Physics Made Simple

Particle physicists have long had faith that when experiments got to really high energies, physics would get much simpler. A number of recent experiments, done at the Fermi National Accelerator Laboratory in Batavia, Ill., and reported last week at the XVII International Conference on High Energy Physics in London, seem to bear out that expectation though they do it in ways that are not exactly compatible with the theories that have had the most respect in recent years. One experiment, done by a group of physicists from FNAL, Brookhaven National Laboratory and Rockefeller University, concerned the total cross sections in the bombardment of protons and neutrons with six kinds of particles at energies up to 200 billion electron-volts (GeV). Three experiments by three groups (FNAL-Columbia, Chicago-Princeton, Harvard-Wisconsin-Pennsylvania) working independently have recorded the direct production of muons and electrons in collisions of 300-GeV protons with atomic nuclei at rates at which such things were not supposed to happen.

The total cross section is the probability that anything at all will happen as the projectile impinges on the target. Cross sections are quoted as areas: Strike within the area and something will happen, maybe the deflection of the projectile particle from its previous path, maybe the creation of new particles out of its energy. At low energies total cross sections tend to decrease as the energy of the projectile particle goes up. Physicists had expected that at higher energies the decrease would gradually stop, and the cross section would reach a constant value, representative more or less of the geometric size of the particle. (The reason why the cross sections are larger at the lowest energies has to do with the wave nature of matter.)

The first shock to this expectation came out of an experiment done at the CERN laboratory in Geneva something over a year ago (SN: 5/14/73, p. 242). This concerned collisions of protons against protons, and it showed that, instead of coming to a constant value, the proton-proton total cross section began to grow as the energy went up. The present experiment confirms the CERN result for proton-proton collisions up to 200 billion electron-volts, and shows that for four other kinds of projectiles, pi mesons with negative and positive electric charge and K mesons with positive and negative charge, the total cross sections show similar rises with energy. The one maverick so far is the antiproton: The cross section for it ceased to fall and became constant between 150 and 200 GeV. There is reason to hope, however, that at still higher energies the proton-antiproton cross section will start to increase too. The cross sections for proton and neutron are nearly equal to each other for each of the probes.

A major conclusion from the results is that the behavior of particles with quite different properties becomes very similar at very high energies. The evidence tends to indicate that the phenomenon of rising cross sections is general and systematic throughout the domain of the hadrons, the class of particles that respond to the strong interaction, the force that holds atomic nuclei together.

The results also show that at ultrahigh energies the operation of the strong interaction is independent of electric charge, just as it is at low energies: The cross section of a pi meson with negative charge on a proton is equal to that of a positive pi meson on a neutron.

Furthermore the results show that cross section of a given particle with proton and that particle's antiparticle with proton, very different at low energies, tend to approach each other as the energy goes up. The difference declines approximately in inverse proportion to the square root of the energy. The theorem that particle and antiparticle cross sections approach each other at high energies was enunciated by the Soviet theorist Isaak Ya. Pomeranchuk in 1958. It is based on important considerations involving the symmetry of matter and antimatter, and its overthrow would be a severe disturbance to theorists.

Although the rising cross sections confound the general expectation, there are theoretical models around that predict such effects. Maybe now they will be getting a closer look.

As we said above, hadron is the general term for particles that respond to the forces of the strong interaction. Those that do not so respond are called leptons. So fundamental does this distinction seem that physicists tend to divide the subatomic world according to it. Some speak of "hadronic matter" and "leptonic matter" as if they were metaphysically two different entities.

What three FNAL experiments have seen is leptons, that is, electrons and muons, being produced directly in collisions of hadron against hadron. The converse, the direct production of hadrons in collisions between two leptons was observed in December 1973 at the Stanford Linear Accelerator. Taken together these experiments seem to blur the distinction between the two classes of particle.

There are two other kinds of force operating in the subatomic domain to which both hadrons and leptons are responsive: electromagnetism and the so-called weak interaction, a force which governs certain kinds of radioactive decay. It is a little difficult to tell how hadrons relate to the weak interaction since in most collisions the effects of the strong and/or electromagnetic interaction will swamp the effects of the weak interaction. The strong interaction is about 10 million times as strong as the weak; the electromagnetic is about one million times as strong as the weak.

It would seem at first blush that if any force makes leptons out of hadrons or hadrons out of leptons, it would be the electromagnetic since that is the strongest force that links the two classes. But the FNAL results don't seem to be coming out that way. With 300-GeV protons probing deeply into the atomic nuclei in metal targets, leptons come out about ten times as often as they should if the electromagnetic interaction was making them. This can mean that, as energy rises, the leptons become subject to the strong interaction, or it can mean that, as energy rises, the weak interaction becomes stronger until the distinction between it and the strong interaction begins to fade. Either would be a great simplification.

Theorists are already at work on models that unite hadrons and leptons. For some time, some theorists have been working on unified field theories that would unite two or all three of the subatomic forces and show them to be aspects of one thing. Perhaps physicists may be nearing the goal desired by many of them, a theory that explains particle physics on the basis of one force and one kind of matter. □