Comments and Addenda

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Experiments on hadronic-atom x-ray intensities of hydrides and deuterides*

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Kaonic-atom x-ray intensities of elements $Z = 3$, 6, 8, 11, and 20 were significantly reduced when the elements were in hydride form. The ratios $I(ZH_m)/I(Z)$ have a noticeable Z dependence. Deuterides of C and O showed slightly less x-ray emission than their hydride counterparts.

In a series of experiments to measure intensities of x rays emitted by hadronic atoms we noticed that hydrides of elements exhibited unexpectedly low intensities.[1] For example, in graphite the intensity of the transition from principal quantum number $n=4$ to $n=3$ was 0.36 x rays per stopped kaon, whereas in polyvinyltoluene (CH) the intensity was 0.09 x rays per stopped kaon.

From bubble chamber experiments it is known that kaons are seldom absorbed by hydrogen in hydrocarbons. Measurements on negative kaons stopped in liquid propane showed that 0.032 of the kaons reacted with free protons.[2] Therefore, we might expect that the hadronic atom x-ray intensity of elements combined with H would be reduced by only a few percent.

In experiments at the Bevatron we compared the kaonic x-ray intensities of NaH to Na and CaH_2 to Ca. We had previously measured Li and LiH, C and CH, and H_2O. Oxygen by itself was not measured. Instead, the intensity for O was estimated by drawing a smooth curve through the intensities of C, N, Na, Mg, Al, and Si. The results of the measurements are given in Table I and a plot of the ratios $I(ZH_m)/I(Z)$ is shown in Fig. 1.

In the following discussion we use the term "capture" to mean the entrance of hadrons into bound atomic states. "Absorption" is reserved for the disappearance of hadrons by interaction with nuclear matter.

It has been observed that only a few kaons decay in targets in which they stop. In ^{4}He 0.02[3] and in condensed matter less than 0.05[1] decayed prior to nuclear absorption. The maximum x-ray intensity of kaonic atoms amounts to about 0.5 per negative kaon stopped.[4] In the absence of arguments to the contrary we assume that at least half of the kaons were lost to nuclear absorption before cascading to sufficiently low n orbits, where dipole radiation overwhelmed Auger emission. Atoms of some parts of the periodic table (around $Z=25$) show intensities of about 0.1. Apparently 0.9 kaons were

TABLE I. Ratios of the kaonic x-ray intensities of elements Z in hydride form ZH_m to the intensities of the free elements. Column 4 gives the absolute $I(Z)$ in x rays per stopped kaon (Ref. 4) for transitions indicated in column 2.

Targets ZH_m, Z	Transition n_i	n_f	$I(ZH_m)/I(Z)$	$I(Z) \pm \Delta I(Z)$
LiH, Li	3	2	0.63 ± 0.06	0.15 ± 0.03
CH, C	4	3	0.24 ± 0.03	0.36 ± 0.06
H_2O [a]	4	3	0.41 ± 0.05	···
NaH, Na	5	4	0.73 ± 0.09	0.38 ± 0.06
	4	3	0.58 ± 0.05	0.30 ± 0.05
CaH_2, Ca	6	5	0.52 ± 0.06	0.32 ± 0.05
	5	4	0.63 ± 0.06	0.33 ± 0.06

[a] The intensity of free O was not measured. It was estimated by interpolation between the intensities of neighboring Z.

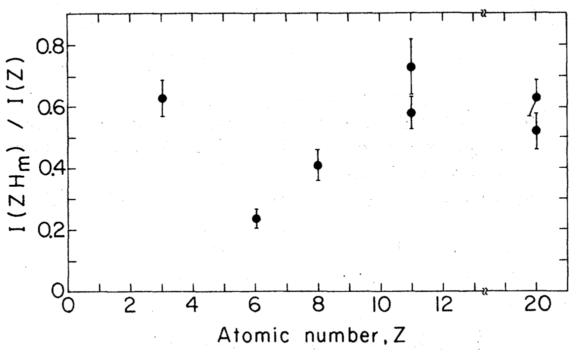

FIG. 1. Ratios of the kaonic x-ray intensities of certain elements Z to the same elements in hydride form are plotted vs Z.

absorbed in early stages of the cascade—presumably from states of high n and low angular momentum l.

The strong Z dependence of kaonic x-ray intensities is assumed to be the result of the atoms' electronic configuration. It has been suggested that intensities depend upon the size of the atoms.[5,1] The authors believe that the x-ray intensities are related to the angular momentum distributions following capture and that these distributions depend upon the electronic configuration. It is possible that succeeding stages of the cascade could be influenced by electronic properties but this seems less likely.

Considering the hydrides we see that the emission of hadronic x rays from atoms bound to H was inhibited. We suppose that kaons were not absorbed by H in the compounds studied because they were only slightly absorbed by H in C_3H_8. Furthermore, Gol'danskii *et al.*[6] reported the probabilities that *pions* were absorbed by H: 0.035 in LiH, 0.0264 in CH_4, 0.004 in H_2O, and 0.002 in NaH. Therefore, it appears that hadron absorption by H in hydrides is insignificant compared to the reduction of x-ray emission. We presume that the presence of free protons influenced the absorption process either by altering the initial l distributions by distortion of the regular atomic electron configuration or that the cascades were interrupted by Stark mixing. We can speculate about how the Stark effect might occur. Assume that the electron that binds the H to the atom Z were ejected by Auger emission due to the mesonic cascade in Z (hydride bond broken), the electric field of the free proton could cause Stark mixing. Such events are plausible. Hydride bonds are shorter than the distance between atoms and binding electrons could be emitted as well as outer atomic electrons. Stark mixing would cause transitions to low l states (n constant). Thus absorption would take place from high n states where transitions are dominated by Auger processes. These speculations led to the idea to compare the x-ray intensities of hydrides to those of deuterides. If the hydride bonds were broken by Auger processes, perhaps the higher mass of the deuterons would tend to increase Stark mixing by slowing down the ejection of the protonic charge from the region of the cascading meson. Increased Stark mixing would further decrease x-ray intensities of deuterides compared to hydrides.

TABLE II. Ratios of the pionic x-ray intensities of C in C_6D_6 to C in C_6H_6 and O in D_2O to O in H_2O.

Targets	Transition n_i	n_f	I(deuteride) / I(hydride)
C_6D_6, C_6H_6	3	2	0.97 ± 0.05
	4	2	0.99 ± 0.11
D_2O, H_2O	3	2	0.96 ± 0.04
	4	2	0.94 ± 0.06

Pions were used in the experiment to compare the intensities of the O lines from H_2O and D_2O and the C lines from C_6H_6 to those of C_6D_6. The results are shown in Table II. The intensities of the deuterides were about 0.95 those of the hydrides. If these results are significant a systematic program to measure the Z dependence of the pionic x-ray intensities of hydrides and deuterides is in order.

We present this note with the hope that it will stimulate investigation of the Z dependence of hadronic atom x-ray intensities and that such studies will eventually lead to a satisfactory description of mesonic-atom formation.

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