RESEARCH WITH HIGH ENERGY ACCELERATORS

by

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I. Introduction

High energy accelerator research is primarily concerned with the study of elementary particles and should consequently be considered from the viewpoint of the requirements of the latter.

The first things to learn about an "elementary particle" are probably that it exists, its charge, mass and decay scheme. Next one can ask if the particle in question interacts strongly with other particles. This basic information can very likely be obtained with least expense from cosmic ray sources. However, the major problems have only begun at this point. We have detailed, quantitative knowledge about only one type of force between elementary particles--the electromagnetic interaction. Almost nothing is known about other elementary particle interactions. It is strongly felt, for instance, that π-mesons are involved in many of the most obvious properties of nuclear forces, but it seems equally likely that some other mesons may also play a role in these. Furthermore, as yet unknown interactions between various types of mesons and neutrons and protons may very well play a part in nuclear binding and structure.

The answers to such questions as these are likely to involve long series of detailed and accurate experimental measurements. These, in all probability, must be done with accelerators. We cannot hope to list in any detail the experiments which could be expected to lead to answers to the above questions. We can, however, suggest the direction which such research has taken. To this we append the remark that each year since

the first artificial π-mesons were produced has seen an increase rather than a decrease in the interesting experiments to be done.

II. Proton Accelerators

The research which can be carried out with artificially accelerated particles changes markedly as the energy available increases. (See Appendix I). In the low energy region of "classical" nuclear physics (energies less than 20 Mev) the central problems are those of nuclear structure and nuclear forces. This energy region is particularly well adapted to the study of nuclear structure. At higher energies (20-200 Mev), it is already less feasible to carry out readily interpretable experiments with complex nuclei and the principal problems of interest are those of the interactions of the fundamental particles, i.e., the nucleon-nucleon scattering. This has in fact been by far the predominant field of experimental research in this energy range.

The situation changes markedly as the threshold for π-mesons production is reached. (290 Mev for nucleon-nucleon collision). At this energy the probing of the details of nuclear structure is a relatively unimportant aspect of the possible research problems and the concentration shifts to the study of the π-meson itself together with the nucleon-nucleon interaction. This shift of emphasis away from the study of complex nuclear systems to the study of the elementary particles is characteristic of the very high energy region and will become increasingly pronounced in the many Bev regions.

As the meson threshold is passed and meson production becomes an appreciable fraction of the total cross section for the nucleon-nucleon interaction (increasing from one or two percent at 340 Mev to 5 to 10% at 450 Mev and to perhaps 50% at one Bev), an array of new experiments becomes

open for investigation. The meson production itself (single and multiple, and the inverse of meson capture by deuterons) presents a manifold of problems because of the multiplicity of charge states for the meson-nucleon system. These experiments involve a detailed study of the angular and energy dependence of the cross sections. At the same time the behaviour of the nucleon-nucleon scattering in this region, where inelastic processes start to become important, is exceedingly interesting. An additional set of phenomena which is at present perhaps the most interesting which has been studied is the scattering of mesons (elastic and inelastic) by nucleons. This investigation makes use of the high intensity and high energy meson beams (up to 225 Mev meson energy at 450 Mev nucleon energy) which result from the copious production of mesons well above threshold.

The experimental work (See Appendix 2) which has been carried out in the past 5 years (principally at Columbia, Berkeley, Rochester, Chicago) in the energy range of 240-450 Mev has yielded a great deal of extremely interesting results on the π-meson properties and on the nucleon-nucleon interactions; much of the work has, however, been qualitative or rather incomplete so that the remaining survey of this energy region will require at least several more years.

The as yet unexplored (except by cosmic ray techniques) energy region above 450 Mev can be divided naturally into two regions; at energies less than roughly one Bev, the possible experiments are simply an extension of these already discussed, namely the interactions of π-mesons and nucleons. At energies above one Bev, it seems possible at present that a variety of new phenomena appear which involve the heavy unstable bosons (τ, V_{01}, ξ, χ) and fermions (K, V_{01}, anti nucleon).

