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Supernova antineutrino interactions cause chiral symmetry breaking and possibly homochiral biomaterials for life

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There is some evidence that non-racemic hydrocarbons occur in meteorites. This would indicate an extraterrestrial origin of the homochirality in living systems (proteins, DNA and RNA). The weak interaction breaks chiral symmetry but a robust process is needed. We propose that an SNII explosion antineutrinos could provide this mechanism in the solar cloud. Pre-simple estimates of this possibility are given here.

Homochirality of Life. For more than a century, there has been evidence for the chiral nature of life forms on Earth. Pasteur was among the first to point this out (1848–1880), and the universal nature of chiral symmetry breaking in DNA and RNA is now very well established for all life forms. Figures 1 and 2 show how the homochirality is manifested at the molecular level.

With the discovery of parity violation in charged current reactions in 1956 and of the weak neutral currents (WNCs) in 1973, two universal symmetry-breaking processes (WNC and β-decay) were uncovered that could have determined the handedness in DNA and RNA. The main problem is the extremely small symmetry-breaking effects ($\Delta E/k_B T \sim 10^{-17}$). However, there are plausible non-linear mechanisms that could have amplified this small symmetry-breaking phase transition up to the full symmetry-breaking level observed in life forms. There is, nevertheless, a long-standing controversy as to whether these non-linear effects are actually large enough to have determined the selection of the handedness of life.[1–11]

For many years, there have been several issues associated with the homochiral structure of biomolecules, as first observed by L. Pasteur in 1848:

(a) Is a homochiral structure necessary for life as we know it?

(b) Did homochirality precede the formation of life (homochiral prebiotic medium hypothesis)?

(c) Is there any reasonable physical mechanism that could have produced the large chiral symmetry breaking the prebiotic medium or in the observed homochiral structure?

(d) Is the homochiral structure an accident that occurred in the biological systems and was later amplified?

(e) Can the homochirality be used as a signature for existing or previous living systems in the solar system or other parts of our galaxy?

(f) Are there any experiments than can be carried out now to clarify the origin of homochirality?

Recently, there has been increasing interest in the chiral nature or handedness of biomolecules. In fact, there are some who claim that the complex biomolecular structure of life must have arisen from a ‘chiral pure’ medium[12,13] and may be a precondition for the emergence of self-replicating biomolecular systems. Table 1 lists some of these ideas, which have been put forward largely by W. Bonner and V. Goldanskii.[12,13] We also point out a recent review[14] (see also ref. 15 for more recent details). This concept, combined with the likelihood that the period on Earth for life to have originated seems to be sometime between 3.8 and 3.5 billion years ago, leaves a small window of 300 million years or less for life to have emerged from the prebiotic medium. Indeed, some speculate that the time could be less than 10 million years.

We now turn to the experiments that study possible asymmetry processes. Over the past 20 years, many experiments have been carried out (see ref. 12 for a nearly complete list). However, it appears that nearly every positive effect that was observed has turned out to be incorrect. In Table 2, we list experimental results that are not yet refuted or in direct conflict with previous null effects. The observation that circularly polarised light destroys L and D isomers selectively (Table 2, entry 1) is now well established.

The other experiment to which we will refer is that of entry 2 (Table 2), the study of Cherenkov light in L or D material with chiral e^- (β-decay).[20] The authors claim an effect of perhaps

Table 1

1. DNA: Self replication would not work with heterochiral systems (50% L and 50% D).
2. Errors in DNA replication: Without a pure chiral structure, the error rate in replication would be unacceptable to long-lived systems (higher animal forms, trees *etc*.).
3. In a prebiotic medium: Homochirality must have been either
   (A) established in a very short time on earth (≤ 100 Myr), or,
   (B) existed in ISM organic materials near the solar system

Table 2 Experiments where a chiral effect has been observed (and not refuted).

