Production of Auger Electrons by Negative K Mesons and π Mesons*

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The mesonic Auger effect has been studied for K^- mesons and π^- mesons. It is expected that the frequency of production of Auger electrons of energy greater than 15 kev should be about 50% greater for K mesons than for π mesons due to the greater mass of the K meson. 200 π-meson stars and 195 K-meson stars in nuclear emulsion have been examined for associated slow electrons of energy greater than 15 kev. For π mesons it is found that 14% of the stars have one Auger electron and 4% have two. For K mesons 25% have one, 6% have two, and 1% have three. Thus 18% of all π-meson stars and 32% of all K-meson stars have one or more associated Auger electrons. Assuming that 54% of all stars are in the heavy elements of the emulsion, it is found that 33% of π mesons and 59% of K mesons captured in silver and bromine have one or more associated Auger electrons. Hence the increase in production by K mesons over that by π mesons is about 75%.

INTRODUCTION

AFTER a negative meson is slowed down and stopped in a solid, it will be captured into mesonic "Bohr" orbits of an atom. The meson will then cascade down to the nucleus by dropping to lower and lower orbits. It is expected that the mesonic atom will drop to a state of low excitation before the meson interacts with a nucleon in the nucleus. In the process of becoming de-excited, the mesonic atom can make radiative and radiationless transitions until it reaches its $1s$ state. The radiative process is that in which the excess energy is given off in the form of a γ ray.[1,2]

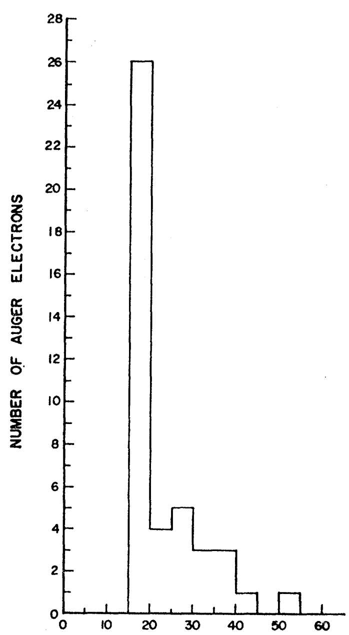

FIG. 1. Frequency of Auger electrons from negative π mesons.

The radiationless transition is that in which the excess energy is used to liberate electrons of the same atom. The energy is transferred to the electron in a direct interaction and the electron is then ejected into a positive-energy state. This is called the mesonic Auger effect and is analogous to the ordinary Auger effect.

Auger electrons from μ and π mesons have been investigated by Cosyns *et al.*,[3] Menon *et al.*,[4] and Fry.[5] In this work Auger electrons from K^- mesons and π^- mesons are studied. The interest in this particular experiment is that it is expected that the frequency of production of the Auger electron is dependent on the mass of the negative meson. The masses of the π meson ($273m_e$) and μ meson ($206m_e$) are so close together that there is little difference in the number of Auger electrons produced by them, and what difference there is probably is too small to be measured in an emulsion experiment. However, the K-meson mass ($965m_e$) is sufficiently greater than that of the π and μ mesons so that the increase in the Auger electron production (above a certain energy) should be easily measurable. According to Burhop,[6] the production of Auger electrons of energy greater than about 15 kev is expected to be about 50% greater for K-meson capture than π-meson capture. Also, it is expected that the K mesons should produce electrons of higher energy than those produced by the π and μ mesons.

PROCEDURE

A stack of 120 Ilford G5 emulsions, 600 microns thick, was exposed to a K^--meson beam at the Berkeley Bevatron. The particles entering the stack had 300 Mev/c momentum and the ratio of K mesons to π mesons in the beam was 1/5000.

