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ABSORPTION OF K^- MESONS IN NUCLEAR SURFACES*

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We present preliminary results of an analysis of the experimental data pertaining to K^- capture on complex nuclei. The theory takes explicit account of the Y_0^* resonance as well as the change in the neutron-to-proton density ratio in going from the nuclear core to the region outside the normal nuclear radius. We obtain results which are in rough accord with experiment, and we conclude that the role of the Y_0^* cannot be ignored in deducing properties of the nuclear surface.

It is well recognized that the interaction of K^- mesons with nuclei heavier than hydrogen leads to their absorption from states of relatively high angular momentum.[1] Since their wave function rapidly increases with the radius, the reaction is bound to occur near the nuclear surface. Furthermore, reactions with neutrons (giving rise to $\Sigma^- + \pi^0$) can be readily distinguished from reactions with protons (which lead to $\Sigma^- + \pi^+$ or $\Sigma^+ + \pi^-$).[2] These reactions have been used to estimate the neutron-to-proton ratio near the nuclear surface.[2,3] The surprising result is that this ratio is five times higher in the silver nucleus than in the nuclei of carbon and oxygen, which predominate in light emulsions. While it is expected that the neutron-to-proton ratio will increase rapidly in silver in the region of decreasing nucleon densities outside the conventional radius of silver, a five-to-one ratio is hard to reconcile with a quantitative estimate based on a reasonable nuclear model (see below).

Actually the Y_0^* resonance must have an important influence on the capture process, as has already been indicated by Burhop.[3] In particular, it is necessary to take into account that the Y_0^*, which is the isosinglet state and can occur only in the $K^- + p$ interaction, manifests itself as a strong resonance at an energy of approximately -30 MeV.[4] Since this resonance cannot affect the $K^- + n$ reactions, it must have a strong influence on the ratio of the rates of these two reactions. The resonance also influences the ratio of $[K^- + p \to \Sigma^+ + \pi^-]$ to $[K^- + p \to \Sigma^- + \pi^+]$, since the $K^- + p$ reaction rate depends on the participation of both the isosinglet ($T = 0$) and isotriplet ($T = 1$) states.

The fact that the resonance occurs at negative energies is relevant, because one must include in the energy balance the energy required to extract a proton from the nucleus. This requires not only that the binding energy of the proton must be made available but that one must take into account the energy of excitation left behind in the nucleus and in the Y_0^* if a proton is suddenly withdrawn and added to the K^- meson. Thus, there is available for the resonating state a negative energy approximately equal in absolute value to the binding energy plus residual excitation energy. This negative energy may lie on either side of the resonance.

Calculations taking into account the above features of the K^--capture process have been made. We present in Table I a preliminary set of results for various nuclei ranging from deuterium to silver. The analysis was based on the compilation of experimental data given by Burhop.[3] These data lead to the tabulated values for A^2 and φ, where A is the absolute value of the ratio

Table I. Results of analysis of K^- capture on various nuclei taking into account the semiphenomenological description of the Y_0^* resonance.[a]

Nucleus[b]	Remarks[c]	A^2[d]	φ[e] (deg)	Γ_0'[f]	Δ, available energy[g] (MeV)	$B(p)$[h] (MeV)	E_x[i] (MeV)
H	Experiment	2.1	- 51	56	0	...	...
D	Corrected	13.7	- 84	58	- 9.8	2.2	7.6
He	Corrected	14.9	-164	40	-58.6	20.6	38.0
C and O	Corrected	31.5	-130	43	-39.4	15.4	24.0
Ag	Corrected	14.5	-109	65	-30.3	6.2	24.3
	Uncorrected	5.2	-101	113	-40.2	6.2	34.0

[a]See Ref. 4.

[b]Nuclei for which data are available.

[c]"Corrected" means that all values, except $B(p)$, have been corrected for the enhanced neutron-to-proton ratio in the region beyond the normal nuclear-matter radius ($\approx 1.10A^{1/3}$ fm), N/Z being the ratio assumed for the core. (Obviously, such a correction could not exist for capture on hydrogen.)

[d]Ratio of squares of amplitudes for capture in $T=0$ and $T=1$ modes.

[e]Relative phase for the $T=0$ and $T=1$ modes.

[f]Altered values of total width of Y_0^* resonance. (Hydrogen is regarded as having the unaltered value.)

[g]Available energy of the K^--p system in the capturing nucleus. This number is the sum of h and i taken with the negative sign.

[h]Binding energy of last proton.

[i] Calculated value for the average excitation energy of residual nucleus after proton capture, taking into account the binding energy in Note h.

of amplitudes for capture in the $T=0$ (or Y_0^*) mode to capture in the $T=1$ mode, and φ is the relative phase of the two modes. Both numbers (A^2 and φ) were then used in a Breit-Wigner approximation of the $T=0$ resonance to deduce values for Γ_0', the effective total width (column 5), and Δ, the available energy necessary in order to produce agreement with the experimental results. It will be noted that Γ_0' is modified somewhat from the free value of 56 MeV, corresponding to capture on hydrogen. These variations are discussed later. Also, it will be seen that Δ lies well above the resonance in the case of H and D, well below in the case of carbon and oxygen, and still further below in the case of helium.

