would presumably correspond an antiparticle,[4] which we shall denote by means of square brackets.

In this scheme, (ii) is ineffective in causing decay because it can change isotopic spin only by integers, whereas in $V_1{}^0 \rightarrow \pi^- + p$, for example, the isotopic spin is 1 on the left and $\frac{1}{2}$ or $\frac{3}{2}$ on the right. Only interactions of type (iii), which do not respect isotopic spin at all, can lead to decay. Moreover, the new unstable particles again are produced only in even numbers.

There is no difficulty associated with stating a generalized Pauli principle for each kind of new unstable particle. For example, let us postulate that the wave function of a collection of V_1's must be totally antisymmetric in space, spin, and isotopic spin. If the wave function of two V_1's is antisymmetric in space and spin, as it would be for particles of identical charge, then the total isotopic spin must be 0 or 2, which includes $V_1{}^+V_1{}^+$, $V_1{}^-V_1{}^-$, and $V_1{}^0V_1{}^0$. If the total isotopic spin is 1, the wave function is to be symmetric in space and spin, which is all right since the charges are then not identical. Similarly, the postulate that the wave function of a collection of τ's must be totally symmetric in space, spin, and isotopic spin leads to no contradictions.

It should be noted that according to this scheme the conservation of the z component of isotopic spin is more stringent than conservation of charge.[5] To see this, let us remark that the τ^+ and τ^0 have z components equal to $+\frac{1}{2}$ and $-\frac{1}{2}$, respectively, like the proton and neutron. Correspondingly the antiparticles $[\tau^+]$ and $[\tau^0]$ have z components equal to $-\frac{1}{2}$ and $+\frac{1}{2}$, respectively, like the antiproton and antineutron. Thus we see that the reactions $\pi^- + p \rightarrow V_1{}^0 + \tau^0$ and $\pi^- + p \rightarrow V_1{}^- + \tau^+$ are allowed, while the reactions $\pi^- + p \rightarrow V_1{}^0 + [\tau^0]$ and $\pi^- + p \rightarrow V_1{}^+ + [\tau^+]$ are forbidden, although all four are allowed by conservation of charge. In order to produce anti-τ's it would be necessary to resort to a reaction like $\pi^- + p \rightarrow n + \tau^+ + [\tau^+]$ or $\pi^- + p \rightarrow n + \tau^0 + [\tau^0]$.

In a similar fashion, all reactions of the form nucleon+nucleon$\rightarrow V_1 + V_1$ and all reactions of the form τ+nucleon$\rightarrow V_1 + \pi$ are forbidden, while reactions such as nucleon+nucleon$\rightarrow V_1 + \tau$+nucleon or $[\tau]$+nucleon$\rightarrow V_1 + \pi$ are allowed.

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[2] A. Pais (unpublished). The author is indebted to Professor Pais for the communication of his results prior to publication.

[3] A. Pais, Phys. Rev. **86**, 663 (1952).

[4] We postulate the principle of invariance under the operation of charge conjugation, which carries every particle into its antiparticle. In the case of charged particles, such as the electron and the π^+, it is obvious that the antiparticles are the positron and the π^-, respectively. A neutral particle, however, may or may not be identical with its antiparticle. Among neutral fermions, it is necessary that the neutron and the antineutron be distinct, while the question of whether the neutrino and antineutrino are distinct is one that must be settled by experiment. Among neutral bosons, the γ ray and π^0 are apparently identical with their respective antiparticles, but there is no reason to believe that this is a general rule. We suppose here that the τ^0 is a neutral boson which is not identical with its antiparticle. A model for such a situation is provided by picturing the τ particle as a complex of a nucleon and an anti-V_1, while the $[\tau]$ is pictured as the corresponding complex of antinucleon and V_1.

[5] Of course the conservation of charge is absolute, while the conservation of the z component of isotopic spin can be violated by interactions of type (iii). Such violations should, however, play no important role in production phenomena.

Differential *p-p* Elastic-Scattering Cross Section at 144, 271, and 429 Mev*

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THE differential *p-p* elastic-scattering cross section at 90 degrees barycentric angle has been determined at 144, 271, and 429 Mev and has been found to be constant with energy within experimental error. In addition, the differential elastic-scattering cross section for 429-Mev protons on liquid hydrogen has been measured as a function of angle by a scintillation counter technique which counts both incident and scattered protons, individually.

