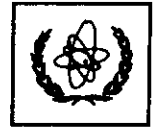


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Introduction to Experimental Aspects of the Origin of Homochirality



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Introduction to experimental aspects of the origin of homochirality

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1. INTRODUCTION

Molecules built up from a given set of atoms may differ in their three-dimensional structure. They may have one or more asymmetric centres that serve as reference points for the steric distribution of the atoms. Carbon atoms, common to all biomolecules, are often such centres. For example, the C_{α} atom between the carboxyl and amino groups in amino acids is an asymmetric centre: looking ON-ward (*i. e. from the carbOxyl group to the amiNo group*) the radical characterizing the amino acid may be to the right (D-molecules) or to the left (L-molecules). 19 of the 20 amino acids occurring in proteins have such a structure (the exception is glycine, where the radical is a hydrogen atom). These pairs of molecules cannot be brought into coincidence with their own mirror image, as is the situation with our hands. The phenomenon has therefore been named *handedness*, or *chirality*, from the Greek word *cheir*, meaning *hand*. The two forms of the *chiral* molecules are called enantiomers or antipodes. They differ in rotating the plane of the polarized light either to the right or to the left. The sense of rotation depends on the wavelength of the measuring light, but at a given wavelength it is always opposite for a pair of enantiomers. Chirality may also occur when achiral molecules form chiral substances during crystallization (for example, quartz forms D-quartz or L-quartz).

Chemical synthesis or natural crystallization always produces equal numbers of the two enantiomers. These are *racemic* mixtures. The *homochirality* of biomolecules means that the most important molecules of living organisms, such as the amino acids and sugars, occur mostly in one form (amino acids in L- and sugars in D-form).

The phenomenon of homochirality was discovered last century by Pasteur who found that bacteria could grow only on one enantiomer of tartaric acids. Understanding the deep meaning of his experiment, he named this phenomenon *dissymmetry* and extended the idea to the whole Universe. It is now known that the dissymmetry of living organisms has its roots in the molecules forming them, as outlined above, and that the specificity of different biochemical reactions demands homochirality. In other words, the present L-amino acid, D-sugar life is a closed circle: a possible opposite system, for example, a D-amino acid, L-sugar system, could exist independently without interference.

Homochirality is such an important property of living systems that it is regarded as a criterion of life, or at least, a criterion of molecules that may form living systems. It has been proposed that, in parallel with the search for extraterrestrial intelligence (SETI), a search should be made for the homochirality of extraterrestrial molecules that may have been the building blocks of living organisms (search for extraterrestrial homochirality, SETH).

Since the middle of last century, when the homochirality of biomolecules became clear, a multitude of papers have dealt with the question of its origin. The problem is surely connected with the more universal problem of how life originated on the Earth. The Earth is known to be 4.5 billion years old. Following its formation., about 500 million years passed

until it cooled down, its crust solidified, the oceans filled up with water, and its primitive atmosphere appeared. There is convincing evidence that living microscopic organisms already existed 3.5 billion years ago. The stromatolites found in Warrawoona, Australia dating from this time display fossils resembling in shape some currently existing microorganisms.

The chemical substances needed for life were produced during the previous 500 million years. This period is the period of *chemical evolution*. The first primitive living systems developed continuously, evolving to yield the present biosphere. The period of *biological evolution* has continued since the time of the appearance of the first living organisms.

Many questions arise in studies of the origin of the homochirality of biomolecules:

- *Did homochirality appear on the Earth during chemical or biological evolution or did it emerge even earlier somewhere else in the Universe and was imported here? What is the timing of the homochirality?*

- *Was homochirality a result of chance or of the action of a certain asymmetric physical agent?*

- *If it appeared by chance, what could be the mechanism leading to such an immense chiral purity?*

- *If it was caused by a physical agent, then which one?*

- *If the effect was small, how was it amplified?*

- *What is the relationship between the origin of homochirality and the origin of life?*

In the following we review the different ideas which seem to be supported by experiments.

