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HYPERNUCLEI (AND STRANGE PARTICLES) — HOW IT ALL BEGAN?*

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The first hypernucleus was discovered in Warsaw in September 1952 by Marian Danysz and Jerzy Pniewski. It happened during a time of confusion concerning the newly detected heavy unstable particles. The study of hypernuclei was of considerable help in understanding the properties of strange particles. An account is given of the early history of strange particles and hypernuclear physics.

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Elementary particle physics began in the 1930s as an outgrowth of experimental studies of nuclear and cosmic ray physics. It started to develop rapidly after the discoveries of the pion and the strange particles in 1947. Its beginnings and development have already been documented in a number of books [1–4]. The discovery of hypernuclei has also been described by one of its authors [5]. The present article contains previously unpublished material pertaining to this discovery, and also statistical data on the first decade of hypernuclear physics. The early efforts to understand the nature and properties of new unstable particles set a stage (see Fig. 1) on which hypernuclei appeared and provided an important piece to solve the jigsaw puzzle.

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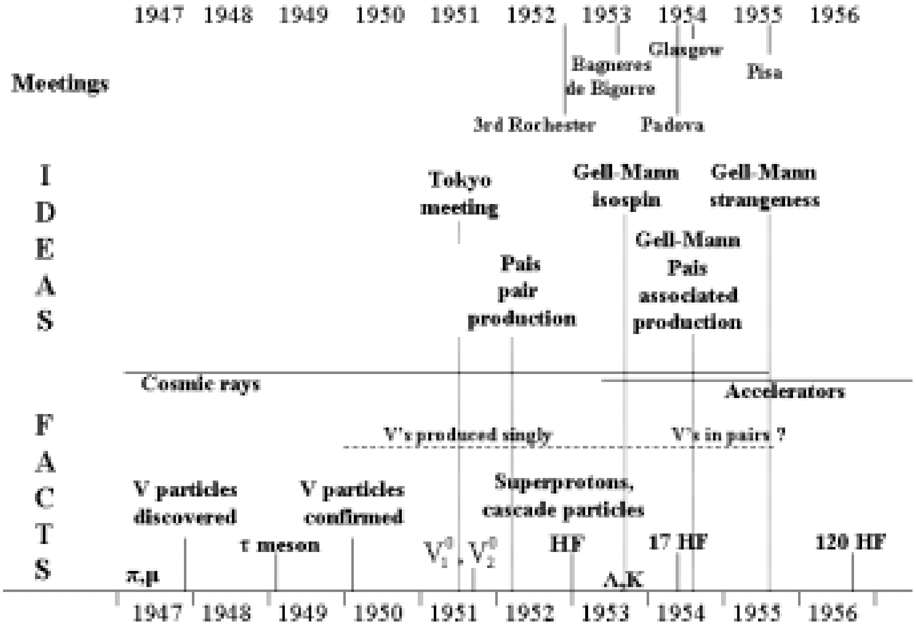

Fig. 1. The timeline of discoveries and ideas concerning strange particles and hyperfragments.

1. Curious particles

In December 1947 George Rochester and Clifford Butler in Manchester reported the first photographs of forked tracks (later called "V particles") [6]. As Rochester later recollected [7]: "After the early discoveries that promised so much, there followed several frustrating years, a period of strain for Butler and myself, when no further examples of the V particles were found." It was happily ended by a letter from Carl D. Anderson to Patrick Blackett, dated 28 November 1949:

"Rochester and Butler may be glad to hear that we have about 30 cases of forked tracks similar to those they described in their article in Nature about two years ago, and so far as we can see now their interpretation of these events as caused by new unstable particles seems to be borne out by our experiments." [7].

The results of Anderson's group were published in May 1950 [8]. Meanwhile, in the consultations between Anderson, Blackett and Niels Bohr, the name "V particles" was adopted for the new objects. In fact, another important discovery of a particle of mass about 1000 m_e was made in Bristol in 1949 [9]. The particle decayed into three charged pions and was named the τ-meson. Several other groups soon published more results on the V-particles [10–12]. In August 1951 Rafael Armenteros and collaborators published a fundamental paper [13] in which through ingenious and systematic analysis they showed that neutral V-particles are of two types: a sort of superneutron decaying into $p + \pi^-$ and a meson decaying into $\pi^- + \pi^+$. The first particle was called V_1^0, the other V_2^0. Their masses were measured as 2203 ± 12 and 796 ± 27 electron masses, respectively. The existence of two types of neutral V-particles, baryonic and mesonic, was confirmed in another work [14].

The V-particles at once showed unusual properties. They were copiously produced in high energy collisions (with cross section of a few percent of that for pion production). Thus, if the same mechanism was responsible for their production and decay, their lifetime should be of the order of 10^{-21} s. The observed lifetime was, however, about 3×10^{-10} s.

The first attempt to solve this conundrum was made by Japanese theorists. On July 7, 1951 they organized a meeting in Tokyo in order to present and discuss ideas about the new particles. There was no doubt that a strict selection rule was needed to provide for the required suppression factor of about 10^{11}. An extensive survey of possible models, including the production of V-particles only in pairs, presented during the meeting, was published in *Progress of Theoretical Physics*, a Japanese journal not yet popular among Western particle physicists [15–18]. The pioneering contribution of the Japanese authors has been largely forgotten, although the papers presented at the Tokyo meeting were duly cited by both Abraham Pais and Murray Gell-Mann.

Pais first presented his solution of the conundrum at the second Rochester Conference on Meson Physics (January 11 and 12, 1952). His paper [19] appeared in June 1952. Pais showed that the abundance of V-particles could be reconciled with their long lifetime by using only interactions of a conventional structure, provided a V-particle was produced together with another heavy unstable particle. The strong selection rules that he proposed can be summarised as follows. Let us assign a number 0 to all 'old' particles (pions and nucleons) and a number 1 to the new particles. Let us then sum these numbers for initial-state particles, and for final-state particles and demand that in all strong and electromagnetic processes these sums for initial-state particles and final-state particles must be either both odd or both even. In weak decay processes one should be odd, the other one even. Thus the reaction $\pi^- + p \to \Lambda + \pi^0$ was strongly forbidden, whereas $\pi^- + p \to \Lambda + K^0$ strongly allowed. However, the 'even–odd rule' of Pais allowed reaction $\mathrm{N} + \mathrm{N} \to \Lambda + \Lambda$, which was never observed.

