Title

KAON MASS MEASUREMENT FROM KAONIC ATOM X RAYS

Authors

Kunselman, Raymond
Wiegand, Clyde E.

Publication Date

1969-07-01

For Proc. of the Hypernuclear Physics Conf.,
Argonne, Ill., May 5-7, 1969

UCRL-19251
Preprint

KAON MASS MEASUREMENT FROM KAONIC ATOM X RAYS

Raymond Kunselman and Clyde E. Wiegand

July 1969

AEC Contract No. W-7405-eng-48

LAWRENCE RADIATION LABORATORY
UNIVERSITY of CALIFORNIA BERKELEY

KAON MASS MEASUREMENT FROM KAONIC ATOM X RAYS

Raymond Kunselman and Clyde E. Wiegand

Lawrence Radiation Laboratory
University of California
Berkeley, California 94720

July 1969

The energy levels of a hydrogenic atom are, according to the Bohr model, $E_n = -\alpha Z^2 mc^2/2n^2$, where $\alpha = e^2/\hbar c$, Z is the nuclear charge, and m is the reduced mass of the nucleus and the orbiting particle. A measurement of E_n (or the difference in energy between two levels) thus gives the mass of the orbiting particle. Several small corrections to E_n are needed in the practical application of the method as discussed below.

The kaon mass is presently known to be 493.82 ± 0.11 MeV,[1] based on measurements in nuclear emulsion of the decay of kaons into three charged pions. It appears that further decay measurements by this method will not improve the mass value, because of systematic errors in the method.[2]

We present in this note the measurements on several x-ray transitions of kaonic atoms and the preliminary results of a new determination of the mass of negatively charged kaons that is not statistically as accurate as the emulsion method but can be improved in future experiments.

The data were taken from the experiment of Refs. 3 and 4. The spectral lines were assumed to come from transitions between circular orbits n, n-1 → n-1, n-2, as discussed in Refs. 3 and 4.

The first step toward determining a new value of the kaon mass is to assume the mass to be 493.82 MeV and calculate the total energy of each observed transition. The total energy consists of the sum of the principal transition energy and several corrections. Since kaons are spinless particles we use, for the principal energy, solutions of the Klein-Gordon equation

$$E_n = mc^2 \left[1 + \frac{\gamma^2}{[n - \ell - \frac{1}{2} + \sqrt{(\ell + \frac{1}{2})^2 - \gamma^2}\,]^2} \right]^{-1/2}$$

where $\gamma = Z\alpha$, $\ell = n-1$, and m is the reduced mass of the kaon-nucleus system.

The largest energy correction is due to the effects of vacuum polarization. This energy was calculated by means of the formula given by Mickelwait and Corben.[5] The differences in vacuum polarization energy between levels are expected to be accurate to within a few percent even though the energy values at the levels themselves may systematically be less accurate.[6]

A small energy correction due to screening by the atomic electrons was estimated by means of a perturbation theory calculation, and found to contribute a shift of 13 eV in the worst case.

The energy correction due to the finite charge size of the nucleus was found to be less than 1 eV for the levels under consideration.

We took into consideration, when applicable, the effect of isotopic composition on the reduced mass of target nucleus and kaon. For example, we used a natural Pb target. The maximum difference in the Klein-Gordon energies among its three isotopes was less than 7 eV.

The last correction that we know of comes from the effects of the strong interaction between the orbiting kaon and the nucleus. In order to minimize the strong interactions we purposely considered only transitions having kaon orbits far from the nucleus. The largest correction encountered appears to be about 50 eV. It was estimated by considering an optical model of the nucleus and using an interaction parameter of 100 MeV between nucleus and kaon. The density of nuclear matter was similar to that suggested in Refs. 3 and 4: a low-density tail of neutrons that should exaggerate the strong interaction effect.

The Klein-Gordon energies and their corrections for each of the kaonic transitions studied are listed in Table I. We now have the total energies of the transitions based on a kaonic mass of 493.82 MeV. These calculated values will be compared with the observed values.