2. TIMING OF HOMOCHIRALITY OF BIOMOLECULES

The history of Earth and the life on it is sketched in Fig. 1. The time-data are firmly established by experiments. Firm experimental evidence concerning whether homochirality originated during chemical or biological evolution on the Earth, or elsewhere in the Cosmos, does not exist. Theoretically both cases are possible. There is no experimental evidence that homochirality originated on the Earth during chemical or biological evolution.

A group of scientists think that the building blocks of the biomolecules arrived from the Cosmos. Some meteorites that have fallen on the Earth contain amino acids. Therefore, the Solar System or other parts of the Universe could, in principle, have provided the necessary biomolecules after the formation of the Earth, *via* the frequently arriving comets, meteorites or when the Earth crossed interstellar dust. Only the chirality found in meteorites fallen to the Earth could have been investigated. Because an excess of L-amino acid may be the consequence of contamination the demonstration of the extraterrestrial origin of the amino acids in the meteorite seemed to be important. The method chosen was measurement of the carbon isotope composition of the amino acids defined as

$$\delta^{13}\text{C} = \left[\left(\frac{^{13}\text{C}}{^{12}\text{C}} \right)_{\text{sample}} / \left(\frac{^{13}\text{C}}{^{12}\text{C}} \right)_{\text{standard}} - 1 \right] \times 10^3$$

The value of $\delta^{13}\text{C}$ for early Precambrian organic material is ≈ -25 , and that for the more recent material is $-(10 \text{ to } 15)$, while for the amino acids in the meteorite it is in all cases positive, *e. g.* for L- and D-alanine $+27$ and $+30$, respectively. For this reason the authors consider that the amino acids in question may not be of terrestrial origin. We think that the

negative value of $\delta^{13}\text{C}$ found in the earliest rocks cannot develop from the arriving material with positive carbon isotope ratio.

The instruments on board of the Giotto spacecraft, exploring the Comet Halley registered different biologically important molecules as CH_4 and HCN , H_2CO , and others. In laboratory experiments to imitate the chemistry in grains occurring in interstellar dust, many other organic molecules have been found. The chirality and $\delta^{13}\text{C}$, however, were not measured.

Experiments show that polymerization of chiral molecules occurs with reasonable rate only if the medium is chirally pure. From that we infer that the homochirality should have occurred before the living cells appeared because for that polymers were absolutely necessary.

3. L-, D-LIFE: CHANCE OR CAUSAL

Our present knowledge suggests that the normal chemical syntheses result in racemic mixtures of enantiomers. Simulation experiments to find possible pathways for chemical reactions that produced the building blocks of biopolymers always produce racemates. It is conceivable that L-, D- and D-, L- polymers and finally L-, D- and D-, L-life could have evolved separately. The coexistence of these two systems, however, is impossible. The simplest explanation is that both fought for the same achiral raw material and one of them won. It is appropriate to cite here Einstein, who, discussing these problems with Wald said: "You know, I used to wonder how it comes about that the electron is negative. Negative - positive - these are perfectly symmetric in physics. There is no reason whatever to prefer one or the other. Then why is the electron negative? I thought about this a long time, and at last all I can think was 'It won in the fight!' ". Wald added, "That is just what I think of the L-amino acids. They won in the fight!"

If we accept this the question arises of whether the victory of the electron (or more generally, electron-proton world (matter)), over the positron-antiproton world (antimatter) also determined 1) the victory of L-amino acids and consequently D-sugars or 2) this was a separate fight in which either of the two could win. In case 1) there should be a *physical force* (probably derived from "matter") exerting a chiral influence on organic molecules; in case 2) a *mechanism* leading to homochirality during evolution should be found. We call case 1) *causal*, and case 2) *chance* origin of homochirality. If it is causal and caused by a physical force derived from "matter", then all life in the Universe should be L-, D-life. Naturally, from statistical aspect, the chance processes should result in the same number of living systems of both sorts.

