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PHYSICS III COMMITTEE

LETTER OF INTENTION ABOUT THE STUDY OF SOME TYPICAL REACTIONS WHICH COULD PLAY A ROLE IN THE FRAGMENTATION OF A NUCLEUS INTO ^{2}H, ^{3}H, ^{3}He and ^{4}He.

Additional interest of some of these reactions.

by

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1) A test has been made in June 1966 aiming at the determination of some of the characteristics and technical conditions which should be known for the main experiment on fragment production by high-energy particles (E 52)(19).

100-μm Be and C targets were bombarded by a beam of about 5×10^{12} protons of 16.7 GeV/c momentum; emulsion detectors were placed in air at various angles and distances with respect to the beam and the targets in order to record the fragments produced.

a) three sensitivities of emulsion have been tried (K1, K0, K-1). K0 type seems to be the most convenient type for this work. It allows a rather heavy exposure and a good record and identification of the light fragments in which we are interested ($Z = 1, 2, 3$; $10 < E <$ few hundreds MeV).

b) the background produced in the emulsions by the halo of the beam and the energetic secondaries coming from the target and from the surrounding material has been measured. It appears that if the contribution of the beam halo and of the surrounding material is reduced to the level of the unavoidable contribution of the target, an exposure with an intensity 10 times higher ($\sim 5 \times 10^{13}$ protons) would still be workable allowing cross section measurements as low as 1 μb or less.

c) various geometrical arrangements of the emulsion detectors have been tried. It appears, in particular, to be very convenient and efficient for the scanning and the measurements to let the fragments enter the surface of a tilted (between 6 and 10 degrees) emulsion. When the particles are entering the edge of the emulsion pellicles the distortion at the entrance is particularly disturbing. This way is only to be used for long fragments (more than 5 mm) which can not be recorded in full in a sheet of emulsion tilted at 10 degrees.

d) cross-sections for fragment production (α, ^{8}Li) have been measured and found much less abundant than those measured at lower energies of bombarding protons. At 16.7 GeV/c for carbon and $E_\alpha > 30$ MeV the helium production cross-section for example is less than 1 mb instead of the 10 mb measured for protons between 100 and 600 MeV bombarding the light nuclei of the photographic emulsion (1).

2) In addition to this technical information, the test has shown that such a simple arrangement can be used for physics studies when made with slightly more care and on a somewhat wider scale. The improvements to be made are:

a) exposures made in vacuum in order to decrease the background and to record slower fragments;

b) cleaner beams and, if intensive enough, other types of beams than proton beams (pion beams, for instance);

c) wider set of targets (Be, C, Al, Mo, Au, Pt, and gaseous targets like helium and deuterium and full angular range of scattering (forward and backward);

d) optimization of the identification methods of the various isotopes produced. There is in this field an obvious, but not general limitation of the emulsion technique. In a further step other devices like semi-conductors, emulsions associated with an analyzing magnetic field, time-of-flight measurements have clearly to be used. However, as is shown in what follows there are some specific reactions of basic importance which can be studied with a simple set-up as the one used in the test.

Moreover, experiments on fragment production would benefit largely of the availability and of the expected quality of both proton and pion beams built in the East Area for the precision measurement of the Λ^{0}. Those beams are foreseen to be very intensive, of small section with a negligible halo and of a rather easy access and parallel running, all conditions making the experiments proposed the most efficient.

3) Some aspects of the physics accessible

In addition to the technical points needed for the test use of more elaborated devices, a simple arrangement like the one used in June and slightly improved seems to be able to give a fair amount of knowledge still missing about various basic reactions which are expected to play a role in the fragment production and in particular in its connection with the chemical composition of the cosmic radiation. (15a)b)c)

Let us, e.g. consider one kind of hypothesis usually made about the structure of the nucleus and its connection with the production of certain types of fragments. It is, e.g. clear nowadays that the old picture of the nucleus as a spherical body of constant density with a sharp edge, characterized by a single parameter, the radius, has to be modified after the experiments of Hofstadter on the scattering of energetic electrons. A second parameter has to be introduced which takes into account the texture of the nuclear surface. On the experimental side how this texture shows up? Do the nucleons simply get wider and wider apart or do nucleons stay in small clusters like "alpha-particles" which themselves get farther apart? Theoretical (2),3),4),7) and experimental work (1),5),6),7) has shown the high probability of nucleon complexes (especially paired and quadruple configurations) being produced in the peripheral region of the nucleus, where the density of matter is low. Furthermore for light nuclei like carbon, there are experimental results $^{(1),8),9)}$ which suggest the existence of intranuclear α particles and their knock-on origin when emitted.

