$$K^- + n \rightarrow \Lambda + \pi^-$$

were such that a Λ hyperon of nearly zero momentum would be formed if the incident K^- were in the momentum range from 300 to 700 MeV/c and if the outgoing π^- were in the forward direction in the lab. A lambda at rest is most likely to replace one of the nucleons without otherwise disturbing the nucleus. Several theorists have been interested in such a reaction and have proposed the existence of strangeness analog states, similar to the nuclear isobaric analog states. The strangeness analog states would be linear combinations of single strangeness exchange resonances that would be described by wave functions that are antisymmetric with respect to the interchange of any neutron and the hyperon.

The production rate for strangeness analog states should be enhanced, some feel, as a consequence of collective coherent effects and would be preferentially excited by reactions induced by K^- in flight. However, other theorists feel that this coherence effect does not exist.

The Torino group studied reactions induced by 390 MeV/c K^- mesons with the π^- detected at a lab angle of less than 10°. Their targets were C^{12}, O^{16} and Al^{27}; the hypernuclear spectrum of the latter two had never before been observed. The target was placed in the middle of a non-focusing, wide-angle double-magnet spectrometer. Trajectories of the incoming K^- and π^- were measured by six pairs of multiwire proportional chambers.

The Heidelberg team worked at a higher K^- momentum—900 MeV/c—and observed hypernuclear states in Be^9, C^{12} and O^{16}. This team consisted of W. Brückner, M. A. Faessler, K. Kilian, U. Lynen, B. Pietrzyk, B. Povh, H. G. Ritter, B. Schürlein, H. Schröder and A. H. Walenta. They too used a double magnetic spectrometer to measure the momenta of the K^- and π^- and ten planes of drift chambers to determine the particle trajectories. This second experiment had an energy resolution of 2 MeV compared to the resolution of 6 MeV for the Torino experiment.

A major problem in both experiments was the large background, primarily from K^- decays and from π^- contamination of the beam. Both groups tried to reduce the background by selecting the $K^-(A,A_\Lambda)\pi^-$ events, using Cerenkov and $\Delta E/\Delta x$ detectors, on the basis of time-of-flight requirements and by making certain cuts on the coordinates of the trajectories. They furthermore studied the background by comparison with the spectrum from K^+ reactions, which do not form hypernuclei.

The Heidelberg trigger was sufficiently clean that their spectra did not require a subtraction of the background.

A question of interpretation

The hypernuclear structure of carbon-12 as measured by both the Torino and Heidelberg groups shows clear structure, but the experimenters differ somewhat on their interpretation of the results. The Torino group sees two peaks, which they interpret to be most probably a ground state and an excited state. They feel that their results, especially the enhancement of the excited state near 10 MeV, are consistent with the predictions of Harry J. Lipkin (Argonne National Laboratory and the Weizmann Institute) and Arthur K. Kerman (MIT), based on the ideas of strangeness analog resonances.[4]

The Heidelberg data, which has higher resolution, shows two peaks that this group interprets as two excited states—one around 11 MeV in which a $p_{3/2}$-state neutron is replaced by a $p_{3/2}$-state lambda and another near 22 MeV in which an $s_{1/2}$ neutron is replaced by a $s_{1/2}$-state lambda. According to the Heidelberg group they do not see the hypernuclear ground state.

No firm conclusions can yet be drawn (see box), but clearly the two experiments have opened a promising source of information on hypernuclear states that should add to our knowledge of nuclear states and of nucleon-hyperon interactions. —BGL

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Fermi Lab produces a 225-GeV electron beam

The Fermi National Accelerator Laboratory has produced a 225-GeV electron beam, a record energy for electrons. According to Thomas Nash, the NAL physicist responsible for the beam's development, beam intensity in the 100–150-GeV range was about 4×10^5 electrons per pulse, in agreement with predicted values for 2×10^{11} protons injected per pulse. Intensity is expected to be over 10^7 electrons per pulse for a full intensity proton beam of over 10^{12} protons per pulse. Of course, intensity at 225 GeV is much lower but is also within the range predicted. The electrons will be used as a source of "tagged" photons, rather than for themselves; NAL already has a muon beam for doing lepton physics, but the ability to produce photons of known energy is unique. Before the NAL beam was produced, the highest energy electron beams were at Serpukhov, USSR (35 GeV) and at the Stanford Linear Accelerator Center (20 GeV).