5a

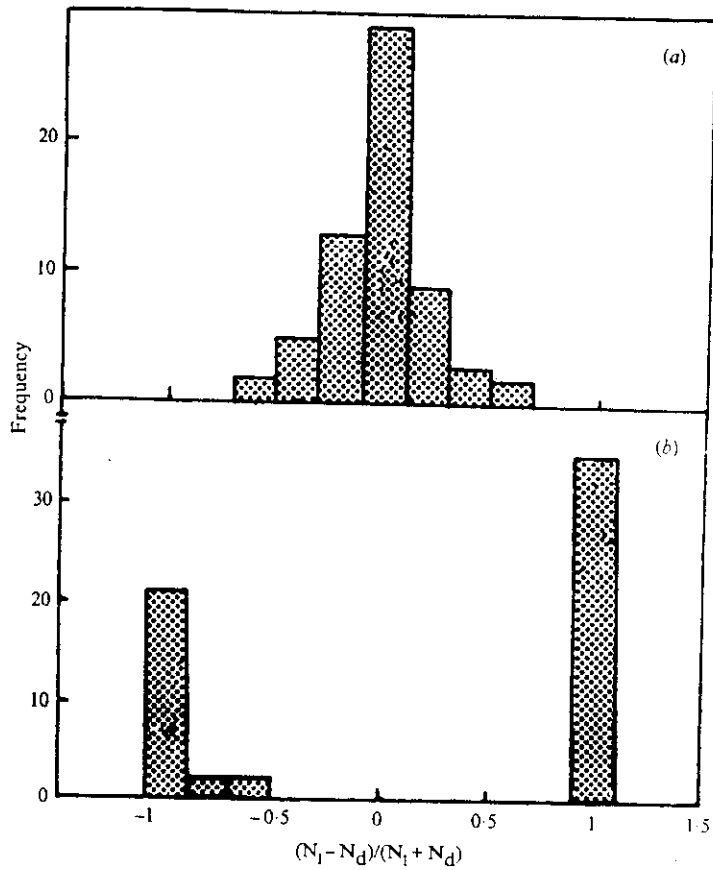


Fig. 1a. Crystallization of NaClO_3 . The histogram in a) shows a Gaussian type distribution of the excess of l- or d-crystals in 63 crystallizations. The histogram b) shows that under stirring either l- or d-crystals are formed. The number of crystallization in this case was 60.

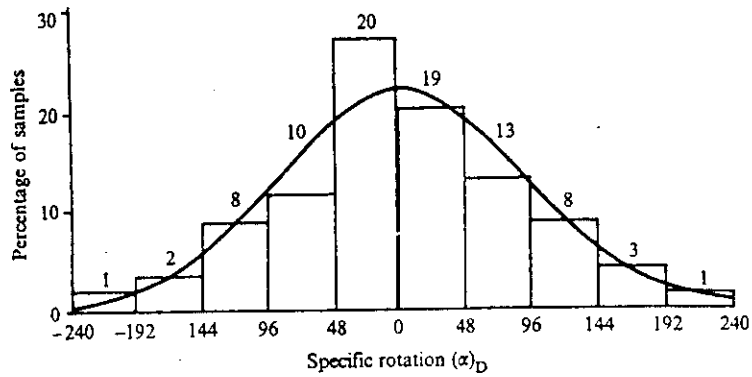


Fig. 1b Percentage of binaphthyl samples giving specific rotation between ± 240 from 200 crystallizations. The curve shows a Gaussian-type distribution.