Following this view point it is natural to consider that elastic and inelastic reactions on these substructures (α,d) could give a contribution of typical behaviour to the production of the α, ^{3}He, ^{3}H, ^{2}H and even ^{1}H particles one seems coming out of the nucleus and it is natural to try to explain the composition of the charge one and the charge two particle spectrum in assuming a more or less abundant "clustering".

There are, in fact, experimental results$^{(10)}$ which seem to indicate a percentage as high as 80% for the energetic (50-500 MeV) ^{3}He content of the charge-two particle component emitted in high-energy nuclear interactions produced by cosmic rays in emulsion; energetic tritons are rather abundant, too. Similarly, in the cosmic raditation at the top of the atmosphere one finds an important energetic ^{3}He component:

$$^3\text{He}/(^3\text{He} + {}^4\text{He}) \approx 0.1 \text{ to } 0.3^{(11)}.$$

This trend is also seen in reactions with Au and Pt at energies as low as 157 MeV$^{(12)}$.

For this reason, reactions of the following types are then to be considered.

(1) $p + d \rightarrow {}^3\text{He} + \pi^0$
(2) $p + d \rightarrow {}^3\text{H} + \pi^+$
(3) $p + d \rightarrow p + d$
(4) $p + {}^4\text{He} \rightarrow 2p + {}^3\text{H}$
(5)a $p + {}^4\text{He} \rightarrow p + n + {}^3\text{He}$
(5)b or $d + {}^3\text{He}$
(6) $p + {}^4\text{He} \rightarrow p + {}^4\text{He}$

One must point out that the majority of these reactions is also interesting for considerations independent of fragment production. In particular, it should be possible to get information on two-body reactions by the analysis of the characteristics of the recoiling fragment and then constitute a kind of missing-mass spectrometer. That applies especially to reactions (1),(2)(7) and (8) and to reactions where together with the recoiling fragment a short lived object is produced.

Furthermore, reactions produced by pions also seem to have a specific interest. Two experimental facts are especially striking:

(i) pions of moderate energy (around 700 MeV) are much more efficient for fragment production than proton in the same range of energy$^{(13)}$;

(ii) the fragment production cross-section above 1 GeV increases rapidly with the incident energy $^{(14)}$ what leads to think that secondary pions in becoming important above 1 GeV could play a role$^{(10a)}$.

Then, one is led to study the following reactions similar to (4), (5), and (6):

(7) $\pi^- + {}^4He \rightarrow {}^3H + n$

(8) $\pi^+ + {}^4He \rightarrow {}^3He + p$

(9) $\pi^\pm + {}^4He \rightarrow {}^4He + \pi^\pm$

The reactions produced by pions on Helium have an additional interest as a test for a possible experiment we are planning to study the π form factor through the π-α scattering. Technically these reactions can be studied in sending the suitable beam (proton and pions) in a box containing at the same time the gas target (helium or deuterium) and the emulsion detectors. In adjusting the gas pressure one makes the compromise between the yield in fragments and the energy threshold one can record.

With the helium target, the separation between ${}^4He$ [reactions (6) or (9)] and ${}^3He$ [reactions (5) or (8)] is made easier by the fact that ${}^4He$ produced only by elastic scattering will be identified by kinematic relations. The same applies, when deuterium target is used, for the separation between deuterons and tritons.

After the experiments on the disintegrations of helium and deuterium and complementary to them come the exposures using various types of heavier targets like Be, C, Al, Mo, Au, Pt where, amongst those of other fragments, the relative abundance and the energy spectrum of ${}^4He$, ${}^3He$, ${}^3H$, ${}^2H$ should be measured and compared with what comes out from interactions with helium deuterium. Technically the problem is difficult especially in what concerns the separation of ${}^4He$ and ${}^3He$. This separation is possible in emulsions for rather fast fragments(10b),(16) ($R_\alpha \geq 5$ cm corresponding to $E_\alpha \geq 500$ MeV) if one combines two independent methods of mass resolution, mainly ionization loss and multiple scattering. At lower energies the emulsion technique is not practicable but the semi conductor technique in measuring E and $\frac{dE}{dx}$ has shown such a separation to be feasible(12). However, this technique has difficulties with the high-energy helium fragments since depletion layers of several centimetres are not commonly available and used until now. Another combination of methods has to be thought of for higher energy fragments:

dE/dx - E scintillation counter(17), time of flight measurements, gas Cherenkov counter(18), or range in emulsion combined with magnetic analysis as we have proposed at CERN(19) where the mass separation is proportional to $M^{2.5}$.

One sees that the complete picture requires numerous data which can be collected only by using various techniques of approach, each of them being the best adapted for a particular range of information. Right now, we cannot make detailed plans covering the whole field sketched here. One position is less ambituous and it is foreseen to start with a limited number of small experiments technically possible in our state, but leading to definite results. However, the whole field should be kept in mind and should develop in taking into account the results, the indications and the experience brought by the various steps.