The observed energies were measured by comparing the positions of their spectral lines with the positions of the lines of radioactive sources of known energies: 121.97 ± 0.05 and 136.33 ± 0.04 keV(^{57}Co),[7] 276.33 ± 0.05 and 302.85 ± 0.05 keV(^{133}Ba),[8] and 279.17 ± 0.02 keV(^{203}Hg).[7] Within the error of measurement the five calibration points fell on a straight line, and it was further assumed that the detector system was linear over the energy intervals between the calibration points. The Pb electronic x rays $K_{\alpha 2}$ at 72.80 keV, $K_{\alpha 1}$ at 74.97 keV, and $K_{\beta 1'}$ at 84.80 keV[7] were used as consistency checks of the analysis of the Pb kaonic x rays.

The main sources of error in the observed energies come from uncertainties in the positions of the lines due primarily to the statistics of the number of x rays in each of the peaks and possible nonlinearity of the detector system. The measured energies and their estimated errors are listed in Table I. Finally the masses corresponding to each of the measured lines were calculated on the assumption that the ratio between the x-ray energy and the true kaon mass was the same as the ratio between the x-ray energy obtained by the Klein-Gordon equation (with all the corrections mentioned above) and the assumed kaon mass used in the calculations. The calculated kaon mass is practically independent of the assumed mass when the new value is nearly the same as the assumed value.[9] The measured values of the K^- mass are listed in Table I and plotted in Fig. 1. The weighted average kaon mass was found to be 493.97 ± 0.22 MeV.

Many of the present uncertainties can be reduced in future experiments. For example, more calibration points will be used and better statistics obtained.

We thank Professor Emilio Segrè for his most valued advice and ideas in the interpretation of the data. We thank Donald Brandshaft for help in checking calculations.

REFERENCES

1. Naomi Barash-Schmidt, Angela Barbaro-Galtieri, Leroy R. Price, Arthur H. Rosenfeld, Paul Söding, Charles G. Wohl, Matts Roos, and Gianni Conforto, Rev. Mod. Phys. 41, 109 (1969).
2. Walter H. Barkas, Ann. Rev. Nucl. Sci. 15, 67 (1965).
3. Clyde E. Wiegand, Phys. Rev. Letters 22, 1235 (1969).
4. Clyde E. Wiegand and Raymond Kunselman, in Proceedings of the International Conference on Hypernuclear Physics, Argonne National Laboratory, May 5-7, 1969.
5. A. B. Mickelwait and H. C. Corben, Phys. Rev. 96, 1145 (1954).
6. R. C. Barrett, Phys. Letters 28B, 93 (1968).
7. C. Michael Lederer, Jack M. Hollander, and Isadore Perlman, Table of Isotopes, Sixth Ed. (John Wiley and Sons, Inc., New York, 1967).
8. J. Barrette and S. Monaro, Nucl. Instr. Methods 63, 235 (1968).
9. Robert E. Shafer, Phys. Rev. 163, 1451 (1967).

Table I. Kaonic atom x-ray energies. All energies are in keV except the kaon mass, which is in MeV. The calculated transition energies are based on a value $m_K c^2 = 493.82$ MeV.

Element	Pb	Pb	Pb	Pb	Ni	^{44}Ca	^{40}Ca	K	Cℓ [a]	Cℓ [b]
Transition	9k-8j	10ℓ-9k	11m-10ℓ	12n-11m	6h-5g	5g-4f	5g-4f	5g-4f	4f-3d	4f-3d
Klein-Gordon energy	290.13	207.38	153.36	116.60	124.99	117.04	116.90	105.46	84.28	84.28
Vacuum-polarization energy	1.56	0.98	0.63	0.42	0.61	0.61	0.61	0.54	0.40	0.40
Electron screening	-0.01	-0.01	-0.01	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00
Finite charge size	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00
Strong-interaction shift [c]	0.01	0.00	0.00	0.00	0.01	0.05	0.05	0.03	0.01	0.01
Total calculated energy	291.69	208.35	153.98	117.02	125.61	117.70	117.56	106.03	84.69	84.69
Measured energy	291.74 ±0.2	208.69 ±0.2	154.13 ±0.2	116.96 ±0.2	125.37 ±0.2	117.64 ±0.2	117.46 ±0.2	106.28 ±0.3	84.80 ±0.2	84.75 ±0.2
Measured K^- mass (MeV)	493.89 ±0.4	494.62 ±0.5	494.31 ±0.6	493.57 ±0.8	492.88 ±0.8	493.57 ±0.8	493.40 ±0.8	494.98 ±1.4	494.38 ±1.2	494.09 ±1.2

a. From $^{44}CaC\ell_2$. c. Estimated as described in text.

b. From $^{40}CaC\ell_2$.