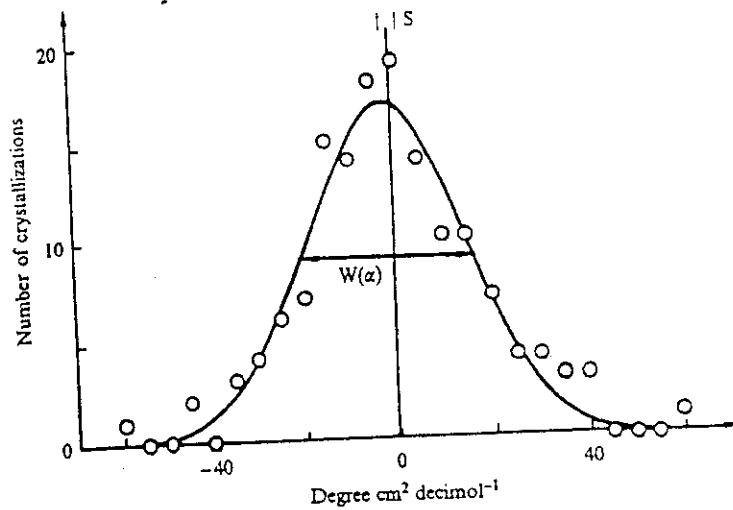


Fig. 1c. Distribution of the crystallizations of tartrate. The curve is a Gaussian fit. $W(\alpha)$ is the width, S the shift of the distribution.

4. MECHANISMS OF CHANCE ORIGIN OF HOMOCHIRALITY

Experiments demonstrate that spontaneous mirror symmetry breaking can occur under readily attainable conditions. Probably the best example is the crystallization of the compound NaClO_3 which itself is not chiral, but which forms chiral crystals. In a simple crystallization L- and D-crystals have grown in the same test-tube together, while in response to stirring only one type of crystals was found. In the latter case, the symmetry was broken in anyone test-tube, but when ≈ 120 crystallizations were performed, the number of L-, and D-crystals were the same within statistical error. In similar experiments, binaphthyl was crystallized ≈ 200 test-tubes and sodium ammonium-tartrate in ≈ 100 test tubes and found a broad but symmetric distribution of L- and D-crystals (Fig. 2).

If it happens that only one side of the distribution is realized than asymmetry appears in such processes. These are supported by well elaborated theories too. The chiral quartz crystals, occurring in Nature everywhere, may have more L- than D-crystals by 1 % (based on analyzing 18000 crystals).

5. MECHANISMS OF CAUSAL ORIGIN OF HOMOCHIRALITY

Since Pasteur's discovery, many ideas have been put forward about physical influences that could direct symmetric chemical syntheses to homochirality. Syntheses which may yield one of the enantiomers in excess are called absolute asymmetric syntheses. Even influences that produce a negligible effect are considered. In such cases amplification mechanisms should follow the synthesis to reach homochirality.

Physical influences may be classified into two large groups: local and universal. Local influences include the asymmetric adsorption of enantiomers on chiral substances, circularly polarized light; and different combinations of electric, magnetic and gravitational fields on the Earth (Table 1). A universal influence is the parity-violating weak force, present everywhere (Table 2).

Global forces

Asymmetric adsorption

The adsorption of amino acids at the surface of chiral crystals is asymmetric. It is well documented that $\approx 1\%$ more L-amino acids than D-amino acids are adsorbed on L-quartz crystals and *vice versa*. Such effects are observed on surfaces of clays as well.

Asymmetric adsorption, though a really existing phenomenon, cannot be regarded as a solution of the origin of the homochirality of biomolecules. It just defers the problem to the question of how the asymmetry of crystals or clays originated.

Circularly polarized light

Many experimental data demonstrate that the irradiation of achiral reactants, or racemic mixtures of chiral molecules with circularly polarized light may induce partial homochirality *via* asymmetric synthesis or decomposition. In the best case, $\approx 1\%$ homochirality can be attained in a synthesis with 100% circular polarization. In decomposition, the homochirality may be much larger, depending on the fraction of the molecules remaining after irradiation. The wave-length of the light should be in the shorter

region, *i. e.* in the deep blue or ultraviolet. Does such circularly polarized light exist now or could it have existed during the early age of the Earth?

The answer is **no**.