Experimental evidence was against pair production of V's. Two papers with the results from cosmic ray studies were published in January 1953 (submitted in September 1952). The CalTech group [20] reported: "An analysis of the 152 examples leads to the following principal conclusions: (1) V-particles result from the impact of mesons and probably also of nucleons, upon nuclei. (2) V-particles are generally produced singly and not in pairs ..."

The Berkeley group [21] concluded that: "Three pairs were observed. This frequency of observation contradicts the hypothesis that V^0's are created only in pairs, unless one V^0 usually has a value of $\beta\gamma$ from 5 to 10 times as large as the other."

For several years the idea of production of V-particles in pairs seemed to be yet another beautiful hypothesis slayed by ugly facts. For that reason Fermi and Feynman considered the possibility that the new particles have large spin (*e.g.* 13/2 for the V_1^0), so that their long lifetime could be explained by a centrifugal barrier.

The results concerning new unstable particles[1] were thoroughly discussed during the Third Annual Rochester Conference (December 18–20, 1952). The summary table (Table I) shows that at that time only three particles, the V_1^0, the V_2^0, and the τ-meson were considered to be well established, whereas there was a lot of doubts concerning the remaining proposed particles. It was not clear whether a given symbol corresponded to a single particle or whether a particle existed at all. The feeling of the participants was that many basic things remain to be understood. It was well expressed in Oppenheimer's conclusion: "I hope our grandchildren when they attend the 2038 conference in Rochester will take it for granted that they know these things" [22].

A curious result was presented by Marcel Schein and collaborators [23] who attempted to produce V-particles by using a 227 MeV π^- meson beam from the Chicago cyclotron. The beam was directed into a $5''$ long carbon target. Two sets of photographic plates were placed at the side of the target and shielded in the direction of the beam and in the backward direction with $8''$ thick lead bricks.

"We have attempted to produce the reaction pi minus $+\ p \rightarrow V_1^0 + (?)$, where the V_1^0 has very small kinetic energy. The V_1^0 decay $V_1^0 \rightarrow p + \pi^-$ was looked for in the photographic plates. For low energy V_1^0 the proton and meson come off in practically opposite directions, and the Q value is the sum of their kinetic energies. Accepting only events in which the meson comes in the backward direction with respect to the pion beam, we found three events in the close plates and no events in the back plates. Two of the

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[1] They were then called "megalomorphs". Oppenheimer explained that since Fermi had become bored with the name "elementary particles", a new name has been coined suggesting something with vast structure.

TABLE I

The table of elementary particles in December 1952 as discussed at the Third Annual Rochester Conference. Only three particles, the V_1^0, the V_2^0, and the τ-meson (shown in bold) were regarded to be well established.

V-particles and heavy mesons (December 1952)

Particle	**lifetime (s)**	**Q (MeV)**	**Mass (m_e)**	**Spin**
?$V_1^\pm \to p + \pi^-$				half integral
$\to (n + \pi^\pm)$?				
$\boldsymbol{V_1^0 \to p + \pi^-}$	$\mathbf{3 \times 10^{-10}}$	$\mathbf{40 \pm 3}$	$\mathbf{2190 \pm 5}$	half integral
?$S^\pm, \chi^\pm, V^\pm \to \pi^\pm + ?$	10^{-8}–10^{-10}		900–1500	—
?$S^\pm, \kappa^\pm, V^\pm \to \mu^\pm + (\gamma + \nu)$?	10^{-8}–10^{-10}		1100	integral
$\boldsymbol{\tau^\pm \to \pi^\pm + \pi^+ + \pi^-}$	$\mathbf{> 10^{-9}}$	**75.8**	$\mathbf{977 \pm 6}$	integral
?$V^\pm \to \pi^\pm + \pi^0 + \pi^0$				integral
$\boldsymbol{V_2^0 \to \pi^+ + \pi^-}$	$\mathbf{2 \times 10^{-10}}$		**950**	integral
$\to (\pi^+ + \pi^- + ?^0)$?				
$\to (\pi^\pm + \tau^\pm$ or $\zeta^0)$?				
?$\zeta^0 \to \pi^+ + \pi^-$			500?	
?$\zeta^\pm$			500?	

three events have been analyzed so far." The Q values of these two events were 32 and 38 MeV, which agreed with the value known for the V_1^0. This preliminary result suggested that V_1^0 could be produced singly at rather low energy. It naturally required confirmation because it contradicted results of some other searches at even higher beam energies.

The International Cosmic Ray Conference for 1953 was devoted entirely to the new particles. It was held 6–12 July at Bagnéres-de-Bigorre on the northern slopes of Pyrenees. It was attended by all the leading cosmic-ray physicists in the world. There were 185 participants from 22 countries (France — 43, UK — 42, Italy — 27, USA — 20, Germany — 12, Belgium — 8, 4 each from India, Ireland and Switzerland, 2 each from Canada, Denmark, Israel, Japan, Sweden, and Turkey, 1 each from Brasil, Hungary, Mexico, Netherlands, Norway, Spain, and Yugoslavia). By common consent it was one of the most remarkable conferences of the century. The Proceedings [24] of the conference are a valuable historical material but are difficult to read by present day physicists because of nomenclature (different symbols used for the same particles). The title page carries a humorous motto "The particles described in this conference are not entirely fictitious and every analogy with the particles really existing in nature is not purely coincidental."

The Bagnéres-de-Bigorre conference was notable because it led to a substantial consensus concerning new particles.

New nomenclature for particles has been agreed upon. Particles heavier than a neutron and lighter than a deuteron were to be called hyperons and received the symbol H (quickly changed into Y). A generic name has been invented because, besides the V_1^0 , there was evidence for at least two other particles of this type, heavier than the proton. The existence of these two hyperons, 'Superprotons' (now Σ) and 'Cascade particles' (now Ξ^-) was well established in the discussion of the results presented during the Conference. The heavy mesons were to be designated with a symbol K. New symbols were adopted for the V-particles: the V_1^0 became Λ, and the V_2^0 was to be called θ^0 [25].

