INVESTIGATIONS OF ELECTRON HELICITY IN OPTICALLY ACTIVE MOLECULES USING POLARIZED BEAMS OF ELECTRONS AND POSITRONS

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We will discuss one possible correlation between the origin of optical activity in biological molecules and the helicity of beta particles emitted in nuclear beta decay. This correlation is based on the supposition of Hrasko and Garay that electrons in optically active molecules possess helicity. Positronium formation experiments are significantly more sensitive to this particular effect than radiolysis experiments although no experiments of any type to date have obtained the sensitivity that our preliminary calculations indicate is necessary. We discuss a new experiment in which positronium is formed in vacuum with a low energy polarized positron beam. An improvement of up to 10^4 in sensitivity to the effect is possible.

The possibility (1,2) that optical asymmetry in biological systems is causally related to lepton (electron, positron or muon) helicity has been considered ever since the violation of parity in the weak interactions was demonstrated (3) in 1956-57. Experiments that exploit the fact that beta particles emitted in nuclear beta decay have, as a direct consequence of parity violation, a net helicity can be classified into two categories: radiolysis experiments that search for asymmetric degradation of one of the isomers of an initially racemic mixture by beta radiation; or electron capture experiments that search for preferential formation of positronium or muonium when positrons or muons with a net helicity interact with L vs. D isomers.

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Reviews (4) of experiments through 1976 conclude that no positive effect had been observed up to that time with the exception of a radiolysis experiment by Bonner et al. (5). This work was however recently shown to be non-reproducible by Hodge et al. (6) so that the situation here remains ambiguous. Concerning positronium experiments, Garay, et al. (7) reported a large asymmetry in the formation of triplet positronium in L vs. D isomers of various amino acids but this effect was also shown to be non-reproducible (8). In addition, it was shown (9) that the largest effect that could be expected in these experiments due to the residual helicity of the positron at positronium formation energies was far smaller than the result reported in reference 7. Finally, we note that experiments involving muons (10) have shown no effect.

The brief summary above indicates that no conclusive demonstration of a connection between lepton helicity and biological asymmetry has been presented in the literature. In this paper we consider one mechanism for producing such a connection and describe an experiment currently underway in our laboratory that has a potential sensitivity to such an effect up to 10^4 times greater than previous experiments. The mechanism that has been considered (11) for connecting optical activity with lepton helicity requires the electrons in optically active molecules to possess helicity, the sign of which depends on the particular isomer, L or D. Preliminary theoretical work here at The University of Michigan (12) indicates this helicity should be less than 10^{-3}. An effect of such a molecular electron helicity would definitely be present in the radiolysis experiments summarized above. However, the effect is proportional to the product of the incident beam and target helicities ($\approx 10^{-4}$ or less) and depends on the small relative contribution of electron exchange to the total ionization cross section (the electron exchange cross section is asymmetric for incident helical beams if the target electrons have net helicity). Thus the asymmetry in the ionization cross section is orders of magnitude too small to be observed in the present radiolysis experiments. Positronium (Ps) formation experiments are a more sensitive method than the above to observe (or set limits on) molecular electron helicity for two reasons: annihilation from the bound state of Ps occurs in a large fraction (20%-30%) of the total annihilations; and the positron velocity when Ps is formed is roughly the same as the electron atomic velocity (thus there is a large difference in the relative velocity, and hence the Ps formation cross section, depending on whether the electron velocity is parallel or antiparallel to that of the positron) (13).

In our present experiment we search for a helicity dependent asymmetry in the formation of the triplet ground state

of positronium when low energy polarized positrons interact with an optically active substance. The apparatus, shown schematically in Fig. 1, consists of a low energy polarized positron beam generator, a Wien filter spin rotator, the optically active positronium formation surface, and the annihilation γ-ray detectors. Polarized positrons emitted by a ^{58}Co source are incident over a 2π solid angle onto a cylindrically symmetric moderator consisting of a 0.2 mg/cm^2 gold foil coated with 4 mg/cm^2 of MgO. The source positrons thermalize in the MgO and approximately 1 in 10^4 are re-emitted as slow positrons. During the thermalization process the polarization $\vec{P} = \langle \hat{S}_i \rangle$ remains virtually unchanged. In this expression for $\vec{P}$ the brackets denote a quantum mechanical average over the particles of the beam and $\hat{S}_i$ is a unit vector in the spin direction of the i^{th} particle. The helicity, h, is defined by $h = \langle \hat{S}_i \cdot \hat{v}_i \rangle = \langle \hat{S}_i \rangle \cdot \langle \hat{v}_i \rangle$, where $\hat{v}_i$ is the unit velocity vector of the i^{th} particle. Since the positrons have essentially random velocities even prior to thermalization ($\langle \hat{v}_i \rangle \simeq 0$) the helicity approaches zero.

