KINEMATICAL CALCULATION OF Λ-NUCLEON STIMULATION REACTION FOR HYPERFRAGMENTS OF MASS A = 50

By S. N. Ganguli and M. S. Swami*

(*Tata Institute of Fundamental Research, Bombay*)

Received December 30, 1966

(Communicated by Prof. R. R. Daniel, F.A.SC.)

Abstract

Energy spectra of fast protons ($E \geqslant 30$ MeV) have been calculated for hyperfragments of mass A = 50, from Λ-proton and Λ-neutron stimulation processes respectively. It has been concluded by comparing with experimental energy spectrum, that $\Lambda n/\Lambda p$ stimulation ratio is ~ 5. It has been estimated, from this ratio, that the emission frequencies of two fast protons, from Λ-single nucleon stimulation, both with $E \geqslant 20$ MeV and with $E \geqslant 30$ MeV, are $\approx 3 \cdot 3\%$ and $\approx 1 \cdot 7\%$ respectively.

1. Introduction

Non-mesic decays of hyperfragments (HFs) are considered to be the result of the stimulated decay of Λ-hyperon in the presence of nucleons, and it is written as:

$$\Lambda + p \rightarrow n + p$$
$$\Lambda + n \rightarrow n + n \quad (1)$$

Some information of this stimulated reaction can be obtained from the study of fast protons of energy, $E \geqslant 30$ MeV emitted in the decay of HFs of range $\leqslant 10\,\mu$m. Detailed studies of short range HFs by Ganguli *et al.*[1] and Burte *et al.*[2,3] have led to the conclusion that $\approx 30\%$ of the HFs in the range group 0–5 μm. and $\approx 70\%$ of the HFs in the range group 5–10 μm. have mass numbers $A \lessapprox 50$. Since the number of HFs in the above two groups is nearly equal, it will be a good assumption that, on the average, the mass of the short-range HFs ($R \leqslant 10\,\mu$m.) is $A \approx 50$. A simple model is therefore

* Now at the Physics Department, Punjab University, Chandigarh, India, on deputation from the Tata Institute of Fundamental Research.

proposed here for understanding the energy spectrum of fast protons from the decay of non-mesic short-range HFs (0–10 μm.) on the basis of single nucleon stimulation process as is described by reaction (1). This model is similar to the ones proposed for understanding fast proton spectrum from π^- and K^- captures in nuclei by Tamor[4] and Gilbert *et al.*[5] respectively.

2. METHOD OF CALCULATION

The calculation has been made using non-relativistic kinematics. The parameter which is needed for this calculation is the internal momenta of nucleons inside a nucleus. It has been found that the Gaussian distribution of the type:

$$\frac{dn}{dp} \alpha \frac{p^2}{p_0^3} \exp.\left(-\frac{p^2}{p_0^2}\right)$$

where p_0 is 170 MeV/C, seems to fit the experimental data best; this has been discussed in detail by Wilcox and Moyer.[6] It is then assumed that Λ inside a nucleus will also have the same momentum distribution.‡ It is further assumed that no momentum is transferred to the nucleus in the stimulation process.

2·1. *Energy spectrum of stimulated nucleons inside a nucleus.*—The energy spectrum of stimulated nucleons is calculated in the following way:

(*a*) If θ is the angle between the two initial momentum vectors of Λ and N, (N refers to a nucleon), the angular distribution $dn/d\theta$ between Λ and N is taken to be isotropic. This system will be referred to as L system.

(*b*) The stimulation process is then transferred to a system, which will be referred to as C system, such that the total momentum of Λ and N in it is zero. The two nucleons after the stimulation process then move with equal and opposite momentum. The angular distribution of these nucleons with respect to the direction of motion of the C system is also taken to be isotropic.

(*c*) The velocities of the two nucleons from the C system are then transferred back to the L system and the correlation between the energies of the

‡ Since the momentum distribution of Λ inside a nucleus is not known, the whole calculation was redone by taking the value of p_0 as 50 MeV/C for Λ spectrum. No significant change in the result was found; the reason is that the Q value in reaction (1), which is 176 MeV, is quite high compared to the value which is $\sim$ 10 MeV from Gaussian distribution.

two nucleons is determined (a detailed calculation is described in the thesis of S. N. Ganguli).[7] In this way the energy distribution of the two final nucleons is known inside the nucleus.

In Fig. 1 is shown the energy distribution of one of the nucleons after the stimulation process.

