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PHYSICS RESEARCH AT UCRL, 1954-1955

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ABSTRACT

A brief review is given of laboratory undertakings in the year ending June 30, 1955. Notable projects include the work leading to identification of the antiproton; new findings on the properties and reactions of elementary particles, on nucleon interactions, and on nuclear properties; and development of new instruments and techniques.

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INTRODUCTION

This paper is a summary of the principal projects and achievements of the University of California Radiation Laboratory from July 1954 through June 1955. The work reviewed here has been treated in detail in the Physics Division Quarterly Reports covering this period: UCRL-2805, UCRL-2920, UCRL-3014, and UCRL-3115.

INTRINSIC PROPERTIES OF THE ELEMENTARY PARTICLES

The study of the intrinsic properties of the elementary particles is one of the most significant fields of current research. Experimental and theoretical work on this problem at the University of California Radiation Laboratory during the last fiscal year included the projects described below.

Mass of the Heavy K Meson

A beam of K mesons was developed at the Bevatron which provided various research groups with large numbers of positively charged K mesons on which mass measurements could be made. The mass of the K^+ meson emerging from this apparatus was determined to be 970 electron masses.

Modes of Decay of the K Meson

Several research groups have been studying the tracks of daughter fragments from K Mesons coming to rest in emulsion. ("K meson" as used here includes all those mesons about 970 times as heavy as the electron.) The investigators have seen these modes of decay:

$$\tau^+ \rightarrow \pi^+ + \pi^+ + \pi^-,$$
$$\tau'^+ \rightarrow \pi^+ + \pi^0 + \pi^0,$$
$$K^+_{\mu 2} \rightarrow \mu^+ + \nu,$$

$K^+_{\pi 2} \rightarrow \pi^+ + \pi^0$,

$K^+_{\mu 3} \rightarrow \mu^+ +$ two neutral particles (inferred),

$K^+_{e3} \rightarrow e^+ +$ two neutral particles (inferred).

By use of τ-decay-fragment data and theoretical arguments, one group has shown fairly conclusively that the τ and the $K_{\pi 2}$ mesons cannot be the same particle with different decay modes. Another group, using electronic techniques, has made a search for K particles and hyperons that decay by direct or indirect photon emission. Still other experiments have been conducted to see if the various types of K mesons are produced by different mechanisms. (Results from these are still forthcoming.) Several groups have been working on indirect mass measurements, made by determining the ranges of these secondary particles in emulsion.

Theoretical calculations have been made on the possible modes of decay consistent with the known properties of the secondary particles.

Lifetime of the K Meson

In scanning emulsions for stopped K^+ particles, one of the groups of workers studying emulsions observed a number of decays in flight. From these they determined the mean lifetime of the K meson (not including τ mesons) as 1×10^{-8} second.

By comparing the number of τ mesons found in an emulsion stack close to the source with the number in a stack far from the source of the τ's, another group also obtained a value of 1×10^{-8} second.

Still another group of workers used electronic techniques to make separate lifetime measurements for the $K_{\pi 2}$ and the $K_{\mu 2}$ modes of decay, and obtained 1.3×10^{-8} second for the lifetime of each mode of decay. The same group also made a search for a meson reported by the MIT cloud-chamber workers to have a lifetime of 10^{-2} second; the UCRL group showed that if such a meson exists, it is no more than 1/1000 as abundant as the above K mesons.

Decay Spectrum of the μ^+ Meson

The shape of the energy spectrum of the positron that is emitted, along with two neutrinos, in the decay of a μ meson (daughter of a π meson) may be expected to yield valuable information on the process of electron emission from unstable nuclei. A spectrometer has been designed to analyze the energy spectrum of the positron. In connection with this work there has been theoretical study of the focusing properties of the spiral-orbit spectrometer.

An investigation was made by the theoretical group on the possibility of obtaining more information on the μ-meson decay spectrum on the assumption that the μ meson is captured in a spin-aligned nucleus.

Theoretical Studies of Properties of Elementary Particles

Theorists have found it convenient (during the last twenty years) to attribute to elementary particles the property called "isotopic spin." The mathematical utility of this concept is undebatable, but the physical significance of isotopic spin is really unknown. Attempts have been made to have the isotopic spin evolve naturally as the consequence of generalizing an existing four-dimensional theory to an eight-dimensional one. It has been shown that the sign of the isotopic spin assignments of the proton relative to that of the antiproton cannot be chosen arbitrarily.

An attempt has been made to explain the K meson as a composite particle consisting of a nucleon and an antihyperon (the hyperon is known to be a composite particle composed of a nucleon and a meson).

