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Beta–Gamma Decay and Stereoselective Molecular Breaking

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Summary. Firm empirical evidence demonstrating that optical activity in biological molecules could result from the violation of parity in the weak interactions has yet to be produced. This effect, when mediated by beta particles or by their subsequent circularly polarized external bremsstrahlung, seems to exist, but it is too small for experimental verification. In this paper, I suggest another mechanism to transfer the dissymmetry from the nucleus to the molecule: a compound beta (or electron capture)–gamma disintegration process which, carrying also the information of parity violation, might be more efficient at the time of a selective breaking of one of the two enantiomers in a racemic mixture. A new type of experiment to test this idea is suggested.

Key words: Optical activity — Parity violation — Beta–gamma decay

Introduction

The occurrence of optically active substances in living systems has intrigued scientists since the time of Pasteur (Walker 1979). One finds, for example, only L-amino acids in natural proteins and only D-sugars in carbohydrates and nucleic acids. One of the theories advanced to explain the origin of this asymmetry is based on the existence of some asymmetric agent influencing the originally racemic prebiotic soup for a period of time. Weak interactions (Lee and Yang 1956; Wu et al. 1957) are a likely candidate that can, in principle, bring about a small asymmetric effect. The first specific mechanism suggested was that the dissymmetry from the nuclei to the molecules was achieved by the longitudinally polarized electrons emitted in β^- decay or by circularly polarized bremsstrahlung produced by these electrons (Ulbricht 1959; Vester 1974). This idea has been examined by irradiating racemic mixtures with beta electrons and (Garay 1968; Darge et al. 1976)/or (Bonner 1974) their bremsstrahlung, and analyzing any stereoselective degradation that might occur. In addition, polarized electron beams with well-defined characteristics, and even muons and positrons, have been used with this aim (Garay et al. 1974; Bonner et al. 1975; Hodge et al. 1979; Spencer et al. 1979; Gidley et al. 1982). The experimental results hitherto obtained are controversial. Positive results that have been claimed by some authors (Garay 1968; Bonner et al. 1975; Darge et al. 1976) could not be confirmed by others (Bonner 1974; Hodge et al. 1979). Quantitatively, the upper limit of the achieved polarization, as given by the error limits, in the electron beam experiments (Hodge et al. 1979), was found to be of the order $\leq 10^{-3}$, while theoretical estimations suggest (Zel'dovich and Saakyan 1980; Hegstrom 1982) the polarization to be $< 10^{-5}$. A second stereoselective mechanism could derive from weak neutral current effects, which are responsible for a tiny energy shift between both chiral molecular partners (Rein 1974; Mason 1984). Another crucial point to be understood is how a small asymmetry, once induced, could be amplified (Kovacs 1979) or even maintained against racemization (Lemmon and Bonner 1979).

Recently, Kodenpudi and Nelson (1985) have remarked on the importance of the autocatalytic processes in biological systems to amplify any minute asymmetric effect (Hegstrom 1985).

Mechanism

In this paper I want to call attention to a parity-violating correlation in β decay (Lee and Yang 1956;

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Wu and Moszkowski 1966), which has not been tested so far in chirality-inducing experiments, and which might be more efficient than the two ordinary mechanisms commented on before. There are many cases wherein the direct beta transition from the ground state of a nuclide to the ground state of the daughter nuclide is highly forbidden. Frequently there exists one or more excited states of the daughter nuclide intermediate in energy between the ground states of the daughter and parent for which the beta transition is less strongly forbidden. A decay branch then takes place through a beta–gamma cascade. One of the genuine manifestations of parity breaking is the polarization effect in the γ radiation following β decay in one of these cascades. This can most easily be seen in the case of $0 \rightarrow 1 \rightarrow 0$ cascade, where 0, 1, and 0 represent the values of the spin of the three nuclear states involved in the process. We know that in β^- decay, if the electron is emitted along the +Z axis, the antineutrino will be emitted preferentially along the −Z direction. The electron has its spin opposite to its momentum and the antineutrino parallel to its momentum. The total Z component of angular momentum carried away by the lepton pair thus is −1 and the intermediate nuclear state should be +1 in order to keep the total Z component zero. The γ-ray emitted in the transition $1 \rightarrow 0$ must carry away the Z component +1. If it leaves in the −Z direction it will be left-handed circularly polarized, but it will be right-handed if emitted along the +Z direction (Boehm and Wapstra 1957; Schopper 1957). The deexcitation should obviously happen before the orientation of the nuclear spin has been perturbed. The only exception to this correlation is to be expected in a pure Fermi transition, i.e., when both parent and daughter states have spin 0 and identical parity.

A nucleus in an excited state can perform a transition to a lower state not only by emitting a light quantum, but also by transmitting energy directly to the electrons surrounding the nucleus in the phenomenon called internal conversion. Likewise, similar polarization correlation happens between the β electron and the conversion electron (Frauenfelder et al. 1958). It is interesting to recall that while a transition $0 \rightarrow 0$ is strictly forbidden for electromagnetic radiation (i.e., there are not monopolar photons), in the case when both states have the same parity, an internal conversion (E0) is possible in which the K electrons take over the energy.

