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REVIEWS OF MODERN PHYSICS VOLUME 30, NUMBER 2 APRIL, 1958

# Summary of High-Energy Nucleon-Nucleon Cross-Section Data*

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## I. INTRODUCTION

In the past ten years a considerable amount of information has been published on nucleon-nucleon cross sections at high energies (taken here to mean above 10 Mev).

Different experimenters have used different techniques in collecting the data and deducing absolute cross sections. As time progressed, the methods of obtaining the absolute cross section have become more refined and have yielded more accurate values. The *n-p* differential cross section is usually obtained by normalizing an observed angular distribution of *n-p* events to the separately determined *n-p* elastic cross section. If an erroneous value is used for $\sigma_{np}$ elastic, the absolute cross-section scale for the differential cross section is in error. Corrections of such errors should be made to several of the earlier works on $\sigma_{np}(\theta)$.

Similarly, several experiments on the *p-p* differential cross section have used the reaction $C^{12}(p,pn)C^{11}$ as a monitor for the proton beam, and improved values of the cross section for this reaction have recently been published. This new cross section for the carbon reaction changes the values of $\sigma_{pp}(\theta)$ reported earlier.

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

This paper gathers together all the data and all the corrections to the data, and is an attempt to show that the results form a consistent picture.

Some confusion exists in the literature about the definitions of the different types of cross sections and the nomenclature used to describe them. We use the following system.

For the differential cross section—commonly denoted by $d\sigma/d\Omega(\theta)$—we use the abbreviation $\sigma(\theta)$. In the experiments summarized in this report the differential cross sections studied in nucleon-nucleon scattering are essentially elastic cross sections. In several cases in which the energy is only a little above the meson threshold the inelastic contribution has been neglected.

Three types of integral cross sections (integrated over the angle $\theta$) are discussed.

The notation $\sigma$ total is used in referring to the removal of incident particles from the beam by all processes, elastic or inelastic, except Coulomb scattering in *p-p* events.

The notation $\sigma$ elastic is used in referring to the scattering of incident particles from the beam by elastic processes only. This cross section refers to nuclear scattering only; Coulomb scattering is not included. In a nucleon-nucleon collision, the interaction must be a two-body reaction throughout. Meson production or bremsstrahlung must be excluded for the event to be elastic. Actually (experimentally) for a 100-Mev incident particles a few Mev could be lost and the event probably would still be considered elastic. For example, when a deuterium-hydrogen subtraction is used to provide a "neutron" target, the 2.2 Mev needed to break up the deuteron would normally be ignored.

The notation $\sigma$ inelastic is used in referring to the removal of particles from the beam by inelastic processes only. Meson production is the most important inelastic process in nucleon-nucleon scattering up to several Bev. Since threshold for $\pi$-meson production is 290 Mev, no distinction is usually made below this energy between $\sigma$ elastic and $\sigma$ total.

The three integral cross sections are related by

$$\sigma \text{ total} = \sigma \text{ elastic} + \sigma \text{ inelastic}.$$

Also included in this report are data on the nucleon polarization as determined in double-scattering experiments.

## II. $\sigma_{np}$(TOTAL) AND $\sigma_{np}$(ELASTIC)

The *n-p* total cross section is usually measured by a good-geometry attenuation experiment. Only a relative beam monitor is needed, since only the ratio of before-scatterer to behind-scatterer counting rates is involved. The efficiency of counters need not be known unless this shows a strong energy dependence. Above 300 Mev a distinction must be made between elastic and total cross sections. Table I summarizes the experiments to measure $\sigma_{np}$ total and $\sigma_{np}$ elastic. Figure 1 shows measured values of $\sigma_{np}$ total and $\sigma_{np}$ elastic and several values for $\sigma_{pn}$ total.

## III. $\sigma_{pn}$ TOTAL

Here the proton is now the high-energy incident particle. Several values have been given for $\sigma_{pn}$ total.

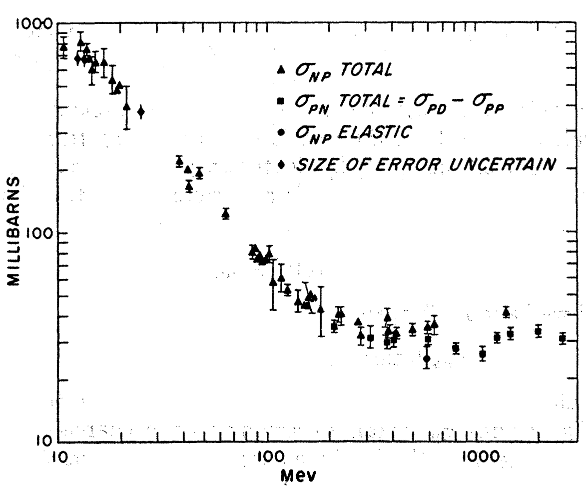


FIG. 1. Experimental values of the total and elastic neutron-proton cross sections and of the total proton-neutron cross sections.

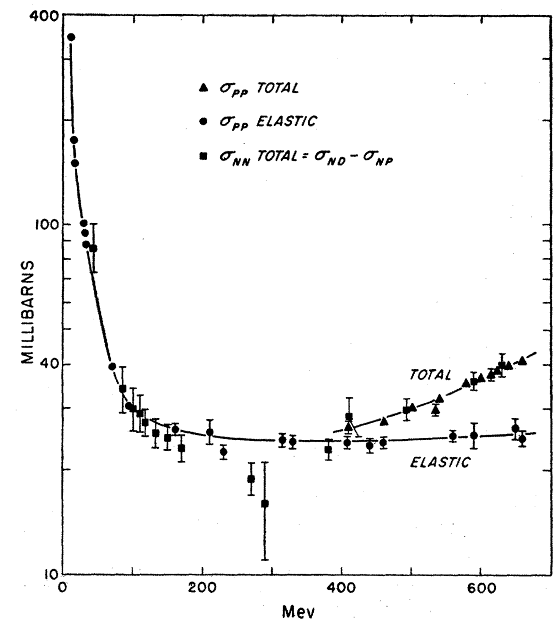


FIG. 2. Experimental values of the total and elastic proton-proton cross sections and of the total neutron-neutron cross section below 600 Mev.

