search & discovery

The parton: "It works even if you don't believe in it"

A picture of the proton at high energies is emerging from the work of many theorists trying to explain the deep inelastic scattering observed with the SLAC electron linac. These theories visualize the proton as consisting of pointlike constituents with charge less than the electron charge and a spin of 1/2. The deep inelastic scattering, they say, measures the momentum distribution within the proton of these pointlike constituents, be they quarks, partons or "stratons" (a term coined by the Chinese to refer to the stratification of atoms, nuclei and nucleons).

To get a clearer idea of the parton picture, we chatted with Victor Weisskopf (MIT) and Sidney Drell (SLAC), who along with J. D. Bjorken (SLAC) and Richard P. Feynman (Cal Tech) and others have been leading contributors to the development of the concept.

The theorists have been studying inelastic structure functions, which are analogous to the form factors used in elastic scattering. These structure functions are roughly total cross sections for a proton to absorb the virtual photon exchanged by the electron and proton; they depend on the energy transferred to the proton by the electron and on the invariant four-momentum transfer.

For elastic scattering the relation between momentum and energy is fixed because the final state of the proton is just the mass of the proton. For inelastic scattering, however, final hadronic states of any mass can be formed, depending on the particles produced; so energy and momentum transfer are two independent dynamical quantities.

Bjorken argued that the structure functions, instead of depending in an arbitrary way on energy transfer ν, and four-momentum transfer squared q^2, depend only on the ratio of those two quantities ν/q^2, when both of them become large, namely in the deep inelastic-scattering region. This scaling concept was put forth even before the SLAC data were analyzed.

Independently Feynman said we can think of the proton sitting still in the laboratory as made of certain constituents tightly bound inside the proton, and these constituents might look very different if we take their snapshot in the bound state than they do as debris that emerges from nuclear reactions in the free final states. For example, on the nuclear scale a neutron inside a deuteron is stable, but when it emerges it lives only a short time. Thus strong binding affects the appearance of constituents.

If instead, we observe the proton from a very rapidly moving frame (say a trolley car) then time dilation makes whatever is living inside the proton last a long time. If we then do deep inelastic scattering, the conditions of the impulse approximation are satisfied. As in nuclear physics, if we give

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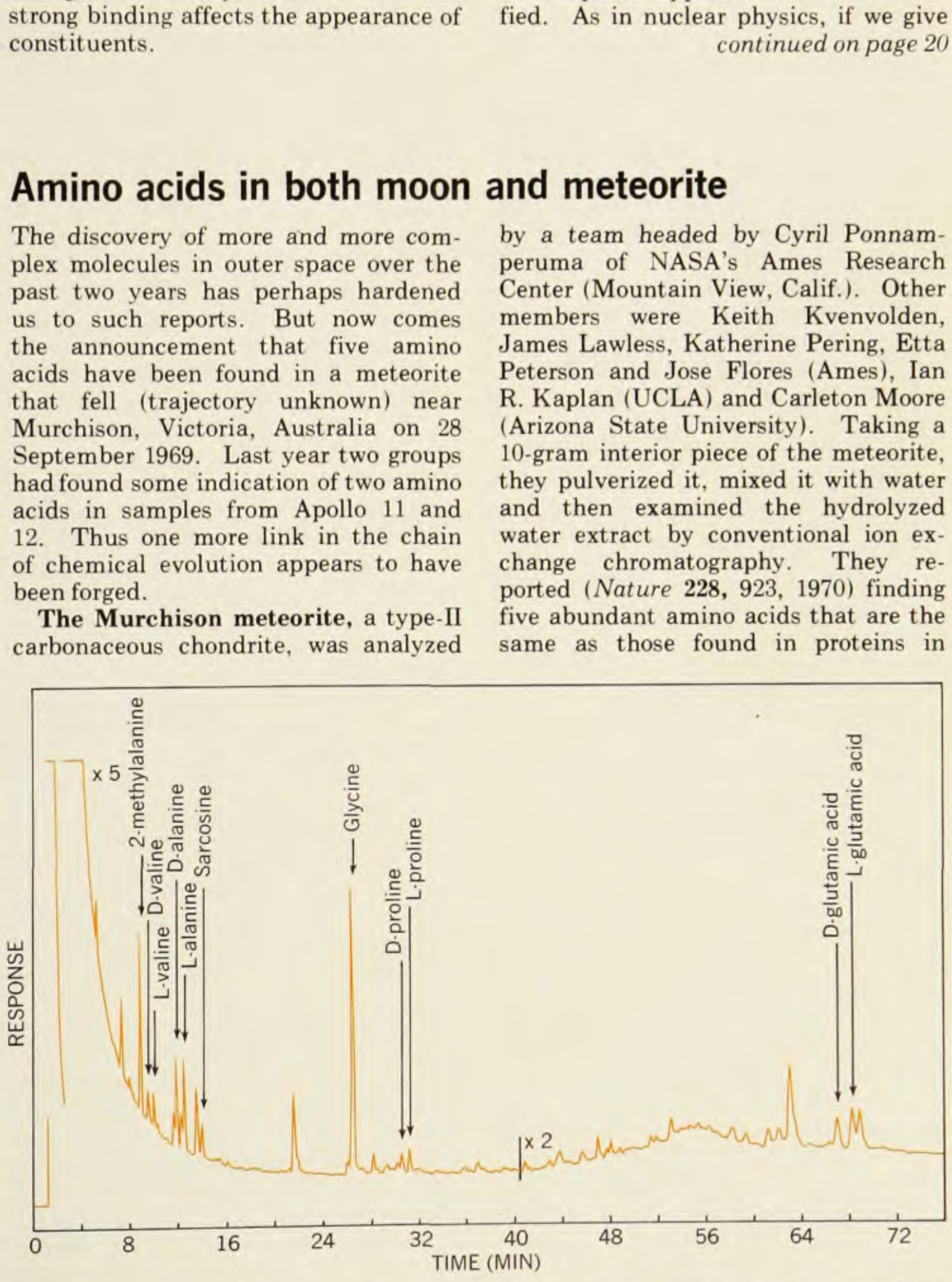
Amino acids in both moon and meteorite