At NAL, which is primarily a proton accelerator, electron-beam production begins in a 40-cm beryllium target in the Proton Area. Here the neutral pions resulting from proton interaction decay to photons, which are converted to electrons in a lead-sheet radiator about three millimeters (half a radiation length) thick. A 290-meter beam transport system, consisting of 15 major magnets and three additional steering magnets, focusses the beam. In the recent tests that produced the 225-GeV beam, roughly two thirds of the beam was installed, with the last six magnets missing. For 300-GeV incident protons, the resulting beam had about 2×10^{-6} electrons per proton, at an energy of 115 GeV. In these tests, pion contamination (the major concern when using a proton accelerator to produce electrons) was 0.3 percent of the electron intensity, an acceptable value for the kinds of experiments planned. However, a two-stage extension of the electron beam further downstream has been designed by Zaven Guiragossian (Stanford) to improve the electron purity such that there will only be 1 part in 10^6 pion contamination. With a beam of this purity, electron physics can be performed at NAL to complement the existing muon beam for lepton physics, comments Guiragossian.

Working with Nash on the beam tests and installation have been Bradley Cox and Roy Rubinstein of NAL; John Cumalat, Rollin Morrison and Frederick Murphy of the University of California, Santa Barbara and Philip Davis, Roland Egloff, George Luste and James Prentice, of the University of Toronto.

Additional tests of the beam are scheduled for this month, with all magnets in place. During tests scheduled for May, Nash tells us, they expect to get the tagging system working. To produce the tagged photons, a 1% radiator will be installed in the electron-beam path, about 25 meters before the final focus. A lead-glass array, acting as a Cerenkov radiation counter, in combination with three magnets that bend the interacting electron beam, will allow the momentum of the recoiling electrons to be measured, thus "tagging" the energy of the photons. Since any pions present will deposit much less energy than the electrons in the lead-glass array, and the array essentially integrates the total energy deposited, it acts as an additional pion-rejection scheme. The noninteracting electrons proceed forward, bent about 15 cm away from the photon beam, and are "dumped" in tungsten about 15 feet before the target.

Experiments may begin as early as May or June, and the first one scheduled is a study of total photon cross section; this will be a collaborative effort of the NAL, Santa Barbara and Toronto groups. Nash points out to us that the Tagged Photon Laboratory will be a good place to pursue the new physics suggested by the recent particle discoveries at SLAC and at the Brookhaven National Laboratory; the new laboratory, along with an already existing broadband photon beam at NAL and with SLAC, is an ideal place to test whether or not these particles are photoproduced. A predicted charm–anticharm pseudoscalar particle might also be produced, and a higher-mass vector meson, which might decay into a hard-to-detect smear of particles, may be observable only indirectly, through the energy dependence of the photon total cross section. —MSR

Meson factories

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subject to some difficulties caused by the novel design and large size of many of the accelerator components. In the cyclotron, negative hydrogen ions are injected into the center at an energy of 300 keV and are accelerated in 200-keV steps to an energy of 500 MeV at a radius of about 308 inches. To maintain particle–field synchronization, the radiofrequency and magnetic fields must be kept constant to within one part in 10^5.

The unique feature here is sector focusing: The focusing force must be extremely good because the slightest vertical velocity component will drive the ions into the resonators, which are vertically separated by only 3.5 inches of space. Specially shaped sector magnets provide this focusing force; the six component magnets form a spiral-shaped, azimuthally varying field whose precise configuration is one of the most critical conditions for cyclotron operation.

Outside the machine, a thin carbon foil strips two electrons from the ions, and the resulting 500-MeV protons are sent on to the targets. To prevent premature stripping of the ions, the accelerator vacuum must be extremely low, 4×10^{-8} Torr. To limit dissociation-induced losses of H^-, the magnetic field must be kept quite low, below 5700 gauss. Thus the magnet must be very large to accomplish its focusing. Hence the construction problems.