A beam of protons was scattered from a beryllium target in the 170-inch synchrocyclotron, was analyzed in the fringing field of the cyclotron magnet, and entered the experimental area through a collimator in the heavy shield. It was further monochromatized in an external magnet in the experimental area, and the proton energy was determined by range measurement. The energy of the collimated beam so obtained was varied by moving the beryllium target in the cyclotron azimuthally and at constant radius so that trajectories of the protons of desired energies would pass through the collimator. In a preliminary experiment similar to that of Oxley and co-workers,[1] these beams were subjected to a second scattering on a beryllium target and analyzed for left-right scattering asymmetry. No asymmetry was found; consequently these beams are considered unpolarized for practical purposes.

The apparatus to determine the differential cross section consisted first of a pair of scintillation counters (No. 1 and No. 2), the sensitive area of each of which consisted of a one-inch square diphenyl acetylene crystal. The incident beam of monochromatic protons passed successively through these two counters and was defined by them. The beam next encountered the scatterer, a container of liquid hydrogen. The container was a Styrofoam double-walled cylinder with axis vertical and perpendicular to the beam. The incident beam passed through the two-inch Styrofoam walls, then through four inches of liquid hydrogen, and emerged through two inches of Styrofoam.

The measurements were made according to two different schemes. From 90° to 54° barycentric angle both elastically scattered protons were detected simultaneously and in coincidence with the incident proton. Below 54° the less energetic proton begins to have too little energy to escape from the scatterer. Owing to the low intensity of the incident proton beam it was impractical to make measurements at smaller angles by decreasing the thickness of the scatterer.

Instead, a second scheme for detection of elastically scattered protons was used, relying on the fact that pion production is nearly always accompanied by a charged particle which is emitted close the the direction of the beam. When a pion is produced the associated nucleons have very little berycentric energy and, therefore, move almost with the center-of-mass velocity, consequently, almost in the direction of the beam. For example, in the reaction $p + p \rightarrow d + \pi^+$, the deuterons are emitted in a cone of a little less than 8° half-angle around the direction of the beam. According to the first method, two liquid scintillators were placed on opposite sides of the beam at angles variable and complementary in the barycentric system. One counter (No. 4) was $9\frac{1}{2}$ inches in diameter at a radius of 14 inches, and the other (No. 3) was $3\frac{1}{2}$ inches in diameter at 30 inch radius and defined the solid angle of the measurement.

The first two counters were connected in double coincidence (1, 2) to count the number of incident protons. All four counters (1, 2, 3, 4) were connected in quadrupole coincidence to count the scattered protons. At the beam intensity which was used to measure scattered protons, the counting losses in the double coincidence were measured to be 7 percent. This correction was avoided by the use of a monitor, a 5-inch diameter liquid scintillator placed below the beam to count protons from a lead scatterer in the beam several feet past the liquid hydrogen.

The monitor was connected in double coincidence $(M, 2)$ with one of the first two counters. The counting rate in $(M, 2)$ was $\frac{1}{16}$ of the counting rate in (1, 2), so that when the counting losses in (1, 2) were as great as 7 percent the counting losses in $(M, 2)$ were negligible.

The ratio $(M, 2)/(1, 2)$ was measured at low beam intensity, and the ratio $(1, 2, 3, 4)/(M, 2)$ was measured at high beam intensity, with and without hydrogen. The cross section is proportional to the product of the ratios with hydrogen minus the product of the ratios without hydrogen.

The background (no hydrogen) count was 14 percent of the count with hydrogen at 429 Mev, 27 percent at 271 Mev, and 12 percent at 144 Mev. The electronics were adjusted for plateaus against delays of each counter and against counter voltages. These plateaus were redetermined for each proton energy, to take into account new delays introduced to compensate for changes in time of travel for incident and scattered protons.

According to the second method, counter 3 was set at variable angle $(+\theta)$ at 30-inch radius from the scattering center to detect the elastically scattered protons, and counter 4 was placed to extend from +5 to −20 degrees to detect deuterons. Counters 1, 2, and 3 were connected in coincidence and counter 4 was connected in anticoincidence $(1, 2, 3, -4)$. Accordingly $(1, 2, 3, -4)$ measured all charged particles scattered at angle θ in coincidence with an incident proton, if no charged particle reached counter 4 simultaneously. So all events $p+p\rightarrow d+\pi^+$ were eliminated, even when the deuteron was subjected to Rutherford scattering in the target.

Furthermore, counter 4 extended over much more than the solid angle in which deuterons could emerge in order to eliminate most of the events in which a pion is accompanied by a free proton and neutron. This occurs in only about 1 out of 5 pion productions[2] at 350 Mev and is probably infrequent at 429 Mev also. A third possible process is $p+p\rightarrow\pi^0+p+p$, but this was improbable of detection because (*a*) it is about 8 times less probable than charged pion production,[3] (*b*) the decay gamma ray was detected with very low probability in counter 3, and (*c*) due to the virtual diproton state the two protons tended to emerge in the same solid angle as the deuterons, and so very probably trigger counter 4.

