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KAONIC ATOM TRANSITION COUPLED TO NUCLEAR LEVEL*

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Abstract

A possible resonance coupling has been found between the first excited state of ^{55}Mn nuclei and transitions from Bohr orbits n = 9 to n = 6 in kaonic Mn atoms.

Among the x-ray lines of kaonic atom spectra, we have found several examples of nuclear γ rays.(1) The γ rays previously reported did not come from excited states of the nuclei of the target elements and their intensities were small compared to the intensities of the principal kaonic x-ray lines. In the kaonic x-ray spectrum of ^{55}Mn there is a line at 126 keV with about the same intensity as the principal kaonic transition $n = 5 \rightarrow 4$ at 100 keV. See. Fig. 1. The energy of the new radiation is the same within experimental error as the kaonic transition $n = 9 \rightarrow 6$, and the first excited state of ^{55}Mn nuclei.

In other elements in which $\Delta n = -3$ transitions are observed, the ratio of intensities, $I(\Delta n = -3)$ to $I(\Delta n = -1)$ is about 0.05; therefore the line cannot be due to kaonic $n = 9 \rightarrow 6$ alone. Its intensity is about a factor 20 too high.

One explanation for the high intensity of the line is a resonance effect due to the overlap of the energies of the nuclear state and the kaonic atom state. Due to the lifetimes of the states, the lines are expected to be broadened by $\Delta E \simeq \hbar/\tau$. The lifetime of the nuclear level is 2×10^{-10} sec; $\Delta E_N \simeq 3 \times 10^{-6}$ eV. The radiation rate from $n = 6$, $\ell = 5$, of kaonic Mn is 6.2×10^{14} sec^{-1}; $\Delta E_K = 0.4$ eV. Unless there is another effect to broaden the lines, the two energies could be the same within about one eV.

Seppi and Boehm,(2) using a bent crystal monochromator, measured the energy of the first excited level of ^{55}Mn and found it to be 125.95 ± 0.01 keV (error 1:12500). If the nuclear γ ray and the kaonic atom transition had the same energy, we could use this information to calculate the mass of K^- mesons. In the Review of Particle Properties(3) the average of the reported masses is listed as 493.83 ± 0.10 MeV and the compiler's fit to the data as 493.84 ± 0.10 MeV (error 1:5000).

It might be argued that the kaonic transitions had nothing to do with the intense line: that the effect was due solely to nuclear excitation by the products resulting from kaon capture. A reason to dismiss this argument is that in our kaonic spectrum of $^{127}_{53}$I there is no nuclear γ ray seen at 57.60 keV (the first excited level of ^{127}I). The spin states of ^{55}Mn and ^{127}I are similar. In Mn the ground state is $5/2^-$ and the first excited state is $7/2^-$ and in ^{127}I the respective states are $5/2^+$ and $7/2^+$. But in ^{127}I there is no kaonic transition to match in energy with the nuclear level and no nuclear γ rays were observed. However, we note an experiment by Temmer and Heydenburg(4) where Mn showed an anomalously high yield of 128 keV γ rays when bombarded by 3 MeV α particles.

There are difficulties in trying to explain the apparent coupling of the nuclear and kaonic states. A serious stumbling block stems from the comparatively long lifetime of the nuclear level, 2×10^{-10} sec and the much shorter lifetime of the kaonic state, about 10^{-15} sec. When (and if) the nucleus becomes excited, how does it radiate before it is destroyed by the kaon that presumably continues its cascade and reacts with a peripheral nucleon?

Also the parity of the system does not change with a radiationless excitation of the nucleus ($J^P = 5/2^-$ to $7/2^-$); therefore, the kaonic transition should be restricted to $\Delta\ell = 0, 2, 4, \ldots.$ instead of the normal dipole radiation $\Delta\ell = 1$.

There are other troubles. Fig. 2 is a schematic level diagram on which are shown the measured intensities in x rays per stopped kaon. Note that the transitions $n = 7 \to 6$ have 0.1 and $n = 6 \to 5$ have 0.13 x rays per kaon. (These could be the same within our experimental accuracy.) But, also feeding $n = 6$ are the $n = 9 \to 6$ transitions of intensity 0.15. Apparently the $n = 9 \to 6$ kaons did not end at $n = 6$, $\ell = 5$ because the sum of the number that arrived at $n = 6$ is greater than the number that reached $n = 5$. One explanation is that the $9 \to 6$ kaons landed at $\ell < 5$, where the capture rate was greater than the radiation rate from $n = 6$, $\ell = 5$. But this situation leads to a dilemma because the $n = 6$ levels of kaonic Mn are not exactly degenerate. In Table I we list the calculated energies of the $n = 6$ and $n = 9$ orbitals. Transition energies between the various angular momentum states can be obtained by subtraction.