THE SEARCH FOR THE ANTIPROTON

Electronic techniques were devised for detecting antiprotons from the Bevatron by determination of the velocities of particles in a beam that had previously been momentum-analyzed. When the velocities and momenta of the various particles in the beam were measured, their masses could be determined. We regard the success in this experiment as a milestone in the field of nuclear physics. A supplementary experiment was designed in collaboration with E. Amaldi of the University of Rome to detect the antiproton in a nuclear emulsion, and the emulsion exposure was made at the Bevatron. (One antiproton track has already been observed in that part of the emulsion now being scanned by the Amaldi group.) A method for detecting with electronics the recoil fragments of the antiproton annihilation has produced signals that may be antiprotons.

Work had already been started on the design of a separate negative-proton beam in which to expose nuclear emulsions, and apparatus had also been designed for stopping the negative proton in lead plates inserted in the cloud chamber.

NUCLEAR INTERACTIONS

Meson-Nuclear Interactions

As the fundamental cause of nuclear forces is the exchange of virtual mesons between nucleons, it is important to understand the basic process of the interaction of a single real meson with a single nucleon or even a group of nucleons. To measure how the pion is deflected by the proton in a scattering process, an experiment has been carried out with low-energy pions whose probe size is about 2×10^{-13} cm. From this experiment it was possible to tell not only how large a target the proton presents to the oncoming pion, but also some of the characteristics of the pion-nucleon interaction. Similar studies have been made with lead as the struck nucleus.

Pion interactions with protons at much higher energy have been studied at the Bevatron by several groups. It has been found that when these pions, whose probe size is 0.05×10^{-13} cm, interact with protons two types of phenomena occur — the ordinary process of elastic scattering, wherein both the pion and the proton retain their identities, and an inelastic process, wherein the final composition is completely different from the initial system. Events have been observed in which as many as five mesons and a proton emerge after the collision. Interactions in which K mesons emerge have also been seen. The theoretical group has made analyses of some of these multiple-pion reactions.

Electronic techniques have been used for measurements of the high-energy pion-proton interaction probability at various energies, and results are in agreement with cloud chamber results. Design work has been done for pion-neutron interaction studies.

Nuclear emulsion techniques have been used for similar measurements for pion-nucleus interactions with the typical nucleus found in the emulsion.

The interactions of K mesons with emulsion nuclei when at rest as well as in flight have been studied, and from the interactions in flight investigators have found that the interaction probability for the negatively charged K meson is about three times as large as for the positively charged K meson. This is in agreement with a recent theoretical prediction. In addition to elastic and inelastic interactions, events have been seen in which a positive K meson has delivered its charge to a neutron in the nucleus and changed into a neutral K meson — a "charge-exchange scattering." A similar process occurs for negative-pion interactions with protons.

Interactions at rest occur only for the negatively charged mesons. These are called nuclear capture. An experiment has been designed to detect the neutrons that are boiled out of a nucleus after a negative μ meson is captured by the nucleus. These studies provide valuable information about the interaction of mesons with nucleons at very low energy.

Theoretical analyses have been made of these capture-type experiments as well as of the pion-nucleon scattering processes. The consequences of isotopic spin conservation on the pion-nucleon coupling have been studied.

Photonuclear Interactions

From a theoretical standpoint the photon-nucleon interaction is one of the simpler types of interactions on which calculations can be made. The theoretical group has made a study of the possible experiments that might be done with polarized photons. Means of producing these photons have been discussed.

The results of measurements of low-energy photon scattering off the protons, as well as off the nuclei of lithium, carbon, and aluminum, are in agreement with theoretical predictions.

In an experiment that has been initiated to measure the scattering of higher-energy photons from the proton, it is expected that effects will be seen that are caused by virtual pions. Measurements have been made of the process in which the deuterium nucleus is disintegrated by a photon into a free proton and a free neutron.

The process of pion production from photon-proton and photon-deuteron interactions, as well as from complex nuclei, has been studied.

Production of neutral pions as a function of the number of nucleons in the struck nucleus has been measured.

The process of nuclear fission induced by high-energy photons has been investigated, and the observations are in agreement with a mechanism that disrupts the nucleus, the production by the photon of a pion within the nucleus. The pion in turn excites this nucleus into some sort of oscillation that finally results in breaking it apart.

A study was made of the possibility of using nuclear emulsion in measuring the energy of photons that are produced in various types of nuclear reactions. A group at the Radiation Laboratory, in collaboration with a group from the California Institute of Technology, began a study of the possibility of using a liquid-hydrogen bubble chamber in the synchrotron photon beam.

Nucleon-Nuclear Interactions

Scattering and Polarization Experiments

Since it has been found possible to produce polarized proton beams, in which as many as 75% of the protons have their spin axes aligned in the same direction, it has been possible to gain far more information about the nucleon-nucleon interaction than had been dreamed of when only unpolarized beams were available.

The behavior of a proton as it undergoes three successive nuclear scatters has been studied, and similar experiments have been done on the proton-neutron triple-scattering processes. An experiment in which the spinning proton is caused to precess by a known amount and then undergo another scatter has yielded additional basic information about the mechanism of nucleon-nucleon scattering. Proton-proton scattering measurements have been made in the region of small-deflection scattering, where the nuclear force produced by virtual pion exchange becomes smaller than the force produced by virtual photon exchange.

