Stars Induced by 350- to 400-Mev Protons*

G. Bernardini, E. T. Booth, and S. J. Lindenbaum
Columbia University, New York, New York
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ILFORD G5 plates with emulsions 400 microns thick were exposed to the 385-Mev proton beam of the Nevis cyclotron. The exposures were made inside the vacuum chamber at maximum orbit radius. Very brief exposures with the ion source off, yielded about 2×10^5 proton tracks per cm^2 in the emulsion, and the average length of each track was greater than 10 mm. These tracks were parallel, on the average, to $\pm1°$.

Four hundred and four stars induced by the protons in the emulsion have been analyzed. The star prongs are classified as "gray" for grain densities less than three times minimum, "sparse black" for grain densities between three and six times minimum, and "black" for grain densities greater than six times minimum. These ranges correspond approximately to proton energies greater than 100 Mev, between 30 Mev and 100 Mev, and less than 30 Mev, respectively. In Fig. 1 is shown the distribution of the number of stars with various numbers of black plus sparse black prongs. In Fig. 2 is plotted the percentage of stars with at least one outgoing gray prong. The incoming proton tracks were observed in all cases but have not been counted in any of the prong statistics.

For 219 of the stars, the distribution of black, sparse black, and gray prongs are summarized in Table I.

The mean free path for the production of stars with one or more black prongs by 350- to 400-Mev protons has been determined by measuring by sampling, the total track length in the emulsion scanned, and dividing by the number (404) of stars found. In this way, a mean free path of 56 ± 9 cm was found. This corresponds to a nuclear cross section for the production of stars in G5 emulsion of 45 ± 6 percent of geometric, indicating considerable nuclear transparency.

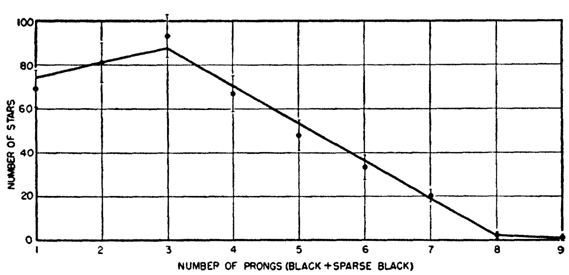

Fig. 1. The distribution curve for number of stars as a function of number of prongs (black+sparse black) with grain densities greater than three times minimum.

The angular distribution of prongs in the different energy ranges was determined for one hundred stars. The gray and sparse black prongs were peaked markedly in the forward direction with respect to the primary proton. The mean angle for these prongs was about 30°. The black prong angular distribution can be interpreted as consisting of $\frac{2}{3}$ isotropic prongs and $\frac{1}{3}$ projected in the forward 90°.

The Wouthuysen[1]-Goldberger[2] model for the interaction of nucleons with the nucleus predicts considerable transparency and

Table I. Properties of 219 stars as a function of the number of black (grain density greater than 6 minimum) prongs.

No. of black prongs	0	1	2	3	4	5	6	7	8	9
No. of stars	6	47	47	48	34	23	10	3	0	1
No. of stars with gray prongs	5	30	20	20	10	5	3	0	0	0
No. of stars with a gray or sparse black prong	6	35	31	32	20	13	3	0	0	0

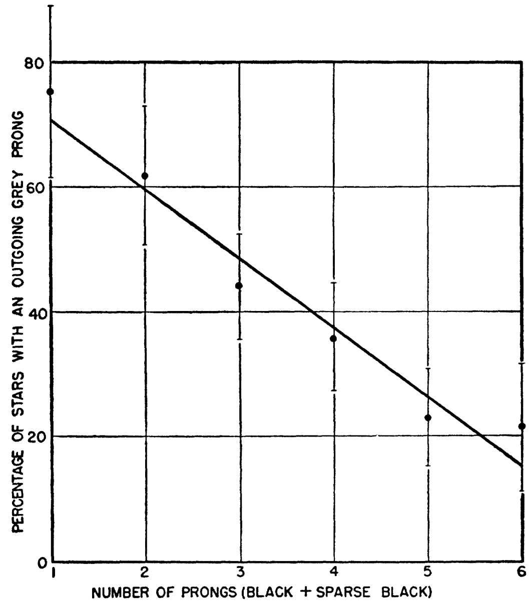

Fig. 2. The percentage of stars with an outgoing gray prong as a function of the number of prongs (black+sparse black) with grain densities greater than three times minimum.

the immediate ejection of sharply projected fast nucleons and some slower less collimated knockons before the evaporation process. All of these features are in agreement with our results.

