go weak interactions, as the process is usually described. They constitute another field of inquiry in which physicists can hope to find answers to their questions.

High energy physics in recent decades has been concerned with identifying the particles created in collisions, defining their characteristics such as mass, charge, and spin, and trying to find rules which will predict how they will be created and destroyed, and how they act during their short lifetimes. Theorists have managed to group particles with similar intrinsic properties into groups of eight or 10, called symmetries. But the number of particles—upward of 200—and the complications involved make the explanations unsatisfactory to physicists who believe that simple explanations must exist.

One simple theory is that all the particles discovered are made up of even more basic particles, called quarks, a name assigned by Dr. Gell-Mann. By assuming three kinds of quarks, with charges of one-third or two-thirds the unit charge, along with three "antiquarks" with opposite charges, all the known particles and their properties could be explained by supposing that they were composed of either two or three quarks and antiquarks.

This attractively simple idea has been stymied by the fact that no quarks have ever been detected. There is an additional problem that no particle has ever been found to have a charge less than the electron's—which a quark must have. But since physicists don't know why charge always comes in unit size, it would not upset them to find that it didn't.

Physicists say that if quarks do exist, they will have a very large mass. Present estimates range between five and 10 Bev, three to six million times the mass of a proton.

The argument goes like this: a proton is supposedly made up of three quarks. Since the proton has much less mass, the excess mass of the quarks when they combine must go into energy which holds the proton together. It would take an equivalent amount of energy at the center of the proton to break it into quarks again.

The world's largest accelerator, the 33 Bev AGS at Brookhaven, can put eight Bev energy at the center of a proton: less than three Bev per quark. Since no quarks have been detected in such experiments at Brookhaven, quarks must have at least 2.67 Bev mass, and a beam stronger than Brookhaven's would be necessary to spring them loose.

Other experiments have been carried out using cosmic rays, another source of high energy particles. If quarks are created in outer space, they should be detectable on earth at a certain rate, depending on how hard they are to create, which again depends on how much mass they have.

A recent experiment by Dr. George Zweig and other scientists at the California Institute of Technology tried to detect quarks with very sensitive spark chamber equipment. Out of 150 million cosmic ray particles detected, not one was a quark. As a result of this and other experiments both here and abroad, the probable mass of the quark, if it exists, was pushed up to between five and 10 Bev.

The search for quarks in accelerators, where experimental conditions are much easier to control, will have to wait for higher energies—one of the major reasons physicists are interested in planned 200 and 300 Bev machines.

Another reason is that nuclear forces are explained by the meson-exchange theory at energies now available, but that theory also predicts certain results at higher energies. If these predictions are supported by experiment, it will reinforce the theory; if something unexpected happens, then the theory would again have to be revised.

A third intriguing prospect is the study of the elusive neutrinos and antineutrinos—having no mass and no charge—which result from weak interactions and can be found more readily at the higher energies.

All these experiments will be interesting. But "the most interesting will be the ones we can't think of now," says Dr. Charles A. Snow of the University of Maryland. "It's always that way." ◈

FROM SCANDINAVIA

The hope for small nations—

Nordic physicists see regional cooperation as their only hope as costs spiral and backwaters become permanent.

A decade ago Swedish high energy physicists planned a 1.2 Bev electron synchrotron at Lund University. National aspirations were still alive. This accelerator, had it been completed on time, would have led the world.

Today the Swedish high energy physicists and their colleagues in the other Nordic countries have no illusions. The Lund accelerator, dogged by administrative and development delays, has long ago been outclassed elsewhere. Its future, probably, is as a useful piece of training equipment.

The future of experimental work lies in international cooperation, both in Europe and within Scandinavia. "We have been able to work on a university scale up to now," says Prof. J. K. Bøggild of the Niels Bohr Institute in Copenhagen, "but it is a necessity to work together now."

For the experimentalists this is a simple matter of survival. For the theorists it is slightly less crucial—wherever two or three physicists are gathered together there is the possibility of the fruitful fusion of ideas—but in the small Nordic countries (Sweden, population 7.6 million, is the biggest) a flourishing person-to-person international exchange of ideas is more and more being seen as a condition of producing top class work.

International cooperation as such is nothing new, of course. The Bohr Institute has always been dedicated to facilitating research across national frontiers and there are today scientists from Red China working in the same building in Copenhagen with researchers from the United States. But at the moment high energy physics in Scandinavia is going through a period of adjustment to a more intense kind of cooperation. Bohr's moral idealism has been supplemented by practical necessity, but cooperation comes hard.

For experimentalists, especially, things are uncertain. The prospects are inviting. Like their colleagues in the rest of Europe they are dreaming of getting to work with the CERN storage rings and the projected 300 Bev accelerator. Meanwhile they are groping their way forward to more efficient cooperation among themselves, and the path is not always straightforward.

At the Bohr Institute work proceeds on the analysis of bubble chamber pictures. The pictures were taken at CERN in Geneva as part of a joint Nordic experiment involving 30 scientists. Part of the significance of working together can be judged from the fact that this was the first time that the

Danes in the research team had worked on bubble chamber analysis, except in training experiments.