These are obtained by measuring the total cross section for protons on hydrogen and for protons on deuterium, and subtracting. At these energies the deuteron can roughly be considered to be a proton and a neutron acting independently, so subtraction should give the effect from the neutron in the deuteron. There is undoubtedly an interference term in the scattering from deuterium so that the subtraction is not really justified, but it is expected that the interference term will be small enough to make the subtraction give nearly the correct value for $\sigma_{pn}$ total. Also there probably is an effect similar to eclipsing that reduces the cross section for the proton and neutron in the deuteron (*G*3). This eclipsing effect has been suggested as a reason why $\sigma_{pn}$ sometimes is lower than $\sigma_{np}$ (*S*1,*C*4). We take

$$\sigma_{pd}\text{total} = \sigma_{pp}\text{total} + \sigma_{pn}\text{total} + R,$$

where *R* is the result of the interference term in the deuterium scattering and the eclipsing effect. If we have $R=0$, then

$$\sigma_{pn}\text{total} = \sigma_{pd}\text{total} - \sigma_{pp}\text{total}.$$

Figure 1 shows that the values for $\sigma_{pn}$ total obtained in this way fall somewhat below the curve for $\sigma_{np}$ total. The value of *R* can be estimated from this, since theoretically we have

$$\sigma_{np}\text{total} \equiv \sigma_{pn}\text{total}.$$

The value obtained in this manner, if *R* is assumed independent of energy, is

$$R = 6 \pm 3 \text{ mb}.$$

This means that the experimental value of $\sigma_{pd}$ total is

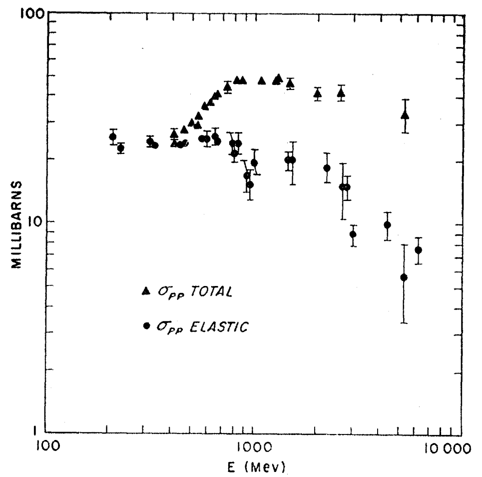


FIG. 3. Experimental values of the total and elastic proton-proton cross sections up to Bev energy range.

~6 mb less than the sum of $\sigma_{pp}$ total and $\sigma_{np}$ total because of the eclipsing and interference effect $R$. This analysis should be expected to break down for low energies, where $R$ may become large.

## IV. $\sigma_{pp}$ TOTAL, $\sigma_{pp}$ ELASTIC, AND $\sigma_{pp}$ INELASTIC

The $p$-$p$ total cross section is usually measured by an attenuation experiment in which the geometry is such that Coulomb-scattered protons are treated as part of the unscattered transmitted proton beam. Therefore the cross section determined is due to nuclear scattering only. Above 300 Mev inelastic events become important. The total cross section can be measured directly. The elastic cross section can be determined either by measuring the fraction of all events that are elastic and multiplying this by the total cross section, or by integrating under the elastic $\sigma_{pp}(\theta)$ curve. Table II summarizes the experiments on $\sigma_{pp}$ total, and $\sigma_{pp}$ elastic, and $\sigma_{pp}$ inelastic. Figure 2 shows measured values of $\sigma_{pp}$ total and $\sigma_{pp}$ elastic below 600/Mev; in addition, the curve has been extended to lower energies by integrating under the measured curves for the $p$-$p$ differential cross section.

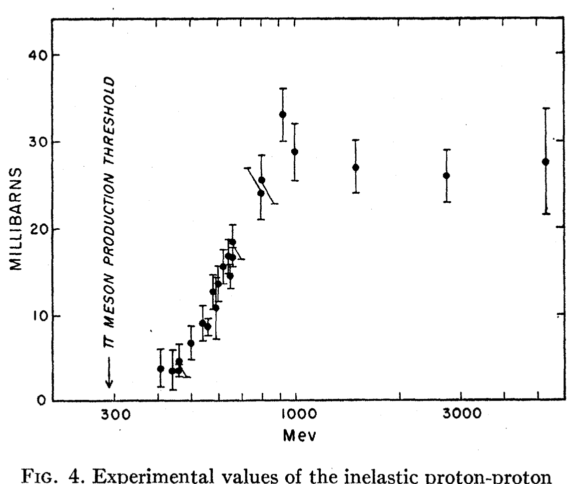


FIG. 4. Experimental values of the inelastic proton-proton cross section.

All the experimental values in Fig. 2 have been treated so that they do not include Coulomb scattering but do include nuclear scattering all the way to $\theta=0°$. Also on this graph are values for $\sigma_{nn}$ total. Figure 3 shows the $\sigma_{pp}$ total and $\sigma_{pp}$ elastic data extended to the Bev energy range. There is apparently a drop in the elastic cross section at high energy, which may be related to the structure of the proton. Figure 4 shows values for $\sigma_{pp}$ inelastic, which primarily represent $\pi$-meson production.

## V. $\sigma_{nn}$ TOTAL

Experiments have been performed to measure $\sigma_{nn}$ total in a manner similar to those that give $\sigma_{pn}$ total.

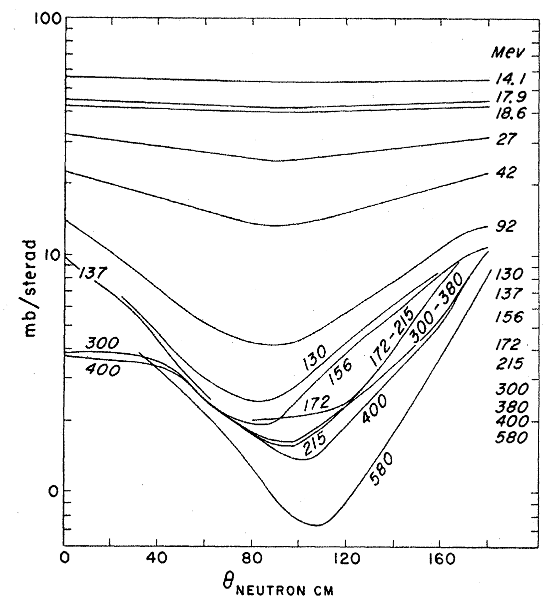


FIG. 5. Experimental values of the differential neutron-proton cross section at various energies.

In this case, $\sigma_{nn}$ total is determined by assigning a value of zero to $I$, the interference+eclipsing term, in the neutron scattering by deuterium; then the neutron scattering from hydrogen is subtracted from that by deuterium to give $\sigma_{nn}$. Thus,

$$\sigma_{nd}\ \text{total}=\sigma_{np}\ \text{total}+\sigma_{nn}\ \text{total}+I.$$

If we have $I=0$, then

$$\sigma_{nn}\ \text{total}=\sigma_{nd}\ \text{total}-\sigma_{np}\ \text{total}.$$

Values of $\sigma_{nn}$ total obtained in this way are plotted in Fig. 2 with $\sigma_{pp}$ total. According to the charge-independence hypothesis these cross sections should be identical. The values of $\sigma_{nn}$ total fall quite close to the $\sigma_{pp}$ total curve. If the interference terms in $p$-$d$ and $n$-$d$ scattering are similar—that is, if $I=R$, as well

TABLE I. A summary of experiments on the neutron-proton total and elastic cross sections. Also given are some data on the neutron-neutron total cross section.

