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Asymmetries as Quasi-Fossils of the Origin of Life and Matter

Fundamental physics knows three discrete symmetries, which are labeled C, P, and T, for the symmetries of the Hamiltonian quantum dynamics under exchange of particles of matter with particles of antimatter(‘Charge conjugation’ C), space inversion, the replacement of the three space coordinates (x,y,z) of all particles by their negative values (-x,-y-z), commonly called P (for parity) and time reversal, commonly called T, corresponding to a reversal of momenta and spins of all particles. Starting with the discovery of parity violation in 1956/1957 it was found that these symmetries are not exact, they are ‘violated’. Also combined symmetries such as the combination CP are found to be violated. These symmetry violations are small and incorporated in the standard model of particle physics(SMPP). Only the combined symmetry operation CPT is still exact in the SMPP, and has not been found to be violated by experiment until today although searches for such violations exist. Interestingly, we observe in our world today an asymmetry, which can be related to these symmetry violations.

We live in a world		
		Symmetry
1.	Of Matter (not Antimatter)	C, CP, CPT
2.	Of L-aminoacids and D-Sugars (and not D-aminoacids and L-Sugars) in ordinary life (Proteins, DNA, RNA)	P
3.	Where time runs forward (and not backwards) (also combinations CP, CPT …)	T

Fig. 1: **The fundamental symmetries C,P, T and current asymmetries as quasi-fossils of the evolution of the universe and of life. What is the origin of this observations? (de facto vs de lege?) Are they basic „quasi-fossils“ of the evolution of matter and life? (after M. Quack , Adv. Chem. Phys. 157(2014) 249-290.)**

We have called these ‘quasi-fossils’ of the evolution of the universe, ‘quasi-fossils’ of the origin of life and matter [1-4]. Symmetries and asymmetries have, of course, many aspects beyond physics and chemistry [1, 2]. Restricting attention to parity, we can identify three fundamental questions on symmetry, relating physics to molecular quantum dynamics and stereochemistry:

(i) To what extent are the fundamental symmetries and conservation laws of physics and their violations reflected in molecular quantum dynamics and spectroscopy, in general?
(ii) How important is parity violation –the violation of space inversion symmetry- for the quantum dynamics and spectroscopy of chiral molecules, in particular?
(iii) How important is parity violation for biomolecular homochirality, i.e. the quasi exclusive preference of L-amino acids and D-sugars in the biopolymers of life (proteins and DNA)?

The observation of biomolecular homochirality can be considered as a quasi-fossil of the evolution of life, the interpretation of which has been an open question for more than a century. While there are many plausible hypotheses and explanations for the evolution of homochirality in the evolution of life, they are contradictory and one does not know which one is correct. The many possible hypotheses can be grouped in two large classes, the *de facto* selection by chance or the *de lege* selection by parity violation. In principle, these could be distinguished by experiment or by observation, say on artificial life forms or extraterrestrial life forms [1-4].

Parity symmetry P leads to a conservation law for the quantum number parity in molecular quantum dynamics and parity violation leads to the primary process of the change of parity with time on a time scale of seconds in molecular dynamics [1, 5, 6]. At the same time parity violation by the weak nuclear force leads to the prediction of a small energy difference D between enantiomers of chiral molecules, on the order of 100 aeV to a few feV or a reaction enthalpy for stereomutation of about 10 to 100 pJ/mol, depending on the molecule. While our theoretical work in 1994-1998 has shown that these energies are larger by one to two orders of magnitude than previously anticipated(confirmed now by many theory groups, see reviews [1, 7]), they still have not been measured by experiment, which constitutes one current frontier of molecular physics and stereochemistry [8, 9]. Confirmation or rejection of the current theory of molecular parity violation would have consequences for both fundamental physics, with potential for ‘new physics’ and for our understanding of the evolution of homochirality and the evolution of life, for which there remain many open questions. This is illustrated in Figure 2.