Entry	Experiment	Beam/Source	Target	Detection	Comments	Reference
1	CPL on L/D/ photo absorption	UV/keV radiation	DC tartaric acid, DL alanine, DL glutamic acid	Observe destructive difference in one chirality	To be expected from optical activity	Norden[19]
2	e^- target → Č light	p^{32} source and Ca^{137} (no chiral electrons)	*R*- or *S*-PBA	Observe different Č light intensity due to chiral electrons	Effect too large to be due to Č radiation from spin effects	Garay *et al.*[20]
3	Co^{60} → γ + (L,D)	Co^{60} γs	D or L alanine	Observe different amounts of L,D after irradiation	Other experiments did not produce this effect	Akabosh *et al.*[21]
4	Introduction of L/D/ chiral particles	Sr^{90}, Y^{90} β-decay	Y^{90} D or L alanine	Detects effects by electron spin resonance technique	The electron spin resonance may be sensitive to spin dependence	Conte *et al.*[22]
5	Low-energy polarized e^- beam	GaAs polarized source 5 eV	Camphor L,D	Observe different electron polarization and beam attenuation in L/D	At such low energy, asymmetry may be too large	Campbell *et al.*[23]

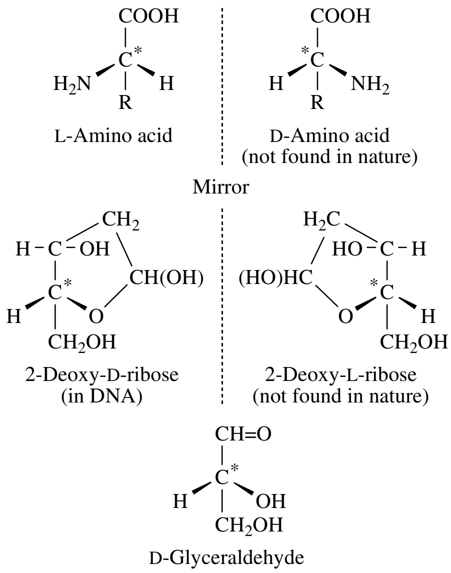
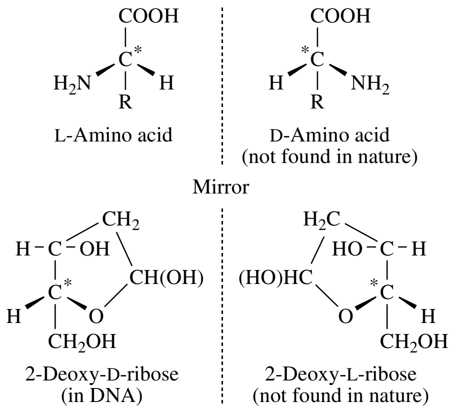


Figure 1 Examples of molecules that are isomers, some of which exist in nature and some that do not.

10^{-2} magnitude. This is, in our belief, far too large an effect, but a future study of Cherenkov radiation from L or D materials with polarised electron beams could be promising.

In Figure 3, we show the current limits or observations of asymmetry. The e^+ measurement of Gridley *et al.*[18] is a very nice experiment (see also refs. 16 and 17). Our conclusion is that no present experiment has reached the level of sensitivity needed to observe an effect. Therefore, it is premature to count

(*a*) Spatial only



(*b*) Electron spin alignment
(spin–orbit interaction in biological materials)

Possible tests for (*a*) or (*b*) or both:
1. CPL destructive
2. Spin–orbit asymmetry of e* beam interactions

Figure 2 Various components of symmetry breaking in molecules.

out the weak force as a determining factor in the origin of homochirality in life.