| Reference | Authors | Energy (Mev) | Cross section (mb) | Remarks | Source of quoted error | Detector |
|---|---|---|---|---|---|---|
| S3 | Sleator (Michigan) | $E=$ 9.3 | 920 ± 80 | | Counting statistics | Ion chamber to count recoil protons |
| | | $E=$ 10.6 | 780 ± 90 | | | |
| | | $E=$ 12.8 | 830 ± 90 | | | |
| | | $E=$ 14.8 | 610 ± 90 | | | |
| | | $E=$ 16.5 | 660 ±100 | | | |
| | | $E=$ 18.1 | 550 ± 80 | | | |
| | | $E=$ 19.6 | 520 ± 90 | | | |
| | | $E=$ 21.1 | 410 ± 90 | | | |
| A1 | Ageno, Amaldi, Bocciarelli, Trabacchi (Rome) | $E=$ 12.5 | 690 | | Counting statistics | Proportional counter proton-recoil telescope |
| | | $E=$ 13.5 | 694 | | | |
| L1 | Lasday (Carnegie Tech) | $E=$ 13.9 | 770 ± 40 | | Counting statistics | Proportional counter telescope |
| P1 | Poss, Salant, Snow, Yuan (Brookhaven) | $E=$ 14.10±0.05 $T(d,n)He^4$ source | 689 ± 5 | | Counting statistics | Scintillator to count neutrons |
| M2 | Meyer, Nyer (Los Alamos) | $E=$ 14.2 | 675 ± 20 | | Not given | $Cu^{63}(n,2n)Cu^{62}$ |
| S4 | Salant, Ramsey (Carnegie Inst. of Washington) | $E=$ 14 | 700 ± 60 | | Not given | $Cu^{63}(n,2n)Cu^{62}$, 13-Mev threshold |
| | | $E=$ 15 | 660 ± 70 | | | |
| D3 | Day, Mills, Perry, Scherb (Los Alamos) | $E=$ 19.655±0.035 | 495 ± 3 | | Not given | Scintillator to count neutrons |
| D2 | Day, Henkel (Los Alamos) | $E=$ 19.93 | 504 ± 10 | | Reproducibility | Scintillator to count neutrons |
| S5 | Sherr (Harvard) | $E=$ 25 | 390 | | Not given | $C^{12}(n,2n)C^{11}$ |
| H2 | Hildebrand, Leith (Berkeley) | $E=$ 42 | 203 ± 7 | Energy not measured | Counting statistics | $C^{12}(n,2n)C^{11}$ |
| | | | $\sigma_D=289\pm13$ | Used in $\sigma_{nn}$ total | | |
| H3 | Hadley, Kelly, Leith, Segrè, Wiegand, York (Berkeley) | $E=$ 90 | 76 ± 1.7 | | Counting statistics | Proportional counter telescope |
| | | $E=$ 42 | 170 ± 8.3 | Energy not measured | | |
| H1 | Hillman, Stahl, Ramsey (Harvard) | $E=$ 88 | 86.1± 2 | Liquid H target | Total | Scintillator to count neutrons |
| | | | 84.5± 2 | $CH_2-C$ target | | |
| | | $E=$ 47.5 | 196 ± 10 | | | |
| T3 | Taylor, Wood (Harwell) | $E=$ 38 | 223 ± 7.6 | | Not given | Proton-recoil proportional counter telescope |
| | | $E=$ 63 | 126 ± 3 | | | |
| | | $E=$ 95 | 73.9± 3 | | | |
| | | $E=$ 126 | 56.9± 1.8 | | | |
| | | $E=$ 153 | 46.4± 1.2 | | | |
| T1 | Taylor, Pickavance, Cassels, Randle (Harwell) | $E_{max}=45$ $E_{peak}=39$ $E_{cutoff}=34$ | 223 ± 7.6 | Data fit equation: $\sigma_{np}=\frac{10\,342}{E}-45.7+0.157E$ ($E$=Mev, $\sigma$=mb) | Not given | Proton-recoil proportional counter telescope |
| | | $E_{max}=74$ $E_{peak}=64.5$ $E_{cutoff}=59$ | 126 ± 3 | | | |
| | | $E_{max}=107$ $E_{peak}=97$ $E_{cutoff}=91$ | 73.9± 3 | | | |
| | | $E_{max}=169$ $E_{peak}=156$ $E_{cutoff}=149$ | 46.4± 1.2 | | | |
| C5 | Cook, McMillan, Peterson, Sewell (Berkeley) | $E$ =85 | 83± 4 | | Counting statistics. +1% for others | $C^{12}(n,2n)C^{11}$ |
| | | | $\sigma_D=117\pm5$ | Used in $\sigma_{nn}$ total | | |

TABLE I.—(*Continued*).

| Reference | Authors | Energy (Mev) | Cross section (mb) | Remarks | Source of quoted error | Detector |
|---|---|---|---|---|---|---|
| D4 | DeJuren, Knable (Berkeley) | $E=$ 95 | 73 ± 1.5<br>$\sigma_D=104\pm4$ | <br>Used in $\sigma_{nn}$ total | Counting statistics | Bi fission counter |
| C2 | Cullar, Waniek (Harvard) | $E=$ 93.4<br>$E=$ 97.2<br>$E=$ 101.1<br>$E=$ 106.8 | 77 ± 5<br>76 ± 3<br>80 ± 7<br>59 ± 16 | | Counting statistics | Proton-recoil scintillation telescope |
| M1 | Mott, Guernsey, Nelson (Rochester) | $E=$ 220±10<br>$E=$ 180± 7<br>$E=$ 156± 5<br>$E=$ 140± 5<br>$E=$ 117± 5<br>$E=$ 97± 5 | 41.3± 3.5<br>44 ± 12<br>50.5± 8.3<br>48.5± 5.6<br>61.5± 8.6<br>74 ± 10 | Pulse-height analysis allows determination at several energies at the same time | Counting statistics | Proton-recoil scintillator telescope |
| A2 | Alphonse, Johansson, Taylor, Tibell (Uppsala, Sweden) | $E=$ 169<br>$E=$ 149<br>$E=$ 132<br>$E=$ 117<br>$E=$ 109 | $\sigma_{D-H}=23.1\pm2$<br>$\sigma_{D-H}=24.8\pm2$<br>$\sigma_{D-H}=25.3\pm2.4$<br>$\sigma_{D-H}=27.2\pm2.4$<br>$\sigma_{D-H}=29.1\pm3.6$ | Used in $\sigma_{nn}$ total | Not given | Proton-recoil scintillation counter telescope |
| T4 | Taylor, Pickavance, Cassels, Randle (Harwell) | $E=$ 153 | 46.4± 1.2<br>$\sigma_{D-H}=24.3\pm2$ | <br>Used in $\sigma_{nn}$ total | Not given | Proton-recoil proportional counter telescope |
| T2 | Taylor (Uppsala, Sweden) | $E=$ 169 | 49.2± 1.6<br>$\sigma_{D-H}=23.1\pm2.0$ | <br>Used in $\sigma_{nn}$ total | Counting statistics | Proton-recoil scintillation telescope |
| D1 | DeJuren, Moyer (Berkeley) | $E=$ 220<br>$E=$ 160 | 41 ± 4<br>51.2± 2.6 | | Counting statistics | Bi fission counter |
| D5 | DeJuren (Berkeley) | $E=$ 270 | 38 ± 1.5<br>$\sigma_{D-H}=19\pm2$ | <br>Used in $\sigma_{nn}$ total | Not given | Bi fission counter |
| F1 | Fox, Leith, Wouters, MacKenzie (Berkeley) | $E=$ 280 | 33 ± 3<br>$\sigma_D=49\pm$ 5 | <br>Used in $\sigma_{nn}$ total | Counting statistics | Scintillator proton-recoil telescope |
| D6 | Dzhelepov, Golovin, Satarov, (Moscow) | $E=$ 380 | 40 ± 4 | Mentioned in D9 | Not given | |
| N1 | Nedzel (Chicago) | $E=$ 410 | 33.7± 1.3<br>$\sigma_{D-H}=28.3\pm4.0$ | <br>Used in $\sigma_{nn}$ total | Total | Scintillators +Čerenkov counter counting recoil protons |
| D12 | Dzhelepov, Satarov, Golovin (Moscow) | $E=$ 380<br>$E=$ 500<br>$E=$ 590<br>$E=$ 630<br>$E=$ 380<br>$E=$ 500<br>$E=$ 590<br>$E=$ 630 | 34 ± 2<br>35 ± 2<br>36 ± 2<br>37 ± 4<br>$\sigma_{D-H}=23\pm1.5$<br>$\sigma_{D-H}=30\pm2$<br>$\sigma_{D-H}=36\pm2$<br>$\sigma_{D-H}=40\pm3$ | Total cross section includes inelastic events<br>Used in $\sigma_{nn}$ total | Counting statistics | Scintillators |
| C4 | Coor, Hill, Hornyak, Smith, Snow (Brookhaven) | $E=$1400 | 42.4± 1.8<br>$\sigma_{D-H}=42.2\pm1.8$ | Total cross section includes inelastic events | Counting statistics | Scintillator telescope with converter to make protons |