Robert W. Thompson presented an original and beautiful analysis of neutral V decays [26] which showed convincingly that both the V_1^0 and V_2^0 undergo two-body decays into $p + \pi^-$ and $\pi^- + \pi^+$, respectively. Their Q-values have been very accurately measured. The mass of the $V_2^0(\theta^0)$, measured as 966 ± 10 electron masses, was found to be identical to that of the well established τ-meson (966 ± 4) which, however, was decaying into three charged pions. It suggested that τ may be identical with θ^0. However, one particle could not decay into two different states of parity which then was regarded to be conserved. It was the beginning of the so-called τ–θ puzzle, which was soon solved through brilliant discovery of the nonconservation of parity by T.D. Lee and C.N. Yang.

M. Schein and collaborators presented [27] an extension of the study reported half a year earlier at the Third Rochester Conference [23]. They now had five events which they identified as V_1^0 decays. The average Q value was 35 ± 3 MeV. Thus, according to the authors, "The conclusions are at present then that there is no apparent basic error. The problem is not completely finished since heavier emulsions should be used to stop pi-mesons and thus get a very accurate value of Q. Such an experiment is now being carried out."

The results of M. Schein *et al.* obviously added to the confusion concerning the production of V_1^0 (now Λ). Fortunately, they were soon disproved by several experiments (see Table II). The Bagnéres-de-Bigorre conference was the first in which newly discovered hypernuclei were discussed (see below).

In 1953 W.B. Fowler, R.P. Shutt, A.M. Thorndike, and W.L. Whittemore [34] observed the first V-particle in experiment at the newly commissioned Cosmotron at Brookhaven. In about 4000 photographs scanned: "Two definite examples of V^0-particles similar to those found in cosmic rays by many workers have been observed in a cloud chamber exposed to a neutron beam from the Cosmotron ..."

TABLE II

Summary of the early searches for Λ production in accelerator experiments in the energy range 300–670 MeV.

Search for Λ^0 production			
Authors	Reaction	Energy (MeV)	Result
Cocconi & Silverman [28] (1951)	$\gamma + \mathrm{C}$	$\leqq 310$	negative
Schein *et al.* [23] (1952)	$\pi^- + \mathrm{C}$	227	positive
Hildebrand & Leith [29] (1953)	$p + \mathrm{C}$	345	negative
Garwin [30] (1953)	$p + \mathrm{C}$	450	negative
Rosenfeld & Treiman [31] (1953)	$p + \mathrm{CH_2}$	430	negative
Schein *et al.* [27] (1953)	$\pi^- + \mathrm{C}$	227	positive
Bernardini & Segrè [32] (1954)	$\gamma + \mathrm{Al}$	$\leqq 330$	negative
Balandin *et al.* [33] (1955)	$\mathrm{N} + \mathrm{N}$	670	negative

Further work at the Cosmotron brought examples of pair production of new particles. In another experiment six pairs of V-particles were observed in pion–proton collisions [35], but the authors concluded that: “Further work is required to determine whether production is always double in these and nucleon–nucleon collisions.”

Presenting these results during the 1954 Glasgow Conference Thorndike commented, perhaps tongue-in-cheek, that: “There seems to be no reason to doubt that the particles observed are the same as those observed in cosmic rays, but there is not much in the way of positive proof of it” [36].

After another year of running the same group reported five additional events with pairs of V-particles [37]. Their conclusion was, however, still rather cautious: “In each case the observations are most naturally interpreted as due to the associated production of a hyperon and K-meson …In most cases, however, our interpretation is to be considered as an hypothesis which fits the observations rather than a demonstrated fact.”

Double production of V-particles has been observed in yet another experiment [38]. On the other hand, G.D. James and R.A. Salmeron [39] concluded that:

"The statistical analysis of the frequency of associated V-events in our cloud chamber does not provide evidence for or against the hypothesis that Y- and K-particles are always produced together. We interpret those associated V-events that we observe as examples of 'plural' production in separate reactions inside the same nucleus."

Thus, associated production of strange particles was still not well-established experimentally at the beginning of 1955. When Pais reviewed the situation at the Fifth Rochester Conference (January 31–February 2, 1955), he would not go beyond saying that he felt "the experimental situation is more encouraging than when he first suggested the idea" [40]. However, the situation changed rapidly because of new experimental evidence.

The original idea of Pais [19] of pair production of new particles had to be modified. After the seminal paper of Murray Gell-Mann [41] on the isotopic spin assignment for the new particles it has evolved into a more sophisticated conception of associated production. It was presented by Gell-Mann and Pais in 1954 [42]. Next year, at the 1955 Pisa Conference on Elementary Particles, Gell-Mann presented his scheme in the final form [43] and officially introduced new quantum number 'strangeness' (it was used in his talks since September 1953).

In Japan Kazuhiko Nishijima proceeded along similar lines as Gell-Mann and also presented his results in the years 1953–1955 [44], but his papers published in Japanese journal *Progress in Theoretical Physics* had less impact than Gell-Mann's. Nowadays, however, his contributions are fully recognized, as reflected in the name of Gell-Mann–Nishijima attached to the fundamental formula which relates for every particle its electric charge, strangeness and the third component of the isospin.

In order to complete the account of the history of new unstable particles we should also mention several less successful attempts to explain their unusual properties. Thus, R.J. Finkelstein [45] assumed that the V-particles are described by a spinor wave function, and that the pion may be treated as a nucleon–antinucleon pair. Writing the decay reaction of the V^0-particle as $V^0 \to \pi^- + p \to \bar{p} + n + p$, he was able to obtain the correct value of its lifetime. H. Suura [46] considered the possibility that the V_1^0-particle is a composite particle made up of a proton and a negative pion. K. Sawada [47] worked with an assumption that the V-particles are produced in two steps through a strongly interacting V'-particle of mass of about 2800 electron masses. M. Goldhaber [48] attempted to systematize the phenomena of production, absorption, and decay of the new unstable particles by assuming one new particle, which he called the η meson, and its "compounds" with nucleons and π mesons. Thus, the V_1^0-particle was assumed to be a compound of η and a neutron, the V_1^+ — a compound of η and a proton, and the τ meson — a compound of η and a pion. The η particle, an isotopic singlet boson, was supposed to be identical with the V_2^0-particle decaying into two pions. R.G. Sachs [49] explored the possibility to classify particles in terms of a single new quantum number, which he called "attribute".