A detailed analysis of the proton-proton scattering process was made with the aid of high-speed computers at the Livermore and Los Alamos laboratories.

Electronic techniques were used to measure elastic proton-proton scattering at much higher energies.

The more complex phenomenon of deuteron polarization was also studied.

Measurements were made with lower-energy protons from the linear accelerator on the inelastic scattering process involving the carbon nucleus. Elastic scattering was studied for a number of complex nuclei.

Extensive emulsion studies have been made, not only on nucleon-nucleus collision processes, but also on nucleus-nucleus collisions. Projectiles such as protons, deuterons, and helium nuclei were used to bombard many complex nuclei. The way in which the struck nucleus disintegrates has been studied in particular.

Measurements have been made on the low-energy photons that emerge from the carbon nucleus after it has been struck by a proton.

The distintegration of oxygen nuclei, both by protons and by neutrons, has been studied with a cloud chamber.

A theoretical analysis was made of the elastic and inelastic scattering processes based on the assumption that the nucleus resembles an optical medium of a given index of refraction. The relationship between the properties of the stable nucleus and the behavior of this nucleus when involved in a scattering process has been studied.

Meson-Production Experiments

On the basis of deuteron-polarization results, a study was made of the fundamental pion-production process involving pion-deuteron formation from a proton-proton collision. The amount of deuteron polarization that is produced in this process yields enough additional information to completely specify the parameters involved in the theoretical analysis of the pion-deuteron-production process. This, again, is far more information than anyone had hoped for prior to the existence of polarized beams.

A similar pion-production process, in which the resulting neutron and proton are free rather than bound into a deuteron, has been studied, and also the neutral-pion production from protons incident on protons, deuterons, and carbon nuclei. The results of the second reaction show that the force between a neutron and a proton is the same as the nuclear force between a proton and another proton.

The theoretical group has made a study of how the neutral-pion-production process is related to the simple process of elastic scattering.

A cloud chamber has been used in measuring pion production by neutrons on deuterons and helium, and the spiral-orbit spectrometer in measuring the pion production from complex nuclei.

Unlike the lower-energy interactions at the 184-inch cyclotron, the nucleon-nucleon interactions at Bevatron energies result in pion production a

large part of the time. Nucleon-nucleon as well as nucleon-nucleus interactions at these higher energies have been studied.

The ratio of K-Meson production to pion production has been studied by use of emulsion techniques. These measurements have been important in the development of the K-meson beams now available at the Bevatron.

INTRINSIC PROPERTIES OF THE NUCLEUS

The angular correlation between the electron and the neutrino that emerge when the radioactive nucleus of neon undergoes beta decay has been studied.

A beta-ray spectrometer has been used to analyze the energy spectra of several of the unstable nuclei produced by proton bombardment.

Various problems of beta decay were studied theoretically; the influence on beta decay of the virtual photons that hold the orbital electrons to the nucleus was investigated. The process of alpha-particle emission was also studied.

Several other theoretical analyses were made that involved the many-nucleon systems as a whole. Attempts were made to predict the spins of complex nuclei. How the force field that holds the nucleus together varies with radial distance has been investigated.

TOOLS AND TECHNIQUES

Bubble Chambers

Liquid hydrogen bubble chamber

The four-inch-diameter bubble chamber was operated both as a physics research instrument and as the pilot model for the contemplated larger chambers. The ten-inch-diameter chamber was in the design and construction stages of development by the end of the fiscal year, whereas the 72-inch chamber was still in the design stage.

The rate at which these bubble chambers would accumulate data prompted a program of analysis using high-speed computers.

Hydrocarbon bubble chamber

A hydrocarbon bubble chamber was under construction.

Other Instruments

The spiral-orbit spectrometer has been investigated, both theoretically and experimentally, as to its resolving power.

A total-absorption photon spectrometer was designed and constructed and was used in an attempt to detect antiprotons.

A bismuth fission chamber was developed to detect high-energy neutrons.

Extensive theoretical calculations were made that led to the design and construction of an extremely high-precision spectrometer for measuring the energies of alpha particles.

Nuclear Emulsion Techniques

Studies have been made on range-momentum relations and range straggling in emulsion. A device for measuring the specific ionization of a particle in an emulsion has been constructed and tested. Several other improvements in technique have been made. Processing equipment was designed for the large emulsion stacks used at the Bevatron.

SUMMARY

At the end of the fiscal year many experiments were still in progress. The antiproton and heavy-K-meson experiments continue with the same high priority, as do the high-energy pion interaction studies. With the conversion of the 184-inch cyclotron to high energies, the trend of physics research throughout the laboratory will be toward the higher-energy regions.

This work was done under the auspices of the U. S. Atomic Energy Commission.