might be—then according to the preceding analysis one should add about 6 mb to the values for $\sigma_{nn}$ total to get the proper values. It would appear that $\sigma_{nn}$ total agrees quite well with $\sigma_{pp}$ total without addition of the 6 mb.

## VI. $\sigma_{np}(\theta)$

To measure this cross section usually the angular distribution of either protons are neutrons is determined from the $n$-$p$ interaction, normalizing the area under the angular distribution to the total cross sections. Table III gives a summary of the measurements of $\sigma_{np}(\theta)$. Table IV lists the experimental values, and also the new values for those cases in which a renormalization has been performed. The renormalizations were usually done because the value for $\sigma_{np}$ total now available is better than the one used by the original authors. In one case (GI), the renormalization is called for because the angular distribution was not measured to very small angles and an extrapolation to 0° was

TABLE II. A summary of experiments on the proton-proton total elastic and inelastic cross sections. Also given are some data on the proton-neutron total cross section.

| Reference | Authors | Energy (Mev) | Cross section (mb) | Remarks | Source of quoted error | Detector |
|---|---|---|---|---|---|---|
| C16 | Cook, Hartsough (Berkeley) | $E=$ 9.7 | 345 | Obtained by assuming $\sigma_{pp}(\theta)=55$ mb/sterad flat to zero degrees $\therefore\ \sigma_{tot}=55\times 2\pi$ | | Scintillators |
| Y1 | Yntema, White (Princeton) | $E=$ 18.2 | 175 | Obtained by assuming average $\sigma_{pp}(\theta)=27.8$ $\therefore\ \sigma_{tot}=27.8\times 2\pi$ | | Scintillators |
| B6 | Burkig, Schrank, Richardson (UCLA) | $E=$ 19.8 | 152 | Obtained by assuming average $\sigma_{pp}(\theta)=24.2$ $\therefore\ \sigma_{tot}=24.2\times 2\pi$ | | Scintillators |
| P2 | Panofsky, Fillmore (Berkeley) | $E=$ 29.4 | 102 | Obtained by assuming average $\sigma_{pp}(\theta)=16.2$ $\therefore\ \sigma_{tot}=16.2\times 2\pi$ | | Nuclear emulsions |
| F3 | Fillmore (Berkeley) | $E=$ 30.14 | 94 | Obtained by assuming average $\sigma_{pp}(\theta)=15$ $\therefore\ \sigma_{tot}=15\times 2\pi$ | | Nuclear emulsions |
| C9 | Cork, Johnston, Richman (Berkeley) | $E=$ 31.8 | 88 | Obtained by assuming average $\sigma_{pp}(\theta)=14$, $\therefore\ \sigma_{tot}=14\times 2\pi$ | | Proportional counters |
| K2 | Kruse, Teem, Ramsey (Harvard) | $E=$ 70 | 39.6 | Obtained by assuming average $\sigma_{pp}(\theta)=6.3$, $\therefore\ \sigma_{tot}=6.3\times 2\pi$. | | Scintillators |
| | | $E=$ 95 | 30.2 | Obtained by assuming average $\sigma_{pp}(\theta)=4.8$ $\therefore\ \sigma_{tot}=4.8\times 2\pi$ | | |
| C1 | Chamberlain, Pettengill, Segrè, Wiegand (Berkeley) | $E=$ 330 | 23.9±1.0 | From $\sigma(\theta)=3.81\times 2\pi$ at 330 and $\sigma(\theta)=3.58$ $\times 2\pi$ at 225 | Counting statistics plus target-thickness uncertainty | Scintillator telescope |
| | | $E=$ 230 | 22.5±1.0 | | | |
| | | $E=$ 160 | 26.1±1.0 | $\sigma(\theta)=4.16\times 2\pi$ at 160 | | |
| C3 | de Carvalho (Chicago) | $E=$ 315±8 | 24.3±1 | | Counting statistics | Scintillator telescope |
| | | $E=$ 208±4 | 25.8±2 | | | |
| | | $E=$ 315±8 | $\sigma_{D-H}=32.5\pm 4$ | Used in $\sigma_{pn}$ total | | |
| | | $E=$ 208±4 | $\sigma_{D-H}=37.0\pm 2$ | Used in $\sigma_{pn}$ total | | |
| M3 | Marshall, Marshall, Nedzel (Chicago) | $E=$ 408 | 24.0±1 | No corrections for meson production | Not given | Scintillator telescope |
| | | | $\sigma_{D-H}=31.6\pm 2$ | Used in $\sigma_{pn}$ total | | |
| D11 | Dzhelepov, Moskalev, Medved (Moscow) | $E=$ 410 | 26.9±0.7 | Total cross sections | Total | Proportional counters and a liquid scintillator |
| | | $E=$ 460 | 27.6±0.4 | | | |
| | | $E=$ 500 | 29.9±0.4 | Includes inelastic events | | |
| | | $E=$ 540 | 32.1±0.5 | | | |
| | | $E=$ 580 | 35.6±0.5 | | | |
| | | $E=$ 600 | 36.6±0.5 | | | |
| | | $E=$ 620 | 38.6±0.5 | | | |
| | | $E=$ 640 | 39.8±0.6 | | | |
| | | $E=$ 660 | 41.4±0.6 | | | |
| | | $E=$ 410 | 3.9±2.1 | Inelastic cross section only obtained by subtracting $\sigma_{elastic}=23\pm 2$ mb from measured values of $\sigma_{total}$ | | |
| | | $E=$ 460 | 4.6±2.0 | | | |
| | | $E=$ 500 | 6.9±2.0 | | | |
| | | $E=$ 540 | 9.1±2.1 | | | |
| | | $E=$ 580 | 12.6±2.1 | | | |
| | | $E=$ 600 | 13.6±2.1 | | | |
| | | $E=$ 620 | 15.6±2.1 | | | |
| | | $E=$ 640 | 16.8±2.1 | | | |
| | | $E=$ 660 | 18.4±2.1 | | | |
| B5 | Meshcheryakov, Bogachec, Neganov (Moscow) | $E=$ 460 | 24.0±0.6 | Elastic cross section | | |
| | | $E=$ 560 | 25.2±0.8 | | | |
| | | $E=$ 660 | 24.7±1.0 | | | |
| | | $E=$ 460 | 3.6±0.7 | Inelastic cross section by subtraction of B5 data from D11 data | | |
| | | $E=$ 560 | 8.8±0.9 | | | |
| | | $E=$ 660 | 16.7±1.2 | | | |