We know now that the elegant and economical scheme of "strangeness" introduced by Gell-Mann proved to be a natural and simple way to understand the properties of hadrons, especially after the discovery of their internal degrees of freedom (quarks).

At the end of this section it is worth to recall the reminiscences of Gell-Mann [50]. "Now let me return to the paper that I did sent off in August 1953 .... Isotopic Spin and the New Unstable Particles. That was not my title, which was: Isotopic Spin and Curious Particles. Physical Review rejected "Curious Particles". I tried "Strange Particles" and they rejected that too. They insisted on: "New Unstable Particles". That was the only phrase sufficiently pompous for the editors of the Physical Review. I should say that I have always hated the Physical Review Letters and almost twenty years ago I decided never again to publish in that journal, but in 1953 I was scarcely in the position to show around."

According to Gell-Mann: "Strange particles ... were not considered respectable, especially among the theorists. I am told ... that when he wrote his excellent paper on the decay of the tau particle into three pions Dalitz was warned that it might adversely affect his career, because he would be known as the sort of person who worked on that kind of things" [51].

It has been confirmed by Dalitz, who remembered that: "Pion physics was indeed the central topic for theoretical physics in the mid 1950s, and that was what the young theoretician was expected to work on. The strange particles were considered generally to be an obscure and uncertain area of phenomena, as some kind of dirt effect which could not have much role to play in the nuclear forces, whose comprehension was considered to be the purpose of our research" [52].

2. The discoverers

Marian Danysz [53] was born in 1909 in Paris. He was the son of a Polish–French physicist Jan (Jean) Kazimierz Danysz, who constructed the first β-spectrometer (1911). He studied electrical engineering at Warsaw Polytechnic and, while still a student, worked in Warsaw Radiological Laboratory under Ludwik Wertenstein. There he co-discovered (1934) a radioactive isotope of fluorine, and co-authored 3 papers [54]. After obtaining the diploma in 1937 Danysz worked as an electrical engineer in a state telecommunication institute. His interest in physics was revived after the war. He approached the physics institute of Warsaw University at 69, Hoża Street, which had personnel decimated by the war and Nazi occupation. With little formalities he was hurriedly given master's degree in physics and employed as an assistant. He then spent two years (1950–1952) first in Liverpool, and next in Bristol, where he mastered nuclear emulsion technique in Powell's laboratory. In 1951, with Owen Lock and Gideon Yekutieli, Danysz claimed [55] discovery of a new particle (ζ^0), which, however, was not confirmed.

Fig. 2. Marian Danysz (right) and Jerzy Pniewski (left), who discovered hypernuclei in 1952.

Jerzy Pniewski [56] was born in 1913 in Płock, the son of a high-school teacher, He studied mathematics, and later physics, at Warsaw University. Pniewski started career in molecular optics, and published two papers in that field (1938). In the years 1948–1950 he was studying β-spectroscopy in Liverpool. After return to Warsaw in 1951 he obtained Ph.D. in nuclear spectroscopy. In 1952 he was persuaded by Danysz to join him in cosmic ray studies using nuclear emulsions. Thus started everlasting friendship and collaboration between the two physicists, who had rather different characters and qualities, but supplemented each other and formed a formidable team.

Marian Danysz had little formal physics background but he was gifted with a fantastic intuition and unusual imagination. Jerzy Pniewski had solid background in physics and mathematics, and was well organized and systematic. He was also a good lecturer and competent and efficient administrator.

Danysz hated administration, lecturing and formalities. For that reason he refused to submit any of his papers for a Ph.D. Thesis. Only much later, in 1977, he was persuaded to accept an honorary doctorate from Warsaw University.

Danysz was a little extravagant, loved fast driving, hunting and good food, and chain-smoked cigars, cigarettes and pipe. Pniewski was kind and quiet, he loved to entertain friends with magic tricks and puzzles. He never smoked but loved good cognac.

3. The discovery

The discovery of the first hyperfragment in 1952 has been lively described by Jerzy Pniewski [57]:

"Late in the evening of September 19 we began to analyse the recorded events one by one. Suddenly Marian exclaimed 'Look, what a strange animal' and showed me two stars connected by a prominent and quite thick track. It was obvious that one of the stars was due to a disintegration of a heavy emulsion nucleus, silver or bromine, by a high energy cosmic radiation proton. The nucleus was split into small fragments and only one of them, distinct by its quite long track, seemed to have mass considerably larger than the others. Its track ended with a four prong star which indicated its spontaneous decay. The energy released in this decay was clearly very high, which was confirmed by subsequent measurements. But then the lifetime of the fragment, estimated from the length of its track, was unbelievably large for such an excitation. We spent nearly three weeks on endless and heated discussions during which we eliminated various explanations of the observed inconsistencies. We concluded that, given the conditions of exposure of the emulsion stack, an accidental juxtaposition of two unrelated events was completely improbable. Twice a day we went for coffee to café "Niespodzianka" and it was there that we suddenly began to see daylight, that so large energy released in the secondary star was comparable to the energy of annihilation of the π-meson, the particle discovered five years earlier. The first hypothesis was that the fragment carried a bound π-meson, similarly to an electron bound in an atom. This very attractive hypothesis had to be rejected because it was improbable that the fragment could capture and carry away one of the mesons produced in a high energy collision. But we were only one step from the proper interpretation that the fragment contained a bound V_1^0-particle. The V_1^0-particle was discovered in 1951 by Armenteros but no one expected that it could be bound in atomic nucleus with protons and neutrons … .