For silver, the calculations show that capture occurs right at resonance, if one takes into account the correction for the change in the neutron-to-proton density ratio in going from the core of the nucleus to the region beyond the normal nuclear radius. In the core this ratio is assumed to be $N/Z=1.3$. Using a simple Fermi-gas model for the nucleus and including the penetration outside the nuclear core of the neutrons and protons leads to an effective average value of 2.0 for this ratio in the silver nuclear surface. The corresponding (corrected) number for A^2 (14.5) is significantly smaller than the value given for carbon and oxygen (31.5). To produce this lower value in resonance the greater value in Γ_0' was required.

The uncorrected values for silver were deduced by assuming a neutron-to-proton density ratio of N/Z everywhere. It will be seen that in this case we get an unreasonably high value for Γ_0' (113 MeV). Even the corrected value $\Gamma_0' \approx 65$ MeV is somewhat large. But this value, along with the other corrected values for Γ_0', are well within the kind of accuracy characterizing our elementary approach to this problem and could indeed be deemed in agreement with the free value of 56 MeV, for all present purposes. It is gratifying, furthermore, that the average excitation energy of the residual nucleus (column 8 of the table) should be similar for carbon, oxygen, and silver. It is also reasonable that this energy should be greater in helium, where extraction of the proton will leave the remaining three nucleons with considerable kinetic energy as compared with the kinetic energy they would have in the tritium ground state. That some kinetic energy should remain in the case of the deuteron (which plays the role of an energy of excitation) can likewise be understood.

The above account of the K^--capture process is, of course, far from conclusive, since we have treated the residual excitation of the nucleus in a very crude way, assuming, as we did, that this excitation was unique. Also, we have neglected the possible interaction of the Y_0^* with

the nucleus. In nuclear matter, the properties of the Y_0^* may be different than when the Y_0^* is formed in the free state through the capture of a K^- on hydrogen. In addition the interaction of the reaction products with the residual nucleus should be taken into account. Nonetheless, our study has shown that the $T=0$ resonance plays a decisive role in the K^- capture and gives a qualitative explanation of the main results. Only after taking the Y_0^* resonance into account can one hope to explore properly the surface properties of nuclei by K^- absorption.

A more detailed account will be published in the near future.

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PHASE CONSPIRACY IN UNOCCUPIED HARTREE-FOCK ORBITALS

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Second order energies and the probabilities of two-particle, two-hole components in the ground states of He^4 and O^{16}, calculated using perturbation theory in Hartree-Fock bases, show that excitations to high lying levels are more important than the shell model predicts. The importance of these excitations stems from the relative phases of the Hartree-Fock wave functions for unoccupied states and this phase relation can be explained quite simply.

Hartree-Fock (HF) calculations are presently being performed in bases sufficiently large that they may be considered complete for light nuclei.[1,2] It is well known, however, that the binding energies thus obtained differ widely from observed binding energies if realistic potentials are used. As Kerman pointed out,[3] this lack of agreement should be expected from experimental single-particle energies and their relation to the HF energy. Thus an HF calculation should serve only to define a convenient basis in which to carry out a perturbation calculation. In such a basis, the first-order correction vanishes and only two-particle, two-hole (2p-2h) states contribute in second order, i.e.,

$$\Delta E = \sum_{m<n} \sum_{a,b} \frac{|\langle mn|V_A|ab\rangle|^2}{\epsilon_m + \epsilon_n - \epsilon_a - \epsilon_b}. \quad (1)$$

Here m,n are the occupied HF orbitals, a,b the unoccupied orbitals; the ϵ's are the corresponding HF eigenvalues, and V_A signifies the antisymmetrized matrix element.

An approximate method for evaluating ΔE has been developed[4] and quite reasonable agreement with experiment was obtained for O^{16} and Ca^{40}. The method was applied to all the even-even nuclei from helium to calcium with similar success.[5] The essential approximations were these: (1) replacing the unoccupied orbitals by plane waves and the corresponding ϵ's by $\hbar^2k^2/2m$, (2) replacing the ϵ's for the occupied states by a constant equal to their average value, (3) taking the Pauli principle into account approximately. In order to evaluate this procedure we have carried out the evaluation of ΔE exactly in a truncated, but very large, basis.

The HF bases were obtained for He^4 and O^{16} in a space consisting of the $1s_{1/2}$ through the $1i_{13/2}$ harmonic oscillator levels and the two-body potential employed was that of Tabakin.[6] All of the particles were treated self-consistently. Doubly closed-shell nuclei were treated because the HF orbitals in this case are all eigenstates of l and j and are degenerate with respect to j_z and τ_z, in the absence of the Coulomb force. This allows a certain amount of geometry to be done analytical-