TABLE II—*Continued.*

| Reference | Authors | Energy (Mev) | Cross section (mb) | Remarks | Source of quoted error | Detector |
|---|---|---|---|---|---|---|
| S2 | Smith, McReynolds, Snow (Brookhaven) | $E=440$ | $23.5\pm1.2$ | Elastic cross section. Normalized to data of Sutton, S9, obtained by integrating under $\sigma_{pp}(\theta)$ curve | Not given | Scintillators |
| | | $E=590$ | $25.2\pm2.0$ | | | |
| | | $E=800$ | $21.5\pm2.0$ | | | |
| | | $E=1000$ | $19.2^{+3}_{-2}$ | | | |
| | | $E=440$ | $3.5\pm2.3$ | Inelastic cross section, obtained by subtracting $\sigma_{\text{elastic}}$ from $\sigma_{\text{total}}$ of Shapiro, S1 | | |
| | | $E=590$ | $10.8\pm3.6$ | | | |
| | | $E=800$ | $25.5\pm2.8$ | | | |
| | | $E=1000$ | $28.8\pm3.2$ | | | |
| S1 | Shapiro, Leavitt, Chen (Brookhaven) | $E=410$ | $26.5^{+1.4}_{-1.3}$ | Total cross sections includes meson production as well as elastic events | Total | Scintillator telescope |
| | | $E=535$ | $29.8^{+1.3}_{-1.1}$ | | | |
| | | $E=615$ | $37.7^{+1.4}_{-1.0}$ | | | |
| | | $E=740$ | $44.4^{+2.8}_{-2.6}$ | | | |
| | | $E=830$ | $47.8^{+1.6}_{-1.2}$ | | | |
| | | $E=850$ | $47.6^{+1.7}_{-1.2}$ | | | |
| | | $E=1075$ | $48.3^{+1.6}_{-1.1}$ | | | |
| | | $E=1275$ | $47.5^{+1.6}_{-1.2}$ | | | |
| | | $E=1295$ | $49.4^{+1.6}_{-1.1}$ | | | |
| | | $E=1490$ | $47.2^{+2.6}_{-1.2}$ | | | |
| | | $E=2000$ | $41.4^{+3.2}_{-1.4}$ | | | |
| | | $E=2600$ | $41.6^{+4.0}_{-1.6}$ | | | |
| | | $E=380$ | $\sigma_{\text{D-H}}=31.0^{+1.5}_{-1.3}$ | Total cross section includes inelastic events used in $\sigma_{pn}$ total | | |
| | | $E=590$ | $\sigma_{\text{D-H}}=31.5^{+1.9}_{-1.7}$ | | | |
| | | $E=810$ | $\sigma_{\text{D-H}}=28.4^{+1.3}_{-1.1}$ | | | |
| | | $E=1060$ | $\sigma_{\text{D-H}}=27.0^{+2.0}_{-1.9}$ | | | |
| | | $E=1260$ | $\sigma_{\text{D-H}}=32.1^{+1.5}_{-1.2}$ | | | |
| | | $E=1480$ | $\sigma_{\text{D-H}}=33.6^{+2.0}_{-1.7}$ | | | |
| | | $E=2000$ | $\sigma_{\text{D-H}}=34.3^{+2.3}_{-1.5}$ | | | |
| | | $E=2600$ | $\sigma_{\text{D-H}}=31.4^{+2.2}_{-1.3}$ | | | |
| B9 | Batson, Culwick, Riddiford, Walker (Birmingham) | $E=650\pm100$ | $\sigma_{\text{elastic}}=26.3\pm1.8$<br>$\sigma_{\text{inelastic}}=14.4\pm1.4$ | Cross section normalized to $\sigma_{\text{tot}}=40.6$ | Not given | Cloud chamber |
| M10 | Morris, Fowler, Garrison (Brookhaven) | $E=800$ | $\sigma_{\text{elastic}}=24\pm3$<br>$\sigma_{\text{inelastic}}=24\pm3$ | | | Cloud chamber |
| H6 | Hughes, March, Muirhead, Lock (Glasgow) | $E=925$ | $\sigma_{\text{elastic}}=17\pm3$<br>$\sigma_{\text{inelastic}}=33\pm3$ | | Counting statistics | Nuclear emulsion |
| D7 | Duke, Lock, March (Birmingham) | $E=950$ | $15.5\pm2.5$ | It is not clear whether corrections have been made for Coulomb scattering | Not given | Nuclear emulsions |
| F6 | Fowler, Shutt, Thorndike, Whittemore (Brookhaven) | $E=1500$ | $\sigma_{\text{elastic}}=20\pm2$<br>$\sigma_{\text{inelastic}}=27\pm3$ | Cross sections normalized to $\sigma_{pp\ \text{total}}=47$ from S1 | | Cloud chamber |
| B8 | Block, Harth, Cocconi, Hart, Fowler, Shutt, Thorndike, Whittemore (Brookhaven) | $E=2750$ | $\sigma_{\text{elastic}}=15\pm2$<br>$\sigma_{\text{inelastic}}=26\pm3$ | Cross section normalized to $\sigma_{pp\ \text{total}}=41.6$ from S1 | | Cloud chamber |

TABLE II—*Continued.*

| Reference | Authors | Energy (Mev) | Cross section (mb) | Remarks | Source of quoted error | Detector |
|---|---|---|---|---|---|---|
| C18 | Cester, Hoang, Kerner (Rochester) | $E=3000$ | $8.9\pm1.0$ | Elastic cross section | Not given | Nuclear emulsion |
| C17 | Cork, Wenzel, Causey (Berkeley) | $E=2240$<br>$E=4400$<br>$E=6150$ | $16.9\pm2.5$<br>$9.0\pm1.4$<br>$6.9\pm1.0$ | Elastic cross sections obtained by integrating under $\sigma_{pp}(\theta)$ curve | 15% error is due only to beam-monitor calibration; other errors are somewhat less | Scintillators |
| W1 | Wright, Saphir, Powell, Maenchen, Fowler (Berkeley) | $E=5300$ | $\sigma_{\text{total}}=32.4\pm6.0$<br>$\sigma_{\text{elastic}}=5.6\pm2.3$ | | Total | Cloud chamber |

needed to normalize to the total cross section. This extrapolation assumed symmetry about 90°, which is now known to be incorrect for this energy. Therefore a correction that changes the cross-section scale was made in the extrapolation process.

Values of $\sigma_{np}(\theta)$ are shown in Fig. 5. Experimental points are omitted because there are so many of them. The lines have been drawn through the experimental points in each case. Since typical total errors are 10%, not much reliance should be put on detail features of these curves. For example, probably the 172-Mev curve does not actually cross the 156-Mev curve near 92°, and probably the 215-Mev curve does not cross the 300-Mev curve near 117°. One would expect fairly smooth energy variations of $\sigma_{np}(\theta)$ at certain angles instead of bumps.