Table 1. Global forces

Asymmetric absorption

Circularly polarize light

Electric, magnetic and gravitational fields

Table 2. Universal force

Parity-violating weak interaction

Electric, magnetic and gravitational fields

The electric, magnetic and gravitational fields on the Earth are asymmetric. A static electric field of ≈ 100 V/m with polarity negative at the Earth's surface is a consequence of the cosmic radiation containing positive particles.

The Earth is a huge magnetic dipole; the poles coincide more or less with the North and South Poles. The field lines follow the sphere of the Earth and therefore the field has a horizontal and a vertical component at any point. Thus, there are components parallel (in the northern hemisphere), antiparallel (in the southern hemisphere) and perpendicular to the electric field. The horizontal and vertical components are largest at the Equator and the Poles, respectively. The value of the magnetic field strength is small, in the range of 0.6×10^{-4} Tesla (0.6 Gauss). Its vertical component depends on the latitude. At present, it points downward in the northern hemisphere and upwards in the southern hemisphere. The orientation of the magnetic dipole reversed many times in the Earth's history as shown by the field lines frozen in magnetic minerals.

The gravitational field points to the centre of mass of the Earth. The rotation of the Earth leads to another force, the Coriolis force which acts on moving objects oppositely in the two hemispheres. Possible effects due to the Coriolis force would then cancel. The asymmetric distribution of lands and oceans, if it existed in the early times, could have caused asymmetric synthesis, at least in theory, if the chemical reactions took place, for example, in the oceans.

All the above forces are very weak. There is no immediate observation at present that would indicate any role of these naturally occurring asymmetric forces in the origin of homochirality. Therefore, we have to turn to theoretical considerations and model experiments. It is also important to consider the true and false chirality of the interactions.

Electric and magnetic fields

The electric field and the vertical component of the magnetic field of the Earth are parallel in the northern and antiparallel in the southern hemisphere. Chemical reactions occurring in the atmosphere (not in water because there the electric field is zero) are under the influence of these two fields.

Claims to induce homochirality in parallel and antiparallel electric and magnetic fields in experiments do exist. These data are questioned. Therefore, at present, the size of the asymmetry that might arise in the fields of the Earth cannot be estimated. Moreover, the effects are opposite at the two hemispheres. The asymmetric distribution of the land and water does not help, because the electric field acts only in the atmosphere. Thus, it is improbable that these fields played a role in the origin of homochirality.

Gravitation and rotation

Measurable optical activity of isophoron oxide appeared if it was synthesized in a confined vortex and simple centrifuge. The axis of the rotation was vertical, *i. e.* parallel to the gravitational field. The rate of rotation, however, was $\approx 10^4$ / minute, far from the rotation rate of the Earth.

In another related study, high-speed stirring (540 rpm) of the monomers of D-, L-(- γ -benzylglutamate)-NCA did not lead to measurable asymmetric polymerization. Thus, the origin of homochirality as a consequence of gravitation and the rotation of the Earth seems to

be very improbable. Even more so because the directions of the Coriolis force are opposite in the two hemispheres.

Universal force

The really universal force comes from the parity-violating weak interaction which has two features of interest in connection with the origin of homochirality:

1) The β -particles emitted by the nuclei are polarized in the sense that their spin is parallel (β^+ -decay) or antiparallel (β^- -decay) to the direction of their motion. The degree of this spin polarization is proportional to v/c , v being the velocity of the electron, and c that of light. Our world is composed of matter, and therefore mostly β^- -decays occur in the Universe. It was suggested that the polarized electrons may induce asymmetric molecules in synthesis irradiating achiral reactants or in asymmetric decomposition of chiral molecules.

This idea for the origin of homochirality was suggested soon after the discovery of the parity-violating weak interaction by Vester and Ulbricht. Though the outcome of their experiments was negative many authors have performed similar experiments. It is apt to name such processes Vester-Ulbricht processes.

