Journal of Molecular Liquids, 44 (1990) 73–78
Elsevier Science Publishers B.V., Amsterdam – Printed in The Netherlands

On the Experimental Determination of the Enantiomeric Energy Inequivalence.

M. W. Evans*

Department of Chemistry, Bourne Laboratory,
Royal Holloway and Bedford New College,
University of London,
Egham, Surrey TW20 0EW,U.K.
U.K.

(Received 19 April 1989)

*Also at
I.B.M., Data Systems Division,
Neighborhood Road,
Kingston, New York 12401,
U.S.A.
and
Honorary Research Fellow,
Dept. of Physics,
University of Lancaster,
Lancaster LA1 4YB, U.K.

0167-7322/90/$03.50

Abstract

A possible experimental method for the determination of the enantiomeric energy inequivalence is developed and suggested. It is based on the observation of differential scattering of right spin polarised neutrons from a right handed enantiomer, followed by the same measurement of differential scattering of left spin- polarised anti-neutrons from a left handed enantiomer. A small difference in the intensity distribution of the differential scattering should be observable because of the parity violation inherent in generating one enantiomer from the other by parity inversion alone, without simultaneous charge conjugation.

Introduction

There is a small energy difference between a right and left handed molecule (enantiomers) due to the weak neutral current interaction {1-5} between the nucleus and electrons and between different electrons. Quantum mechanical calculations {6,7} of the magnitude of this difference are available, producing an order of magnitude of 10^{-38} J. The enantiomeric energy inequivalence is a parity violating phenomenon of the type first discovered by Wu et al. {2} after a suggestion by Lee {1}. The parity violating weak neutral current terms in the hamiltonian are odd under space inversion, and the energies of two enantiomers are affected in opposite senses by the weak neutral current terms in the hamiltonian. The existence of parity violation of this kind in achiral molecules and atoms has been confirmed experimentally in several ways. Apart from the original experiment of Wu et al. {2} there have been observations {8-10} of minute but real optical rotations in atomic vapours of heavy metals. Other observations have revealed parity violating differential scattering from right and left spin polarised high energy electron beams by nucleons in hydrogen and deuterium {11}. Parity violation causes the rotation of the spin vector component perpendicular to the propagation direction (**k**) of a beam of polarised neutrons passing through crystals of ^{137}Sn isotope {12}.

In this short paper we propose an experimental method for the detection of parity violating phenomena in scattering of elementary particle beams from right and left handed enantiomers. We are looking for a small difference in seemingly equivalent experiments on the right and left handed specimens (or targets) which may be crystals, liquids, or vapours.

Symmetry Considerations, the CPT Theorem.

Let C be the charge conjugation operator which converts elementary particles into their equivalent antiparticles. Thus C (neutron, right spin) gives the antineutron, right spin; C (electron, right spin) gives the positron, right spin; C (neutrino, left spin) gives the antineutrino, left spin; C (proton, right spin) gives the antiproton, right spin; and so on.

Let P be the parity reversal operator, which effects (X, Y, Z) $\rightarrow$ (-X, -Y, -Z) for each particle in the system under consideration.

Let T be the time reversal operator, which reverses the velocities of each particle in the system, and leaves time independent properties unchanged.

The CPT Theorem of Luders, Pauli and Villars then states {13,14} that the hamiltonian of the system of elementary particles in the laboratory frame is invariant to the product of operations CPT even if it is not invariant to one or more of the operators considered separately. This Theorem is derived from relativistic quantum field theory {14} and no counter example has yet been found. Parity violation and time reversal violation (CP violation) have been observed separately {15}.

The CPT operation produces strict energy equivalence, i.e. leaves the energy of the system exactly the same as that of the original. Thus, the CPT operation on a right handed enantiomer produces the left handed enantiomer with all charges reversed. The right handed enantiomer exists in the real world and the left handed equivalent generated by CPT exists in the anti-world. Chirality is time-even in nature, according to Barron {15}, so that one enantiomer is generated from the other by a combination of parity and charge conjugation reversal

$$CPT \rightarrow (-C)(-P)T \tag{1}$$

The Effect of CPT on Elementary Particle Beams

The combined operation CP interconverts a left handed electron and a right handed positron. These elementary particles therefore have chirality and are enantiomers themselves. Similarly, the left spinning neutron is converted by CP in to the right spinning anti-neutron; the left handed or left spinning proton in to the right handed or right spinning anti-proton. For particles without mass, such as the photon or neutrino, chirality is defined precisely, since they always move at the velocity of light. Omly left-handed neutrinos and right-handed anti-neutrinos exist in nature {15}, their other-handed equivalents are not observed. Thus an experiment in the real world using a beam of left spin- polarised neutrons is converted by CP into an experiment in the anti-world with a beam of right spin-polarised anti-neutrons. Therefore, left spin-polarised neutrons scattered by a left handed enantiomer (a target liquid) in the real world is exactly equivalent energetically to right spin-polarised anti-neutrons scattered by a right enantiomer with reversed charges in the anti-world. Similarly, the scattering of left spin polarised electrons by a left enantiomer target in the real world is exactly equivalent to the scattering of right spin polarised positrons by a right enantiomer with reversed charges in the anti-world.