Accelerating the slow positrons emitted from the moderator into an axially polarized beam restores the helicity of the beam. The rehelicitized beam is then transported to a cylindrical mirror energy analyzer where electric fields change the beam velocity by 90° but leave the spin direction unchanged. The then transversely polarized beam (h=0, $\vec{P}$

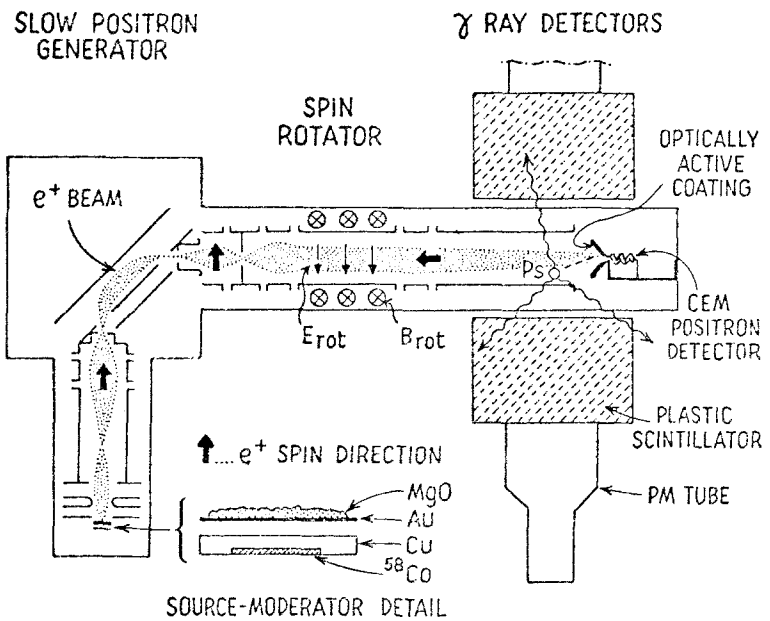

Fig. 1. The experimental arrangement.

perpendicular to $\langle \hat{v}_i \rangle$) enters the Wien filter where $\vec{P}$ is rotated parallel to the beam velocity ($h>0$) or antiparallel to the beam velocity ($h<0$). Using this spin rotator we have measured (14) the polarization of the beam to be $P=0.22\pm0.02$. The positrons of a selected helicity and energy ($\approx$ 100 eV) are focused onto the coated surface of a channel electron multiplier (CEM) and are detected through the emission of secondary electrons. We have succeeded in coating the CEM surface with the amino acids leucine, tryptophan, and alanine while maintaining high positron detection efficiency.

The incident positrons slow down to approximately 10 eV in the optically active coating and should sustain only minor loss of helicity while slowing down. Then, with 15-25% efficiency, they form positronium in the triplet ground state. Ps so formed leaves the coated CEM surface and lives for approximately 140 nsec in the surrounding vacuum chamber before annihilating into three γ rays. Detection of one or more of the annihilation γ rays in large pilot B plastic scintillators allows the lifetime of each positron event to be directly measured and recorded with a conventional time-to-amplitude converter-multichannel analyzer system.

The positron lifetime spectrum so obtained consists of a prompt peak of freely annihilating positrons and singlet Ps whose decay occurs within one nsec of the CEM start pulse, and a 140 nsec exponential component due to triplet Ps decay. Defining $N^+(N^-)$ to be the number of Ps events occurring in a background corrected time window from 10 ns to 300 ns for incident positron helicity positive ($h>0$, N^+) and then negative ($h<0$, N^-), the asymmetry in triplet positronium formation is defined to be

$$A = \frac{N^+ - N^-}{N^+ + N^-} .$$

With our anticipated slow positron rate of 3×10^4 sec^{-1} we should be able to set statistical limits of $\pm10^{-4}$ on A in one day of data acquisition, a factor of 100 improvement over previous positronium experiments.

We assume that the only external factor responsible for an asymmetry in the positronium formation rate is the helicity of the positrons at the time Ps is formed. In addition, we assume that Ps formation occurs only at positron energies of order 10 eV. The measured asymmetry can then be related to the estimated residual helicity h' of the positrons and the helicity h_e of the captured molecular electrons by the relation $|A| = c|h'h_e|$ where c is a constant estimated to be about 0.1.

Our initial experiment will measure $|A|$ at the level of 1 part in 10^4. With $|h'| = 0.2$ this will set an upper limit on h_e of 5×10^{-3}. By contrast, no asymmetry in Ps formation has been observed at better than the 1% level. Since we estimate h' for previous experiments to be less than 1% no meaningful upper limit can be placed on h_e. Straightforward improvements in our beam intensity and longer data acquisition times will reduce the statistical error by a factor of 10. Assuming that systematic errors at this level can be overcome, we would set an upper limit of about 500 ppm on h_e. We thus hope to obtain the most stringent quantitative limit on the connection between nuclear parity violation and molecular asymmetry obtained by workers in this area to date.

In summary, the features of our experiment which represent major departures from, and improvements on, previous work are:

1) The use of a low energy positron beam. In previous positronium asymmetry experiments the positron velocity randomizes in the slowing down process and thus the helicity is very nearly zero when positronium formation occurs. By contrast, we calculate that our 100 eV incident positron beam will have $h\simeq0.15$ when Ps is formed.

2) The helicity of the positrons is reversible. Therefore it is not necessary to change the optically active isomer from L to D in order to measure A. This eliminates one of the most serious systematic concerns in the earlier experiments associated with changes in the Ps formation fraction due to differences in the impurity levels of the two isomers. Of course, if an asymmetry is observed the opposite isomer will be tested to see if the sign of A changes as expected.

3) The measured lifetime of the Ps formed on the optically active coating is about 140 nsec instead of the pick-off shortened 1 nsec lifetime of positronium decaying inside solid amino acids. This long lifetime provides unambiguous separation of the triplet positronium decay component from the prompt annihilation peak in the lifetime spectrum. Consequently the sensitivity of our measured values of N^+ and N^- to systematic drifts in our timing system (such as t=0 drifts or shifts in system linearity) is reduced by at least a factor of 140 nsec/1 nsec $\approx 10^2$.

4) The effect of timing system drifts can be reduced by a factor of 10 by means of an averaging process based on frequent helicity reversals.

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