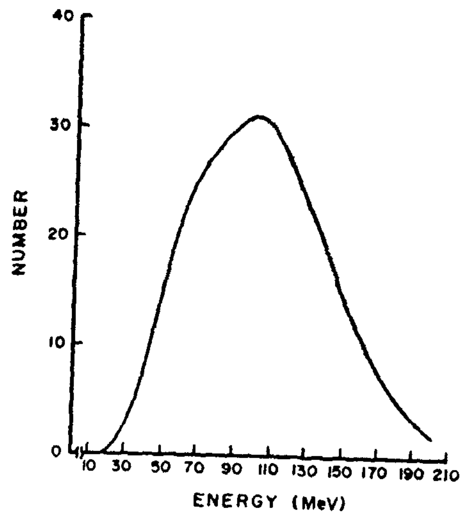

FIG. 1. Energy spectrum of nucleon inside a nucleus of A = 50 from Λ-N stimulation process.

2.2. *Calculation of collision probabilities of nucleons after stimulation process inside a nucelus.*—The number of collisions made by the two nucleons, arising from stimulation process, with nucleons of the nucleus before reaching the nuclear surface is calculated by assuming that:

(*a*) the stimulation process takes place randomly at any point inside the nucleus;

(*b*) the two nucleons, after the stimulation process, move in opposite direction;

(*c*) the final state interactions are negligible; and

(*d*) the collision mean free path inside the nucleus is 4×10^{-13} cm. (Combe[8]); in order to see the sensitivity of this parameter, its value was varied from $3{\cdot}7$ to $4{\cdot}3 \times 10^{-13}$ cm., but no significant change in the result was found.

The results of this calculation are presented in Table I.

2.3. *Laboratory energy spectrum of fast protons from stimulation process.* —The two nucleons from the stimulation process can make collisions with nucleons of the nucleus of A = 50 with the probabilities tabulated in Table I. This has been made as follows:

TABLE I

Collision probability inside nucleus of A = 50

J	J	Probability
0	0	0·1669
	1	0·1357
	2	0·0836
	3	0·0415
	4	0·0173
1	0	0·1357
	1	0·0836
	2	0·0415
	3	0·0173
	4	0·0062
2	0	0·0836
	1	0·0415
	2	0·0173
	3	0·0062
	4	0·0019
3	0	0·0415
	1	0·0173
	2	0·0062
	3	0·0019
	4	0·0005
4	0	0·0173
	1	0·0062
	2	0·0019
	3	0·0005
	4	0·0001

I = Number of collision by particle 1.
J = Number of collision by particle 2.

(*a*) The core nucleus of A = 50 is assumed to have equal numbers of protons and neutrons, therefore stimulated nucleons collide with equal probability with protons and neutrons of the core nucleus. The nucleon-nucleon collisions are taken to be isotropic in the centre of momentum system.

(*b*) If the stimulated nucleon is to make two or more collisions, the nucleon which carries away the larger part of the energy in the preceding collision is allowed to make the next collision and so on. The effect of this restriction is negligible on the energy spectrum of fast protons.

(*c*) If after a collision, either of the two nucleons carries energy $\leqslant 26$ MeV, the collision is disallowed because of Pauli principle, and the initial nucleon is assumed to proceed with its original energy. In this way the energy spectrum of nucleons is known at the nuclear surface.

Since we are interested in the energy spectrum of protons outside the nucleus, *i.e.*, laboratory energy spectrum, the minimum energy which a proton needs to come out of a nucleus is to be estimated. This minimum energy is the sum of the maximum Fermi energy and the binding energy of a proton in a nucleus of $A = 50$; this turns out to be 35 MeV. Therefore, after subtracting 35 MeV from the energy of protons at the nuclear surface, we get the laboratory energy spectrum of protons from the stimulation process. These energy spectra of fast protons from stimulation of Λ with neutron and that with proton are shown in Fig. 2 by solid and dotted curves respectively.

The results from the above calculation made on CDC 3,600 computer of TIFR are summarised in Table II. It is to be remarked, that as is seen

TABLE II

Details of calculation on Λ-nucleon stimulation process

Stimulation process	Probability of emission of protons of energy $\geqslant 30$ MeV	Probability of emission of two protons each of energy		Average energy of fast protons in MeV
		$E \geqslant 20$ MeV	$E \geqslant 30$ MeV	
1	2	3	4	5
Λ-neutron	0·19	0·016	0·007	51·2
Λ-proton ..	0·69	0·12	0·07	67·2

from columns 3 and 4 of Table II, this calculation predicts the emission of two fast protons from stimulation reaction of Λ with single nucleon.