FIGURE CAPTION

Fig. 1. Measured values of the K^- mass.

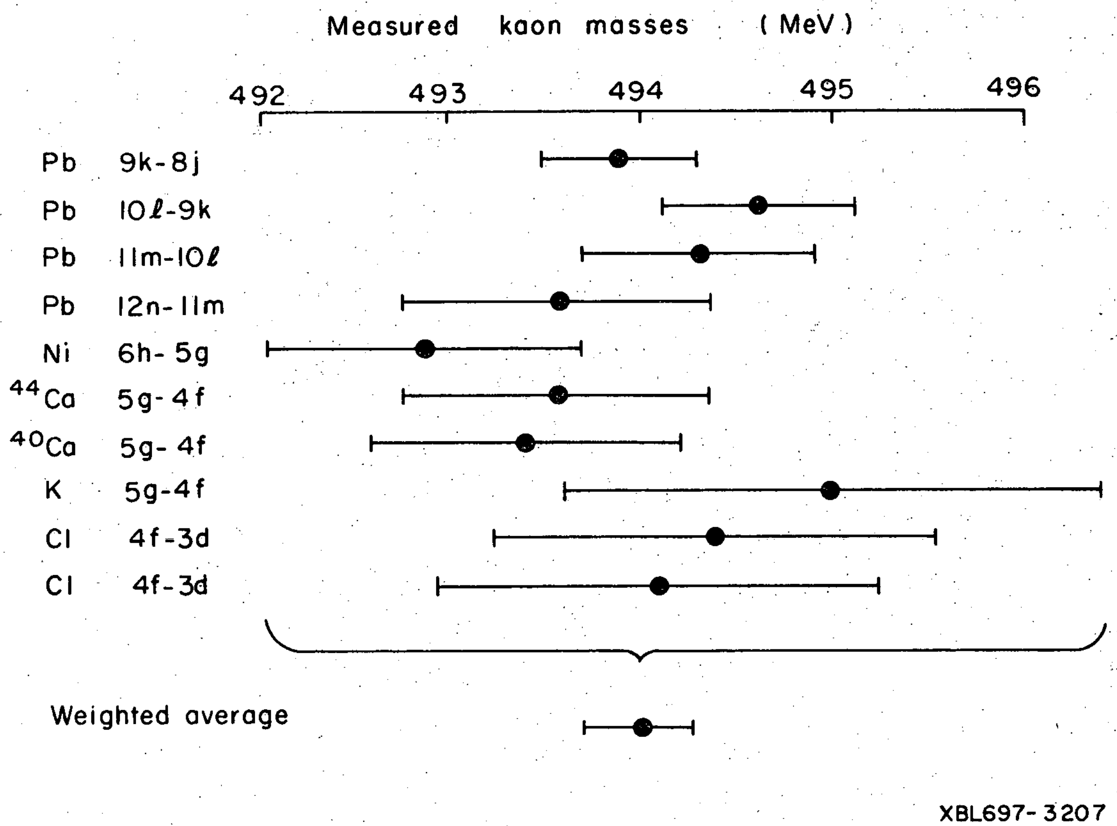
Measured kaon masses (MeV)
492
493
494
495
496
Pb 9k-8j
Pb 10ℓ-9k
Pb 11m-10ℓ
Pb 12n-11m
Ni 6h-5g
44Ca 5g-4f
40Ca 5g-4f
K 5g-4f
Cl 4f-3d
Cl 4f-3d
Weighted average
XBL697-3207

Fig. 1

TECHNICAL INFORMATION DIVISION
LAWRENCE RADIATION LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720