Electric Monopole Transitions in C^{12} and O^{16}

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SCHIFF[1] has considered the $0^+ \rightarrow 0^+$ electric monopole transitions between the 7.68-Mev state and ground state of C^{12} and between the 6.06-Mev state and ground state of O^{16}, from the point of view of both the alpha-particle and the individual-particle models of the nucleus. He found that the α-particle model gave a value four times too large for the matrix element $\sum_p r^2$ of the monopole operator whereas his independent-particle calculation for C^{12} gave a value six times too small. In this Letter we point out that his shell-model configurational assignment for the excited 0^+ state is not a reasonable one, and that if one takes a configuration consistent with the results of intermediate coupling the value for $\sum_p r^2$ could quite easily agree with experiment.

Although the spectra drawn by Inglis[2] were derived by interpolating between the $L-S$ and $j-j$ coupling extremes, subsequent exact calculations have shown that his results are qualitatively reliable. In the configuration s^4p^8 for C^{12} Inglis shows no 0^+ level in the first 15 Mev of excitation for any degree of coupling. The 0^+ state observed at 7.68 Mev should therefore come from some excited configuration. This argument is confirmed from the 0^+ state in O^{16} at a similar excitation 6.06 Mev, which must come from an excited configuration since the lowest configuration s^4p^{12} for O^{16} is a closed shell having only one level, the 0^+ ground state. The excited 0^+ state in O^{16} must therefore be composed of some mixture of the configurations

(i) $(1s)^3\ (1p)^{12}\ (2s)$,
(ii) $(1s)^4\ (1p)^{11}\ (2p)$,
(iii) $(1s)^4\ (1p)^{10}\ (1d)^2$,
(iv) $(1s)^4\ (1p)^{10}\ (2s)^2$,
(v) $(1s)^4\ (1p)^{10}\ (1d,2s)$,

each of which is doubly excited above the ground configuration $(1s)^4\ (1p)^{12}$ if one assumes an oscillator well. The excited 0^+ state in C^{12} will consist of similar configurations with four less $1p$ particles. In its present form, the individual-particle model only predicts the relative positions of levels within a configuration. It does not predict the position of one configuration relative to another since this would be analogous to a binding energy calculation for which the model is inadequate. It is admittedly unsatisfactory that the individual-particle model has not yet explained why these excited configurations are so low, but since they are observed we must introduce them in an empirical way. A detailed study of the low excited configurations in and around O^{16} is being carried out at Harwell to try to answer this question.

Since configurations (iii), (iv), and (v) differ in two particles from the ground state they cannot contribute to the $E0$ transition. The configurations (i) and (ii) do contribute, and, putting in oscillator wave functions with their parameter fitted to the nuclear size, we find the values 6.8×10^{-26} cm^2 and 8.8×10^{-26} cm^2, respectively, for the matrix element $\sum_p r^2$. The observed value, measured by Devons, Goldring, and Lindsey,[3] is 3.8×10^{-26} cm^2, so that if the mixture of configurations contains a total of about 50% of configurations (i) and (ii), which is a reasonable requirement, the matrix element calculated on the individual-particle model will be in agreement with experiment.

[1] L. I. Schiff, Phys. Rev. **98**, 1281 (1955).
[2] D. R. Inglis, Revs. Modern Phys. **25**, 390 (1953).
[3] Devons, Goldring, and Lindsey, Proc. Phys. Soc. (London) **A67**, 134 (1954).

Ratio of K^- Mass to K^+ Mass*

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MEASUREMENTS on the mass of the positive K particle have recently been carried out by direct comparison of the ranges of K^+ and τ^+ mesons and by comparison of ranges of K^+ mesons and protons of the same momentum.[1–4] For negative K particles no such direct comparison is possible. Hornbostel and Salant[5] determined the K^- mass by a range-momentum method as $931 \pm 24\ m_e$.

In order to compare the negative K-meson mass with the positive K-meson mass, we have exposed stacks of nuclear emulsions to the focused K^+ and K^- beams[1,2] of the Bevatron, maintaining the geometry constant and reversing the magnetic field[6] in the focusing spectrometer.