The plates were area scanned under 100× power for K-meson stars. After 210 K^--meson stars were located,

* Supported by the U. S. Atomic Energy Commission and the Research Corporation.
[1] E. P. Hincks, Phys. Rev. **81**, 313 (1951).
[2] W. Y. Chang, Revs. Modern Phys. **21**, 166 (1949).
[3] Cosyns, Dilworth, Occhialini, Schoenberg, and Page, Proc. Phys. Soc. (London) **A62**, 801 (1949).
[4] Menon, Muirhead, and Rochat, Phil. Mag. **41**, 583 (1950).
[5] W. F. Fry, Phys. Rev. **83**, 594 (1951).
[6] E. H. S. Burhop, *The Auger Effect* (Cambridge University Press, Cambridge, 1952), Chap. 7.

the stars were investigated under 1000× power for Auger electrons. Certain criteria were established for identification of Auger electrons. Each star was examined by two people to eliminate personal bias. No electron was considered associated with a star unless the first grain was within 2 microns of the center of the star. Careful comparison with recoil particles from the K^--meson stars was made. Clumps of grains or "blobs" at the centers of stars were noted down. Careful range measurements of the electrons were made under 1000× power.

Also, 200 π-meson stars found in the same stack were treated similarly for comparison with existing data.

RESULTS

In this work 200 π^--meson stars and 195 K^--meson stars were observed for Auger electrons. The energy of the Auger electrons was determined from the range-energy graph of Zajac and Ross.[7] Clumps of grains which were possible electrons or nuclear recoils were noted as "blobs." The results on the frequency of production of Auger electrons are given in Table I. The energy distributions are given in Figs. 1 and 2.

TABLE I. Frequencies of production of Auger electrons from K^--meson and π^--meson stars.

	π^- mesons	K^- mesons
Number observed	200	195
Frequency of stars with 1 electron of energy >15 kev	14%	25%
Frequency of stars with 2 electrons of energy >15 kev	4%	6%
Frequency of stars with 3 electrons of energy >15 kev	0%	1%
Frequency of stars with 1 or more electrons of energy >15 kev	18%	32%
Frequency of stars with "blobs"	28%	29%

The data on π mesons can be compared with the results of other work on π mesons. Menon *et al.*[4] found that 21% of the π^- mesons which produce stars have Auger electrons. Fry[4] found that 18.6% of π^- mesons have Auger electrons. The results are in agreement with the value of 18% found in the present work.

DISCUSSION

It must be noted that there may be errors in the number of Auger electrons due to difficulties of observation. These are attributed to (1) high scattering of low-energy electrons, (2) coincidence of background slow electrons with meson endings, and (3) difficulty in distinguishing between low-energy electrons and nuclear recoils.

The high scattering of Auger electrons, because of their low energy, may cause difficulty in following some electrons to the ends of their ranges, resulting in some being lost completely and not counted and others being counted with incorrect ranges. It is believed that few electrons were lost in this way since the plates were fairly heavily developed.

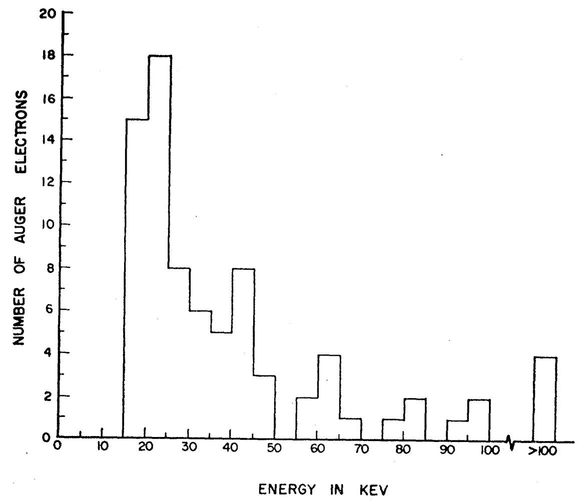

FIG. 2. Frequency of Auger electrons from negative K mesons.

