ries, separate values of $D(\theta)$ for right and left scatterings were calculated from the observed asymmetries and the p-p polarization data[5] at this energy. The values of $D(\theta)$ obtained for left and right scatterings were then combined statistically, giving the following result:

$$D(30°) = 0.19 \pm 0.02,$$

$$D(60°) = 0.33 \pm 0.03.$$

The errors include the above-mentioned uncertainty in alignment. Figure 1 shows the experimental points along with the predictions[1] of solutions a through d. Our preliminary values of $D(\theta)$ at 210 Mev strongly substantiate the choice[1] of solution b or c and indicate some preference for b over c. With the $D(\theta)$ values at 310 Mev, the data yield an over-all energy dependence of $D(\theta)$ which favors the $D(\theta)$ measurement at 150 Mev by the Harvard group[6] rather than the Harwell result.[7]

The accuracy of the data is being improved and the work extended to other angles.

*Work done under the auspices of the U. S. Atomic Energy Commission.

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CAPTURE OF K^- MESONS FROM HIGH S ORBITALS IN HELIUM*

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It would be quite interesting to know from which atomic orbital a K^- meson will be captured after stopping in liquid helium. For, if it can be established that, in all likelihood, the capture of the K^- meson occurred from S states, a study of the angular distribution of the mesonic, two-body decay of the hyperfragment ${}_\Lambda He^4$ or ${}_\Lambda H^4$ can determine the spin of the hyperfragment. If the spin of the ${}_\Lambda H^4$ or ${}_\Lambda He^4$ turns out to be zero, then the experiment of Block et al.[1] determines that the K^--Λ parity is odd.

The problem for helium is completely different and quite a bit more complicated than that for hydrogen, studied previously.[2,3] As a consequence, the result is not as conclusive as that for hydrogen, although it does indicate that S-state capture will again predominate.

We will outline qualitatively, here, the principal processes which occur after K^- mesons are stopped in a liquid helium bubble chamber.[4] When the K^- meson is first captured by a helium atom (into a state which best overlaps the wave function of the electron it replaces, i.e., with principal quantum number $n \sim 30$), it almost immediately de-excites and kicks out the remaining electron by the usual Auger process. The state to which it must fall about the unshielded alpha particle in order to release the 24.56 ev electron ionization energy has $n \sim 27$, and an average radius of $\sim 0.4 a_{el}$ (electronic Bohr radius). This is substantially smaller than the electron's average radius in a helium atom, and so, the $(K^-, \alpha)^+$ atom looks roughly like a proton to the surrounding helium atoms. In particular, it is energetically forbidden to pick up another electron.[5,6]

This, then, leads to an examination of the atomic and molecular processes in which a $(K^-, \alpha)^+$ atom can participate.[7] One possibility is that a metastable molecule might be formed with another helium atom. The $(p, He)^+$ molecule is well known,[8,9] although the three-body recombination problem involved in its formation has not been studied extensively in liquids.[10] However, while these recombination times are expected to be very short, it is not essential for our purposes, here, that the molecule actually form. Rather, we make only the simpler assumption that the $(K^-, \alpha)^+$ atom feels the molecular potential (e.g. Fig. 1 of reference 8) while in collision with a nearby helium atom. Then, by using the Hellman-Feynman theorem[11] we can differentiate this curve to get the electric field at the $(K^-, \alpha)^+$ atom,[12] and we have recovered our Stark effect.

In order to have some idea of the time scale within which the various atomic processes must compete, we give first, the rate for direct capture from an (nS) state,

$$\Gamma_{\text{cap}}(nS) \simeq 2\times10^{19}/n^3 \text{ sec}^{-1}, \tag{1}$$

(where capture by neutrons is treated as equal to that by protons); next, the rate for direct capture of a K^- meson from an (nP) state via S-wave interaction with a nucleon (i.e., due to the finite size of the nucleus),

$$\Gamma_{\text{cap}}(nP) \sim 4\times10^{15}/n^3 \text{ sec}^{-1}. \tag{2}$$

Now, in order to estimate the average capture of a K^- meson from an $(n, m_l = 0)$ level by the molecular Stark effect, we compute the rate for a fixed $(K^-, \alpha)^+$ - He distance, as if the molecular electric field were static. Then, we perform a suitable average over possible interatomic distances and impact parameters in an average collision between the $(K^-, \alpha)^+$ atom and another helium atom.[4] In this way, we define an average transition rate for this process, and find

$$\langle\Gamma_{\text{Stark}}(n, m_l = 0)\rangle \sim 2\times10^5 n^6 \text{ sec}^{-1}. \tag{3}$$

A factor of $(1/n)$ has been incorporated, since there are n degenerate levels with the magnetic quantum number $m_l = 0$ which are mixed and decay together in such a static external electric field, when all levels are populated statistically.[3] [A similar $1/n$ factor should multiply Eq. (2) to give the Stark capture from P states for $m_l = 0$ before comparison is made with Eq. (3).]