The curves up to 90 Mev are quite symmetrical about 90° c.m., but at 300 to 400 Mev the curves are higher at 180° than at 0° c.m.

## VII. $\sigma_{pp}(\theta)$

The $p$-$p$ differential cross section is normally measured by detecting one or both protons resulting from a collision of a beam and a target proton and monitoring the beam with an absolute monitor. Knowing the thickness of the target and the solid angle of the detectors, the absolute cross section is calculated directly by the formula:

$$\frac{\text{detector counts}}{\text{monitor protons}}=\sigma_{pp}(\theta)[\text{target atoms/cm}^2) \times[\text{detector solid angle}].$$

In comparing $\sigma_{pp}(\theta)$ and $\sigma_{pp}$ total a factor of 2 arises from the fact that two protons are produced from each collision:

$$2\sigma_{pp}\,\text{total}=\int_{4\pi}\sigma_{pp}(\theta)d\Omega.$$

Table V summarizes the experiments on $\sigma_{pp}(\theta)$. Table VI lists the experimental values for $\sigma_{pp}(\theta)$ and the new values when renormalization has been necessary. The renormalizations here all result from new measurements of the cross section by Crandall *et al.*, (C14) for the reaction $C^{12}(p,pn)C^{11}$, which has been used as an absolute monitor for studying $\sigma_{pp}(\theta)$. Values from Aamodt (A6) for the cross section for $C^{12}(p,pn)C^{11}$ were used by several of the original workers. Recent work at Chicago (R4) on the cross section for $C^{12}(p,pn)C^{11}$ gives still lower values than the recent Berkeley work (C14). The measurements were made at different energies; therefore perhaps both answers are correct. The difference in the values, if it is real, may be due to the self-absorption correction. The Berkeley group included $\beta$-$\gamma$ coincidences as well as $4\pi$ counting to get this correction. In this paper the Berkeley values for the cross section are used because of the particle energies involved. If the Chicago data turn out to be better, the nucleon-nucleon cross sections affected must be reduced still further.

Quoting from Crandall *et al.*: "The most significant difference from earlier experiments is the shape of the $C^{12}(p,pn)C^{11}$ excitation curve in the neighborhood of 350 Mev. Readjusting the excitation function both in shape and in absolute value will have important effects on seemingly unrelated experiments because of the widespread use of the reaction as a beam monitor. For example, the $p$-$p$ scattering cross sections measured at 240 Mev by Oxley *et al.* (O1,T6) should certainly be modified. Even though they intercalibrated their counter with a beta standard used by Aamodt *et al.*, the revised shape of the excitation function requires a 41/49 reduction in their values. If a cross section of 36 mb for the $C^{12}(p,pn)C^{11}$ is used, their values are further reduced and are in excellent agreement with the results of Chamberlain *et al.* (C8).

"The $p$-$p$ scattering cross sections measured by Birge *et al.*, (B4) at 105 and 75 Mev may be reduced directly by the ratio 36/41. The revised values are in agreement with the Berkeley measurements.

"Cassels *et al.*, (C11) measured the $p$-$p$ scattering cross sections at 146 Mev by using two methods to calibrate their beam monitor. One of the methods involved the use of the $C^{12}(p,pn)C^{11}$ cross section and gave a $p$-$p$ scattering cross section of $4.61\pm0.55$ mb/sterad.

TABLE III. A summary of experiments on the neutron-proton differential cross section.

| Reference | Authors | Data normalized | Energy (Mev) | Monitor | Target | Counters | Source of quoted error | Data renormalized here: Yes or No | By how much | Why | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| S8 | Seagrave (Los Alamos) | None needed. Flux and solid angles known and yield measured | $E=14.1\pm0.05$ $T(d,n)He^4$ | Counting alpha particles from reaction $T(d,n)He^4$ | $CH_2$ | 2 proportional counters +NaI scintillator | Counting statistics +beam spread | No | ... | ... | (a) Measure $E\frac{dE}{dx}$ with two pulse-height counters (b) 4% error possible in neutron flux |
| A4 | Allred, Armstrong, Rosen (Los Alamos) | None needed. Know flux and Ω and measure yield | $E=14.1\pm0.1$ $T(d,n)He^4$ | Count alphas from reaction | $CH_2$ | Nuclear plates | Counting statistics | No | ... | ... | |
| G2 | Galonsky, Judish (Oak Ridge) | Yes—to $\sigma_{tot}=535$ mb | $E=17.9\pm0.1$ $T(d,n)He^4$ | Propane recoil counter | $CH_2$ | 2 proportional counters and NaI counter | Total | No | ... | ... | |
| B2 | Baldwin (Carnegie Tech) | No | $E=10.6$ $Be^9(\alpha,n)C^{12}$ $E_{cutoff}=18$ | Thorium fission ion chamber | $CH_2-C$ | Proportional counter telescope | Total | No | ... | ... | Gives $\frac{\sigma_{np}(180)}{\sigma_{np}(90)}$ |
| R1 | Remley, Jentschke, Kruger (Illinois) | No | $E=28.4$ spread of 0.5 $T(d,n)He^4$ $E=13.7$ spread of 0.8 $D(d,n)He^3$ | (a) $Au(n\gamma)$ (b) Current from cyclotron (c) Geiger counter (all relative) | Scintillation crystal | Scintillator | Counting statistics +calibration errors +geometrical effects | No | ... | ... | (a) Gives relative $\sigma_{np}(\theta)$ (b) 13.7-Mev data essentially flat (c) 28.4-Mev data superimposed on Brolley data (B3) and agrees well |
| B3 | Brolley, Coon, Fowler (Los Alamos) | Yes—to 360 mb per Adair (A3) | $E=27.2\pm0.6$ $T(d,n)He^4$ | Cyclotron beam current | $CH_2$ | Proportional counter telescope | Counting statistics | No | ... | ... | Systematic errors ~4% |
| H3 | Hadley, Kelly, Leith, Segrè, Wiegand, York (Berkeley) | Yes—to 76 mb for 90 Mev | $E_{peak}=90$ $E_{upper}=105$ $E_{lower}=70$ $E_{cutoff}=66$ | $CH_2$ target +prop. ctr. telescope and Bi fission counter | $CH_2-C$ | Proportional counter telescope to count protons | Counting statistics | 90 Mev yes | $\frac{78.3}{76}$ | Better measurement of $\sigma_{tot}$(S7) | (a) S6 says need correction near 180° (b) "40"-Mev neutron spectrum never measured only calculated by stripping theory (c) Call $E=42$ Mev according to H2 since their cross sections are used |
| | | and to 170 mb for 40 Mev | $E_{peak}\cong42$ $E_{cutoff}=28$ | | | | | 42 Mev yes | $\frac{203}{170}$ | New measurement of $\sigma_{tot}$ fits $\sigma$ *vs* energy curve better (H2) | |
| C6 | Chamberlain, Easley (Berkeley) | Yes—to data in H3 at 36° | $E_{peak}=90$ $E_{upper}=105$ $E_{lower}=70$ $E_{cutoff}=60$ | Bi fission counters | Liquid H | Neutron scintillation telescope | Counting statistics | Yes | $\frac{78.3}{76}$ | Better measurement of $\sigma_{tot}$ (S7) | |
| C7 | Chih (Berkeley) | Yes—to 76 mb | $E_{peak}=90$ $E_{upper}=105$ $E_{lower}=75$ $E_{cutoff}=40$ | None | $H_2$ gas | Cloud chamber | Counting statistics | Yes | $\frac{78.3}{76}$ | Better measurement of $\sigma_{tot}$ (S7) | Other errors might be ~2% |

