Title
RADIATIVE CAPTURE OF K- MESONS FROM ORBITAL P STATES OF K-MESONIC ATOMS



Author
Frye, Graham.

Publication Date
1958-09-09

UCRL 8443

# UNIVERSITY OF CALIFORNIA

# *Radiation Laboratory*



BERKELEY, CALIFORNIA

UCRL-8443

UNIVERSITY OF CALIFORNIA
Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

# RADIATIVE CAPTURE OF $K^-$ MESONS FROM ORBITAL P STATES OF K-MESONIC ATOMS

Graham Frye

September 9, 1958

For publication Physical Review Letters

Printed for the U. S. Atomic Energy Commission

# RADIATIVE CAPTURE OF $K^-$ MESONS FROM ORBITAL P STATES OF K-MESONIC ATOMS*

Graham Frye

Radiation Laboratory
University of California
Berkeley, California

September 9, 1958

## Abstract

The photon spectrum accompanying the radiative capture of $K^-$ mesons from orbital P states of K-mesonic hydrogen atoms is discussed.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

# RADIATIVE CAPTURE OF $K^-$ MESONS FROM ORBITAL P STATES OF K-MESONIC ATOMS

Graham Frye

Radiation Laboratory
University of California
Berkeley, California

September 9, 1958

The strong reaction of a K meson and a proton to produce a $\Sigma$ hyperon and a $\pi$ meson may be phenomenologically represented by a direct local interaction. The transition amplitude for capture from a bound Coulomb S state is then proportional to the value of the wave function at the origin. If the interaction Hamiltonian contains a factor $\vec{\sigma} \cdot \vec{\nabla}/m$, direct capture may also occur from a bound P state, with an amplitude proportional to the gradient of the wave function at the origin. There is another mechanism that can give rise to (direct) capture from a P state. It is the K-mesonic atom analog of the radiative capture of orbital electrons, which has been studied by Glauber and Martin.[1]

In the electron case, the weak nuclear decay through the capture of a K electron is accompanied by electromagnetic radiation arising from the refilling of the vacated electronic levels. The x-radiation may occur as a process, separate from the nuclear reaction, in which the spectrum will consist of several sharp lines; or it may occur together with the orbital-electron capture as part of a two-step process. In this second case the energy released by the capture is shared with the photon, giving it a continuous spectrum with typical resonance peaks corresponding to the x-ray lines.

Radiative capture of an orbital K meson from an nP state may take place in quite the same way. The K and proton system may make a radiative transition to any one of many (intermediate) S states from which the capture process producing the $\Sigma$ and $\pi$ can take place. Included as a particular case is that special intermediate state which has the same energy as the initial and final states and for which the photon energy is just the energy-level difference between the initial P state and the intermediate S state. The relative contributions of the various intermediate S states (labeled by the principal quantum number n of the atomic state and the photon momentum $\vec{k}$) is given in second-order perturbation theory as

$$\sum_{n'} \langle \Sigma\pi k \,|\, H^{c} \,|\, n'\vec{k} \rangle \langle n'\vec{k} \,|\, H^{R} \,|\, n \rangle / (E_{n'S} - E_{nP} + k) \quad , \tag{1}$$

where $H^{c}$ and $H^{R}$ are the capture and radiation Hamiltonians. The resulting photon spectrum will have poles corresponding to the resonant energies, which may be removed by including radiation and nuclear-level broadening. The spectrum we give will then be the sum (including interference) of the line shapes for transitions from the initial nP state to each of the n'S states that is energetically accessible; the other n'S states contribute to the high-energy tail.

The result of this calculation may be expressed as the ratio of the transition rate for radiative capture from the nP state to that for direct capture from the 1S state,

$$w(nP,rc)/w(1S,c) = (\alpha^{3}/3\pi)\int_{0}^{k_{max}} kQ_{nP}^{\;2}(k)\,dk, \tag{2}$$

where k is measured in the natural unit of the binding energy of the 1S state, $\mathcal{E}_{1S} = \alpha^{2}m/2 = 8.6$ kev, and $k_{max}$ is the maximum photon energy given by

$k_{max} = (E_{0}^{\;2} - (m_{\pi} + M_{\Sigma})^{2})/(2E_{0})$ . Here $E_{0}$ is the total initial energy, equal to the mass of the bound K meson plus the mass of the proton (1432 Mev), and $M_{\Sigma}(m_{\pi})$ is the mass of the $\Sigma(\pi)$ particle. The function $Q_{nP}(k)$ is a dimensionless integral which Glauber and Martin have tabulated for n = 2,3. The value of w(1S,c) may be estimated from the experimental absorption cross section,[2]

$\sigma_T$ , and the 1S state wave function $\phi_{1S}$ of the K-proton system, as

$$w(1S,c) = \phi_{1S}^{2}(0) \left[(k/m)\,\sigma_T(k)\right]_{k=0} \simeq 4.7 \times 10^{17}\ \mathrm{sec}^{-1} \quad , \tag{3}$$

where k is the center-of-mass momentum and m is the reduced mass of the $K^-$-proton system. The photon spectrum is then given by

$$dw(nP,rc)/dk = 2.6 \times 10^{8}\, kQ_{nP}^{\ 2}(k)\cdot 1/\mathrm{kev\text{-}sec} \quad , \tag{4}$$

where k is measured in kev. A particular value of the dimensionless function for argument $k = 1.79\ \alpha^2 m/2 = 15.4$ kev is $Q_{2P}(1.79) = 0.34$. The curve is given in Fig. 1 for n = 2,3. Inclusion of nuclear damping does not change the shape of the curve in the part plotted. The rest of the curve may be approximated by a normal line shape with a maximum of roughly $10^{12}\ \mathrm{sec}^{-1}\ \mathrm{kev}^{-1}$ and a width of 0.31 kev.