We treated it as an excited nucleon. Our interpretation made it the third component of atomic nuclei besides protons and neutrons…

We dispatched a short paper[2] to the Bulletin of the Polish Academy of Sciences and then we sent letters to several foreign physicists, including W.C. Heisenberg, C.F. Powell, and D. Skobeltzyn …”.

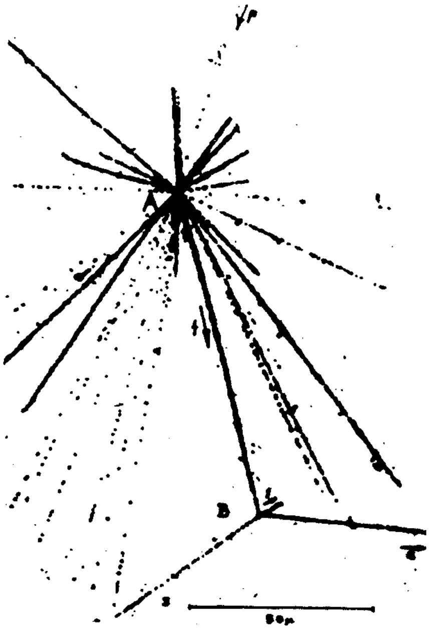

Fig. 3. The first observed decay of a hypernucleus. It was produced by a cosmic ray particle (track p) which interacted with a nucleus in the emulsion at A. The ejected hyperfragment (track f) was brought to rest at B where it decayed into three charged particles (from [58]).

Neither Danysz nor Pniewski knew Heisenberg, hence the letter was sent to Klaus Gottstein, with whom Danysz worked in Bristol. The choice of Skobeltzyn, a Russian pioneer in cosmic radiation studies, could have been politically motivated. The political situation in Poland in 1952 was far from comfortable, so that Danysz and Pniewski were eager to show to the oppressive regime their willingness of cooperation with the East. Anyway, the

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[2] The paper [58] was submitted on October 20, 1952 and appeared in the beginning of 1953.

answer from Skobeltzyn never arrived and it was not even clear whether he received Danysz's letter. The correspondence with Gottstein and Powell has been preserved in Warsaw University Archives. Parts of it are reproduced below.

From Danysz's letter to Powell of October 26 one can learn that the Warsaw particle physics group had to be built from scratch.

> Dear Professor Powell,
>
> It is more than four months as I am back in Warsaw ... From September the work has begun, and I hope we have some prospects for the future. I have easily found people who are interested in emulsion work, three scanners are active since the end of September, problem of microscopes seems to find a satisfactory solution. At present the only base of our work are Bristol plates, they will be good as material for starting work, for teaching people the technique and may serve for some research — unfortunately, they are rather distorted ...
>
> With this letter I enclose a short note concerning a star of a rather exceptional character. We have worked on it with my friend J. Pniewski who will — I hope — continue to work with me in plate technique. If you find the whole problem not unreasonable we might send later a fuller account to Phil. Mag. We would be very grateful for all suggestions and criticisms.
>
> Yours most sincerely,
> M. Danysz

The first answer, quite enthusiastic, came from Gottstein:

> Göttingen, 10th November, 1952.
> Dear Danysz,
>
> Thank you very much for your letter of October 26th and the preprint of your paper which, I think, is very interesting. Prof. Heisenberg has also read it with great interest. He agrees that the event cannot be explained as the delayed disintegration of an excited nucleus since the time 10^{-11} sec is much too long. On the other hand, the probability for the event being a "delayed σ-star" is extremely small, too. The binding energy of a π^--meson in the K-shell is of the order of 1 MeV whereas the average energies of the mesons ejected in the disintegration at A are apparently much greater. So it is unlikely that a π^--meson would have been captured by the fragment. But even if it had been captured, it would have to be expected to interact with the nucleus within a time much shorter than 10^{-11} sec.
>
> Your suggestion that the event might be explained in connection with the V_1^0 or a similar particle seems to be very reasonable, however. The V_1^0-particles appear to be different from the nuclear force mesons in that they may be created and annihilated only in conjunction with

> their anti-particles. In your event the V_1^0 may have been separated from its anti-particle, which flew off in a different direction, and was left within the fragment where it decayed after its life-time had elapsed.
>
> I wonder what the future will teach us about all these funny particles.
>
> With best wishes,
> Yours sincerely,
> K. Gottstein

Powell's response to Danysz, dated November 19, 1952, was rather reserved.

> Dear Danysz,
>
> Thank you very much for your letter of the 26^{th} October. The event is certainly most striking, but I feel that you would be well advised not to publish it at this stage. Inspite of the most remarkable precision with which the heavy particle ends its range at the point of origin of the second star, you still have to meet the objection that you are dealing with a chance juxtaposition of unrelated events. Because of this, I think that it would be best, either to wait until a second example of the same phenomenon is found, or, to publish a photograph of it with a minimum of descriptive material. There seems to be no point, for example, in giving a detailed description of the big star from which the heavy particle was emitted ...

The rest of the letter pertained to Bristol emulsion results concerning heavy mesons. Powell also invited Danysz to a special meeting at the Royal Society on January 29, 1953, a full day discussion on elementary particles. Unfortunately, Danysz was not able to visit England at that time.

4. The rise of hypernuclear physics

Meanwhile Danysz received a letter from E.P. George of Imperial College, London. The letter, dated November 19, 1952, said:

> Dear Danysz,
>
> We have recently observed the following event. A star of 19 heavy tracks and 1 shower particle emits a heavy fragment of charge of about 12 units. This particle comes to rest in the emulsion as shown by its taper down. At the point where it comes to rest there is a small 3-prong star. I enclose a rough sketch of the event. Menon tells me that you have recently observed a very similar event and mentioned the possible explanation in terms of trapped π-mesons.
>
> He suggested that we might publish a short note on this jointly. I would be glad to do this, if you think it is a good idea, two events

> being better than one. I would imagine a note or a letter in Phil. Mag. would be the thing. Would you let me know what you think. In any case, I would be glad to receive further details of your event.
>
> With best wishes, Yours sincerely,
> E.P. George

Danysz considered the proposal attractive, so he replied to George on 28 November 1952:

> Dear George,
>
> Thank you for your letter of the 19th November and the news concerning your case of a delayed disintegration of a heavy fragment. Obviously two events of such a kind are much better than one, and I quite agree that it is a good idea to publish this jointly in a note or letter in Phil. Mag. ...
>
> Not to lose time we suggest that you would write a rough draft of the letter or note in question and send us a copy before publication as we may have some suggestions or remarks to make ...

