WHAT ACCELERATORS FOR FUTURE NUCLEAR AND MESON PHYSICS?

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Having heard so much about the remarkable performance of present cyclotrons and advanced new projects, let us examine the possible trends of future development and the role cyclotrons may play among other accelerator types. We will limit ourselves to an energy range of, say, below a few GeV, above which cyclotrons are unlikely to play any role, even as injectors.

Before looking ahead, let us look back at the impact cyclotrons have had on nuclear science in the past. Though many "firsts", like the α-particle induced nuclear reaction of Rutherford in 1919 or the discovery of the mesons in the thirties, used nature's accelerators radioactivity and cosmic rays, almost our whole knowledge of the nuclear world -- still modest in its scope-- comes from accelerators. Among these the cyclotron has, for three decades, played a dominant role, rapidly leaving behind in energy the static accelerators. After the first fully man-made nuclear reactions in 1931, two big steps led forward to the region of relativistic particle energies, at first thought to be inaccessible by principle to the cyclotron: Phase stability in the synchrocyclotron permitted energies of several hundred MeV culminating in the first pion produced by man in 1948 in Berkeley. Before being definitively left behind in energy by the synchrotron, this type of machine indeed helped to establish the foundations of modern particle physics.

Then the key to high beam intensities was found in the isochronous, sector focussed cyclotron. This type of machine now dominates the field of accelerators in the range from 10 MeV to 1 GeV. Let us see what this remarkably versatile machine does for research and what further developments could be achieved. At the lowest energy range we have the "compact cyclotron", mainly aiming at flexible production of isotopes for medical application. The particular need of a very economical source for quasi-industrial production of isotopes, however, would call for energies of at least 50 MeV at high intensities (above 100 to 200 μA). Then we have the isochronous cyclotrons in the range of 50 to 100 MeV or more, devoted to research in nuclear structure physics mainly. Here the need is to develop further these machines towards flexibility of operation and accelerating many types of particles including especially medium heavy ions. To continue the work of static accelerators towards higher energies, energy resolution and stability must further be improved. Due to the inherent spread in beam momentum, elaborate external spectrometers are necessary, requiring both better beam stability and higher primary beam currents. This again can only be achieved without trouble if the rate of extraction of the beams can be further increased to limit the problems due to radioactivity. A further mode of operation increasingly important for research is the production of polarized beams of protons and deuterons. Here much can still be done to achieve higher intensities to allow routine experimental techniques and higher stability as is necessary for crucial experiments like, possibly, parity violating processes.

A new field of application of the isochronous cyclotron which is really booming, as this conference has shown, is the exciting domain of heavy ions. Here the cyclotron is not only in competition with the linear accelerator, it often can be combined with other types of accelerators, like electrostatic ones, in two or more stage machines. Here the cyclotron can bring in its unique advantages of compactness and economy, making use also of the new superconductivity techniques.

In meson physics at medium energies, high intensity accelerators have opened a wide field of research and applications. What are the requirements accelerators have to fulfill? In nuclear structure physics with mesons, elaborate pion spectrometers are needed and intensities should be further increased in the future to allow, for example, two-leg coincidence work. In nucleon physics the emphasis is on easily variable energy and polarized beams. Also in this field large analyzing spectrometers or time of flight beams of neutrons are very useful. Unfortunately multi-particle operation at these energies does not seem to be reconcilable with high intensities. In the main part of medium energy physics, pions and muons are required in beams of ever increasing intensity and quality. For the latter, freedom of contamination and background, and especially a high duty cycle are important. This is particularly the case for a whole class of possible rare events which have recently received a large attention in relation to the new gauge theories. Very elaborate spectrometers and particle detectors of large size and solid angle are also required for such experiments.

The high intensity meson beams becoming available have made the systematic use of higher precision crystal spectrometry of mesonic atoms (both π and μ) possible. The new technique of proton targets directly used as source of pionic X-rays is worth mentioning.

The rapidly expanding and very interesting field using muons as tools in solid state physics and chemistry calls for the development of special techniques for producing intense stopped muon beams, like superconducting channels and high aperture surface muon channels.