2) The electromagnetic and weak interactions were unified by the theoretical work of Weinberg, Salam and Glashow in the electroweak interaction. Experiments with elementary particles and with atoms confirmed the theory of electroweak interaction.

An important consequence of the theory is the existence of the neutral current that generates parity-violating interactions between electrons and electrons, and between electrons and neutrons. In enantiomeric molecules the interaction is opposite, *i. e.* it induces a small difference between the energies of the isomers of the same molecules. It became possible to calculate the parity-violating energy difference PVED (for example between the L-, and D-amino acids).

Vester-Ulbricht process

Since 1957, many papers have dealt with the problem of whether spin-polarized electrons could induce absolute asymmetric synthesis or preferentially destroy one of the enantiomers in a racemic mixture. The quantity looked for in these experiments is

$$A = \frac{I_l - I_D}{I_l + I_D}$$

where A is the expected relative asymmetry from the interactions I of the polarized β -particles with the enantiomers. I could be decomposition, synthesis, positron annihilation, *etc.* The experimental data, however, do not withstand the rigorous criticism and thus do not confirm the early expectations.

In parallel with the experiments, theoretical estimations appeared on the difference in decomposition of the enantiomers by spin-polarized electrons. If 100 keV β -particles irradiate a racemic mixture of amino acids, then the relative increase in decomposition of one of the enantiomers is in the range 10^{-10} - 10^{-11} . After slowing down to energies of a few eV, positrons form positronium atoms with the electrons of the material. The positronium atoms may be in the singlet (spins of the positron and electron antiparallel) or triplet state (spins parallel). Theory states that the probabilities of triplet positronium formation are different in amino acid enantiomers, the relative difference being 10^5 times larger than the difference for decomposition with 100 keV β -particles (in this respect, positrons and electrons do not differ). This advantageous theoretical prediction made the study of triplet positronium

formation in amino acids attractive. In experiments, an upper limit of 10^{-4} was found for amino acids and consequently the experimental limit i for A is 10^{-9} for the 100 keV β -particles. Finally, the theory cannot determine which of the enantiomers has this very small advantage. These limits ensure that previous claims to the finding of the asymmetric decomposition of amino acids cannot be correct.

Parity-violating energy difference (PVED)

Calculations show, that the value of PVED is $\approx 1 \times 10^{-17}$ kT (kT = 0.025 eV at room temperature) for the amino acids. An important result of the calculations is that the L-amino acids and D-sugars (with some exceptions) have the smaller energy, *i.e.* the compounds of the L-molecules and D-molecules occurring in living systems are more stable. Table 3 contains values of PVED calculated for different compounds (McDermott, 1995). Moreover, the theory predicts that PVED increases in proportion to the 6th power of the atomic number Z , of the atom in the asymmetric centre. The increase may be even higher if relativistic effects are taken into account. The theory shows that PVEDs are extremely small. It seems very difficult to determine them experimentally. Though the theory is on a firm basis, the experimental confirmation of the theoretical result is important because of its assumed influence in the origin of the homochirality of biomolecules. Direct experimental results are not known. Therefore amplification mechanisms, necessary anyhow, should be considered.

Table 3. Values of parity-violating energy difference (PVED) of bio-related molecules

Molecule (‘natural’ enantiomer)	More or less stable than enantiomer	PVED/kT per molecule or monomer
L-alanine, L-valine, L-serine, L-aspartate, (in solution, α -helix, and β -sheet)	more stable	10^{-17}
D-glyceraldehyde	more stable	10^{-17}
D-desoxyribose (C2-endo RNA conformation)	more stable	10^{-17}
D-ribose (C3-endo RNA conformation)	less stable	10^{-17}
C2-endo THF	more stable	10^{-17}
right-hand B DNA	more stable	10^{-17}
right-hand A RNA	less stable	10^{-17}
right-hand glycerol-based DNA analogue, A and B	more stable	10^{-17}
right-hand -O-PS ₂ -O-linked DNA analogue	more stable	10^{-16}
right-hand -S-S-CH ₂ -linked DNA analogue	more stable	10^{-14}
l-quartz	more stable	10^{-17}

6. AMPLIFICATION OF ASYMMETRIES

The degree of asymmetry, a result either of fluctuation or of an asymmetric physical force, is extremely small. To reach the prevailing state of homochirality, amplification must have occurred.