TABLE III.—(*Continued*).

| Refer-ence | Authors | Data normalized | Energy (Mev) | Monitor | Target | Counters | Source of quoted error | Data renormalized here: Yes or No | By how much | Why | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| F2 | Fox (Berkeley) | Yes—to smooth curve drawn through H3 data | $E_{peak}=90$ $E_{upper}=105$ $E_{lower}=70$ $E_{cutoff}=85$ | Scintillation telescope+$CH_2$ target | $CH_2-C$ | Scintillation telescope | Counting statistics | Yes | $\frac{78.3}{76}$ | Better measurement of $\sigma_{tot}$ (S7) | S6 says data should be corrected near $\theta=180°$ |
| W2 | Wallace (Berkeley) | Yes—to data in H3 | $E_{peak}=92$ $E_{upper}=107$ $E_{lower}\cong 73$ $E_{cutoff}=2$ | None | $H_2$ gas | Nuclear emulsions | Counting statistics and geometry | Yes | $\frac{78.3}{76}$ | Better measurement of $\sigma_{tot}$ (S7) | |
| S6 | Selove, Strauch, Titus (Harvard | Yes—to data in H3 in region $\theta=155$–$167$ | $E_{peak}=93$ $E_{upper}=102$ $E_{lower}$ never down to $\frac{1}{2}$ height $E_{cutoff}=84$ | 2 proton-recoil telescopes with same energy sensitivity | $CH_2-C$ | Scintillation telescope counting protons | Counting statistics | Yes | $\frac{78.3}{76}$ | Better measurement of $\sigma_{tot}$ (S7) | Corrections for finite sizes made here=should be made in reference H5 and F2 near 180° |
| S7 | Stahl, Ramsey (Harvard) | Yes—to $\sigma_{tot}$ of $78.5\pm 3$ | $E_{peak}=93$ $E_{upper}=102$ $E_{lower}$ never down to $\frac{1}{2}$ height. Absorbers adjusted to make $E_{Av}=91$ | Proton-recoil scintillation telescope | Liquid H | Scintillation telescope (Protons) adjusted at each $\theta$ to keep $\bar{E}$ the same | Counting statistics and fitting errors for combining data | No | ... | ... | Normalization good to 5% |
| *E*1 | J. W. Easley (Berkeley) | Yes to data in K1 at 37.8° | $E_{peak}=90$ $E_{upper}=105$ $E_{lower}=70$ | Bi fission counter | Liquid H | Scintillation telescope counting neutrons | Counting statistics | No | ... | ... | |
| | | Yes to data in H3 at 36° | $E_{peak}=290$ $E_{upper}=330$ $E_{lower}=260$ | | | | | | | | |
| B1 | Brueckner, Hartsough, Hayward, Powell (Berkeley) | No | $E_{peak}=100$ $E_{upper}=120$ $E_{lower}=80$ $E_{cutoff}=40$ | None | $H_2$ gas | Cloud chamber | Counting statistics | No | ... | ... | (a) Gives relative $\sigma_{np}(\theta)$ (b) Shows symmetry around 90° |
| T5 | Thresher, Voss, Wilson (Harwell) | None needed. Counter calibrated in direct beam | $E=105$ and $E=137$ Spectrum calculated. Mean energy measured by *C* absorption | $BF_3$ counter | Liquid H | Large scintillator for neutrons | Total $\cong$8% at 105 Mev Total=10% at 137 Mev | No | ... | ... | (a) Polarization correction made (b) Check absolute value by measuring differential elastic scattering from *C*, integrating and comparing with measured total—good to 10% |
| R3 | T. C. Randle (Harwell) | Yes to $\sigma_{np}$ total =55.2 mb | $E_{peak}=130$ $E_{upper}=145$ $E_{lower}=115$ | Not given | Not given | Diffusion cloud chamber | Not given | No | ... | ... | |

TABL III.—(*Continued*).

| Reference | Authors | Data normalized | Energy (Mev) | Monitor | Target | Counters | Source of quoted error | Data renormalized here: Yes or No | By how much | Why | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| G4 | T. C. Griffith (London) | Yes to data in T5 at $\theta$ 60° | $E_{Av}=95$<br>$E_{upper}=120$<br>$E_{lower}=70$<br>$E_{peak}=140$<br>$E_{upper}=160$<br>$E_{lower}=120$ | None | $CH_2-C$ | Nuclear emulsion | Not given | No | ... | ... | |
| R2 | Randle, Taylor, Wood (Harwell) | Yes—to 46.4 mb | $E_{peak}=156$<br>$E_{cutoff}=137$<br>$E_{max}=172$ | $BF_3$ counter in shielding wall | $CH_2-C$ | Proportional counter telescope | Not given | No | ... | ... | |
| G1 | Guernsey, Mott, Nelson (Rochester) | Yes—to $\sigma_{tot}$ $=41.3\pm3.5$ | $E_{peak}=215$<br>$E_{upper}=230$<br>$E_{lower}=180$ | $CH_2$ target scintillation telescope | $+CH_2-C$ | Scintillation telescope (protons) | Counting statistics | Yes | 3% increase | Assumed symmetry about 90° not valid (See Fig. 5.) | (a) Pulse-height height analyzed and protons picked corresponding to neutrons of $E=172$ and 215 Mev<br>(b) Counter calibrated in proton beam |
| K1 | Kelly, Leith, Segrè, Wiegand (Berkeley) | Yes—to $\sigma_{tot}=35$ | $E_{peak}=260$<br>$E_{upper}=310$<br>$E_{lower}=210$<br>$E_{cutoff}=200$ | Bi fission counter | $CH_2-C$ | Proportional counter telescope | Counting statistics | No | ... | ... | |
| D8 | DePangher (Berkeley) | Yes—to $\sigma_{tot}=35$ mb | $E_{peak}=308$<br>$E_{upper}=328$<br>$E_{lower}=280$<br>$E_{cutoff}=155$ | None | $H_2$ gas | 10-atmos cloud chamber | Counting statistics | No | ... | ... | |
| H4 | Hartzler, Siegel, Opitz (Carnegie Tech) | Yes—joined to data in H6 and normalized to $\sigma_{tot}=33$ mb | $E_{peak}=390$<br>$E_{upper}=410$<br>$E_{lower}=325$<br>$E_{cutoff}=365$ | $CH_2$ target +scintillation telescope | Liquid H and $CH_2-C$ | Neutron scintillation telescope | Counting statistics | No | ... | ... | |
| D9 | Dzhelepov Kazarinov (Moscow) | Yes—to $\sigma_{tot}=33$ mb | $E_{peak}=400$<br>$E_{upper}=430$<br>$E_{lower}=300$<br>$E_{cutoff}=300$ | Proportional counter telescope and Bi fission counter | $CH_2-C$ | Proportional counter telescope | Counting statistics | No | ... | ... | (a) Error in absolute value of $\sigma\sim15$ to 20%<br>(b) Unpolarized beam used |
| K3 | Kazarinov, Simonev (Moscow) | Yes—to $\sigma_{tot}=26$ mb | $E_{peak}=610$<br>$E_{upper}=670$<br>$E_{lower}=540$<br>$E_{cutoff}=450$ | Not given | $CH_2-C$ | Scintillation counter telescope | Counting statistics | No | ... | ... | |
| D10[a] | Dzhelepov, Golovin, Satarov (Moscow) | Yes—to $\sigma_{nd}$ total $-\sigma_{np}$ total $=22$ mb | $E=300$ | | $D_2O-H_2O$ | Bi fission counter | Not given | No | ... | ... | The interference term in scattering from deuterium is taken to be zero |
| D13[a] | Dzhelepov, Golovin, Kazarinov, Semenov (Moscow) | Yes—to $\sigma_{np}(\theta)$ at 590 Mev | $E_{peak}=610$<br>$E_{upper}=670$<br>$E_{lower}=540$<br>$E_{cutoff}=470$ | Scintillation telescope | $D_2O$, $H_2O$ $CH_2$ and C | Scintillation telescope with converter | Not given | No | | | |