Figure 2 shows that as the number of black prongs increases, the percentage of stars with gray prongs decreases, gray prongs were not observed in stars having more than six black prongs. This is interpreted to mean that for the 7-, 8-, or 9-prong stars most of the primary proton energy was absorbed by the nucleus. In these cases, the average energy associated with a black prong is 50 Mev, in approximate agreement with values measured in stars produced by cosmic rays.[3]

Reference to Table I shows that for stars between 2 and 5 (inclusive) black prongs, the percentage of stars which have a gray or sparse black prong is approximately constant and equal to 60 percent. Furthermore, less than 7 percent of all stars have two or more outgoing gray or sparse black prongs. Allowing for the fast neutrons which are not visible, the inference is that in nearly all stars there is at least one outgoing fast nucleon.

The authors wish to thank Miss E. Wimmer for assisting with the analysis of the plates.

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[1] S. A. Wouthuysen, Phys. Rev. 75, 1329 (1949).
[2] M. L. Goldberger, Phys. Rev. 74, 1269 (1948).
[3] Brown, Camerini, Fowler, Heitler, King, and Powell, Phil. Mag. 40, 862 (1949); Bernardini, Cortini, and Manfredini, Phys. Rev. 79, 952 (1950).

The Nuclear Spin of $_{43}Tc^{99}$

Karl G. Kessler and William F. Meggers
National Bureau of Standards, Washington, D. C.
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THE emission spectrum of Tc^{99} has been investigated in this laboratory,[1] the wave-lengths of the principal lines have been reported[2–4] and an analysis of the spectrum has now been prepared.[5]

A 2.1-mg portion of the Tc^{99} sample was used in making a series of interference spectrograms with a liquid-nitrogen-cooled beryllium hollow cathode discharge tube filled with helium gas at about 1 mm pressure. Fabry-Perot interferometers having 3.75

TABLE I. Interval ratios for the line 4238.19A.

Theory spin	Ratio
7/2	1.000:0.800:0.600
9/2	1.000:0.833:0.667
11/2	1.000:0.857:0.714
Experiment	1.000:0.831 ±0.011:0.654 ±0.011

and 5 mm invar separators were used with aluminum-coated quartz interferometer plates. Hyperfine structure patterns were observed in the 30 strongest lines of Tc between 2900A and 5000A.

Up to 8 components were resolved in lines attributed to transitions involving levels with $J\geq 7/2$, thus showing that $I\geq 7/2$. Interval-ratio calculations for the 4-component line 4238.19A($4d^5$ $5s^2$ ${}^6S_{5/2}-4d^5$ $5s$ $({}^7S)$ $5p$ ${}^6P_{3/2}{}^{\circ}$) are compared with measured interval ratios in Table I. Theoretically, the intervals should be in a ratio $(I+J):(I+J-1):(I+J-2)$, that is, for $J=\frac{3}{2}$, $(I+\frac{3}{2}):(I+\frac{1}{2}):(I-\frac{1}{2})$.

These data indicate clearly that the spin of Tc^{99} is $9\hbar/2$ as predicted by Feenberg and Hammack,[6] and in agreement with the model proposed by Mrs. Mayer.[7] The line 4031.63A ($4d^6$ $({}^5D)$ $5s$ ${}^6D_{9/2}-4d^6$ $({}^5D)$ $5p$ ${}^6D_{9/2}{}^{\circ}$) shows only 6 components resolved, but the end of the pattern is consistent with a spin of $9\hbar/2$.

The magnetic moment of Tc^{99} is now being determined and will be reported soon.

[1] Loaned by the AEC.
[2] W. F. Meggers and B. F. Scribner, J. Opt. Soc. Am. **39**, 1059 (1949).
[3] W. F. Meggers and B. F. Scribner, Oak Ridge Spectroscopy Symposium Abstracts, March 25, 1949.
[4] W. F. Meggers and B. F. Scribner, J. Research Nat. Bur. Stand. (to be published).
[5] W. F. Meggers, J. Research Nat. Bur. Stand. (in preparation).
[6] E. Feenberg and K. C. Hammack, Phys. Rev. **75**, 1877 (1949).
[7] M. G. Mayer, Phys. Rev. **78**, 22 (1950).

Erratum: Nuclear Isomerism and Shell Structure

[Phys. Rev. **79**, 1021 (1950)]

R. D. HILL
Physics Department, University of Illinois, Urbana, Illinois
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SEVERAL points in Fig. 1 were incorrectly located. This figure should be replaced by the accompanying plot.

