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SEARCH FOR NEW STABLE PARTICLES

On the occasion of the 60-th birthday
of Edoardo Amaldi

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Introduction

Everybody knows the extraodinary contribution which Edoardo Amaldi has given to the development of Modern Physics, from X ray to molecular Physics, from his classical neutron investigations to problems of nuclear techniques etc., not to speak of his great merits in forming young scientists and, last but not least, in organizing modern Physics in Italy (and not only in Italy!)

As a rule the research work of Amaldi is fundamental and quantitative in character, a fact which is evident also in all his first class numerous books and review articles, and yet he occasionaly likes to perfome brave, qualitative experiments whose significance is going together with a very small a priory probability of finding a positive result (for example, the search for magnetic monopoles, or several unpublished old time experiments "a porte chiuse" performed in Rome). For this reason I would like to dedicate the present paper to my friend Edoardo, with whom my first steps in science are closely connected, in the hope that he will not form a too severe judgement of this extremely naïve piece of fantasy.

In modern accelerators, to the development of which Amaldi in devoting much of his time, the available collision energy is steadily increasing, so that the question naturally arises among physicists as to whether there migth not exist unknown and entirely unpredictable "stable particles" which are produced in such accelerators.

Here stable particles are defined as objects with a mean life $\geq 10^{-8}$ sec; as it will be explaned below, the figure 10^{-8} sec is arbitrary and corresponds simply to the shortest available pulse of accelerated protons in modern machines.

There has been already performed a number of experiments in order to search for new stable particles/1/. All the relevant investigations and proposals made up till now are characterized by the following circumstances:

a) the search is made for electrically charged particles,

b) for the identification of such particles a beam well resolved in momentum is analysed and various quantities (momentum, ionisation, time of flight...) are measured without the decay properties of the new particles being investigated.

Below a method is proposed for the search of both neutral and charged "stable" particles. The advantage of a method which may be operative for neutral as well as for charged particles is immediately evident if one keeps in mind that among the known particles the number of neutral object is about equal to the number of charged ones.

In order to discover the new particles it is proposed to study their radioactivity properties with the help of a special method.

The Idea of the Experiment

There are reasons to assume as a working hypothesis that new particles with mean lives $\geq 10^{-8}$ sec might exist, that is that the transformation of such particles into lighter particles is strongly forbidden in some way. As an illustration we could think, for example, that the decay of the new particle is due to the second order weak interaction in G , the Fermi constant being $G = 10^{-5}/M_p^2$. Then the probability of decay will be $\frac{1}{\tau} \approx G^4 E^9$ where E is a certain energy characteristic of the process, If, for example, the Ξ-hyperon had a mass $\leq$ 1115 MeV, instead of 1315 MeV, its mean life could be longer than hours! Besides, the existence of a hyperon with strangeness -2 and mass $\leq$ 1115 MeV might lead to the appearance of long living quasi-nuclei (a sort of hypernuclei) with special properties and, in particular, to a new form of radioactivity of matter, in which the decay energy is not measured in MeV's but is of the order of 100 MeV. However I wish to stress again that this example is only an illustration and the possibility that the metastability of the new particles, if they realy exist, is to be found outside the boundaries of the known physics seems to me much more plausible. Such metastability might be related to the existence of yet unknown quantum numbers, or to something else, for example, to an unusual combination of known quantum numbers/2/.

Generally speaking, the body of information accumulated in the region of atomic and nuclear physics tells us that metastability is a property appearing in the most various phenomena, from phosphorescence to nuclear isomery, from the existence of strange particles to the decay $k^+ \to \pi^+ + \pi^0$, etc.

I am just proposing to use electronic methods for the search of a new type of high energy radioactivity, related to the existence of particles which, due to a forbidness of unknown nature, decay with a very long mean life ($\geq 10^{-8}$ sec). Below the assumption will be made that these new particles are strongly scattered by nucleons. As to the production mechanism of such particles, there will not be made any hypothesis.

How to Detect the New Particles?

I shall illustrate here the case when the new particles are electrically neutral. Then the discovery of the neutron and of its properties tells us how it is possible, in principle, to detect new neutral particles. As it is well known, neutrons may be detected in many ways:

1. There are detected nuclear recoils in elastic collisions of fast neutrons with nuclei (especially protons). Such a method is not adequate for the discovery of new particles, because their flux is expected to be very small, so that the number of nuclear recoils due to the new particles is negligible in comparison with the number of recoils produced by neutrons.

2. Nuclear reactions produced by fast neutron bombardment with the emission, for example, of protons, alpha-particles, etc., are looked for. Such a method is also inadequate for detecting new particles, because their flux is very small.

3. There are observed nuclear reactions (n, γ), (n, p), (n, α), fission, etc. produced by neutrons after they have been slowed down. The possibility of slowing down new particles is not to be excluded, but since such particles are expected to be generated with an energy of several 10^{10} eV, the slowing down process requires very large dimensions of moderator (a fact with greatly complicates the detection of the new particles, whose intensity is very small at best). Under certain circumstances, however, (see below) slowing down of new particles could be used.