The ratio $(1, 2, 3, -4)/(M, 2)$ was measured at high beam intensity and the ratio $(M, 2)/(1, 2)$ was measured at low beam intensity, with and without hydrogen. The cross section is proportional to the product of the ratios with hydrogen minus the product of the ratios without hydrogen.

At 54° the cross section obtained by the first method was found to be equal within experimental error to that obtained by the second method. The results are summarized in Table I. There is no certain deviation from isotropy within the statistical errors of these results, but there is an indication of some decrease in cross section at smaller angles. A similar behavior is suggested by the corresponding data at 345 Mev,[4] although there also the trend is not much larger than the experimental errors.

TABLE I. Differential elastic p-p scattering cross section at 429 Mev. Method *a* is detection of two scattered protons. Method *b* is detection of the more energetic scattered proton in anticoincidence with a second charged particle emitted at small angles.

Millibarns per steradian	Method	Barycentric angle
3.42 ±0.13	*a*	90°
3.51 ±0.23	*a*	80°
3.11 ±0.19	*a*	65°
2.84 ±0.12	*a*	54°
2.80 ±0.21	*b*	54°
3.18 ±0.21	*b*	43°
2.86 ±0.20	*b*	28°

The isotropic character of the present data at 429 Mev is in considerable disagreement with the shape of the elastic-scattering curve observed by Mott *et al.*, at 435 Mev.[5] On the other hand, the absolute value of the cross section in the neighborhood of 90° is in good agreement with their data.

It is interesting to compute the total p-p cross section at 429 Mev using the present data. Assuming isotropy and a differential scattering cross section of 3.3 mb/sterad one computes 20.7 mb for the total elastic scattering. To this must be added the π^0 production cross section, 0.45 mb,[3] and the π^+ production cross section. A measurement of the latter is being made by A. H. Rosenfeld of this laboratory, who privately reported a preliminary value of 3 mb. One finds 24.2 mb for the sum of these data. This is to be compared with, and agrees well with, the value 24±1 mb determined by transmission at the same energy.[6]

The cross sections reported in Table II for lower energies are much smaller than values reported by previous workers[7-10] although in agreement with a new result, 3.5±0.4 mb/steradian for the energy interval 150 to 350 Mev, from the Berkeley group, written to us by Owen Chamberlain. Our work differs from previous counter experiments in that the incident protons are counted individually. Previous workers have used radioactive methods, Faraday cages, or ion chambers to determine the incident flux.

TABLE II. Differential elastic p-p scattering cross section at 90° barycentric angle.

Millibarns/steradian	Energy (Mev)
3.21 ±0.11	144 ±5
3.67 ±0.34	271 ±9
3.42 ±0.13	429 ±14

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The Attenuation Cross Sections of 37-Mev Pions in Hydrogen

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WE previously reported[1] 16.0±1.0 millibarns for the attenuation cross section of 37-Mev positive pions and 17.3±1.4 millibarns for negative pions in hydrogen. In arriving at these numbers we overlooked an important correction[2] due to the $\pi-\mu$ decays which occur between the second and third crystals of the telescope. Applying this correction and a further small correction due to a refinement in the calculation of our geometry, these numbers become $\sigma(\pi^+)=11.8\pm1.0$ millibarns and $\sigma(\pi^-)=12.9\pm1.7$ millibarns.[3] The π^+ value agrees with that obtained from our measured angular distribution.[4] The measurement of the π^- angular distribution at this energy is not yet completed.

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[3] These values represent the cross sections for scattering into the angular region ~50° to 80° in the laboratory system. [For the π^- mesons the charge-exchange scattering for the entire angular range (0° to 180°) is included.]

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Neutron Total Cross Section for Bismuth and Uranium between 45 and 160 Mev*

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NEUTRON total cross sections for bismuth and uranium have been measured in a good geometry transmission experiment, using a time-of-flight instrumentation.[1,2] The source of neutrons was the stripped deuteron beam of the 184-inch synchrocyclotron. The results are shown in Fig. 1. Uncertainties are shown in terms of standard deviations, due to counting statistics only, and to energy channel width.

The distribution of values indicates a "dip" in cross section in the vicinity of 60 Mev for the two elements, similar to results first obtained by Taylor and Wood for lead.[2-4]