Organic Molecules in Space and the Possible Role of Nearby Supernovae and Neutron Stars. One of the main themes of recent attempts to understand life on earth is the likelihood that most of the early organic material on Earth was brought in by comets and asteroids. A nice introduction, from different points of view, to this concept was given elsewhere.[15] There are some interesting 'large numbers' to consider in this regard:

(1) The estimated amount of dust matter in the galaxy is $\sim 10^{-4}$ m_G, or $\leq 10^7$ solar masses, largely in the form of dust grains. A fraction of that material is in the form of organic materials.[26]

(2) It has not been possible to measure the amount of interstellar dust that has accumulated on the Earth (bringing organic material).[27,28]

(3) In a molecular cloud of density 10^4 M cm^{-3} and 1 parsec radius, there could be a complex organic matter equal to 100 solar masses.

(4) The Earth revolves around the galaxy with a period of ~250 million years, and it likely encounters several dense layers of molecular clouds in this trajectory.

(5) It is likely that large quantities of organic material were deposited in the Earth in the first one billion years.

The above information was obtained by the infrared scattering from the dust in the galaxy and by modeling various UV-driven processes here on Earth.[26] Ultraviolet photo processing plays an important role in the organic chemistry of dust particles[27] (see also ref. 28), Figure 4 shows the nature of the dust gram with prebiotic molecules inside.[29]

We discuss here two scenarios where chiral interactions in the ISM could have led to a preponderance of homochiral molecules. These two concepts are outlined in Table 3, with Figure 5 giving a fairly complete description of the hypothesis. The second hypothesis is illustrated in Figure 6, where the possibility of the relative survival of the e± polarization deep within the cloud is also illustrated. Of course, during this time, the effect of the WNC can be driving the system towards a homochiral state.

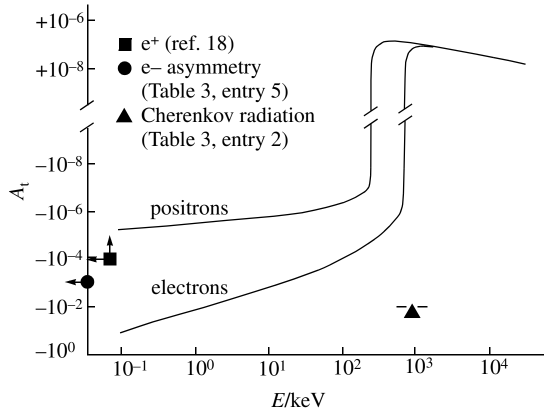


Figure 3 Most recent published calculations of the expected asymmetry for the scattering of e* from chiral molecules.[17] We also include some recent measurements of limits on such an asymmetry.

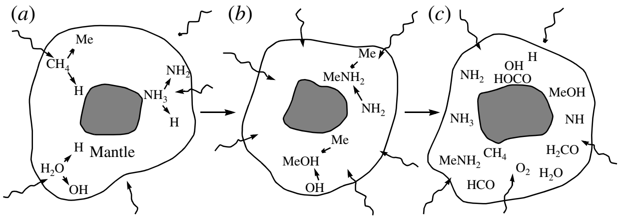


Figure 4 Structure of grains when they initially accrete is inferred from laboratory simulations in which mixtures of water, methane, ammonia and other simple molecules are subjected to UV irradiation at 10 K. Each grain begins as a silicate core that condensed in the atmosphere of a cool giant star. Around this core a mantle of ice forms. Ultraviolet radiation breaks some of the mantle molecules into radicals or reactive molecular fragments (*a*). The radicals can then recombine in new ways (*b*). Over a longer period the continued UV irradiation of the grain can give rise to ever more complex mixtures of molecules and radicals (*c*). Data from ref. 29 and used in the talk of M. Greenberg at the Homochirality Symp., Santa Monica, 1995.

Let us consider the rate of these three effects:

(1) For $\bar{\nu}_e$ absorption and a supernova 1 parsec away (or inside a 1-parsec dense cloud), the number of interactions will be ~10^{-3} per 1 kg of material for 100 M_O of organic material (which would be 10^{12} g of organic matter that is active), therefore, the positron from the $\bar{\nu}_e$ interactions would lose energy at a rate of 10^{-19} MeV cm^{-1} and thus travel over a parsec ($\bar{\nu}_e$ is an antielectron neutrino).