In a similar way, we can find an average transition rate for the principally competing process, wherein the meson de-excites and directly ejects an electron from the nearby helium atom (the external Auger process).[13] By again assuming a statistical distribution, and considering only those transitions energetically possible and most favored by the selection rules, we get

$$\langle\Gamma_{\text{Aug}}(n = 25)\rangle \sim 5\times10^{12} \text{ sec}^{-1},$$

$$\langle\Gamma_{\text{Aug}}(10)\rangle \sim 1\times10^{11} \text{ sec}^{-1},$$

$$\langle\Gamma_{\text{Aug}}(7)\rangle \sim 5\times10^{8} \text{ sec}^{-1}. \tag{4}$$

In general, the Stark capture rates from S states and from P states for $m_l = 0$ would have to be modified by some factor which depended on the distribution of mesons in the levels of the atom, and on the directional properties of the electric field felt by the $(K^-, \alpha)^+$ atom.[3] However, two circumstances would seem to argue that the factor of $(1/n)$ incorporated in Eq. (4) is probably sufficient, if not already an overestimate of the reduction necessary because of the number of degenerate states involved in the Stark capture. The first is the fact that in liquid helium, positive ions lead to large clusters due to polarization forces.[14] This gives rise to weak electric fields whose directions change rapidly, which then destroys the $m_l = 0$ selection rule for the ordinary Stark mixing. The second circumstance arises in the initial capture of the K^- meson by a helium atom. For, when this occurs, angular momentum barriers seem to prevent anything like a statistical distribution of mesons for the high l states, but rather, favor the population of low and intermediate angular momentum sublevels.[15] This kind of population will be accentuated by Auger transitions.[16] This has the effect not only of changing the factor $(1/n)$ in Eq. (4) to something like $(2/n)$, but also of decreasing the estimate of the external Auger rates, which were given in Eq. (4) for a statistical distribution.[17]

Hence, for the high n values considered here, $n \sim 20$-30, the S state capture via the molecular Stark effect will be ~ 10-50 times faster than the nearest competing process, the external Auger process. However, it should be pointed out that if the meson succeeds in getting to much lower n values, i.e., $n \sim 10$, where the external Auger process becomes negligible, the dominant reaction will be capture from P states via the Stark effect.

We would like to thank Professor L. S. Rodberg and Professor J. Sucher for many interesting discussions.

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*This research was supported in part by the U. S. Air Force Office of Scientific Research of the Air Research and Development Command and in part by the U. S. Atomic Energy Commission.

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SYMMETRY BETWEEN MUON AND ELECTRON

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As is well known, muons and electrons appear to have identical couplings. Their masses are, however, different. Such a situation seems rather peculiar and has recently received much attention.[1] In this note we shall (1) define a formal operation of muon-electron symmetry; (2) show how the total Lagrangian, excluding weak couplings, can be written in a form exhibiting such a symmetry, if electromagnetic coupling is minimal; (3) show that it is impossible to satisfy such a symmetry when universal weak interactions are included, if only one neutrino exists; (4) show that it is possible to have such a symmetry in a two-neutrino theory; (5) point out the close connection of muon-electron symmetry to a principle forbidding the transformation of muons into electrons.

The present investigation is related to some recent papers[2-4] dealing with the elimination of particular muon-electron couplings. Of the above points, (2) is already contained in reference 3. We shall also make use of the general theorem of reference 4.

We first define a formal operation of muon-electron symmetry. We introduce a two-dimensional e-μ space, which we call L space (lepton space). The e-μ symmetry, or L symmetry, is performed by an unitary operator $\mathcal{S}$, such that

$$\mathcal{S}^{-1}\psi\mathcal{S} = \sigma_1\psi, \qquad (1)$$

where ψ is a vector in L space describing the electron and muon fields and σ_1 is a Pauli matrix in the usual notation. In the representation in which the components of ψ are e and μ the operation (1) just amounts to the substitution $e \rightleftharpoons \mu$.

A general renormalizable Lagrangian, excluding weak interactions, can be written as[3,4]

$$\mathcal{L} = -\bar{\psi}[\gamma\cdot\partial(A+\gamma_5 B) + (C + i\gamma_5 D)]\psi + \mathcal{L}_\gamma + \mathcal{L}_S, \qquad (2)$$

where $\mathcal{L}_\gamma$ is the free-photon Lagrangian, $\mathcal{L}_S$ is the strong Lagrangian that we assume does not contain e or μ, and A, B, C, D are Hermitian matrices in L space.[5] The requirement of invariance under L symmetry implies that A, B, C, D all commute with σ_1.

A theorem, whose proof can be found in reference 4, states the existence of a nonsingular