The simplest process might be as follows: the absolute difference between the numbers of enantiomers caused by the asymmetric decomposition or synthesis increases in parallel with the linear rise in the number of molecules. When this difference exceeds the statistical fluctuation, then one of the enantiomers will have an advantage. Estimations exist for the case of the Vester-Ulbricht process. Assuming realistic values for the rate of production of amino acids and the quantity of β^- -particles emitted by natural radioactive sources on the Earth, taking into account the limit for the relative increase in decomposition of one of the enantiomers, and the rate of racemization for amino acids, gaining of advantage through this process is impossible mainly because of the racemization. More optimistic estimations appeared based on some possible strong local radioactive sources on Earth (uranium detrital deposits, a natural reactor in Gabon) and/or the radioactivity of ^{26}Al due to cosmic impact instead of the average radioactivity. We consider that estimations based on these local sources open up possibilities, but not necessities, because of their local character.

The parity-violating energy differences are given in Table 3 in units of kT. The reason for this is that $\varepsilon = \text{PVED} / kT$ appears in the Arrhenius equation as the difference in the activation enthalpies. It is easy to see that the ratio of reaction rates between L-L and D-D molecules is equal to ε .

The influence of this small ratio increases in polymerization or crystallization with the number of monomers in the polymer or molecules in a crystal. We consider the case of polymerization first. The probability of obtaining a homochiral polymer of n monomers is $n \times \varepsilon$ times larger for the enantiomer with lower energy. Since ε is small, a large number of monomers (at least 10^{13} - 10^{14}) should polymerize to yield measurable differences. Formation of such long polymers is dubious.

There is hope to detect PVED in crystallization because macroscopic crystals contain a large number of molecules. If there is an enantiomeric selection in crystallization from a racemic solution, a racemic mixture of pure right and left crystallites will be separated. The optical activity of the dissolved crystalline material, however, is not zero as for the racemic solution, but, if a large number of crystallizations are carried out, a distribution appears around zero optical activity (Fig. 2). This is due to the finite number N of the crystallites in each vessel. A Gaussian fitted to the distribution gives the width of the distribution $W(\alpha)$ and the shift or its upper limit from the zero value S . The width $W(\alpha)$ related to the optical activity of the pure enantiomer (α) is equal to the scatter in the number of crystallites $\sqrt{N/N}$. The number of molecules in the individual crystallites n is equal to the weight of the crystallized material in one vessel multiplied by the Avogadro number (6×10^{23}) and divided by N times the molecular weight of the substance. There may be an advantage proportional to ε in growing crystallites of one of the enantiomers. The proportionality factor may be the number of molecules in the crystallites n , which would be correct if the crystals were growing linearly. They grow, however, on the surface or in the bulk, when the proportionality factors

\sqrt{n} and $\sqrt[3]{n}$ must be taken into account. In this way the following equations may be used for the determination of ε from a crystallization experiment:

$$\varepsilon_1 = \frac{S}{n}, \quad \varepsilon_2 = \frac{S}{\sqrt{n}}, \quad \varepsilon_3 = \frac{S}{\sqrt[3]{n}} \quad (11)$$

In Table 4. the three mentioned crystallization experiments (Fig. 2) are evaluated. It may be seen that the ε_1 values are smaller than the theoretical values. Therefore, the most probable upper limits are the

ε_2 values or values between ε_2 and ε_3 .

Another, until now mainly theoretical, process relies in the analysis of the behaviour of growing systems.