Things, however, went differently, because of Powell's firm stand. It turned out that the Imperial College physicists had found their event earlier than Danysz and Pniewski but did not understand it and put it aside. Only after learning about the daring Warsaw explanation they decided that perhaps their event could be interpreted along similar lines. When Powell learned that he insisted that the priority of Danysz and Pniewski must be assured. It was decided that the papers describing the two events will be published one after the other in the same issue of the *Philosophical Magazine*, which at that time was a very prestigious journal for particle physics. Thus, on 9 February 1953, Danysz wrote to A.J. Herz:

> Dear Herz,
>
> ... After receiving a letter from Menon, concerning Powell's proposition, we have sent the material related to our case to Bristol, and left all the decision concerning the publication to Powell. So I hope all is O.K. Of course we are pleased to have another note in the same issue of the Phil. Mag. supporting our observation ...

The two papers were published in the March 1953 issue of the *Philosophical Magazine*, The Warsaw event carried the submission date of December 1, 1952 [59], whereas it was December 15, 1952 for the Imperial College event [60]. Very soon the third similar event was found in Paris by Crussard and Morellet and published with the date of January 5, 1953 [61].

The new phenomenon was first discussed during the Bagnéres-de-Bigorre conference. Neither Warsaw nor the Imperial College physicists were among the participants, so that only the Paris event was presented [62]. W.B. Cheston and E. Primakoff [63] gave a quantative discussion of the possibility that a Λ^0 hyperon bound to nucleons might undergo non-mesonic decay. Their more complete analysis was published a little later [64]. Another early theoretical paper on Λ binding in nuclei was published by D.C. Peaslee [65], who proposed a new quantum number in order to inhibit a fast decay of such a particle.

Powell retained his scepticism for several months. In September 1953 he wrote:

"Further examples have now been observed of the process, first observed by Danysz, in which a heavy nuclear fragment ejected from a nuclear explosion reaches the end of its range and disintegrates. It appears that π-mesons are frequently emitted as one of the products of the secondary disintegration. It is possible that these events are due to the presence, in the nuclear fragment, of a nucleon in an excited state; but alternative explanations cannot at present be excluded" [66].

Meanwhile, the number of events interpreted as decays of Λ^0 bound in nuclear fragments grew quickly. At the Padova Conference in April 1954 M. Grilli and R. Levi Setti presented a summary of 17 known events [67]. They concluded that "in none of the cases the total energy release in the disintegration of the fragments is inconsistent with the hypothesis first suggested by M. Danysz and J. Pniewski, that a neutron in the fragment is simply replaced by a Λ^0."

In July 1954 Levi Setti had a summary of 28 known events and gave "a first classification of these fragments into two classes: those which undergo mesonic and non-mesonic decay". His sample contained 8 mesonic, 14 non-mesonic, and 6 doubtful events. He had the following comment on the first available estimates of the Λ^0 binding energy: "The fact that the binding energy of the Λ^0 in tritium and helium nuclei is definitely lower than that of the neutron would suggest that the interaction mechanism between the Λ^0 and nucleons is probably different from that of nuclear forces between nucleons, since, if the forces acting between the Λ^0 and nucleons are supposed to be ordinary nuclear forces, one should expect the binding energy of the Λ^0 in a nucleus to be greater than that of a neutron, due to the greater mass of the Λ^0 and the non-operation of the Pauli exclusion principle between the Λ^0 and the neutron" [68].

There were several names proposed for the new kind of events, such as: excited nuclear fragment, meson active fragment, unstable fragment, delayed disintegration of a nuclear fragment, V-nucleus, Λ-fragment, and Λ-nucleus. Following a suggestion of M. Goldhaber, in February 1955

W.F. Fry, M. Schneps, and M.S. Swami [69] first used the name "hyperfragment" and proposed the use of symbols such as ${}_{\Lambda}X^{A}$ (*e.g.* ${}_{\Lambda}\mathrm{Be}^{9}$, ${}_{\Lambda}\mathrm{He}^{4}$, ${}_{\Lambda}\mathrm{Li}^{8}$). The symbols were later changed to ${}^{A}X_{\Lambda}$ and then to ${}^{A}_{\Lambda}X$.

The importance of hyperfragments discovery was described by Powell: "The original discovery suggesting that Λ^0 hyperons can exist not only as free particles but also bound within nuclei was due to Danysz and Pniewski ... An excited hydrogen atom, to use the simplest example, consists of a proton and an electron in a state of higher energy than in the normal atom. The analogy might then suggest that the excited nucleon consists of a proton and an associated π^- — that the Λ^0 is a composite particle. Such a view could not have been finally excluded while our knowledge was confined to the decay of the free Λ^0 particle ... These considerations suggest that the Λ^0 particle is an excited nucleon in a different sense from that suggested by familiar analogies. We are entering a new field where basically new concepts remain to be established" [70].

Charles Peyrou had this to say about the discovery of Danysz and Pniewski: "The hypothesis was made that the nuclear fragment contained a bound Λ^0 in a nucleus like an ordinary nucleon ... It is an essential fact in the chain of reasoning which makes of hyperons just a new species of baryons, and hence leads to SU3, quarks *etc.*" [71].

The first systematic review of hyperfragments by A. Filipkowski, J. Gierula and P. Zieliński was presented at the Cosmic Ray Conference in Budapest, in September 1956 [72]. A re-analysis of about 120 reported events and careful selection left a "pure sample" of 72 hyperfragments. The authors found the binding energy B_Λ in hypernuclei to increase linearly with A.