The coincidence of background slow electrons with meson endings was estimated by examining 200 proton endings for apparent Auger electrons. It was found that the coincidence of electrons of energy greater than 15 kev with proton endings is low. In fact, of the 200 endings examined none had such electrons which appeared to have originated from them. However, 4.5% were found to have blobs associated with them and hence it is expected that about 4.5% of the blobs associated with meson endings are accidental. All electrons of energy greater than 15 kev were counted and represented in the histograms. However, electrons of range less than 3–4 microns could be confused with nuclear recoils from the stars. Thus in the 15–20 kev region it is expected that a small percentage may be nuclear recoils rather than electrons. Electrons and recoils with ranges less than 2.2 microns were grouped together as "blobs." It is clear from visual observation that many of these are electrons but it is difficult to determine what the percentage is. Out of 200 π^- mesons and 195 K^- mesons, blobs were found at the ends of 55 and 57 meson endings, respectively.

The Auger electrons observed came from both light (C, N, O) and heavy (Ag, Br) elements of the emulsion. However, it is expected that most of them come from the heavy elements (as many as 10–15% may come from the light elements)[6] and as a first approximation, in order to determine the frequency of production in the heavy elements, we assume that all are produced in the heavy elements. Then all we need to know is the fraction of negative mesons which stop in the heavy as compared to the light elements of the emulsion. We determine this for μ^- mesons in the way suggested by

[7] B. Zajac and M. A. S. Ross, Nature **164**, 311 (1949).

Fry and Morinaga.[8] Knowing the composition of the emulsion, assuming that the probability for capture in the light elements is proportional to Z, and that the probability for capture of the meson by the nucleus (as opposed to decay of the meson) is proportional to Z^4, we find that 85% of μ^- mesons captured in the light elements decay. Then from the experimental result that 39% of all μ^- mesons captured in emulsion decay,[8] we find that 39/0.85=46% are captured in light elements, and hence 54% are captured in heavy elements.

We assume that the 54/46 ratio for heavy and light elements also applies in the case of π mesons and K mesons. However, we must take into account the fact that we only observed π mesons and K mesons which make stars. In the case of π mesons, Menon *et al.*[4] have found that 54% of those which make stars are captured in heavy elements, so we assume that this number holds also for our π-meson stars.

In the case of K mesons, about 20–25% make zero-prong stars or stars with one minimum-ionizing prong and are not included in our observations. We wish to estimate how many of these occur in heavy and light elements. The zero-prong stars are due mainly to the reactions

$$K^- + \text{nucleus} \rightarrow \Lambda^0 + \pi^0 + \text{invisible recoil},$$

$$K^- + \text{nucleus} \rightarrow \Sigma^0 + \pi^0 + \text{invisible recoil}.$$

The stars with one minimum prong are due to

$$K^- + \text{nucleus} \rightarrow \Lambda^0 + \pi^- + \text{invisible recoil},$$

$$K^- + \text{nucleus} \rightarrow \Sigma^0 + \pi^- + \text{invisible recoil}.$$

[8] W. F. Fry and H. Morinaga, Nuovo cimento **10**, 308 (1953).

Gilbert, Violet, and White[9] have studied the reactions

$$K^- + \text{nucleus} \rightarrow \Sigma^+ + \pi^- + \text{recoil},$$

$$K^- + \text{nucleus} \rightarrow \Sigma^- + \pi^+ + \text{recoil},$$

which are very similar to the above reactions. They find that most of the captures are in the heavy elements and that the number is consistent with that found for μ^- mesons, possibly somewhat higher. Thus we assume that 54% of the K^- stars are in heavy elements.

From the above discussion and the results in Table I we find that 33±9% of the π^-mesons and 59±10% of K^- mesons produce one or more Auger electrons in silver and bromine. The error includes only the statistical error and therefore is only significant in comparing the value for K^- mesons with that for π^- mesons, since it is expected that any systematic errors will be the same in either case. The increase in frequency of production of Auger electrons by K^- mesons over that by π^- mesons is about 75%. Burhop[6] suggests that it should be about 50%, which is consistent with our result.

We also point out, as seen in Figs. 1 and 2, that the K^- mesons produce more high-energy electrons than the π^- mesons, as expected.

ACKNOWLEDGMENTS

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[9] Gilbert, Violet, and White, Phys. Rev. **107**, 228 (1957).