The stacks were exposed with the plane of the emulsions in the vertical direction. The horizontal

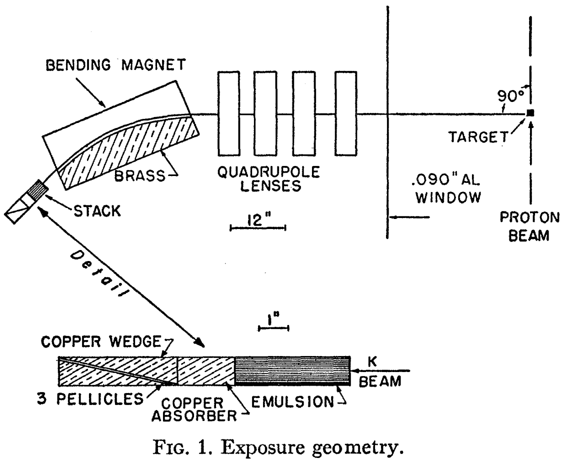

FIG. 1. Exposure geometry.

momentum dispersion in the analyzing magnet gives rise to a momentum spread across the stacks. The momentum in the K^+ stack (forty 600-μ Ilford G.5 pellicles) varies from about 315 Mev/c to 335 Mev/c, and that of the K^- stacks (one hundred and thirty-two 600-μ pellicles) from about 280 Mev/c to 355 Mev/c. Immediately behind the stacks, a copper absorber and wedge were placed to stop the positive and negative π mesons in the respective exposures. The geometry of the exposure is shown in Fig. 1.

The scanning method used in this experiment was "scanning along the track." Tracks were picked on the basis of their ionization (grain density) at the entering edge of the emulsion in the negative stack and 1 cm from the edge (i.e., after the region in which the protons of the same momentum stop) in the positive stack. The limits of the grain density at which a particle was selected were chosen so as to include particles between the mass of 700 m_e and 1300 m_e. All K mesons that underwent a nuclear scattering (scattering $>20°$ for $E_K > 30$ Mev) were eliminated from the sample chosen for the K^--mass determination. Three K^- mesons and two K^+ mesons were eliminated in this fashion. The method employed for the K^--mass determination was as follows:

1. The ranges of the positive K mesons were used to determine the momentum of the positive channel. The mass of the K^+ used for the momentum determination is $M_{K^+} = M_\tau = 965.4\ m_e$. It should be noted that the M_{K^-}/M_{K^+} ratio is not sensitive to this assumption. Figure 2 shows the range distribution of the positive K mesons.

2. Both the positive and negative π mesons were stopped with a copper absorber and wedge (under the same geometry), permitting us to determine the π^+ and π^- range difference. This was accomplished by observation of stopping π mesons in pellicles placed in the wedge. The knowledge of the momentum in the positive channel and of the difference in the π^+ and π^- ranges permits us to calculate the momentum in the negative channel. This calculation was carried out by integrating the function dp/dR, by use of Aron's tables.[7] The difference in the momenta obtained from the pion range difference ($R_{\pi^+} - R_{\pi^-} = 1.46$ cm in emulsion) is 9 Mev/c. This method is not affected by the over-all accuracy to which the range-energy relation is known since it uses dE/dx to bridge across only a small momentum difference. The range distribution of the positive and negative π mesons is shown in Fig. 3.

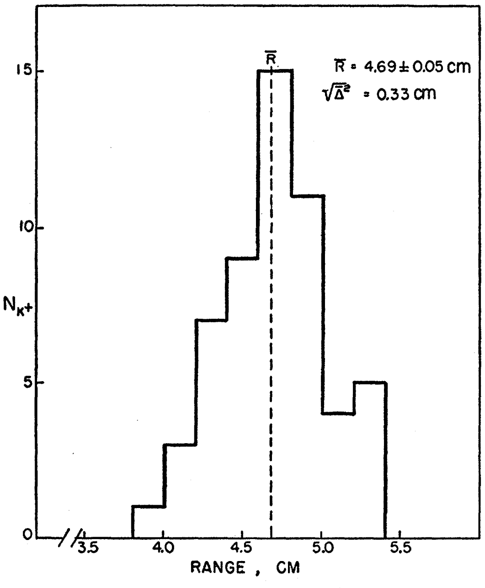

FIG. 2. Range distribution of positive K mesons.