In the early years of hypernuclear physics most of the information on hyperfragments has come from studies in nuclear emulsions. Because of the low frequency of hyperfragments (Table III) the scanning for them was long and tedious. Only the double-star events with sufficiently long connecting track could be reliably analysed and eventually identified as hyperfragments. The events with very short connecting track were jocularly designated as GOK's (an acronym for 'God Only Knows') and rejected from further studies. The early experimental papers on hyperfragments have been full of tables and distributions of range, angles, number of prongs, and charge (if it could be estimated). The frequency of mesonic and nonmesonic decays was estimated for light and heavy hyperfragments and compared with theoretical models. Other topics included estimation of lifetime, spin and the binding energy B_Λ which was essential to understand the Λ–N interaction.

The mass of the Λ hyperon is defined as $m_\Lambda c^2 = (m_p + m_{\pi^-})c^2 + Q_\Lambda$ where Q_Λ is the sum of kinetic energies of its decay products, the proton and the negative pion. The binding energy of Λ hyperons in hypernuclei is

TABLE III

Frequency of hyperfragments from the early studies in nuclear emulsions (from [73]).

Frequency of hyperfragments	
Experiment	Hyperfragments/stars
Cosmic rays	$61/119,000 = 5.1 \times 10^{-4}$
3 GeV π^-	$72/80,000 = 9.0 \times 10^{-4}$
3 GeV p	$33/34,480 = 9.1 \times 10^{-4}$
6 GeV p	$7/10,000 = 7.0 \times 10^{-4}$
K^- stars	$46/1001 = 4.6 \times 10^{-2}$

defined as

$$\begin{aligned} B_\Lambda &= (m_\Lambda + M_{\text{core}})c^2 - \sum m_f c^2 + Q \\ &= Q_\Lambda - Q + \left(M_{\text{core}} + m_p + m_{\pi^-} - \sum m_f\right) c^2 , \end{aligned}$$

where M_{core} is the mass of the nuclear core to which Λ hyperon is bound, m_f are the masses of disintegration products, and Q is their total kinetic energy. Thus, a precise value of Q_Λ was required to determine the Λ binding energy in hypernuclei. However, the two early determinations [74,75] of this quantity gave conflicting results: $Q_\Lambda = (36.92 \pm 0.22)$ MeV and $Q_\Lambda = (37.9 \pm 0.4)$ MeV, respectively. In consequence, the initial compilations of B_Λ suffered from considerable statistical and systematic errors. For example, the use of an average value $Q_\Lambda = (37.22 \pm 0.2)$ MeV in [73] led to $\mathrm{B}_\Lambda = (0.2 \pm 0.5)$ MeV for the ${}^3_\Lambda\mathrm{H}$. Therefore, several experimental groups [76–79] undertook very accurate measurements of Q_Λ, which provided consistent results and a new (1961) average value of $Q_\Lambda = (37.60 \pm 0.13)$ MeV. This, in turn, allowed a reliable determination of B_Λ for hypernuclei well identified at that time.

The Λ hyperon produced in a heavy emulsion nucleus may be bound with a large residual part of the target nucleus. In this case the production star and the decay star practically coincided. Such directly undetectable hyperfragments were called cryptofragments. Nevertheless, their frequency and properties could be estimated indirectly.

Ten years after the discovery of the first hyperfragment, the first hypernucleus containing two bound Λ hyperons was found, again in Warsaw, during the work of the Warsaw-Bristol-Bruxelles-CERN-Dublin (Institute of Advanced Studies and University College)-London (University College and

Westfield College) Collaboration [80]. The event had a very complicated topology and was difficult to analyse. It has been finally identified as a hypernucleus of ^{10}Be which disintegrated according to the scheme

$$\begin{array}{l} {}^{10}_{\Lambda\Lambda}\mathrm{Be} \to {}^{9}_{\Lambda}\mathrm{Be} + p \ + \ \pi^- \\ \qquad\qquad \searrow \\ \qquad\qquad\quad p \ + \ {}^{4}\mathrm{He} + {}^{4}\mathrm{He} + \pi^- \end{array}$$

This important discovery provided first information on the hyperon–hyperon interaction, impossible to obtain in other ways.

The first International Conference on Hyperfragments, organized under the auspices of CERN, was held 28–30 March 1963 at St. Cergue, near Geneva. There were 68 participants from 14 countries. All aspects of hypernuclear research have been discussed and summarized in 17 talks, subsequently published in the Proceedings [81]. Thus, ten years after the discovery of the first hypernucleus, hypernuclear physics came of age and became a distinct branch of high energy nuclear physics.

5. Some statistics 1952–1963

The database of papers on hypernuclear physics, compiled by using *Physics Abstracts* and Proceedings of some important conferences, contains 409 papers in the years 1952–1963 (dates of submission, not of publication,

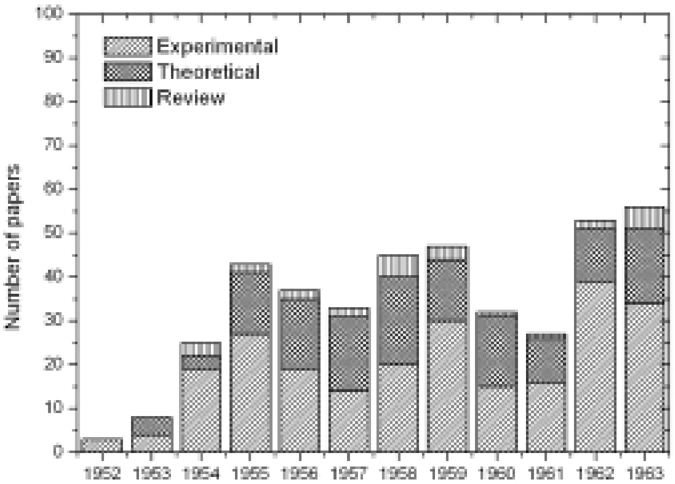

Fig. 4. The number of papers on hypernuclei in the period 1952–1963.

have been used to distribute the papers among subsequent years). There are altogether 504 authors from 23 countries. The sample does not include papers on related subjects (*e.g.* the Q_Λ value, the Λ–N force), which are listed in another database. The selected statistical data are presented in Fig. 5 and Tables IV–VI.

