for a medium heavy nucleus. In no case should the collision cross section be less than the geometric cross section. Since the antiproton is attracted into the nucleus, a considerable fraction of the cross section should correspond to a disintegration process. If an antiproton is not likely to escape from the interior of a nucleus, scattering experiments with antiprotons may give a particularly clear picture of the decrease of the nuclear potential outside the nucleus.

An attraction between a proton and antiproton may lead to the formation of a bound pseudoscalar state which can be identified with the π meson.[3] Since in our view the main part of the nuclear potential is not caused by π mesons, it would be satisfying to follow the reverse procedure and explain the π mesons in terms of the postulated nuclear fields.

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Recoil Broadening of Internal Conversion Lines Associated with Alpha Decay

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THE energies of γ rays emitted from nuclei, which have been set in motion by recoil, are altered in virtue of the Doppler shift. Such Doppler shifts have been detected in light nuclei recoiling during nuclear reactions, and have been used to obtain information on the lifetimes of short-lived excited states.[1]

Internal conversion electrons emitted from recoiling nuclei may exhibit a significant broadening in the conversion line, as a simple consequence of addition of velocities. Such effects are entirely negligible in β decay, but are appreciable for recoil nuclei associated with alpha decay. If the conversion electron is emitted at an angle θ with respect to the direction of recoils, then the momentum p of the electrons is given by the relation,

$$p=p_0[1+(v_\alpha/v_\beta)\cos\theta],$$

where p_0 is the momentum of the electron emitted by a stationary nucleus, v_α is the velocity of the recoiling nucleus at the time of emission, and v_β is the velocity of the conversion electron. Assuming, for simplicity, that there is no angular correlation between the alpha particles and the conversion electrons, then for an ideally thin source situated in vacuum on an ideally thin backing, the momentum distribution will be a triangle with a base $2\Delta p$ equal to $2(v_\alpha/v_\beta)p_0$, and with a relative half-width $\Delta p/p$ equal to v_α/v_β. The relative half-width of the corresponding energy or momentum distribution obtaining with the unconverted γ rays, because of the Doppler shift, is v_α/c, where c is the velocity of light. For low energies the recoil broadening of the conversion lines will be considerably greater than the Doppler broadening of the unconverted γ rays.

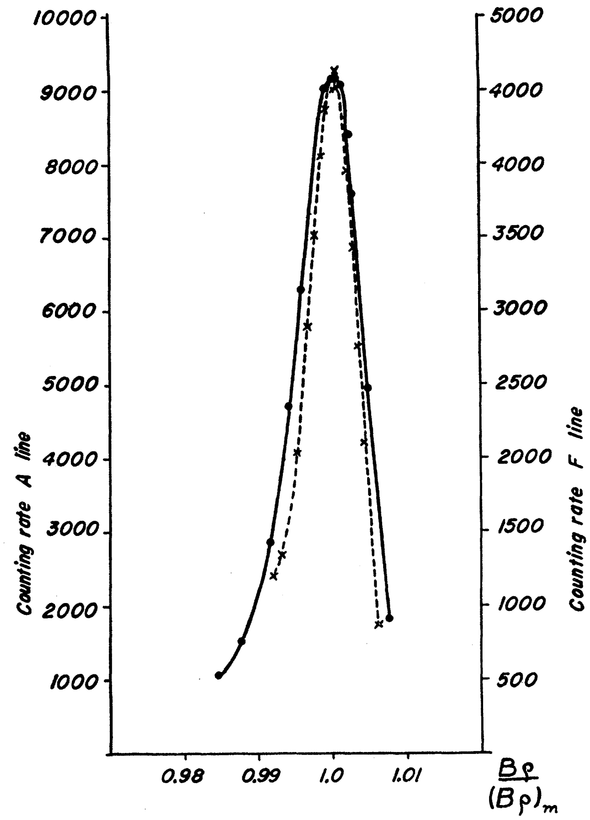

FIG. 1. Comparison of the line shapes of the "A" line and "F" line from thorium active deposits, using a resolution of 0.8%. The momentum distributions are plotted as a function of $B\rho/(B\rho)_m$, where $(B\rho)_m$ is the peak momentum, in order to facilitate comparison. The full curve corresponds to the "A" line (ordinate scale on left). The broken curve corresponds to the "F" line (ordinate scale on right). The half-width of the "F" line is 0.8%. The half-width of the "A" line is 1.0%.

Line broadening and shifts arising from α recoil have been observed for the L_1 conversion electrons of the 40-kev transition in ThC″ (Tl^{208})—the "A" line from thorium active deposit. The energy of the conversion electron is 24.5 kev corresponding to a velocity v_β of 9×10^9 cm/sec; the energy of the α particle leading to the 40-kev level is 6.04 Mev, leading to a recoil velocity v_α of 3.3×10^7 cm/sec. The relative momentum half-width for an ideal source should thus be 0.36%. Figure 1 shows a comparison of the widths of the thorium "F" line (148 kev) and "A" line obtained from the same source (a ThB source prepared by recoil on 0.17 mg/cm² aluminum and in equilibrium with its products) using a short-lens spectrometer at a resolution of 0.8%. Since the conversion electrons giving rise to the F line follow β decay, no detectable recoil broadening should be present.