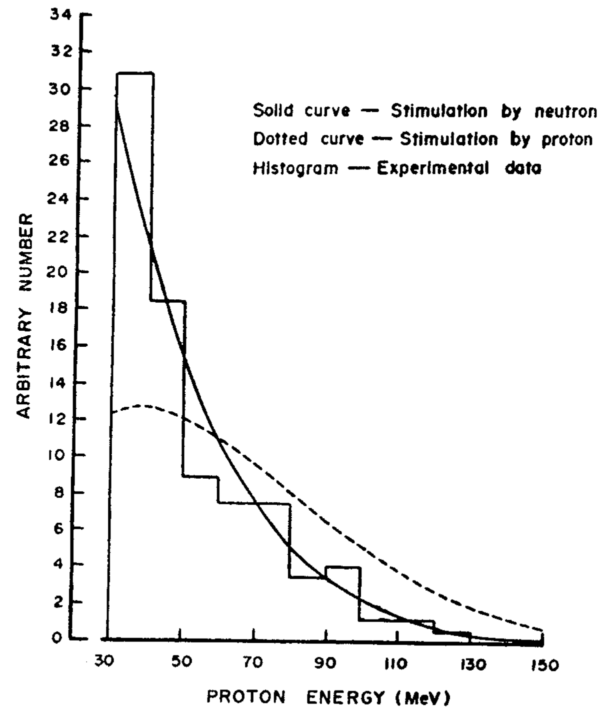

FIG. 2. Histogram represents observed energy spectrum of protons of E $\geq$ 30 MeV from HFs of range $< 10\,\mu$m. Solid and dotted curves represent expected laboratory energy spectra of protons from stimulation of Λ by neutron and proton, respectively, from a nucleus of A = 50.

3. THE RATIO OF Λ-NEUTRON TO Λ-PROTON STIMULATION

The ratio of neutron to proton stimulation can be obtained in two ways: (*a*) by matching the experimental energy spectrum of fast protons with the predicted spectra from proton and neutron stimulation reactions, and (*b*) by reproducing the observed percentage of fast protons from the predicted values of proton and neutron stimulation processes. These two methods are discussed below:

(*a*) The experimental energy histogram for fast protons (energy $\geqslant$ 30 MeV) from investigations of Ganguli *et al.*[1] and Burte *et al.*[2,3] associated with short-range HFs is shown in Fig. 2. The expected energy spectra of protons from neutron and proton stimulations are also shown in the same figure by the solid and dotted curves respectively. From this figure it is quite evident that stimulation of Λ by neutron is the predominant one. It is estimated from this that the ratio of neutron to proton stimulation is $\gtrsim 4$.

(*b*) The observed fraction of events with fast protons, with energy $E \geqslant 30$ MeV among the 483 short-range HFs, is 0·36; however this value has to be corrected for HFs with $N_h = 0$ and 1 which were not noted in the scanning. The fraction of HFs with $N_h \leqslant 1$ can be estimated from N_h distribution of π^- capture stars in light (C, N, O) and heavy nuclei (Ag, Br). From the work of Ammiraju and Lederman[9] and Menon *et al.*[10] it is known that about 20% and 70% of all π^- absorptions in light and heavy nuclei, respectively, give rise to stars with $N_h \leqslant 1$. Since the average mass of short-range HFs is A = 50, which lies between that for light and heavy nuclei mentioned above for π^- capture stars, it will be assumed that ≈ 50% of the HFs with ranges ⩽ 10 μm. give rise to stars with $N_h \leqslant 1$; further the number of HFs with $N_h = 0$ and that with $N_h = 1$ will be taken to be equal as is observed in π^- stars with $N_h = 0$ and 1. Now, the contribution of fast proton events among HFs with $N_h = 1$ is estimated as follows: It is inferred from the work of Azimov *et al.*,[1] who studied π^- absorptions in heavy nuclei of emulsion, that the percentage of fast proton events remains constant irrespective of the N_h of π^- star. Details of fast protons from π^- star and short range HFs are presented in Table III; it is seen from this that the

TABLE III

Emission frequency of fast protons from π^- stars and decay of HFs

N_h	Number of fast protons, $E \geqslant 30$ MeV from	
	π–stars [11]	Decay of HFs [1–3]
1	2	3
1	(18·4 ± 2·3)%	..
2	(22·2 ± 3·3)%	(38·2 ± 3·8)%
3	(10·7 ± 4·0)%	(35·1 ± 3·4)%
4	(26·3 ± 10·0)%	(33·7 ± 4·9)%
5	..	(27·8 ± 10·5)%
6	..	(25·0 ± 21·0)%

percentage of fast proton events from HF decay is also independent of the N_h of HF. So, we assume that ≈ 36% of the HFs with $N_h = 1$ should decay by emitting a fast proton. With this correction it is estimated that ≈ 27% of the short-range HFs decayed with the emission of a fast proton of energy ⩾ 30 MeV. The expected emission frequencies of fast protons with E ⩾ 30 MeV from Λ-proton and Λ-neutron stimulation processes are given in column 2 of Table II. From this it is estimated that the neutron to proton stimulation is ≈ 5·0.