Differential Scattering from Left and Right Enantiomer Targets

A left and right enantiomer in the real world are **not** energetically equivalent due to the neutral weak current nucleus- electron and electron-electron terms. The key to experimental observation of the enantiomeric energy inequivalence appears therefore to be the inequivalence in the real world experiments such as the following.

1) Scattering of left spin polarised neutrons {12} from a left handed enantiomer liquid.

2) Scattering of right spin polarised anti-neutrons from a right handed enantiomer liquid.

Parity violation also causes the rotation of the spin vector component perpendicular to the propagation direction of a beam of polarised neutrons passing through crystals of the 137 isotope of tin {12} and minute but real optical rotations in atomic vapours of heavy metals {8-10}. Because of the parity violating enantiomeric energy inequivalence in targets of molecular enantiomers, we expect that the electron-electron parity violating weak current interactions in one molecular target enantiomer will rotate the plane of polarised electromagnetic radiation in one direction which will be minutely **different** from the rotation for the other enantiomer. This goes against all the received wisdom that the rotation of the plane of plane polarised electromagnetic radiation is exactly the same but opposite for molecular enantiomer pairs. Such differential rotations might also be expected for beams of polarised elementary particles. This opens up a range of exciting opportunities of observing experimentally the effects of the parity violating weak field interactions in molecular enantiomers.

Optimisation of Experimental Conditions

The last type of experiment, where plane polarised radiation is rotated differentially by liquid enantiomer targets is perhaps the most accessible experimentally. To optimise conditions we need a chiral molecular target where the rotation angle is maximised. We need to amplify the rotation still further by maximising the length of the sample, perhaps through the use of a White (multi- pass) cell. Finally, the sensitivity of the apparatus to the angle of rotation must be optimised. The apparatus used in references {8-10} for the measurement of parity violating rotations in atomic vapours would probably suffice for similar measurements in vapours of molecular enantiomers. Using liquids would considerably enhance the rotation, which is conventionally proportional {16} to the sample length multiplied by number density. The differential rotation might possibly be in the region of one degree in a million or less, but this is observable using samples which can rotate the plane of radiation by thousands of degrees per unit sample length, such as optically active biopolymers. A rotation of some millions of degrees might be obtainable with a sample length of a few metres with frequencies at which the probe plane polarised radiation is not absorbed by the sample.

The enantiomeric energy inequivalence would cause a rotation of a million degrees in one direction for one enantiomer, accompanied by one of say a million and one degrees in the other direction for the other enantiomer.

Acknowledgements The Universities of London and Lancaster are thanked for positions and IBM for the award of a Visiting Scientist position.

References

{1} T. D. Lee and C. N. Yang, Phys. Rev., 104 (1956) 254.
{2} C. S. Wu, E. Ambler, R. W. Hayward, D. D. Hoppes, and R. P. Hudson, Phys. Rev., 105 (1957) 1411.
{3} E. Fermi, Z. Phys., 88 (1934) 161.
{4} S. Weinberg, Phys. Rev. Lett., 19 (1967) 1264.
{5} A. Salam, in "Elementary Particle Theory", ed. N. Svartholm (Almquist and Wiksell, Stockholm, 1968).
{6} S. F. Mason and G. E. Tranter, Mol. Phys., 53 (1984) 1091.

{7} ibid., Proc. Roy. Soc., 397A (1985) 45.

{8} P. G. H. Sandars in "Fundamental Interactions and Properties of Matter" ed. K. Crowe, J. Duclos, G. Fiorentini, and G. Torelli (Plenum, New York, 1980).

{9} E. N. Fortson and L. Wilets, Adv. At. Mol. Phys., 16 (1980) 319.

{10} M. A. Bouchiat and L. Pottier, Sci. Am., 250 (1984) 76.

{11} C. Y. Prescott et al., Phys. Lett., 77 (1978) 347.

{12} M. Forte, B. R. Heckel, N. F. Ramsey, K. Green, G. L. Greene, J. Byrne and J. Pendlebury, Phys. Rev. Lett., 45 (1980) 2088.

{13} D. C. Cheng and G. K. O'Neill, "Elementary Particle Physics", (Addison Wesley, Reading, Massachussetts, 1979).

{14} V. B. Beretinskii, E. M. Lifshitz and L. P. Pitaevskii, "Quantum Electrodynamics", (Pergamon, Oxford, 1982).

{15} L. D. Barron, Chem. Soc. Rev., 15 (1986) 189.

{16} P. W. Atkins, "Molecular Quantum Mechanics", (Oxford University Press, Second Ed., 1983).