4. There are observed the radioactive properties of the neutron (generally speaking, of the nucleon). Today the observation of the free neutron decay is not a difficult problem; however it is necessary to have a very intense neutron beam to observe the decay of free neutrons. The detection of the decay of the new particles in their free state is a very unpractical proposition, especially if their mean life exceeds 10^{-7} sec. But the detection of neutrons turns out to be quite effective if the decay of bound neutrons (that is if the beta radioactivity induced by neutron bombardment) is looked for. The analogy for new particles would be the search for a special type of radioactivity of pseudonuclei, that is of quasi-nuclei within which the new particle is found together with ordinary nucleons (I do not call these quasi-nuclei hypernuclei,

because by definition hypernuclei are Λ quasinuclei: hypernuclei cannot have a mean life much longer than 10^{-10} sec).

It is natural to expect that the new particle, (probably produced together with other particles) in high energy collisions of protons or γ quanta with nuclei, as a rule will leave the original nucleus and then will be "stopped", either suddenly (after a few collisions) or gradually after slowing down by many collisions. For such "stopping" of the new particles a large amount of condensed matter is required; I will not discuss here the corresponding experiments and I shall note that only rediochemistry, which permits to separate a "pure" source of quasi-nuclei from a large amount of irradiated material may give positive results (if the lifetime is long enough).

Below, however, I shall consider the relative rare but experimentally favourable possibility that in a proton or photon collision with a nucleus a new particle is produced, which is trapped "at the place of birth" (that is, which is found eventually inside the nucleus product of spallation); in such a circumstance, a radioactive quasi-nucleus, analogous to a hypernucleus, will be produced. Of course this requires that the new particle is being strongly scattered (and attracted) by nucleons. Thus the experiment, which will discussed below, consists in the search for a new type of "radioactivity" (with mean life $\geq 10^{-8}$ sec) in a target, irradiated in a very high energy accelerator, the radioactivity being notable for the high energy of its decay products (hundreds of MeV instead of MeV's as in the ordinary radioactivity).

Immediately there arises the question: what limits on the production cross section of such particles can be obtained from experiments already performed? If the mean life of the new particles is less than a few days, there are no limits for the cross section, because at the best of my knowledge no relevant experiments have been performed. Some limits on production cross sections, for mean lives greater than say, a few days, can be obtained from the underground experiments of Reines et al./3/ on the degree of accuracy with which the baryon conservation law is known. In these experiments it was found that the carbon nucleus has a mean life longer than 10^{27} years (for high energy decays). If we take into account that the carbon compound, of which the detector was made, had been irradiated at the earth surface by a cosmic ray nucleon flux of 10^{-4}-10^{-5} cm^{-2} sec^{-1}, the upper limit for the production cross-section by nucleons of a radioactive quasi-nucleus turns out to be quite large - 10^{-30} cm^2/nucleus.

Possibilities of the Method Proposed

Let us discuss now what possibilities are given by the method just proposed. At estimate will be made for the case of the Serpukhov accelerator, although it is clear that such experiments could be performed on an accelerator of the CERN, Brookhaven or SLAC types. Let us consider for example a mean life of the new type of radioactivity of the order of days; in such a case the radioactivity can be investigated far away from the accelerator, in conditions of low cosmic ray background. In spite of the fact that radiochemical separations will not be considered here, still a detection efficiency of about 0.2 or more can be achieved. With an average intensity of 10^{12} protons per second, at saturation it is possible to detect the production of radioactive quasi-nuclei with a cross section of the order of 10^{-40} cm^2/nucl., which corresponds to about one decay event day. If the production cross section of quasi-nuclei by protons colliding with nuclei is known, one may then obtain the cross section for the production of new particles in nucleon-nucleon collisions after the introduction of a small coefficient. It is just the requirement that the new particle is found inside the spallation product which leads to the necessity of introducing this small coefficient, the value of which, of course, cannot be estimated a priori. However, if we fantasticate on the analogy between the process considered here and the well-known process of hypernucleus production, we may give a rough estimate, starting from the corresponding experimental data on hypernuclei. It is known that the probabilities of hypernucleus production in photoplates by K-mesons of energy 3, 5 and 10 GeV are (3±0.1)%/4/, (2.2±0.1)% and (1.2±0.1)%/5/ of the total nuclear collision probability, respectively. Unfortunately at present there are no available data for higher energy kaons but from the quoted information, and also from the fact/6/ that for 25 GeV protons the fraction of nuclear interactions in emulsions which results in hypernucleus formation is 0.5%, we may guess a value of 0.005 for the indicated small coefficient.

Thus the proposed method is capable of revealing cross sections for the formation of new particles in nucleon-nucleon collisions which are ten orders of magnitude smaller than the total nucleon-nucleon cross section (of course, if the assumptions made are true).

