Negative - kaon mass*

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The mass of the negative kaon has been determined to be 493.66±0.19 MeV from measurements of kaonic-atom x-ray energies. The value depends upon considering calculated contributions to the complete atomic cascade.

[NUCLEAR REACTIONS Measured K^- x rays, calculated atomic cascade, calculated energies, deduced K^- mass.]

The kaon is the lowest-mass strange particle and is used in methods to determine higher-mass particles. A good measured value of the kaon mass is thus a necessity. We present here results from revisions in the calculations of the x-ray energies and from revisions in the relative contributions to the various transitions of kaonic atoms. The final result is a more accurate value of the kaon mass.

Proceeding as previously,[1] we calculate the total energy E_T of each observed transition as a function of the kaon mass. The Coulomb energy E_C is obtained from the Klein-Gordon equation with the usual reduced mass. The effect of the finite nuclear-charge size is negligible. Corrections for nuclear motion and relativity are included.[2]

The largest energy correction is from the lowest-order $\alpha^2 Z$ vacuum polarization E_L. Corrections for finite nuclear size and wave-function modification are included.[2] The energy corrections from higher-order ($\alpha^3 Z$, $\alpha^4 Z^3$, $\alpha^6 Z^5$, $\alpha^8 Z^7$) vacuum polarization E_H are included.[2] These previously were calculated from an erroneous formula. Other energy corrections E_0 such as effects from muon-pair vacuum polarization and nuclear polarization are included.[2] The energy correction from screening of the nuclear charge by the atomic electrons E_E, was estimated from calculations by Vogel.[3] The energy correction from the strong interaction between the kaon and the nucleus was minimized by considering only transitions where the kaonic orbits of importance were far from the nucleus. The corrections were estimated by use of a computer code due to Seki[4] and are usually negligible as pointed out by Koch and Sternheim.[5] When appreciable for small l values they were considered as an additional error but made little difference in the final result. As an example, even if the shift for Pb in the state $n=8$, $l=5$ was 1 keV, it is weighted by a factor of 0.001 and contributes a negligible error in the averaged energy. Examples of the magnitudes of the energies involved for the 9, 8–8, 7 (n_1, l_1–n_2, l_2) transition of Pb for a kaon mass of 493.715 MeV are (in keV): $E_C=290.081$, $E_L=1.582$, $E_H=-0.023$, $E_0=0.004$, $E_E=-0.027$, and $E_T=291.618$.

The main contribution to all of the radiative transitions was from the $l=n-1$ orbits ("circular"), but there were other contributions from smaller l values. These were neglected previously. The smaller l values do not contribute a large fraction of the total because the strong interaction absorbs low-l orbits rapidly. The relative intensities of contributions to a transition were calculated from a computer code due to Leon and Seki who compared relative intensities with available kaonic-atom x-ray data.[6] The ratios of the intensities of $\Delta n=2$ to $\Delta n=1$ transitions were a sensitive test of the parameters used. An interaction parameter of $A=0.60+i0.71$ fm was used for the strong interaction.[7] Several values for the interaction parameter were tried and the differences in the relative intensities were small. Similarly, differences in initial atomic-capture distributions were considered and treated as additional uncertainties. The reliability of the relative intensities is discussed below.

The total energies E_i and relative intensities I_i are shown in Table I for the various contributions to transitions for Pb as an example. The contributions are labeled by an index i for the difference between the value of n and l (for example E_1 and I_1 are the $l=n-1$ energy and relative intensity). The calculated energies were averaged over the contributions to compare E_A with the measured energies E_M for each transition.

For the data, if only the $l=n-1$ contributions to the transitions were considered the kaon mass was found to be 493.81 ± 0.19 MeV compared to 493.87 ± 0.19 MeV with the previous wrong calculations.[1] However, if all contributions were considered the kaon mass was found to be 493.662 ± 0.19

TABLE I. Kaonic-atom x-ray energies and relative intensities for Pb transitions. The calculated energies are in keV and are total transition energies based on a kaon mass of 493.715 MeV. The subscripts of the energies and intensities refer to the value of $n-l$ for a particular contribution of the transition. The averaged calculated energy of a transition is given by E_A and the measured energy by E_M.

Tran.	E_1	I_1	E_2	I_2	E_3	I_3	E_4	I_4	E_5	I_5	E_A	E_M
9–8	291.618	0.810	292.222	0.189	293.175	0.001					291.734	291.74 ± 0.21
10–9	208.277	0.671	208.569	0.275	208.964	0.054					208.394	208.69 ± 0.21
11–10	153.911	0.568	154.063	0.297	154.261	0.113	154.541	0.021			154.008	154.13 ± 0.21
12–11	116.938	0.481	117.022	0.307	117.127	0.144	117.271	0.057	117.474	0.011	117.016	116.96 ± 0.25

MeV, in agreement with a recent result 493.691 ± 0.040 MeV.[8]

There is an important assumption that affects the accuracy of the intensities and hence the final result. The strong interaction parameters have not been tested for many nuclei and extending the value determined for light nuclei for $n=2$ and $n=3$ to cases for heavy nuclei and large values of n may not be correct.[7] This possible inaccuracy is presently difficult to accurately determine and assign an uncertainty to the determined kaon mass.

The other kind of measurement of the kaon mass is from range measurements in nuclear emulsion and further measurements by this method will not improve the mass value because of systematic errors in the method.[9] From this technique the best measurement of the negative-kaon mass is 493.7 ± 0.3 MeV,[10] which is in agreement with all of the x-ray determinations.

In the determinations from x-ray measurements, contributions from other than $l=n-1$ levels are important and further experimental tests of the strong interaction parameters and cascade calculations are needed.

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