We checked our Coulomb energy calculations against those of Shafer(5) and found excellent agreement. For example, the sum of the Klein-Gordon, vacuum polarization, and finite size energies for pionic 4f→3d in Ca is 72.352 keV by our calculation: Shafer gives for the sum of the same energies, 72.348 keV.

Some of the transition energies are indicated in Fig. 2. For example, n,ℓ = 9,6 to 6,5 is 126.012 keV but would not be allowed because $\Delta\ell \neq 1$, for radiationless excitation of the nucleus, and besides, the intensities do not add sensibly. On the other hand, n,ℓ = 9,5 to 6,3 has $\Delta\ell = 2$ but the energy is 126.241 keV and this is not compatible with equality to the nuclear γ ray, 125.95 keV.

There is, however, the possibility that the level, $n = 6$, $\ell = 3$, is displaced due to the intense absorption of kaons by the nucleus. For example, in Cl the $n = 4 \rightarrow 3$ transition is 0.77 ± 0.4 keV lower than the Coulomb energy.(6) If this were the situation, we could use the kaon mass to obtain an accurate value of the level shift.

These are some of the problems encountered in trying to explain the enhanced line. At this juncture we conclude only that the kaonic transition $n = 9 \rightarrow 6$ might be coupled to the first nuclear level in ^{55}Mn. If the relationship could be established, we would have a method of determining the kaon mass accurately and independently from the pion mass.

TABLE I. Energies of n = 6 and n = 9 states of kaonic ^{55}Mn based on kaonic mass of 493.84 MeV. Energies are in keV and are the sum of Klein-Gordon, vacuum polarization, and finite nuclear size.

ℓ	0	1	2	3	4	5	6	7	8
n = 6	-201.167	-222.861	-227.011	-226.889	".742	".632			
n = 9	-93.182	-99.525	-100.763	-100.727	".682	".648	".620	".597	".577

FOOTNOTE AND REFERENCES

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CAPTIONS FOR FIGURES

Fig. 1. Kaonic x-ray spectrum of ^{55}Mn.

Fig. 2. Schematic level diagram of kaonic ^{55}Mn. The transition energies are based on $m_K = 493.84$ MeV.