Remarks on the Proposed Method

If possible, the irradiation of the target should require a time comparable with the mean life of the activity which is looked for. For short mean lives one should use the extracted particle beam (at Serpukhov such beam will consist of 30 proton pulses the length of each pulse lasting $1.5.10^{-8}$ sec.); this permits also to take the measurements in the immediate proximity of the target. By means of the classical delayed coincidence method (when the radioactivity is looked for in the time interval between accelerated proton pulses) one may search for mean lives of the order of 10^{-8} sec. with effective beam intensities of a few percent of the full beam intensity and of the order of 10^{-6} sec or more at full beam intensity. When investigating mean lives from 10^{-8} sec to a few microseconds one must pay attention to the pion and muon background.

By the way, when searching for the new type of radioactivity with a mean life in the microsecond region, the most adequate beam time structure is to be found in electron linear accelerator (SLAC and Kharkow), where the beam time length is of the order of microseconds with a repetition rate of 100 Hz.

An extracted proton beam is convenient also when looking for mean lives less than a few hours, although in such a case the internal target may be used.

The shortest mean life which can be looked for in the internal target of the Serpukhov accelerator is of the order of millisecond (as such is the time required to put the target into the beam). It the internal target is used, it is highly desirable to take measurements in one of the straight sections, because this allows a larger solid angle to be seen by the detector at the target.

In the search for activities with mean lives greater than a few hours, the internal target can be removed and investigated in conditions of very low cosmic ray background and a high solid angle detector. One can consider the possibility of using a liquid internal target, which can be easily removed from the vacuum chamber.

In the search for "radioactivities" with long mean lives there are two difficulties which are present also, to a less degree, in the search for shorter mean lives.

1. The main source of background is due to cosmic ray muons, the integrated flux of which at the earth surface is about $0.01\ \mathrm{cm}^{-2}\ \mathrm{sec}^{-1}$, and also to nuclear "stars" produced by cosmic ray neutrons. It is evident that investigating the target "radioactivity" underground has great advantages in the search for long mean lives. In the most deep existing underground laboratories the cosmic muon intensity decreases by a factor of 10^8. In such conditions there is no background even in the absence of an anticoincidence system. Such system, which can easily decrease the muon background by a factor of 1000, should be used if the measurements are made near the earth surface.

2. The irradiated target is strongly active due to the presence of spallation products. This has the effect that no full advantage for decreasing the cosmic ray muon background can be made of the

fact that a target of very small dimensions (say $< 1\ cm^2$) can be used; as a matter of fact, there will be many accidental coincidences between the counters through which pass cosmic muons and the small area counter, placed in the immediate proximity of the small target. It may be necessary to place a filter between the target and the detector to decrease strongly the beta radioactivity.

One of the detector elements must be an energy spectrometer, let us say a NaI chrystal (or a lead glass spectrometer, etc. if high energy gamma's are looked for).

If the measurements are made at the earth surface it may turn out to be necessary to use some kind of track chamber to reject the events in which the particles are not coming out of the (small) target.

Here I would like to mention another possible registration arrangment. When a heavy ($Z \gg 80$) quasi-nucleus decays, the decay products may induce with reasonable probability the fission of the nucleus. Consequently there arises the probability of searching for a "radioactivity" with emission of fission fragments in a thin heavy target (made of an element not undergoing spontaneous fission, let us say Th) irradiated by high energy particles. The interest in this arrangement is due to the possibility of detecting (even at the earth surface) very rare fission events of a substance having an extremely high beta activity.

One might also consider the search deep underground for a delayed emission of a few neutrons from a heavy material irradiated by high energy particles, because it is well known that a heavy nucleus excited at a few hundred MeV emits many evaporation neutrons.

Conclusion

The well known methods of observing neutral particles (decay in flight, missing mass spectrometer) are adequate only if the mean life is short enough or if the corresponding production cross section is relatively large.

It is evident that the present proposal (a search for a "radioactivity" of a special type) is quite naïve, a fact which I fully recognize. However the proposal is relatively simple and, indipendent of the ideas expressed in this paper, the suggested experiment has a definite phenomenological interest.

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P.S.

After this paper was written, Dr. Giacomelli has kindly informed me about an interesting investigation/7/, which is relevant to the question discussed above from an experimental point of view although it originated from a completely different "phylosophy". A search was made for magnetic monopoles, which might have been produced in collisions of high energy protons with nuclei. In order to detect the products of a possible monopole-antimonopole annihilation, the authors looked for an high energy radiation from a target irradiated by 27.5 GeV protons. No effect was found, the detector being sensible to electrons and photons in the time interval from 0.1 sec to 1 day after the "production of the monopole-antimonopole pair" in targets of Al , polyethilene and Cu . According to this investigation the upper limit for the production cross section in light elements of a radioactive quasi-nucleus of the type discussed in this paper turns out to be several orders of magnitude smaller than that from reference/3/.

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