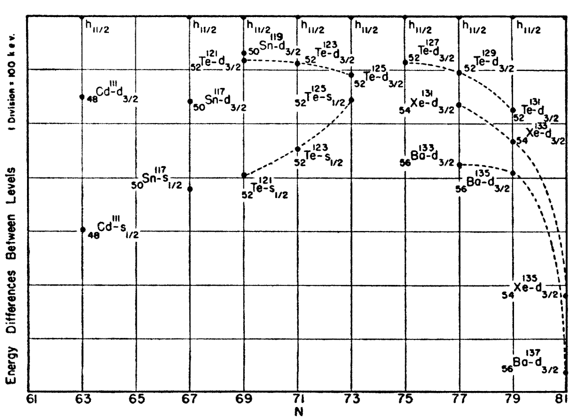

FIG. 1. Plot of level positions against odd neutron numbers for the even-odd isomers of the fifth nuclear shell. Only isomers exhibiting internally converted gamma-ray transitions are shown.

Subsequent to the communication of the letter, another isomer, Xe^{133m}, has been investigated.[1] This new point, ${}_{54}Xe^{133}-d_{3/2}$, falls accurately on the $Xe-d_{3/2}$ curve and further emphasizes the consistent level trends particularly in this region.

[1] I. Bergström and S. Thulin, Phys. Rev. **79**, 538 (1950).

On the π-Meson Absorption and Emission Mechanisms in Nuclei

P. CÜER
Université de Strasbourg, Strasbourg, France
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TWO groups of Berkeley experimenters[1] have recently reported preliminary results on the pp-interaction producing π^+ mesons which may indicate a high probability to find the resulting proton and neutron in a bound state. In this connection we would like to recall some considerations we made in 1948 which might be still of interest and which stress more precisely a possible analogy between the number of particles involved in the π^- absorption and production processes in nuclei.

After a preliminary analysis of σ-stars we concluded[2] that the most probable process of the primary act of π^- absorption in a nucleus was not a radiative one but the emission of a high energy neutron, the momentum being balanced by a recoil aggregate (nucleon, H^2, H^3, He^4 or more, depending on their instantaneous presence in the absorption spot). These primary particles could afterwards heat the residual nucleus and give rise to an evaporation process. The hypothesis was worked out by Heidmann and Leprince-Ringuet[3] and was found to be in accordance with experimental results, however with poor statistics. Further experimental data by Perkins[4] indicated a considerable probability of ejection of pairs of nucleons. Later studies agreed that emitted particles could be divided in two main groups, an analysis[5] showed that a peculiar scheme in which a neutron and a recoil triton were produced was close to the truth as for the relative number of high energy protons of σ-stars found in β-sensitive emulsions.

An extensive analysis performed recently by the Bristol group[6] gives strong support to the hypothesis of fast neutrons in the primary act for light elements. In the heavy component, as the authors find a ratio of fast protons lower than that predicted by Tamor[7] in the nucleon-nucleon model, mainly in light elements, they conclude that the process is not likely. The argument may be not so serious as appears at first sight because we have found[8] that fast particles of $|e|$ charge ($E>25$ Mev) are ejected in Berkeley plates exposed to 80-Mev neutrons in only 10 percent of the stars, this ratio being lower for light elements. These are also the approximate figures found in σ-stars. However, in these plates a phenomenological study of the number of prongs as a function of the known incident energy (free from the uncertainty arising in the classification of stars) indicates a higher excitation energy for σ-stars ($\sim$70 Mev for the heavy emulsion component) than do 80-Mev neutrons ($\sim$50 Mev for the same component).

As the ratio (3 prong/4 prongs) is very sensitive in the 100-Mev region and lies between 80- and 150-Mev neutrons, it is likely that recoils of $M>1$ are sometimes involved. It seems then that the Bristol excitation value for evaporation stars in BrAg (100 Mev) is overestimated, Fujimito's model which they use does not appear to fit with current evaporation calculations.[9]

Protons of $\sim$100 Mev as occasionally found suggest cases in which the effective recoil is at least a Be^8 clustering balancing the moment of a neutron of about 125 Mev. Deuterons, tritons, and even α-particles with energies well above the mean temperature have also been detected.

It has commonly been assumed hitherto that mesons arise in nuclei by nucleon-nucleon collisions, the threshold energy of production being lowered by the internal dynamics of the systems.[10] For such threshold calculations Barkas[11] has given an ingenious method similar to that used in nuclear physics. Such an analogy between nuclear dynamics and meson production seems, however, to be somewhat strained. In an ordinary nuclear reaction, as the whole nucleus contributes to the excitation which is given up to the products much later, we are entitled to consider only the initial and final states.

In a meson production at threshold incident energy the residual nucleus, if any, is generally heated after the π-emission by the reacting particles at rest in the c.m. system. It appears then that some definite hypothesis must be made for the primary event, as