The energetic thresholds for the production of these particles are approximately known at present and are listed in Appendix 3. It is not entirely clear that the cross sections for production will be appreciable near threshold but the production may become comparable with that of the π-mesons in the many Bev regions.

At any rate, as the threshold for the production of new particles is reached, the same type of experiments that are important in the pion region now can be carried out for the new class of particles. The complexity of the processes also increases since the number of types of fundamental particles involved increases. It is not possible to discuss in detail the types of experiments that will prove of interest, since our knowledge of this energy region is very limited. It would appear, however, that the multiplicity of obvious experiments to be done together with the experimental difficulties encountered will insure that a large variety of interesting experiments will be available for a rather considerable period.

III. Electron Synchrotrons

Comments similar to those made for proton accelerations are relevant for electron accelerators. The research possible with the bremsstrahlung beams of high energy photons, which are the most useful research tool for this type of accelerator, also markedly changes with energy. The π-meson threshold is reached at 150 Mev; above this point the most interesting experiments are the photoproduction of $\pi^{\pm}$ and π^{0}-mesons from protons and deuterons. The electromagnetic properties of the nucleons themselves can be studied through Compton scattering; these experiments are however exceedingly difficult and have not as yet been carried out. In the energy range up to about 600 Mev, the experiments continue to be restricted to the study of pions (produced singly or multiply) and their interactions with nucleons and γ-rays. Above this energy the

energetic thresholds for production of the heavy unstable particles start to be reached and the cross sections may become appreciable. Consequently, just as for the proton accelerators, the manifold of possible experiments expands very rapidly above roughly a Bev.

The electron accelerator has certain characteristics which make experiments rather more difficult than with the proton accelerators. These are particularly the energy spread of the bremsstrahlung beam (a 1/E spectrum up to the maximum) and the very high electron background which is inevitably associated with the high energy gamma rays. The intensities are also not comparable with those of a proton accelerator. These disadvantages are to be weighed against the somewhat greater simplicity of the electron accelerator for energies less than a few Bev (above which the protons are also extremely relativistic and accordingly behave in acceleration as do electrons).

III. Conclusions

It seems probably that accelerators in the 300 to one Bev range will provide interesting experiments in the field of pion-nucleon and nucleon-nucleon and gamma-nucleon-pion interactions for at least several more years. The field of study opens up, however, very rapidly as soon as the threshold for the production of heavy unstable particles is reached so that it would probably be desirable to be able to operate to some extent into this interesting region, with energies somewhat above a Bev (another interesting threshold is passed at 5.6 Bev where nucleon pair threshold is passed). The proton accelerator is probably the more useful type in this field of research.

Appendix I

Proton Accelerator

I. Energies from 0 to 20 Mev.

A. Nuclear structure

B. Nuclear forces

C. Nucleon-nucleon scattering

II. Energies from 20 to 250 Mev.

A. Nucleon-nucleon scattering

B. Nuclear structure (to a lesser extent)

III. Energies from 250 to 1000 Mev.

A. Nucleon-nucleon scattering

B. Meson production of low multiplicity in nucleon-nucleon collisions

C. Meson-nucleon elastic and inelastic scattering

D. Meson absorption in nuclei and deuterium

IV. Energies from 1000 Mev to 5.6 Bev

A. Multiple meson-production

B. Highly inelastic meson-nucleon scattering

C. Near threshold production of heavy unstable particles (τ, Λ, K, V_0) with determination of decay schemes, lifetimes, Q-values

V. Energies from 5.6 to 100 Bev

A. Possible nucleon pair formation with low cross section

B. Highly inelastic nucleon-nucleon and meson-nucleon scattering

C. Appreciable cross sections for the production, scattering, and absorption of heavy unstable particles

VI. Energies from 100 Bev

A. Showers of mesons, kappa mesons, perhaps nucleon pairs and other heavy particles produced in elementary particle collisions