It takes up to half an hour to analyze each picture, and one experiment produces many thousands of pictures. To cut out much of the laborious manual analysis there are well advanced plans for a Nordic center for automatic picture analysis, but the Norwegians plan instead to go ahead with their own unit, the Finns appear negative, and it looks as if the $350,000 involved will end being split two ways instead of four—to no one's benefit.

Other Nordic projects have gone the same way in the past. Five years ago there were plans for a Nordic 10 Bev accelerator, but they fell through when the physicists failed to agree among themselves.

The future, however, is creating new reasons to cooperate. As one Swedish physicist says, the Scandinavians must cooperate among themselves if they are to utilize the CERN equipment effectively. None of the Scandinavian countries provides more than 4 percent of the CERN budget or research manpower.

"The cream of the experiments go to the scientists at CERN," says the Swede. "The Scandinavians need to work together to mount really interesting experiments and get them accepted."

Meanwhile, besides the accelerator equipment to which they have access, the Scandinavians are working with cosmic rays. In the high energy field a useful experiment was completed recently by Jorgen Damgaard of Denmark, and Norwegian colleagues. The experiment was carried out underground at Bergen. No quarks were found, but the experimenters were able to conclude that there must be a fairly high lower limit for the mass of a quark, if such exist. A paper on this experiment will be published shortly.

On the theoretical front there is greater optimism and much activity, a good deal of it designed to keep international lines of communication open. Nearly all Scandinavian physicists spend some time working abroad, mostly in the United States. Equally important is to get foreign scientists to visit Scandinavia.

An important initiative to this end was carried out by the Niels Bohr Institute's high energy group this summer. The group has had difficulty in establishing itself in the wake of the nuclear tradition left by Bohr, but the group asserted itself by organizing a Summer Institute lasting two months from late June to early August.

The group attracted 16 lecturers plus 35 participants. If judged a success the Danes hope the Summer Institute, which had strong contingents from Princeton and Israel, can become annual.

The center of high energy work in Scandinavia lies in Sweden, where there are three strong groups, at Gothenburg, at Lund and in Stockholm. There are also well established groups in each of the other three countries.

Whether or not they produce any really seminal work is, domestically, not of the first importance. The point is that all the main Scandinavian groups are big enough to produce first class work, given native ability, while at the same time they ensure that Scandinavia is fully conversant with the most advanced theoretical work, in itself a victory for the physicists. *H. J. Barnes*

FROM BRITAIN

Alone or together

Pending the decision on how closely to tie to the 300 Bev, scientists proceed with development of a national program

In June, Britain opened her second big laboratory for nuclear research, the Daresbury Nuclear Physics Laboratory. It seconds the Rutherford Laboratory at Chilton in Berkshire which has been a mecca for physicists for decades.

The accelerator at Daresbury is known as NINA, National Institute Northern Accelerator. It was built in record time by Prof. Alec Merrison and his colleagues. NINA, an electron accelerator, is petite in comparison with other atom smashers. It is a mere 70 meters in diameter, having magnets totaling only 500 tons, compared with 7,000 tons for the 7 Bev proton NIMROD, and 27,000 tons for the proposed 300 Bev.

NINA, however, packs a powerful punch: a high density electron beam of four Bev with which to probe the structure of the nucleus.

One experiment planned for NINA is to accelerate positrons, the anti-particles of electrons, to see whether the same physical laws obtain in the looking glass world—appropriate enough for scientists working at the birthplace of Lewis Carroll.

There is hope of using NINA's powerful electron beam as the input for a far more powerful machine, of 15 Bev, that would encircle the present one. But this is a project that must await Britain's final decision whether or not to participate in the big machine, Europe's proposed 300 Bev proton synchrotron.

Much nearer fruition at Daresbury is a scheme to put NINA on-line with its big computer.

Meanwhile, among the work in hand at Daresbury are studies, by the laboratory's own staff, of electromagnetic interactions over very small distances, among a class of particles known as leptons.

In addition, a number of nearby universities have experiments running. Liverpool scientists are investigating the photoproduction of zero-charged pi and eta mesons. A Manchester team is measuring the cross-section for photoproduction of kaons from photons in a liquid hydrogen target. And the Glasgow group is measuring the polarization of protons in elastic electron-proton scattering.

Although Europe's sights are set on the proposed 300 Bev machine, the site for which is expected to be chosen finally by the CERN Council early next year, there is no lack of activity this side of the Atlantic. CERN already has well in hand two major pieces of technology. One is a large hydrogen bubble chamber, being developed by groups from Geneva, Heidelberg and Saclay. The other is the construction of intersecting storage rings, two huge magnet rings that will allow beams of protons to meet head on.

Nevertheless, British and European physicists make no secret of their belief that the future of high energy physics in Europe depends upon their building the big machine. This, according to the CERN Study Group, will take six years to construct (SN: 7/8) and, says Prof. Eduardo Amaldi, chairman of the European Committee for Future Accelerators, if authorized next year "would be in a condition to start producing physics in 1977." It would then need a staff of around 2,500, including 200 experimental physicists.

But physicists still see importance in national support in the shape of smaller or more specialized machines; in other words, a club that would constantly interchange staff and techniques with CERN. The club will probably include a 45 Bev proton machine, most likely in France, in addition to the two accelerators in Britain, the 7 Bev electron machine in Hamburg and another in Bonn, and a meson factory that Switzerland is to build. *David Fishlock*