Despite these construction difficulties and inflation-induced staff limitations, a full-energy beam was brought out this past December, at a current of ten nanoamperes. Maximum planned intensity is 100–200 microamps. The duty cycle will be effectively 100%.

Comparison of meson factories

Facility	Range of proton energy (MeV)	Maximum beam intensity (10^{-6} amp) Planned	Reached	Macro duty factor (%)	Polarized beam (10^{-9} amp)	
SIN	590	100	12	100	300	(60%)
TRIUMF	180–520	100–200	0.01	100	60	(85%)
LAMPF	600–800	100–1000	10	6	15	(85%)
Nevis	560	10–40	—	60	None	
Dubna	700	25–50	—	50?	None	
CERN	600	7	0.3	>50	None	

Table adapted from J. Reginald Richardson, as presented at the Laval Conference, August 1974.

Eventually, beams of protons, polarized or unpolarized neutrons, pions and muons will be available in two main experimental areas—proton and meson. One advantage of TRIUMF is that it can provide eventually four simultaneous beams and vary the energy and intensity of each continuously. (Energies at LAMPF are variable too, but, with convenience, only in discrete steps of 10 MeV initially.) The proton hall will provide two beams, one for nuclear structure studies and the other for nucleon–nucleon and nuclear-chemistry research. The meson hall will consist of two meson-producing targets and a total of four experimental channels: high-resolution pions, stopped pions or muons, positive or negative polarized muons and negative pions for medical research.

During the first few months, when the extracted beam intensity will not be more than one microamp, experiments will be limited to those that use low-intensity proton beams. The studies planned for the first year include proton scattering on light nuclei, radiative pion-capture experiments, a study of nucleon–nucleon interactions, a study of pionic and muonic x rays and an investigation of the (p,π^+) reaction with polarized and unpolarized protons. Also planned is a series of experiments that use the polarized muon beam to study the chemistry and physics of condensed matter. In addition, there will be a study of heavy fragments resulting when high-energy protons disintegrate nuclei.

New work at SIN. The second period of experiments has begun at SIN, which extracted its first full-energy proton beam last January and commissioned its first pion beam about a month later. (The first experimental period ended in August, with a three-month shutdown to prepare for higher intensities.) The laboratory director is Jean-Pierre Blaser. At SIN, an injector cyclotron provides 100 microamps of 72-MeV protons to the main ring cyclotron, which continues the acceleration up to 590 MeV. The ring cyclotron receives particles on an internal radius of 2.05 meters and accelerates them by means of four rf cavities to a radius of 4.5 meters. The special feature here is that, because of the injection cyclotron, the ring cyclotron effectively has no central region. High accelerating voltages can therefore be applied in the rf cavities, and the result is considerable separation between turns at extraction energy, and a predicted 95% extraction efficiency. The injector cyclotron is itself a source of ions and polarized proton beams of variable energy for low-energy experiments.

By the end of March the injection beam was furnishing 100 microamps of 72-MeV protons at 50.67 MHz in the injector mode. In April, after beam stability had been proven, it was modified to allow rapid changeover from the 50.67-MHz injector mode to the 4 to 17-MHz variable energy mode. During trial operation, the 590-MeV proton beam intensity was typically 0.1 to 4 microamps. The major source of difficulty was the rf system of the injector; even minor fluctuations in the injector cyclotron affected the extracted beam.

When the experimental areas are completed, the proton beam line will contain two targets: one thin, for high-quality pion beams with good energy resolution, and the other thick, for high-intensity pion, muon and neutron beams. Two separate experimental areas will be reserved for low-energy beams from the injector cyclotron. Two pion beams will be available from the thin target—one beam (πM1) with an advantage in resolution and the other (πM3) with higher energy and intensity. This target will eventually provide a polarized proton beam.

The thick target will provide particles for three additional pion channels, an 8-meter long superconducting muon channel and an unpolarized neutron beam. The pion channels consist of a high-energy, high-intensity beam (πE1), a medical pion beam (πE3) and a low-