Among the application of mesons produced by medium energy accelerators, the use of negative pions in cancer radiotherapy has received great attention and shows promise. Either very high proton intensities or elaborate superconducting multichannel applicators are required. For medical use a high availability of the beams is a condition which is quite difficult to be met by accelerators. Also, a complete decoupling of a medical program from the physics research is desirable.

How do the accelerators now in operation in medium energy range compare in meeting these specifications? The modified synchrocyclotron, in the low range of intensity, has the possibility of accelerating other particles than protons, e.g., ^{3}He. The linac at present holds the record for high intensities and its low duty cycle can be very desirable in neutrino experiments or pulsed neutron sources (see below). The negative hydrogen ion cyclotron has its advantage in true variable energy and multiple nucleon beams. The isochronous ring cyclotron for protons has, since complete beam extraction has been realized, probably the best potential for extension into the range of several milliamperes while keeping the advantages of high duty cycle, compactness and low operating power.

What seems to be desirable as improved or new research tools and what are the technical possibilities

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for the next decade? Besides the necessary improvements discussed above, a considerable interest exists in higher energy accelerators in order to make a "kaon factory" available. Negative kaons in mesonic atoms would be excellent probes for nuclear properties whereas positive ones would give new information on hadron-nucleus interaction. Kaons would therefore be of considerable interest if available in intense beams of preferably high duty cycle. Though some 2 to 3 GeV suffice to produce kaons, the production cross section and the relativistic kinematics lead to much higher proton energies as optimum. It seems unlikely that truly continuous accelerators could be economically pushed close to 10 GeV. Medium energy accelerators could, on the other hand, be the injectors into a cycling, higher energy stage.

Another field where higher intensity medium energy accelerators are very likely to play an important role is spallation neutron sources. Indeed, they may represent the generation following high flux research reactors. With their low energy production per neutron, independence from fissile material and much simpler safety problems, spallation sources should be an ideal tool of great flexibility for research with neutrons in solid state physics and biology. With pulsed accelerators like linacs or synchrotrons, extremely high instantaneous thermal fluxes will be produced and epithermal neutrons newly made available. On the other hand, continous machines like a ring cyclotron or a c.w. linac would provide the best cold neutron beams in addition to thermals. To equal present high flux reactors, proton currents in the few milliampere range are necessary. For an unchallenged new generation of neutron sources, currents in the tens of mA will be required. At this level one also reaches fields which may be of highest practical interest for the future of energy technology: electrical breeding of fissile material, transmutation of nuclear wastes by nuclear reactions as well as materials testing for fusion reactors. In speculations about what accelerators could possibly produce such an intensity, one most important new boundary condition turns up, however: that of producing beam energy as cheaply as possible in capital cost as well as in mains power. In view of this condition, even cyclotrons may be a competitor to the first-sight choice of the continuous linac.

Summing up, we find that the role of accelerators, and cyclotrons in particular, in nuclear and meson physics, as well as their applications in other branches of science and medicine, will remain an important one for many years. It will call for ingenuity and use of new technologies on the side of the machine builders. If accelerators enter directly or as auxiliary devices into energy technology, an enormous development will set in and no doubt will give us a number of exciting cyclotron conferences in the future.

** DISCUSSION **

Y. JONGEN: Why are such high proton energies required for the neutron source?

J. BLASER: The yield of spallation neutrons per kW of beam power increases with energy up to 800 MeV approximately. Below 300 MeV it would be too low. In making a comparison with reactors, the energy dissipated in the target is less at higher energies, about 40 MeV per neutron in a spallation source versus 200 MeV for a fission source.

S. OH: A 50 mA proton beam at 600 MeV onto the neutron generator generates 30 MW of heat. Isn't cooling a problem if you keep the size as small as you indicated?

J. BLASER: The cooling problem is, of course, very serious, but it is in a sense simpler than with a reactor because you don't have the same safety problems. For our spallation source, we plan to start operation in 1983 with beam power of something like 2 MW. We expect to use a circulating liquid lead target, which allows us to keep the beam rather concentrated. It is a serious engineering problem, but it doesn't seem to be insoluble.