(2) For the coherent $\nu_x + N \rightarrow \nu_x + N$ and for the carbon in the hydrocarbons, we would have ~10^2 more or ~10^{14} g of active material. Note that ν_x stands for all types of neutrinos. This effect could be very important in light of the small energy difference that separates L and D molecules and the possibility of large coherent effects.

(3) For the Al^{26} over the half-life, there would be ~10^{50} decays producing ~10^{50} positrons that lose energy at a rate of 10^{-19} MeV cm^{-1}; for MeV positrons, the range of which would be of order of a parsec (ignoring possible magnetic-field effects).

(4) Direct interaction of the supernova II neutrino.

Consider the example where 0.001 M_O of Al^{26} is produced and assume (M_O is the mass of the sun), for simplicity, that the energy of the e^+ is 1 MeV and is contained in the gas cloud. Assume that the cloud has a density of 10^4 atoms cm^{-3} and that 10^{-3} of the atoms are organic, then the stopping power for e^+ will be

$$dE/dx \sim \text{MeV g}^{-1}\,\text{cm}^{-3}$$

and for a density of $\rho = 10^4$ atoms cm^{-3} ~ 10^{-17} g cm^{-3}, we find

$$dx \sim (\text{MeV}/\rho)dE \sim 10^{19}\,\text{cm}\ (\sim 3\ \text{parsec})$$

and for an average energy exchange of 10 eV, we have

$$10^5_e\ \text{collisions/A}l^{26}\ \text{decay}$$

For 0.001 M_O of Al^{26} and 10^{-3} organic fraction, we obtain a total of ~10^{50} collisions of polarised positrons with organic materials in the cloud assuming all of the e^+ stop in the cloud. (We assume that only one of the collisions can result in spin exchange). There will also be the same order of polarised photons from the $e^+e^- \rightarrow \gamma\gamma$ annihilation. It was estimated[17,24]

Table 3 Possible sources of CPL (UV/keV) radiation in dense molecular clouds.

Primodial Soup – Molecular Clouds (ISM)	
1. Synchronotron radiation from neutron stars[12,26]	– CPL helicity depends on position (*i.e.*, above or below star). – In principle, this mechanism works. However, on the 250-Myr orbit around the galaxy, this effect is expected to average out.
2. Radiation from weak interaction processes[30] – injection into molecular cloud	– Processes: supernova II $\bar{\nu}_e$ interaction, Al^{26} from nearby supernovas *etc*. – Because of grain structure, d*E*/d*x* will be very different from that of solids, gases or liquids. – Always gives the same chiral symmetry breaking. – Can act as a chiral impulse along with WNC.

