the one-loop approximation it is possible to generate a heavy top quark mass dynamically while the other fermions remain massless [10]. We find that non-zero solutions for $m_{\rm t}$ do exist and they are always greater than 70 GeV for all values of cutoffs $\Lambda=5\,m_z$, $10\,m_z$, $20\,m_z$ and is the only Higgs mass explored in the problem.

One may thus be led to conclude that, while a heavy top quark mass can be generated dynamically, the observed masses of the light fermion cannot be generated in this approach.

Recently, Ruiz-Altaba, Gonzalez and Vargas [11] extended this to a two-loop calculation predicting $m_{\rm t}=124$ GeV, $m_{\rm H}=234$ GeV and the weak mixing angle $\sin^2\theta_{\rm w}\simeq 0.24$.

Our physical motivation is to remove the fermion masses arbitrary parameters of the standard model and treat them as parameters determined by the dynamics in the sub-TeV region. Rather than cancel the divergences, they impose and interpret the standard model $\mathscr{L}$ as an effective lagrangian in order to determine the physical masses. Thus using Sakita's formulation, we get the result

$$T_{\rm c}=\frac{\langle\varphi\rangle}{10^3}\exp\left[-2/g_{\rm eff}\sigma(1-4\sin^2\theta)\right]\approx 2.5\times 10^2\ {\rm K}. \tag{6.3}$$

The exponential factor gives $\exp(-26) \approx 10^{-10}$. Assuming that $\sigma(0) \approx m_Z^2$ we obtain $g_{\text{eff}}\sigma(0) \approx 1$.

7. Now we go on to the supersymmetry case. The symmetry resolves the dilemma of hierarchy. In a theory possessing fermion–boson symmetry because of the presence of both fermionic and bosonic radiative loops, the radiative shifts for scalar fields are not quadratically divergent. In the limit of broken supersymmetry, the shifts in v^2 only depend logarithmically on the cutoff Λ.

To guarantee that $g_{\text{eff}}\sigma(0) \approx 1$, we must take some mass in the theory which is large enough. The simplest mass is obtained by taking supersymmetry such that

$$\phi_0 \to \phi_0 + \alpha[\Delta M^2] \ln \frac{\Lambda}{\phi_0}, \tag{7.1}$$

where ΔM^2 is the mass splitting between supersymmetry fermions and is of order 1 TeV [12] which gives $\Delta M^2/92\, m_z^2 \approx 1$ and thus $g_{\text{eff}}\sigma(0)$ of the order of unity once again.

This paper started with the possibility of defining a science of life based on atomic physics. What we have shown is that if the model is Z_0 it is possible to have the quark instead of the nucleons. The mass of Z_0 is ≈ 100 GeV, while the mass of the quarks is ≈ 200 GeV so that if Z_0 loops are considered the $t\bar{t}$ quarks go through these loops. The g_{eff} which is proportional to $m_{\bar{Z}}{}^2$ then is of the right magnitude to be able to let these quarks make composites which are manifested through their passage through these loops.

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