The discovery of more and more complex molecules in outer space over the past two years has perhaps hardened us to such reports. But now comes the announcement that five amino acids have been found in a meteorite that fell (trajectory unknown) near Murchison, Victoria, Australia on 28 September 1969. Last year two groups had found some indication of two amino acids in samples from Apollo 11 and 12. Thus one more link in the chain of chemical evolution appears to have been forged.

The Murchison meteorite, a type-II carbonaceous chondrite, was analyzed by a team headed by Cyril Ponnamperuma of NASA's Ames Research Center (Mountain View, Calif.). Other members were Keith Kvenvolden, James Lawless, Katherine Pering, Etta Peterson and Jose Flores (Ames), Ian R. Kaplan (UCLA) and Carleton Moore (Arizona State University). Taking a 10-gram interior piece of the meteorite, they pulverized it, mixed it with water and then examined the hydrolyzed water extract by conventional ion exchange chromatography. They reported (*Nature* **228,** 923, 1970) finding five abundant amino acids that are the same as those found in proteins in



Gas chromatogram of hydrolized water extract from Murchison meteorite shows left-handed (L) and right-handed (D) forms of four amino acids are present in roughly equal quantities. Ponnamperuma and his colleagues say that the even distribution supports the idea that the amino acids are not recent biological contaminants.

muons from either forward or backward decays. Purity of the muon beam is expected to be better than about 90%, with contamination from pions (5%), protons (1%) and electrons (1%). Muon polarization will be 0.4–0.7 for backward decays and up to 0.9 for forward decays, which are, however, harder to separate cleanly.

The pion and particle-physics channel will have positive and negative pions at high energy (100–600 MeV) and high intensity (up to 10^{10} per sec).

Nucleon physics. High-quality nucleon beams at 300–800 MeV—two neutron beams and one low-intensity proton beam (about 50 nanoamp)—are planned for area B. Neutrons will be generated in a liquid-deuterium target, scattering in the forward direction with the proton energy and intensities greater than 10^7 cm^{-2} sec^{-1}. This area will be used mainly for medium-energy nucleon–nucleon research (see the article by Michael J. Moravcsik, PHYSICS TODAY, October, page 40). A polarized proton beam (polarization approximately 0.9) is planned for later.

High-resolution proton spectroscopy. The spectrometer is already under construction in area C. It will have resolution up to 30 keV for 800-MeV protons, angular resolution of 0.8 milliradians, counting rate of 10 counts per second for a 1 microbarn/sr cross section. Users will be offered the complete set-up including a high-resolution detection system and on-line computer analysis.

Other areas to be developed at LAMPF are those for nuclear chemistry, for which several irradiation stations are planned, and for the biomedical uses of pions in radiobiology and therapy.

Users group. More than 250 prospective users of the LAMPF meson factory met at the site last October. They constitute less than half of the total number of prospective users, who represent 159 institutions between them. Chairman of the users group for 1971 is Gerald C. Phillips, of Rice University; Lewis Agnew of Los Alamos Scientific Laboratory is liaison officer.