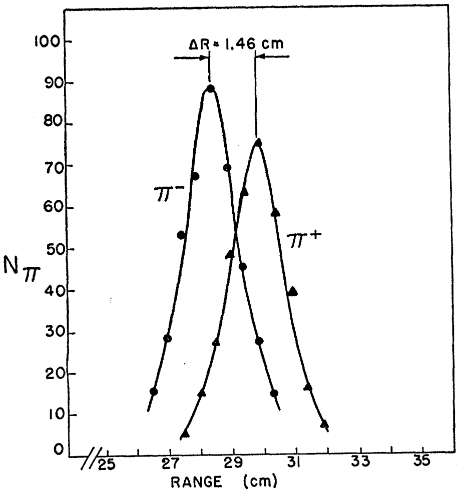

FIG. 3. Range distribution of positive and negative pions. The mesons traversed the stack and the copper absorber and wedge. The equivalent emulsion range is given by ρ emulsion$=3.85$ g/cm^2.

3. The range of the negative K mesons, and the momentum in the negative channel obtained by Method 2, permitted us to determine the K^- mass.[8]

For the K^--mass determination we used the ranges of 42 K^- mesons found in the central part of the stack. Any error in the mass due to the error in the measurement of the momentum dispersion is thus negligible. The momentum dispersion was measured by wire trajectories[1] and checked by us with the range of protons in the positive channel. The uncertainties that contribute to the error in the K^- mass are (a) statistical errors; (b) alignment errors, which are of the same order as the statistical errors; (c) errors in range measurements, which are negligible compared with (a) and (b). As all our measurements were carried out relative to the K^+ range, systematic errors would tend to cancel. A mass histogram for these 42 mesons is shown in Fig. 4.

The ratio of the negative K-meson mass to positive K-meson mass thus obtained is

$$M_{K^-}/M_{K^+} = 0.998 \pm 0.013.$$

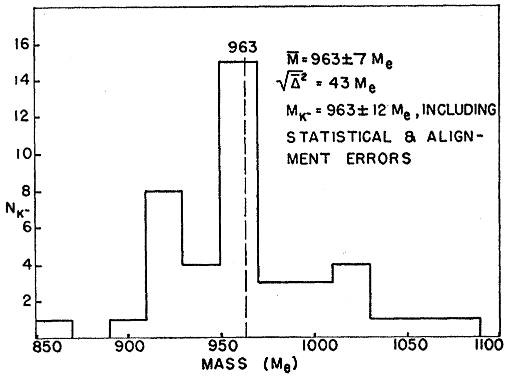

FIG. 4. Mass histogram of the negative K mesons (assuming $M_{K^+}=M_{\tau^+}=965.4\ m_e$).

The mass of the K^-, if we assume $M_{K^+}=M_\tau=965.4\ m_e$, is

$$M_{K^-}=963\pm12\ m_e.$$

The above mass determination corresponds to the mass of K mesons present, after a time of flight of 1.4×10^{-8} sec in the proper system of the K mesons.

We are greatly indebted to Dr. E. J. Lofgren and the Bevatron crew for their assistance in carrying out the exposures. We also wish to thank Mr. H. H. Bayona, G. M. Wike, and Mrs. C. Toche for their help in scanning the emulsions.

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[1] Birge, Haddock, Kerth, Peterson, Sandweiss, Stork, and Whitehead, Phys. Rev. **99**, 329 (1955).

[2] Birge, Peterson, Stork, and Whitehead, Phys. Rev. **100**, 430 (1955).