For comparison we mention the total radiative transition rates from 2P and 3P states,

$$w(2P \to 1S) \sim 4 \times 10^{11}\ \mathrm{sec}^{-1}$$

$$w(3P \to 2S) + w(3P \to 1S) \sim 1 \times 10^{11}\ \mathrm{sec}^{-1} \quad .$$

We may also estimate the direct nuclear capture rate from the 2P state to be given by

$$w(2P,c) \sim \frac{\alpha^2}{128}\ w(1S,c) = 4 \times 10^{11}\ \mathrm{sec}^{-1} \quad .$$

I would like to thank Professor Robert Karplus for suggesting this problem and for his advice.

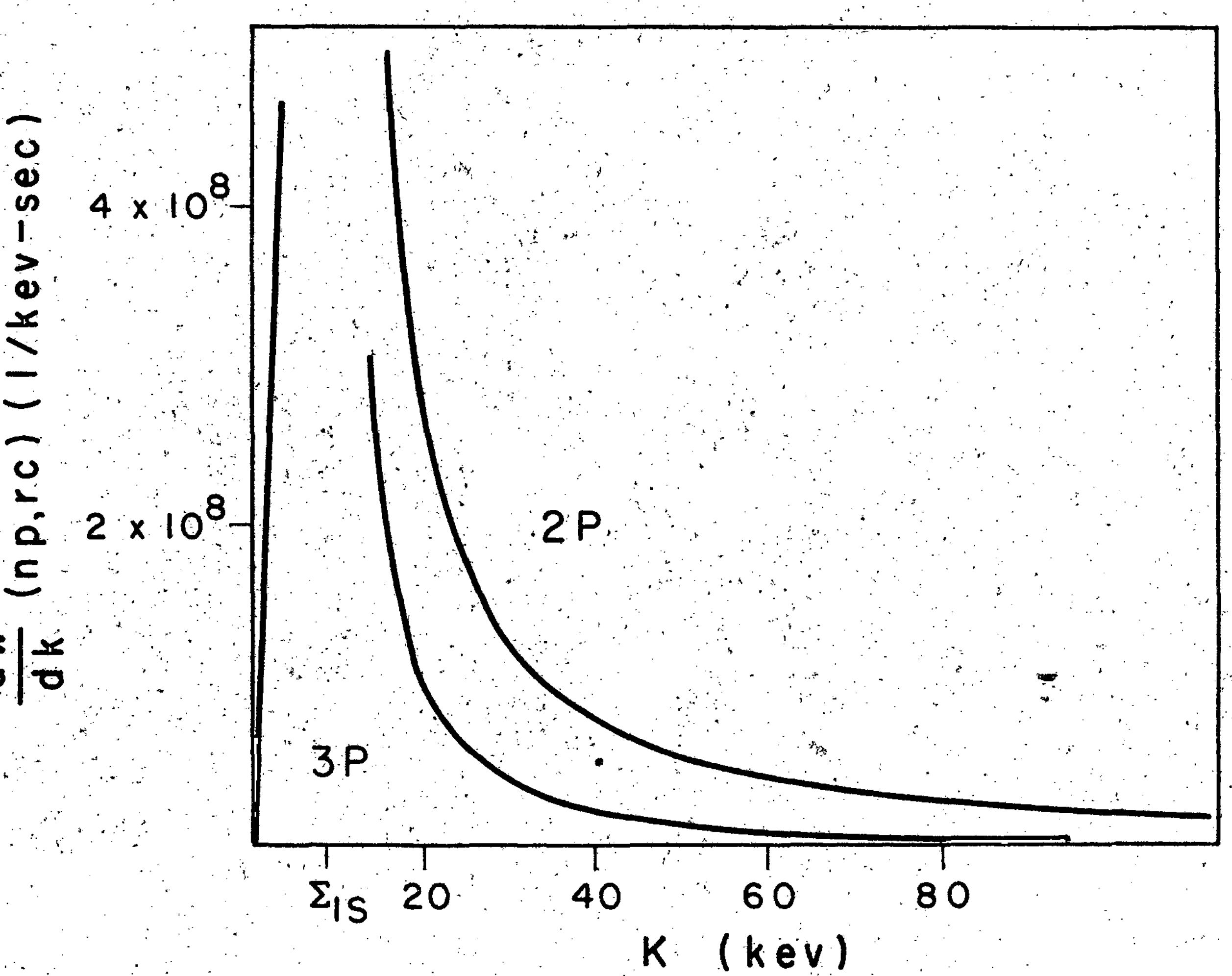
CAPTION FOR THE FIGURE

The photon spectrum for the radiative capture from the 2P and 3P orbital states of the K-meson-proton system.

FOOTNOTES

1 R. J. Glauber and P. C. Martin, Phys. Rev. 104, 158 (1956); 109, 1307 (1958).

2 Estimated from current experimental work; private communication from Donald Miller (UCRL).



$\frac{dw}{dk}$ (np,rc) (1/kev-sec)
4 x 10^8
2 x 10^8
2P
3P
$\Sigma_{1S}$
20
40
60
80
K (kev)


51240-1