4) Proposed experiments

Up to a certain extent the order of the experiments proposed would be a function of physics involved, results needed first and availability of technical facilities (especially of beams).

We propose then the following experiments:

a) Study of the helium disintegrations under proton bombardment following the reactions (4), (5) (6) at 16 GeV.

The gas target and the emulsion pellicles are placed in a metal box of about 50 litres (~ 50 x 50 x 20 cm^3).

<u>Emulsion used:</u> preferably K2, maybe K1 or K0; between 200 and 300 pellicles 600μ thick, 3" x 1" for each exposure (~0.25 litre).

<u>Total intensity required:</u> between 10^{13} and 10^{14} protons depending on the pressure inside the box; the pressure can go from a fraction of an atmosphere allowing to record low energy α's ($E_\alpha \geq 5$ MeV) to several atmospheres if one is interested in more energetic fragments which are less abundant.

<u>Set-up:</u> the box could be placed at the end of the ejected proton beam e_{2n}.

<u>Preparation time:</u> about three months.

<u>Manpower:</u> over a period of three months a total amount of:

1 technician-month and 4 physicist-months, and during the running period: 3 physicists.

It is hoped that a part of the manpower could come from outside laboratories (Valencia and Clermont-Ferrand), interested in this field of research.

<u>Technical preparation:</u> the main item to be built is the vacuum box (about 50 x 50 x 20 cm^3) which has to be made as elaborate and flexible as possible in order to allow:

-(i) a quick loading and unloading of the emulsion detectors and of the target material (it could be solid targets instead of helium gas),

-(ii) an easy adaptation to experimental conditions of similar type (vacuum, gas under pressure, other disposition of the detector, introductions into a standard PS bending magnet etc.).

Our estimate is: one month for the design of the box, two months to construct and test it.

<u>Scanning time:</u> first results (rough cross section and energy spectrum for ^{4}He, ^{3}He and $^{3}H_{1}$ production) are expected after about 10 scanner-months

of scanning - Valencia, Clermont-Ferrand and probably Warsaw can take part in the scanning which makes the forces strong enough for that purpose.

b) the same experiment should be repeated at lower proton energy (600 MeV or less).

The amount of time and effort required will depend largely of the availability and of the quality of the extracted beam to be expected at the SC in the next six months.

Instead of going immediately to the SC we propose to stay at the PS in the same position and proton energy and

c) to perform exposures with various solid targets, (Be, C, Al, Mo, Au). Each exposure will again require 10^{13} to 10^{14} protons and some 100 pellicles of emulsion, 600μ thick, 3" x 1", that is to say in total for the five exposures, about half a litre. If, for these exposures, the box is placed inside a one-metre bending magnet (which is feasible at the end of e_{2n}) the separation between ^{3}He and ^{4}He which is proportional to $M^{2.5}$ should be possible up to energies higher than 100 MeV.

d) After that and depending on the success of the exposure with the target helium, one can envisage to make an exposure with deuterium gas in the same conditions as it was made with helium gas.

e) Alternatively, it could, however, be better to envisage a test with pions of both signs and helium gas target if a suitable beam (a_9: 1.05-GeV/c π^- for the Λ^0 magnetic moment) is available.

The beam intensity is in this case critical; more calculations are needed to estimate the chances of success of such an exposure. At any rate more machine time will be needed since a rough estimate of the minimum intensity required reaches between 10^{10} and 10^{11} pions. These figures are by two orders of magnitude at least lower than those required for proton beams; the fragment yield per unit of time could be raised by increasing the pressure of the Helium gas (10 atm. corresponding to the absorption of 10 MeV α's after 2 cm of range) and decreasing as much as possible the distance between the detector and the target, which requires a beam with a negligible halo. Moreover, it should be pointed out that the separation between ^{4}He and ^{3}He in the reactions with helium gas which is based on the identifications of ^{4}He by the kinematics of the reaction (6) needs a parallel beam (divergence smaller than ± 0,5 degree) with a section as small as possible ($<$ 1 cm in diameter). With a positive pion beam at 1.05 GeV/c momentum without(20) separation, the proton contamination is certainly disturbing. The expected proton percentage is about 30%.

However, it is not excluded that, in taking advantage of the kinematics of the reactions involved (5), (6), (8), (9) and in using what could be learned otherwise from proton and π^- reactions separately, particles coming from positive pions (especially the elastic contribution of it) could be isolated from the general background. This point could be, in particular, of technical interest for any experiment designed to study pion electromagnetic form factor in comparing the elastic scattering of positive and negative pions from α-particles.

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