[3] Fung, Pevsner, and Ritson (to be published).

[4] Heckman, Smith, and Barkas, University of California Radiation Laboratory Report No. UCRL-3156, 1955 (unpublished).

[5] J. Hornbostel and E. O. Salant, Phys. Rev. **99**, 338 (1955).

[6] The stray field of the Bevatron increases the magnetic field of the strong-focusing spectrometer for exposures to positive particles and decreases it for exposures to negative particles. A compensation for the stray field was made which almost cancelled this effect.

[7] Aron, Hoffman, and Williams, University of California Radiation Laboratory Report No. UCRL-121, 1949 (unpublished).

[8] Range-energy tables of W. H. Barkas and G. Hahn [University of California Radiation Laboratory Report No. UCRL-2579 (unpublished)] were used in this work.

Heavy Meson Fluxes at the Cosmotron*

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A MOMENTUM-analyzed K-meson beam was obtained at the Brookhaven Cosmotron using a combination of two strong-focusing magnetic quadrupoles followed by a deflecting magnet, as shown in Fig. 1. The quadrupoles were of 6-inch aperture by 12-inch length with a minimum possible spacing of 15 inches. The deflecting magnet had a 3-inch gap with 9×18 inch polefaces, giving a maximum possible deflection of 32° for 290 Mev/c. With the system at 60° to the beam direction the following beam fluxes were obtained from 5.6×10^{12} protons of 2.9 Bev incident on a $\frac{1}{8}\times\frac{1}{8}\times\frac{1}{2}$ inch copper target: 3.6×10^5 protons/cm², 1.7×10^5 light tracks (mainly pions)/cm², and 280 ± 40 K_L-mesons/cm². This particular exposure took 15 minutes of beam.

In the 114-Mev Bevatron K-meson beam,[1] the proper time between target and emulsion is 1.27×10^{-8} sec. In this experiment the proper time is 1.9×10^{-8} sec. The π/K ratio in our emulsions was (600 ± 90) as compared to (70 ± 7) in similar-type Bevatron exposures to 6.2-Bev protons. Assuming a K-meson lifetime of 10^{-8} sec and correcting the observed π/K ratios for decay in flight only, the π/K ratio at the Bevatron target is then about 20 compared to about 90 for the Cosmotron at the respective laboratory energies and angles.

Scanning was by means of following gray tracks picked up at a heavy meson residual range of 2 cm. A total of 328 heavy mesons was found; of these 304 had a single lightly ionizing secondary (in 19 cases the secondary could not be found, so the primary had to be determined by grain-counting), 21 were taus, and 3 had a secondary heavier than ~1.7 times minimum. The latter three were all alternate taus and none were $K_{\mu3}$. In spite of the handicap of large π/K ratio, by restricting ourselves to certain angle, grain density, and visual scattering criteria, 80% of the tracks followed turned out to be heavy mesons. About 35% of the heavy mesons were missed when this fast scanning was used, but this does not affect the relative frequencies. Scanning rates of 18 heavy mesons per 8-hour day were achieved. Our K to tau ratio (304:21) is the same within statistics as that obtained in the Bevatron K-beams which are at 90° from a copper target bombarded by 6.2-Bev protons.[2,3]

According to the Bevatron ratios, we should have found about 4 alternate taus and about 2 $K_{\mu3}$'s. Our results of 3 and 0, respectively, are not inconsistent with mean values of 4 and 2. Lifetime measurements

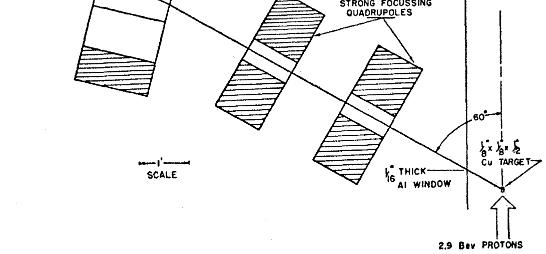

FIG. 1. Experimental setup for 80-Mev K-meson beam at the Cosmotron.