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DOI-Nr.: 10.26125/0naq-8g83

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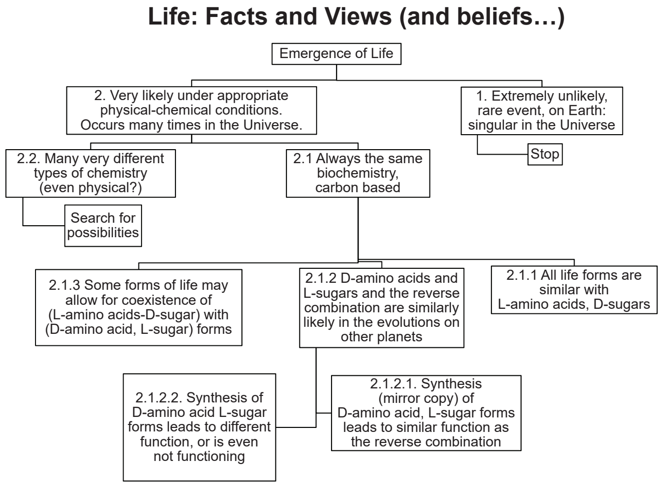

Fig. 2: Decision diagram (‚flow diagram‘) for the evolution of life (after M. Quack, Adv. Chem. Phys. 157 (2014) Homochirality as a quasi-fossil of evolution)

This figure can be read as a flow diagram or decision diagram. For instance at the first decision on top one can have either the hypothesis of a high probability of the evolution of life, ‘frequent life’ in the universe, or a low probability of the evolution of life, life on Earth being essentially singular in the universe. The current majority opinion seems to be ‘frequent life’, but at earlier times the hypothesis of rare, singular life was also popular, as represented, for example, in the famous book ‘Le Hasard et la Nécessité’ (1970), by Jacques Monod or the concluding section of the Nobel lecture by Vladimir Prelog (1975). In actual fact we simply do not know, which hypothesis is correct. The diagram should be self- explaining otherwise. For instance further down in the diagram one finds the contradictory hypotheses of either de facto selection of homochirality in life (by chance), leading to equal probability for ‘L amino-acid life’ and ‘D amino-acid life’, or the de lege hypothesis leading to a preponderance of one form, say ‘L amino-acid life’ because of parity violation. The current majority opinion seems to favor chance selection, but in actual fact we do not know which hypothesis is correct. But, in principle, this could be decided by experiment or observation: ‘We need to know! We shall know!’ (citing freely from David Hilbert) For detailed discussion we refer to the cited literature.

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Martin Quack studied Chemistry and Chemical Physics in Darmstadt, Grenoble, Göttingen and at the École Polytechnique Fédérale de Lausanne, where he received his doctoral degree in 1975. He was 1976/77 Max Kade Fellow at the University of California Berkeley and habilitated in Göttingen in 1978. He was appointed full professor (C4) at the University of Bonn in 1982 and Professor Ordinarius for Physical Chemistry at ETH Zurich in 1983, where he stayed since then. He was also Hinshelwood lecturer and Christensen Fellow of St. Catherine’s College at Oxford University (1988) and visiting Miller Research Professor at the University of California Berkeley (2005). In recognition of his research on molecular kinetics and spectroscopy he received numerous prizes and honors, among which is the Paracelsus Prize of the Swiss Chemical Society, and he holds an honorary doctorate from the University of Göttingen. After mandatory retirement from his teaching and administrative functions at age 65 in the fall of 2013 he continued as Professor Emeritus at ETH with research of his group concentrating on some of the most fundamental problems of molecular primary kinetics, in particular also concerning parity violation and tunneling in chiral molecules with support from an ERC advanced grant and grants from the SNFNS and ETH Zurich. He has been elected member of several academies, and also as foreign honorary member of the American Academy of Arts and Sciences, and corresponding member of the Göttingen Academy of Sciences and the Academy of Athens, Greece. In 2014 he was elected as member of the presidium of the Leopoldina (reelected 2019).

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