EmC 62/39

3rd October 1962

PROPOSAL (preliminary version)

MEASUREMENT OF THE BINDING ENERGY OF THE Λ-HYPERON IN HEAVY NUCLEI PRODUCED BY A HIGH ENERGY K^- BEAM

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1. Introduction.

Up till now the study of hypernuclei has been limited to cases where a nuclear fragment with relatively high energy is emitted by the parent nucleus. The charge of this fragment can be determined from the trackwidth distribution along its path.

The binding energy of the Λ in the hypernucleus can be obtained by measuring the energies of the outgoing prongs of the decay star. Most investigators concentrated on the study of the mesonic desintegration of the bound Λ, as then the evaluation of the binding energy becomes relatively easy. The investigation of heavy hypernuclei becomes rather difficult because of the rare abundance of these fragments and of the non-occurence of the mesonic decay when the binding energy of the Λ exceeds the Q-value of its decay. Some of these heavy hypernuclei become visible when photographic emulsion is exposed to K^--mesons of high momentum. The ranges of the so-called cryptofragments are then of the order of a few microns and lower, so that they become visible as connecting tracks of double centred stars. Preliminary data seem to indicate that in an emulsion irradiated with 790 MeV/c K^--mesons, 10% of all stars are double centred if one goes down to ranges of a few tenths of a micron. No minimum range was observed, so that the percentage can increase when the resolving power of the microscope is improved.

Obviously, cryptofragments are produced under other conditions than hyperfragments. Jones et al. (Proc. Aix en Provence Conf., 1961, I, page 363 and recent preprint) proposed the following production mechanism:

After the impact of the incident K^- with the nucleus, at which a Λ-hyperon is produced, most of the available energy is taken away by mesons, nucleons, α-particles and other minor bodies.
The remaining part of the nucleus binds the Λ and gets, because it is the heaviest product of the reaction, most of the momentum of the incident K-meson. With this momentum the nucleus can travel over the observed distance. Approximately the hypernucleus would be 20 - 30 nucleon masses lighter than the original nucleus.

2. Identification of the cryptofragments.

Also if the double centred stars can be spatially resolved, no charge or mass measurement of the hypernucleus is possible because of the extreme short length of its track. A charge determination could, however, be carried out if the identity of the parent nucleus were known. The first star shows a number of outgoing protons, deutrons, α-particles etc. that can be identified by their blob density and range or their trackwidth distribution. If an appropriate correction is made for these prongs that are too steep for being measured, the charge of the remaining nucleus can be calculated. The experiment should therefore be carried out with emulsion that is loaded with small pieces of pure elements. Crystals with a diameter of 2 microns would be convenient for this work. At area scanning those stars would be selected that originate inside a crystal.

3. Elements to be used for loading the emulsion.

The elements to be applied for manufacturing the loaded emulsion should satisfy several conditions. First they should have no chemical influence on the components of the emulsion or change the photographic properties. All alkali metals, earth metals and rare earths are eliminated by this condition. For a number of metals that sensitize the emulsion when applied in colloidal form, no difficulties should arise when the crystals have a size of a few microns. The second condition is, that the atomic volume of the applied elements should be large, as the mean free path of the cryptofragment is proportional to this quantity. Metals like gold and tungsten and the platinum group do not fulfil this condition.

In table 1 some data are presented about the expected ranges of different hypernuclei. The elements are chosen according to our second condition, but do not all fulfil the first one. For making an estimate of the range of a heavy nucleus with momentum of 1 GeV/c, energy loss by ionization may be neglected. At the low velocities involved, even the outer electron shells are completely occupied. Energy loss occurs through Coulomb recoils against the nuclei of the medium; the theory has been developed by Bohr and Knipp and Teller (Phys. Rev. 59, 659, 1941). We will make our calculations under the assumption, that the cryptofragment has the same mass as the nuclei of the crystal. Actually the mass is somewhat smaller, which lengthens the path of the cryptofragment. This effect is highly overcompensated by the fact, that single collisions and change of direction are not taken into account, so that the real ranges will come out lower than the values presented in the table.