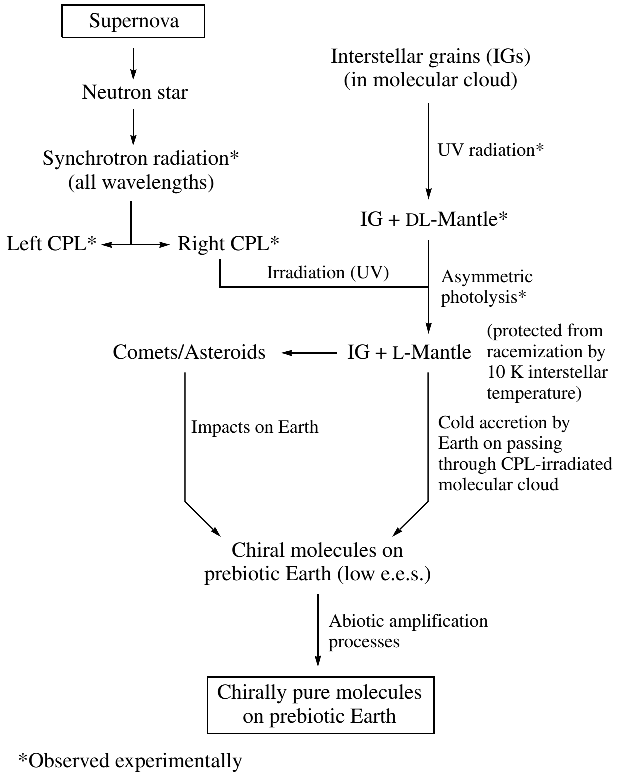


Figure 5 Possible extraterrestrial origin of terrestrial homochirality.

that the asymmetry due to the weak interaction would be of order 10^{-11} to 10^{-6}, depending on the positron energy {it scales like $\alpha^2[\alpha/(v/c)]^2$}. Thus, it takes $N \sim 10^{22}$ interactions for the asymmetric to become statistically important. In this example, there are far more interactions.

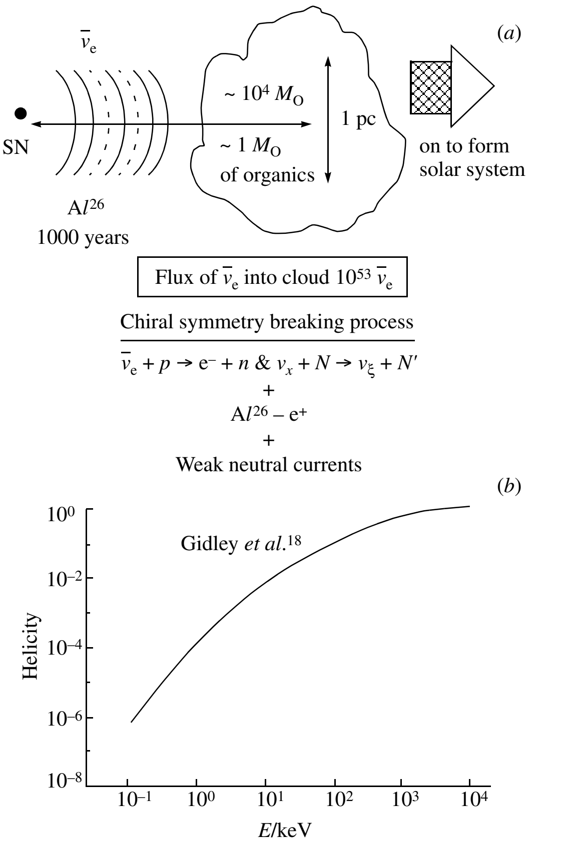


Figure 6 (*a*) Schematic representation of the effect of a supernova II on the organic molecules in a dense molecular cloud. (*b*) Estimated polarization of the β* decay particles as the energy decreases by ionization in H_2O and in the dense molecular cloud. One observation of the polarization of low energy e* by the Michigan group.

Table 4 Estimated rate of ν_e interactions in the dense presolar cloud.

[$N_{\bar{\nu}} \sim 10^{57}$ from SN II][Assume SN 1 parsec from cloud] Assume: cloud density 10^4 protons cm^{-3} [fraction of organic material] 10^{-3} range of e^+ 1 parsec. Number of $\bar{\nu}$ interactives ~ 10^{35} = Number of e^+ for interaction with organics in cloud > 10^{30}. We estimate that only 10^{22} interactives are necessary to produce asymmetry. From this it is clear that this produces a much larger asymmetry.

More recently, we have considered the main effects of an SN II explosion in a hydrocarbon cloud. We estimate that the larger anti-neutrino interaction rate would cause a chirality breaking effect and estimate this effect in Table 4.

It appears that supernova neutrinos could include a chiral symmetry breaking in the ISM that could be transferred to the biomolecules of life. This work was stimulated by very useful conversations with Professor V. I. Goldanskii while he was a Regents Lecturer at UCLA, and I regret his passing (see ref. 5).

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