Rosen told the assembled users that LAMPF policy will be to make the facility available to all qualified research teams. He praised the prospective users for the help they have already given in the design of equipment, and hoped they would continue to supply guidance in setting specifications. —JTS

Partons

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the constituents a very sharp, swift jab and do the kinematics in the right way, we can think of the neutrons and protons as being instantaneously free during the moment that they are being hit. We think of finding an insolated proton inside the nucleus and kicking it out.

Applying the same impulse-approximation arguments to electron–proton scattering, we think of doing elastic scattering from one of the constituents of the proton. Deep inelastic scattering when viewed from the trolley car satisfies this condition of the impulse approximation. That is, of taking an instantaneous snapshot of its constituents. Then scaling is observed.

The ratio of the momentum and energy transfer is fixed by the elastic condition, and the structure functions are measuring the momentum distribution within the proton of the constituents of the proton. Viewed from the trolley car the protons have large momentum, and we measure how the momentum along one direction is shared by the constituents; the structure functions measure the probability of finding the constituents with different fractions of the momentum.

What are the constituents like? It is generally agreed that they have spin 1/2 because the cross section for scattering transverse photons is much bigger than the longitudinal cross section for deep inelastic scattering. It is observed that the scattering is proportional to the squares of the charges, and it looks as if the charges come out with a value considerably less than the electronic charge.

Weisskopf thinks of fast-moving protons as consisting of a probability distribution of *n* partons, where *n* is greater than or equal to three. We can learn the relative momentum of those partons, whether they have 1/2 the momentum, or 1/3, or 1/4, and so on. Then, for example, if the object doing the scattering has 1/3 the momentum of the proton, then the proton would consist of four such partons. "This all sounds like quarks," Weisskopf remarks. "The proton may consist of three quarks, and with a certain probability distribution it consists of five quarks or seven quarks. It may be three quarks and then in addition a quark–antiquark pair or two quark–antiquark pairs." One could imagine something like a sea of quark–antiquark pairs floating around in an undefined quantity.

The original SLAC measurements reported by Richard Taylor and his collaborators were for protons. At the "Rochester" conference held in Kiev in September the group reported measurements on neutrons, which showed that the scattering is lower for neutrons. On the basis of a simple quark picture the structure functions for both neutrons and protons are too low. On the other hand, the ratio of neutron scattering to proton scattering predicted by the simple picture is 3/2, agreeing roughly with experiment. (The neutron would have one quark of charge 2/3 and two with charge-1/3. The proton would consist of two quarks with charge 2/3 and one with 1/3. The ratio of the sum of the squares is 3/2.) As the number of partons increases beyond three the ratio of neutrons to protons approaches one. Thus the neutron and proton difference would become less significant as the number of quark–antiquark pairs is increased.

In a more complicated quark model, one can assume configuration mixing of higher quark states (5, 7, 9, 11) and a neutral "gluon" sea (particles that use up excess proton momentum and don't contribute to electrical properties) to make the value of the structure functions as small as the SLAC experimenters observe.

Drell and his collaborators (T. M. Yan, now of Cornell, and Donald Levy, now at Berkeley) have shown how to apply the conditions for the impulse limit in a canonical, relativistic field-theory formulation and derived scaling behavior. They were then able to predict for colliding-beam experiments that the annihilation cross section has the same energy dependence as if the annihilation was to pointlike particles, in agreement with a scaling prediction. He explained that you think of the proton as a series of point partons.

When you annihilate, you make them in pairs, which then decay into physical pions and nucleons. Similarly, when you scatter, you scatter from the partons, which are simply the bare or free pointlike constituents that appear in the perturbation expansion of a physical proton.

It's all a question of scale, Drell went on. When we do elastic scattering from an atom, we see a charge distribution, but when we do hard scattering from the atom, we see scattering from point constituents—the electrons or the nucleus. Similarly when we do hard scattering from a nucleus, the proton and the neutron look like points. When we look at the proton and do elastic scattering we see an extended charge-current distribution and observe that the proton behaves like a bowl of jelly. But when we do deep inelastic scattering, we see point constituents inside the jelly. So the proton looks less like jelly and more like raspberry jam—with seeds.

Weisskopf, who has always been skeptical about quarks, still is dubious. However, he tells the story of Niels Bohr, who visited a friend's house, noticed a horseshoe over the door and asked what it meant. His friend told him, "That brings luck."

Bohr said, "Do you really believe in this?" His friend said, "Oh, I don't believe in it. But I am told it works even if you don't believe in it." —GBL□