The equation describing it is the following (in greatly simplified form):

$$d\eta/dt + a\eta + b\eta^3$$

where η denotes the chiral polarization defined as

$$\eta = \frac{L - D}{L + D}$$

where L and D are the concentrations of L- and D-molecules, and the values of the parameters a and b include and vary with the concentration of the achiral reagents or the flux of energy through the system, kinetic parameters of the underlying reactions. *etc.*

The main point of such studies is to find realistic parameters for the system as it slowly evolves through the bifurcation point determined by many parameters for a more or less quantitative answer to the question of whether the advantage coming from PVED could outgrow the fluctuation, and this way, push the system into the known direction at the so called bifurcation point (Fig. 3). In a study plausible kinetic constants were used for the rates of reactions: the concentrations are ≈ 1 mM below and ≈ 100 mM above the bifurcation point; they increase in 10^4 years from 0.5 to 1.5 times of the concentration at the critical point; and $\varepsilon = 10^{-17}$. If the size of the homogeneous reaction vessel is 4×10^9 litre, *i.e.* a lake 1 m deep with a surface of 2×2 km², then the probability of selection of the favourable enantiomer is 0.98. That size seems to be unrealistic.

Salam recently pointed out that quantum mechanical cooperative and condensation phenomena may give rise to second order phase transition below a critical temperature T_c (transformation of D-amino acids to L-amino acids that have lower energy). T_c is probably very low. Such a temperature could exist only in space. The idea therefore implies that the L-molecules were condensed in and carried from space to the Earth by meteorites or comets.

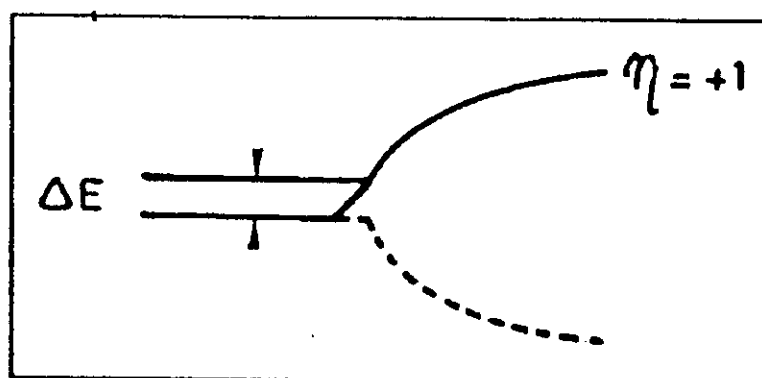
The negative results of the experiments performed in laboratories at very low temperatures (mK) yielded negative results. They do not mean, however, that such transitions may not occur in the Cosmos during a very long time and at even lower temperatures.

Table 4. ϵ -values (parity violating energy difference PVED/kT) calculated from different crystallizations

Author	Theory	ϵ_1	ϵ_2	ϵ_3	Material
Kovács	1×10^{-17}	$< 10^{-19}$	$< 7 \times 10^{-13}$	$< 3 \times 10^{-10}$	tartrate
Pincock	1×10^{-17}	$< 5 \times 10^{-21}$	$< 1.3 \times 10^{-11}$	$< 1.7 \times 10^{-8}$	binaphthyl
Kondepudi	$5 \times 10^{-15}^*$	$< 1.6 \times 10^{-22}$	$< 2.8 \times 10^{-12}$	$< 7 \times 10^{-9}$	Na ClO ₃

*Putative, based on $Z=17$ (Cl)

Fig. 2. Bifurcation with advantage



7. CONCLUSION

In the light of the above discussion, I reach the conclusion that *the chance origin of homochirality is more probable than the causal origin*. This does not mean, however, that research in the causal direction is superfluous. There are many reasons for this: new knowledge may accumulate on the basic nature of the chirality; the chiral interaction; the absolute asymmetric synthesis; the electroweak interaction; *etc.* Naturally, a verification of the causality in the origin of homochirality is never excluded from any chiral interaction not considered so far.

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