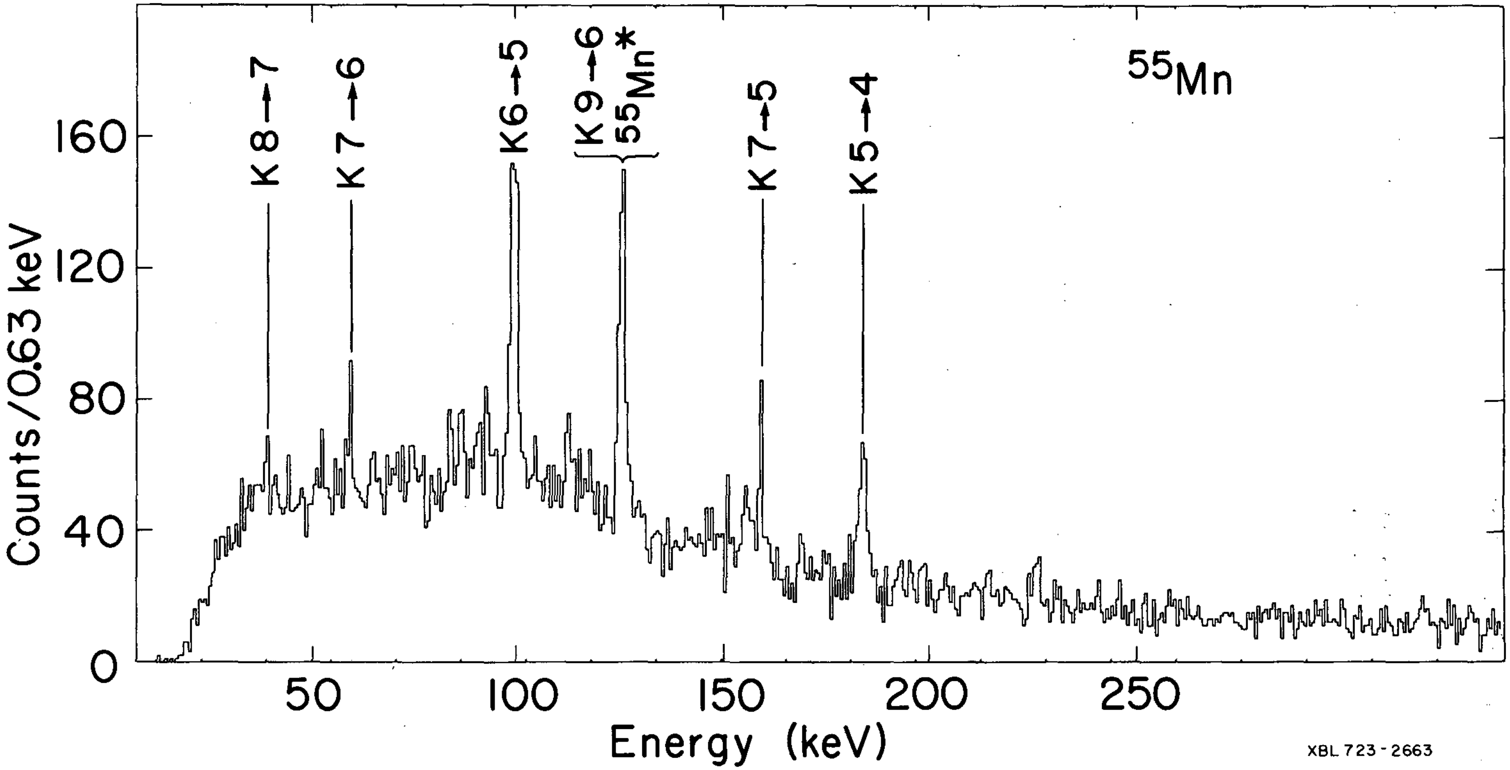

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Fig. 1

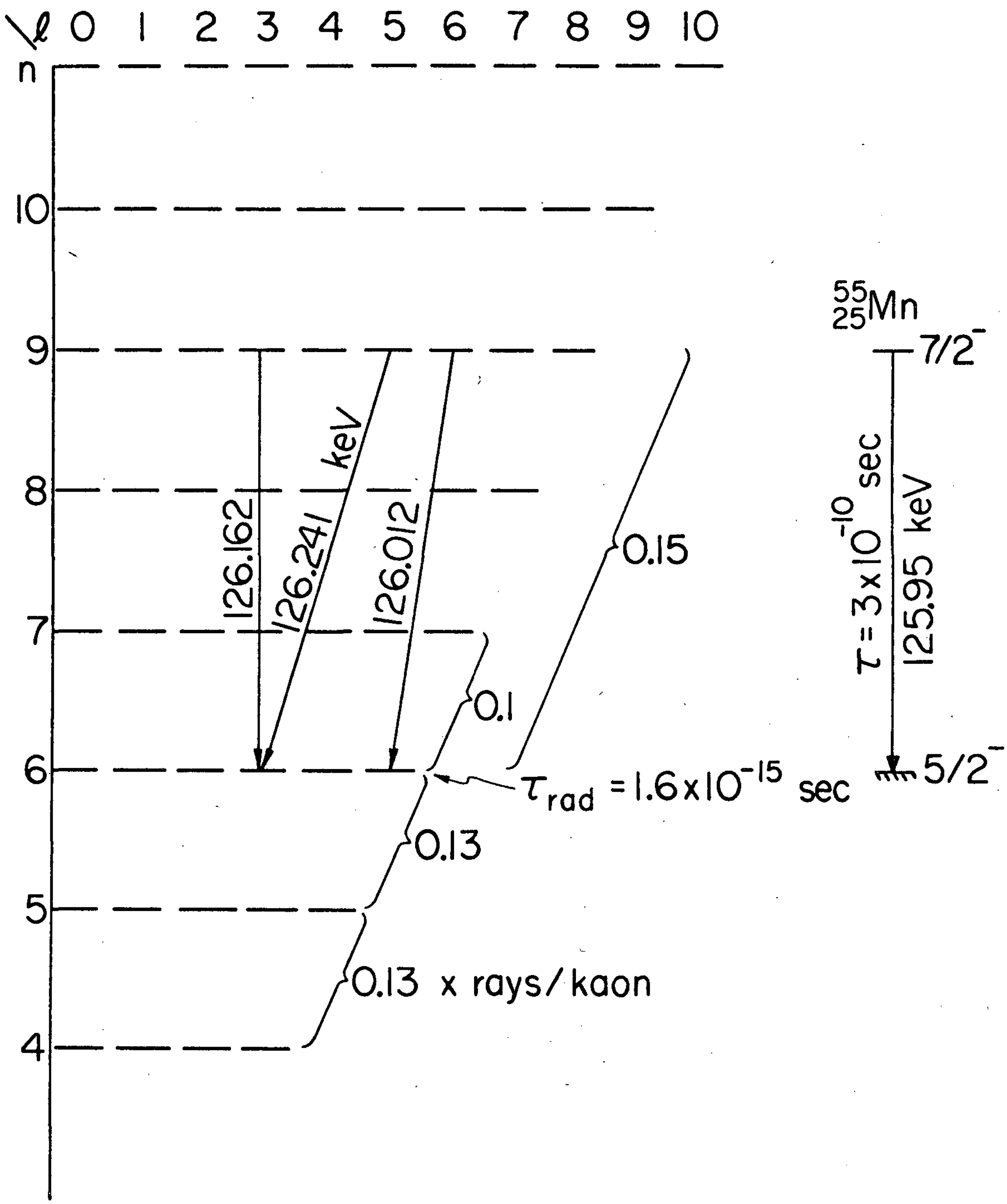

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Fig. 2

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