In electron-capture (EC) decays, since the neutrino has no ionizing properties, parity violation is more apparent when one looks at its radiative correction known as internal-bremsstrahlung–electron-capture (IBEC). It results in the production of a continuous spectrum of electromagnetic radiation during EC decays. Due to the nonconservation of parity, the internal bremsstrahlung (IB) coming from unpolarized nuclei is circularly polarized; this polarization would be that of a positron emitted in a β^+ decay, i.e., the photons are right-handed circularly polarized. Roughly speaking, radiative corrections have a branching ratio of about 1/137 times the width of the nonradiative decay mode. In EC decays, as in β^+ decays, when the weak process leads to an excited nuclear state, there exists a correlation between the IB photon and the subsequent γ-ray: the polarization of the latter is proportional to the cosine of the angle between the two photons (Bambynek et al. 1977). This type of correlation also exists between an IB photon and a succeeding atomic x-ray, which is present in all EC decays.

Thus, when in $\beta^\pm$ decays the daughter is an excited state, a pair $e^\pm$–γ is emitted, so that if the angle between them is small, their respective polarizations are $(L–R)_{\beta-}$ and $(R–L)_{\beta+}$, but if the angle is large (>90°), we have $(L–L)_{\beta-}$ and $(R–R)_{\beta+}$. In EC systems, a similar correlation γ–γ exists between IB photons and the subsequent γ-rays or x-rays. In any case, we have a pair of ionizing radiations with correlated polarizations, carrying a chiral signal, hence they interact distinctly with left- or right-handed molecules, and my suggestion is to check this phenomenon experimentally. To test this idea it is necessary to mix very finely the racemate and the radioactive material. This experimental configuration differs from the usual one where both substances are well separated. As they should be together, for security reasons, the activity should not be too high, and/or the half-life moderately short. We should look for both: a moderate nuclear recoil after the β ejection (i.e., a not large β energy release) and a short time delay (picoseconds) between both radiations, in order not to lose spin coherence. ^{60}Co seems to be a candidate, but neutron-induced reactor experiments should also be appropriate, provided the condition of fine mixing be fulfilled. While in an experiment using, e.g., ^{32}P, the molecules of the racemate suffer single collisions by left-handed electrons or left-handed photons, if ^{60}Co is in the nearest neighborhood, each individual molecule might receive, in a broad angular range, two (or even three) simultaneous impacts, with correlated polarizations of an electron and a photon.

The efficiency of this mechanism to induce a stereoselective breaking is difficult to estimate theoretically, and it seems to depend on the type of chiral molecules used and the relative spatial position between the molecule and decaying atom. However, one can figure out why the two chiral radiations produced in a compound transition are stereoselectively more efficient than a single chiral radiation. Circularly polarized light in the ultraviolet range "sees" (using the language of optics) an appreciable part of a molecule to be able to distinguish between both enantiomers. This is experimentally verified. On the contrary, the polarized particles from β decay (either electrons or photons) are too energetic. They have such a short wavelength that when they interact, the "illuminated" volume is so little that they are unable to perceive the molecular electronic cloud as a whole, and consequently their interaction is not stereoselective. As the β (γ) particles are slowed down (degraded) in matter, the longitudinal (circular) polarization disappears. Therefore, when they reach softer energies, the chiral message they carried is practically lost. But, if a molecule received two "primary" impacts in an interval of picoseconds, those radiations may take a picture of two distinct areas of the molecule almost simultaneously. This provides much more information on the molecular electronic cloud than in the former case, which might lead to a more effective radiolysis asymmetry. One has to admit, in any case, that the magnitude of the two-impact cross section would be smaller than the one-impact cross section, but the advantage stated before could largely compensate for this inconvenience. Hence, the radiolysis asymmetry for a system of chiral molecules would be dominated by the two-impact events. The decaying atom might be peripherally bound to the chiral molecules depending on the chemical nature of both and that of the medium.

The radionuclides used so far in chirality-inducing experiments are, with some exceptions, pure β^- emitters. This is the case with ^{32}P and ^{14}C (Bernstein et al. 1972; Vester 1974; Darge et al. 1976). In the decay of ^{90}Sr, in 0.011% the first excited state of ^{90}Zr is fed, which decays by E0 internal conversion. The correlation mentioned above between the two electrons could be a possible explanation of the successful result observed by Garay (1968). This correlation would not exist in the experiment by Bonner (1974) or in those where electron beams were used (Bonner et al. 1975; Hodge et al. 1979). In an old experiment (Futrell and Spialter 1960), the γ-rays from a ^{60}Co source were used on molecules of benzene, but the β particles were completely left out. In the decay scheme of ^{104}Rh, in 1.9% a β–γ cascade exists; however, a reported experiment (Goldanskii and Khrapov 1963) was not favorable because no mixing existed between both substances.

Finally, we can ask the following question: in case the β–γ correlation were the actual mechanism that induced a slight asymmetry in the prebiotic soup, which radioactive substance was specifically responsible for that selective breaking? The radioactive nuclides present in those times (Hegstrom et al. 1985) might have only two different origins: (1) primordial nuclear synthesis, and (2) cosmic ray and solar proton interactions with the atmosphere and interplanetary dust. We find ^{40}K, and ^{7}Be, and ^{26}Al as the most significant candidates. ^{40}K constitutes by far the largest single source of radioactivity in the ocean now, therefore the IBEC–γ (or x-ray) mode in the $^{40}K \rightarrow {}^{40}Ar$ transition seems to be the natural candidate.

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