4. Spatial resolution.

For carrying out the investigation it is necessary to study the double centred stars, although at least the first star lies outside the photographically sensitive part of the emulsion. A spacial reconstruction of the double centred star can be achieved by measuring the coordinates of different points of the tracks and constructing straight lines through them by means of a least square procedure. An apparatus to carry out this measurement has been constructed by us; the data are punched into tape and handled by a computer. Preliminary results, obtained with G 5 emulsion show, that resolution within a few tenths of a micron is possible. The method can probably be improved by using fine grain emulsion. In plotting back the tracks to their origin the aim is, to extract the greatest amount of useable information from each track. For this reason weight functions have been calculated that determine the way in which the subsequent points of a track take part in the least square procedure. These weight functions depend on measuring error and multiple scattering of the particle. The method reaches its limit for short prongs where the multiple and single scattering are of great importance.

Special methods should be developed for these prongs.

Up till now we do not use the third dimension for our reconstruction, as the measuring error in this direction is considerable. If a star is double centred, however, the first part should be submitted to a three-dimensional reconstruction, in order to make sure that it lies inside the crystal.

5. Energy measurement.

The binding energy of the Λ must be calculated from the energies of the outgoing particles and nuclear fragments. The identification can be carried out by mean gap length versus range measurement for the gray tracks. On the short black tracks beam profile measurements should be carried out. Recent experiments (Alvial et al., Nuov. Cim. XV, 25, 1960; Ammar et al., Nuov. Cim. XV, 181, 1960; 4th International Symposium on Nuclear Photography, 1962; and own observations) showed, that charge determination of light nuclei is possible even for prongs of less than 100 microns. By far the best results can be achieved if the tracks can be compared with identified tracks in their immediate neighbourhood. Although calibration with α-particles from radioactive materials is possible, a method of iterative comparison of all the tracks of a same star would be preferred.

6. Calibration of the energy measurement.

The energy measurement is certainly the most difficult part of the experiment. No identification of very steep outgoing prongs will be possible, the mass of the nuclear fragments is uncertain and the energy of single neutrons is unknown anyway. One could make corrections by adopting general principles of the dynamics of star explosion. From this it becomes clear that there will be very few cases, where a double centred star can be completely identified and that the binding energy of the Λ-hyperon cannot be computed without corrections. The experiment will necessarily be a statistical investigation,

An all-over calibration of the energy measurement can be obtained by comparing the Λ-desintegration stars with the capture stars of stopping negative pions. The same type of loaded emulsion that is exposed to the K^--beam should be exposed to a stopping pion beam (actually the loading meterial in the pion beam should be 25 nucleon masses lighter than in the K-beam). The energy released in a π-absorption is probably not much different from that released at the desintegration of a cryptofragment, as the binding energy and the Q-value partly cancel.

7. Exposures.

The stacks for this experiment should consist of a few loaded pellicles sandwiched between a number of ordinary ones. The thickness of the loaded part should be equal to the beam height. An array of two scintillation counters in coincidence would be used for adjusting the stack. The grain of the loaded emulsion should be the smallest which is obtainable. As the loading percentage is limited for optical reasons and will probably not surpass 1%, a high intensity of incoming particles should be chosen in order to get reasonable numbers of useable events.

8. Beams.

The stacks should be exposed to an electrostatically separated K^--beam with momentum of at least 1 GeV/c. Up till now it has not been shown that cryptofragments are produced in beams with momentum higher than 790 MeV/c. It is worth while to study the abundance of cryptofragments in stacks exposed to the 3.5 GeV/c K^--beam now becoming available at CERN. The range of the cryptofragments roughly rises with the square of the beam momentum. Duplicates of all stacks should be exposed to a stopping π^--beam of the CS.

9. Preliminary program.

Before exposing stacks with different loadings to a K^--beam, some preliminary experiments should be carried out. The items to be investigated are:

a. The optimal loading percentage and the optimal thickness of the loaded pellicles,

b. The spacial resolution of the reconstruction method for loaded emulsion,

c. The choice of elements and the size of loading crystals.

These items could be studied by exposing emulsion to a stopping pion beam.

d. The optimal momentum of the K^--beam.

To investigate this point, unloaded emulsion could be located behind the bubble chamber during the K^--run.

TABLE 1

Range of heavy atoms in the crystal of the same element.

Element	Charge	Mass	Atomic volume (cm^3/gramatom)	0.5 Gev/c range in μ	1.0 Gev/c range in μ
Se	34	79	16.5	1.0	7
Cd	48	112	13.0	0.3	1.4
Te	52	128	20.5	0.3	1.4
Eu	63	152	28.9	0.3	1.1
Yb	70	173	24.9	0.2	0.7
Bi	83	209	21.3	0.1	0.4