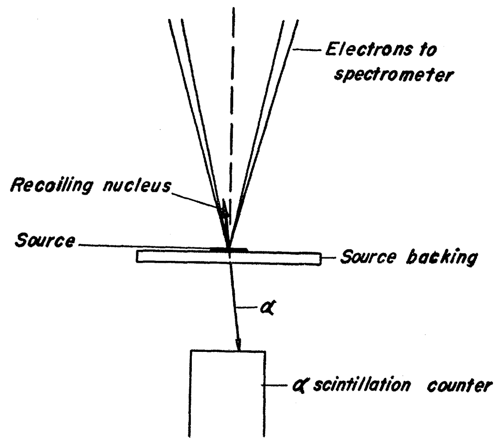

FIG. 2. Schematic diagram of arrangement used for detecting coincidences between conversion electrons and α particles.

In further experiments, the line shape of the "A" line was compared with the line shape obtained in coincidence with the 6.04-Mev α particles, which were selectively detected by a fast scintillation counter, situated behind the source in the lens spectrometer, as shown schematically in Fig. 2. This coincident arrangement selects conversion electrons which are emitted from recoil nuclei moving outwards from the source into vacuum. If the α detector subtends a small solid angle at the source, the resulting coincident peak should show only a small recoil broadening and should have a mean momentum close to the maximum momentum of the recoil distribution which is $p_0[1+(v_\alpha/v_\beta)]$. The results are shown in Fig. 3, where it is seen that the coincidence peak is indeed narrower by about 0.2% and is shifted to higher energies by 0.24%. The measurements were taken at a resolution of 1.2%. Similar behavior has been observed in the low-energy L Auger spectrum (6–12 kev) coincident with the 6.04-Mev α particles.[2] The width of the A line coincident with α particles was found to be about the same as the width of the F line when examined under the same spectrometer resolution. This shows that electron scattering in the source cannot be an important factor contributing to the observed broadening of the lower energy A line.

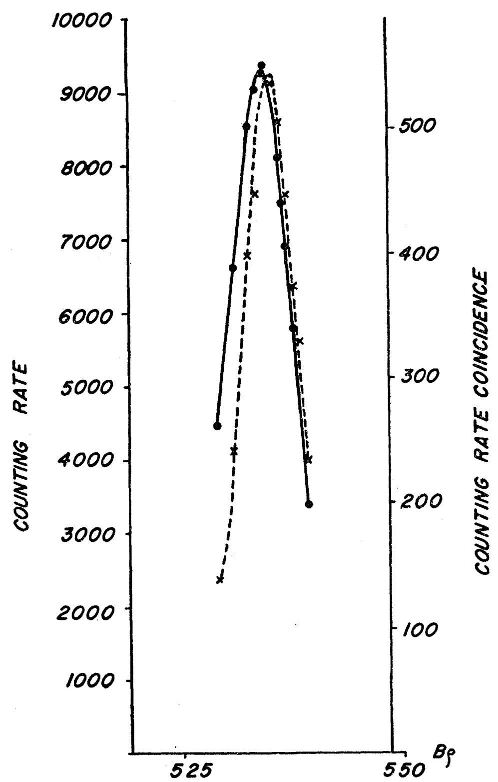

FIG. 3. Comparison of the single and α coincident peaks for the "A" line. In this experiment the α counter subtended an average solid angle of about 1 steradian at the source. The full curve corresponds to the single peak (ordinate scale on left). The broken curve corresponds to the coincident peak (ordinate scale on right).

A detailed analysis of the results has been made, taking into account the finite resolution of the spectrometer, and the possible loss of energy in the source backing suffered by electrons coming from recoil nuclei, which have buried themselves in the source backing. Good agreement with the observed shifts is obtained only if we assume that only the nuclei recoiling into the vacuum give rise to significant shifts. This leads to the conclusion that the nuclei recoiling into the source nuclei lose most of their momentum in the source backing *before* the conversion electrons are emitted. Assuming a linear relation between velocity and residual range for the recoil nuclei[1] and using a value of about 6 $\mu g/cm^2$ for the average range of the recoil nuclei in the aluminum (as measured in this laboratory), we conclude that the recoil nuclei are slowed down in aluminum in about 2×10^{-13} sec. It follows that the lifetime of the 40-kev transition must be greater than 2×10^{-13} sec. An upper limit of 7×10^{-11} sec is given by the experiments of Graham and Bell.[3] An attempt is being made to fix the lifetime between these limits using recoil shifts. The methods may be useful for lifetime measurements in other high-specific-activity α emitters.

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Mean Life of K^+ Mesons*†

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CURRENTLY the best evidence supports the view that there are at least two types of K-mesons in the mass range of 900 to 1000 m_e. The τ meson appears not to have both the spin and parity of the