B. Scattering and reaction cross sections for elementary particles of all varieties.

Electron Accelerator

(Experiments in addition to those possible with proton accelerator)

I. Energies from 0 to 150 Mev

A. Nuclear photo effect

B. Compton scattering of gammas by elementary particles

C. Electron shower theory

II. Energies from 150 to 1000 Mev

A. π-meson photo production with a low multiplicity

B. Electromagnetic properties of nucleons

C. High energy nuclear photo effect

D. Electromagnetic phenomena involving μ-mesons pairs and electrons

III. Energies from 1.000 to 3.75 Bev

A. Near threshold photoproduction of heavy unstable particles

B. Multiple photo-production of pions

C. Electromagnetic phenomena involving μ-mesons pairs and electrons

IV. Energies from 3.75 to 100 Bev

A. Possible photo production of nuclear pairs with low multiplicity

B. Multiple production of heavy unstable particles

V. Energies above 100 Bev

A. Photo production of multiple showers of pions, kappa mesons, nuclear pairs

Appendix 2

Survey of present experimental results

I. Nucleon-nucleon scattering; moderately well measured up to 300 Mev for N+P and 400 Mev for P+P

II. Nucleon-nucleon meson production (and inverse)

A. $P + P \rightarrow P + P + \pi^0$ — Rather small cross sections very roughly measured at 300-450 Mev

$P + P \rightarrow N + P + \pi^+$ — Incompletely measured at a few energies from 330 to 400 Mev

$\rightarrow D + \pi^+$

$N + P \rightarrow N + P + \pi^0$ — Incompletely measured at 400 Mev

$\rightarrow D + \pi^0$

$N + P \rightarrow P + P + \pi^-$ — Incompletely measured at 340 Mev

III. Meson-nucleon scattering

A. A few points on the angular distribution at 50, 78, 110, 135 Mev

B. Total cross sections for π^+-mesons from 30 to 150 Mev, for π^--mesons from 50 to 225 Mev.

IV. Photo-production of mesons

A. $\gamma + P \rightarrow P + \pi^0$ — Rough angular distributions and excitation functions up to 300 Mev.

$\rightarrow N + \pi^+$

V. Decay of mesons

A. $\pi^0 \rightarrow 2\gamma$ — Relative yield measured, life time estimated

B. $\pi^\pm \rightarrow \mu^\pm + \nu$ — Life time measured

Appendix III

Energetic Thresholds

I. $P + P \rightarrow P + P + n\pi$ (nucleon-nucleon production of mesons)

E (Mev)	Multiplicity (n)
290	1
602	2
934	3
1288	4
1662	5
2058	6

II. $P + P \rightarrow P + P +$ n (pairs) (Production of nucleon pairs)

E (Bev)	No. of pairs
5.63	1
15.0	2
28.1	3
45.0	4
65.7	5

III. $\pi + P \rightarrow P + \pi + n(\pi)$ (Meson-nucleon meson production)

E (Mev)	No. of mesons (n) produced
190	1
364	2
578	3
812	4

IV. $\gamma + P \rightarrow P + n\pi$ (Photo production of mesons)

E (Mev)	n
150	1
322	2
514	3
728	4
963	5

V. $\gamma + P \rightarrow P +$ n (pairs) (Production of nucleon pairs by gamma rays)

E (Bev)	n
3.75	1
11.24	2
22.5	3
37.5	4
56.3	5

VI. $P + P \rightarrow P + P + X$

E (Mev)	X (Type of particle)	Mass (in electron masses)
603	Zeta I, 0 (2π decay)	(550)
1128	Tau (3π decay)	(975)
1136	V_{o_2} (2π decay)	(980)
2060	χ ($\pi + \Lambda$ decay)	(1450)
5630	Nucleon-anti nucleon pair	