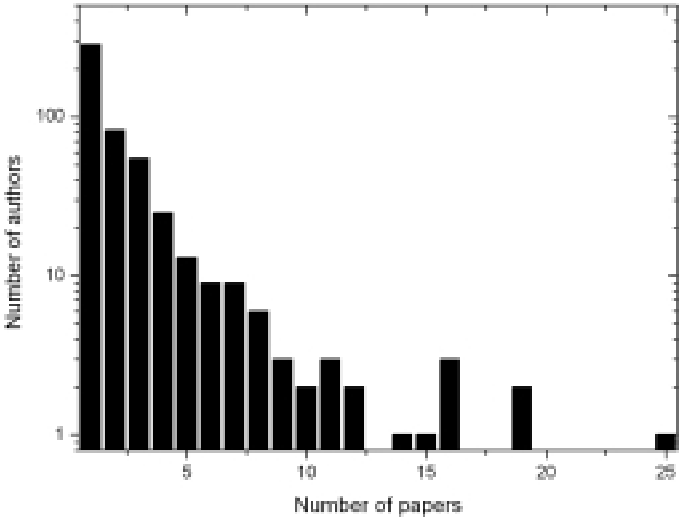

Fig. 5. Distribution of the number of papers on hypernuclei published by different authors in the period 1952–1963.

It follows from Fig. 5 that 369 authors (73.2%) published only 1 or 2 papers, so that their contribution to hypernuclear physics in the considered period was incidental. By selecting only the authors who published 3 or more papers on hypernuclei we obtain a restricted sample (Table V). It appears that in the considered period sizable hypernuclear communities existed only in 5 countries: the United States, the United Kingdom, Italy, Poland, and the Soviet Union.

It is interesting to notice that the largest number of papers was published in the Italian journal *Il Nuovo Cimento* (and its *Supplemento*), which at that time enjoyed a lot of prestige (Table VI).

The list of most prolific authors is headed by R. Levi-Setti (Milano and Chicago) who published 25 papers on hypernuclei during the considered period. The second place on the list is held jointly by theoretician R.H. Dalitz (Oxford and Chicago) and experimentalist D.H. Davis (London and Chicago) who published 19 papers each. Then we find R.G. Ammar (Chicago and Evanston), W.F. Fry (Madison and Padova), and J. Zakrzewski (Bristol and Warsaw) — 16 papers each, O. Skjeggestad (Oslo and Chicago) — 15 papers, and J. Sacton (Bruxelles) — 14 papers.

TABLE IV

Statistics of countries, authors and papers on hypernuclei in the period 1952–1963.

Statistics of papers and authors		
	Papers	Authors
USA	153	166
UK	55	74
ITALY	47	83
USSR	39	52
POLAND	31	15
FRANCE	19	19
BELGIUM	17	8
INDIA	14	16
GERMANY*	13	28
JAPAN	11	18
SWITZERLAND	10	15
NORWAY	8	7
IRELAND	7	13

*including the DDR.

Also 19 papers by 30 authors from Australia, Austria, Canada, Czechoslovakia, Denmark, Israel, Netherlands, Pakistan, Sweden, and Yugoslavia.

TABLE V

Distribution of authors who published 3 or more papers on hypernuclei in the period 1952–1963.

Number of authors with 3 or more papers	
USA	41
UK	23
ITALY	22
POLAND	12
USSR	11
BELGIUM	5
FRANCE	5
IRELAND	5
SWITZERLAND	4
NORWAY	3
INDIA	2
GERMANY	1
JAPAN	1

TABLE VI

Distribution of papers on hypernuclei among the journals in the period 1952–1963.

353 papers published in journals		
Il Nuovo Cimento (and its *Suppl.*)	146	(41.4%)
Physical Review	64	
Zhurnal Eksp. Teor. Fiziki	29	
Physics Letters	21	
Nuclear Physics	17	
Physical Review Letters	14	
Comptes Rendus Acad. (Paris)	9	
Progress in Theoretical Physics	8	
Philosophical Magazine	7	
other 22 journals	38	

6. The renaissance of hypernuclear physics

The study of hypernuclei with the use of nuclear emulsions yielded hundreds of thousands individually analysed hypernuclear events and led to identification of 22 different hypernuclides, from hypertritium to hypernitrogen [82]. Then, the counter technique allowed to expand this list and reach much heavier hypernuclides. The recent list [83] includes 35 hypernuclides known in 2003.

It appears that fifty years after the discovery of hyperfragments, hypernuclear physics has entered its renaissance — a phrase used on the cover of the April 2003 issue of CERN Courier. There is now an extensive hypernuclear physics program in Jülich in Germany (COSY), Newport News in USA (TJNAF), BNL in USA, Dubna in Russia (Nuclotron), KEK in Japan, and Frascati in Italy (FINUDA at DAΦNE) [83, 84].

7. Concluding remarks

Louis Pasteur once said that “In the field of observation, chance only favours those minds which have been prepared” [85]. Cecil Powell stressed the importance of luck as another decisive factor in research. In the after-dinner talk at the St. Cergue Conference he said:

“I am reminded of a famous remark of Napoleon. Whenever he was presented with a young man for military advancement, he invariably asked the question: ‘Is he lucky?’ This was by no means a casual inquiry. The important quality for which he was seeking was — does this man put himself in a situation where he can be lucky? If you fail to put yourself in a situation where it is possible to have good fortune then you cannot have any success; if you do, you may” [86].

Now, the first hyperfragment was found in Warsaw just after the start of scanning of new emulsion plates in a new laboratory of very little experience. It was an incredible piece of luck or a miracle. Then, the first (and only) double hyperfragment was again found in Warsaw (one of the eight collaborating laboratories) — another incredible piece of luck or a miracle.

In my opinion Danysz and Pniewski were both lucky and well prepared. Another of their achievements was the first discussion of hypernuclear isomerism [87]. Still later, when Danysz's health deteriorated and he withdrew from active research, Pniewski pressed on and was instrumental in initiating hypernuclear spectroscopy [88].

The discoverers of hypernuclei were simply brilliant physicists.

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