It is thus concluded that the ratio of Λ-neutron to Λ-proton stimulation is ∼ 5. Lagnaux *et al.*[12] also concluded high value for the stimulation from their work on short-range HFs. This high value of Λ *n* to Λ |*p*| stimulation ratio suggests, following Dalitz,[13] that the Λ-neutron stimulation has a strong spin dependence and it is weaker in the singlet configuration.

4. Emission Frequency of Two Fast Protons

Since the two final nucleons from Λ-single nucleon stimulation process undergo collisions with the nucleons of the nucleus before reaching the nuclear surface, it is possible to observe the emission of two fast protons from this type of mechanism. This has been calculated in Section 2 and the results are given in columns 3 and 4 of Table II. In Section 3, it has been estimated that Λ*n*/Λ*p* stimulation is ∼ 5; using this ratio and the results presented in columns 3 and 4 of Table II, it is estimated that the emission frequencies of two fast protons both with E ⩾ 20 MeV and with E ⩾ 30 MeV, from decay of HFs with A = 50, are expected to be ≈ 3·3% and ≈ 1·7% respectively. The experimentally observed frequencies of two fast protons,[14] after appropriate correction for HFs with $N_h = 0$ and 1, both with E ⩾ 20 MeV and with E ⩾ 30 MeV are ≈ 3·2% and ≈ 1% respectively; thus there is good agreement between the calculated and experimental frequencies. Using this data it has been concluded by Burte *et al.*[14] that the contribution of Λ-multinucleon interactions, if they exist, can only be a few per cent.

5. Conclusion

From calculations of Λ stimulation with a single nucleon inside a nucleus of A = 50, the following conclusions are drawn:

(i) The stimulation of Λ hyperon by a neutron seems to be the dominant mode for non-mesic decay of short-range HFs; Λ-neutron to Λ-proton stimulation ratio is ~ 5.

(ii) The emission frequencies of two fast protons both with $E \geqslant 20$ MeV and with $E \geqslant 30$ MeV, from decay of short-range HFs, are expected to be $\approx 3 \cdot 3\%$ and $\approx 1 \cdot 7\%$ respectively. These frequencies when compared with experimentally observed values lead to the conclusion that Λ-multinucleon interaction, if they exist, can only be a few per cent.

6. Acknowledgements

We are grateful to Prof. R. R. Daniel and Mr. S. N. Tandon for helpful discussions.

7. References

1. Ganguli, S. N., Rao, N. K. and Swami, M. S. — *Nuov. Cim.*, 1965, **36**, Part I, 35.
2. Burte, D. P., Ganguli, S. N., Rao, N. K., Ray, A. K., Rengarajan, T. N. and Swami, M. S. — *Ibid.*, 1965, **36**, Part II, 733.
3. ——, Chaudhari, K. N., Ganguli, S. N., Rao, N. K. and Swami, M. S. — *Proc. Ind. Acad. Sci.*, 1966, **64**, Part IV, 213.
4. Tomar, S. .. *Phys. Rev.*, 1950, **77**, 412.
5. Gilbert, F. C., Violet, C. E. and White, R. S. — *Ibid.*, 1957, **107**, 228.
6. Wilcox and Moyer .. *Ibid.*, 1955, **99**, 875.
7. Ganguli, S. N. .. *Thesis*, Bombay University, 1966.
8. Combe, J. .. *Suppl. Nuov. Cim.*, 1956, **3**, 182.
9. Ammiraju, P. and Lederman, L. M. — *Nuov. Cim.* 1956, **4**, 283.
10. Menon, M. G. K., Muirhead, H. and Rochat, O. — *Phil. Mag.*, 1950, **41**, 584.
11. Azimov, S. A., Guliamov, U. G., Zamchalova, E. A., Nizametdinova, M., Podgoratskii, M. I. and Iuldashev, A. — *Sov. Phys., J.E.T.P.*, 1957, **4**.

12. Lagnaux, J. P., Lemonne, J., Sacton, J., Fletcher, E. R., O'Sullivan, D., Shah, T. P., Thompson, A., Allen, P., Heeran, M. Sr., Montwill, A., Allen, J. E., Davis, D. H., Garbutt, D. A., Bull, V. A., March, P. V., Yaseen, M., Pniewski, T. and Zakrzewski, J. *Bulletin No.* **13**, Universite De Bruxelles, 1964.

13. Dalitz, R. H. .. *Proceed. Int. Conf. on Hyperfragments*, held at St. Cergu, 1963, C.E.R.N., **64-1**.

14. Burte, D. P., Chaudhari, K. N., Ganguli, S. N., Rao, N. K. and Swami, M. S. *Proc. Ind. Acad. Sci.*, 1966, **64**, Part III, 203.