[a] This experiment is a measurement of neutron-neutron differential cross section.

This result should be reduced in the ratio 43/57 to $3.56\pm0.42$ mb/sterad. Their value based on a photographic-emulsion calibration remains high compared with other measurements."

Figures 6 and 7 show values of $\sigma_{pp}(\theta)$. (Again experimental points have been omitted for simplicity.) There are a great many data from 170 to 430 Mev, all of which statistically agree with 3.7 mb/sterad in the region from 20° to 90° c.m.

Data from Fischer (F4) and Pettengill (C13) tend to indicate that the Coulomb-nuclear scattering interference term is small in the region of 300 Mev.

## VIII. $\sigma_{nn}(\theta)$

Some data are available on $\sigma_{nn}(\theta)$ (see Table VII, the last entry in Table III, and Fig. 8). This has been obtained, as in the total cross section measurements, by

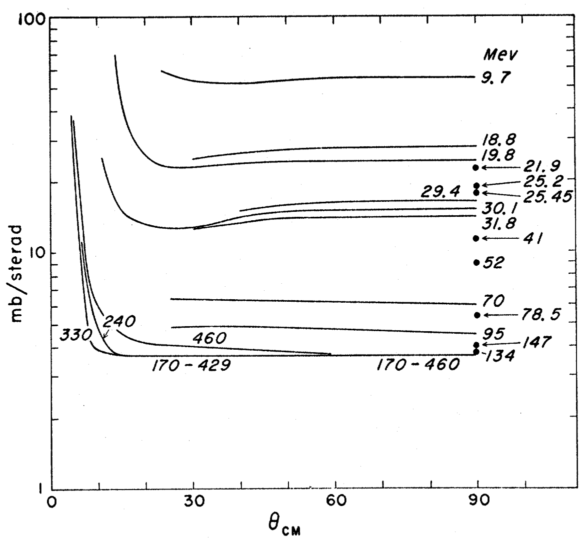


FIG. 6. Experimental values of the differential proton-proton cross section at various energies up to 500 Mev.

neutron scattering from deuterium and hydrogen:

$$\sigma_{nd}(\theta)=\sigma_{nn}(\theta)+\sigma_{np}(\theta)+I(\theta).$$

If we have $I(\theta)=0$, then

$$\sigma_{nn}(\theta)=\sigma_{nd}(\theta)-\sigma_{np}(\theta).$$

An estimate of $I(\theta)$ as a function of $\theta$ has been made by Golovin (mentioned in D10). These values are included in Table VII. They are small enough so that the process above seems reasonable.

Values of $\sigma_{nn}(\theta)$ are shown and also a line representing the best data on $\sigma_{pp}(\theta)$ at 300 Mev and 590 Mev. The values of $\sigma_{nn}(\theta)$ and $\sigma_{pp}(\theta)$ agree statistically, in agreement with the charge-independence hypothesis.

## IX. POLARIZATION OF NUCLEONS

That a beam of nucleons could be polarized was first demonstrated conclusively by Oxley, Cartwright,

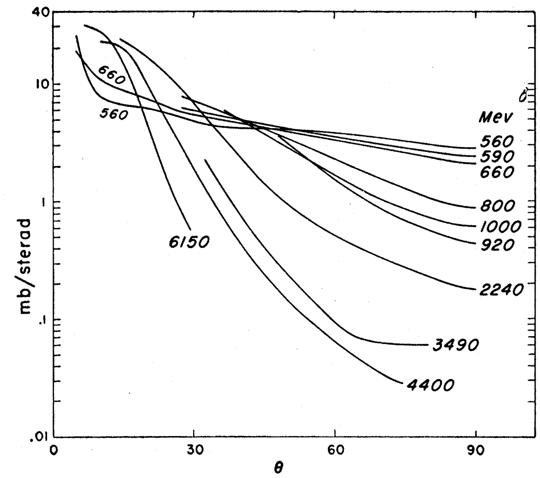


FIG. 7. Experimental values for the differential proton-proton cross section at various energies above 500 Mev.

and Rouvina (O2). Earlier experiments by Wouters (W4) had not given a definite answer.

Double-scattering experiments are performed using nucleon beams to study polarization. The first scattering polarizes the beam, and the second analyzes the polarized beam (Fig. 9). The intensity of the beam scattered to the left and that of the beam scattered to the right are measured (left and right are as seen by an observer looking in the direction of *motion* of the beam; Fig. 10). The asymmetry of scattering, $e$, is usually defined (L3) as

$$e=\frac{I(\theta_2)\text{ left}-I(\theta_2)\text{ right}}{I(\theta_2)\text{ left}+I(\theta_2)\text{ right}}=P_1P_2,$$

where $P_1$ is the polarization of the beam caused by the first scattering, and $P_2$ is the polarization caused by

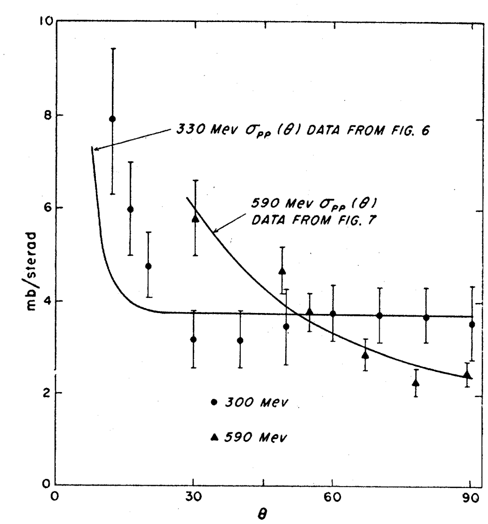


FIG. 8. Experimental values for the differential neutron-neutron cross section at 300 Mev and at 590 Mev. Superimposed for comparison are the $\sigma_{pp}(\theta)$ curves for 300 Mev from Fig. 6 and for 590 Mev from Fig. 7.

TABLE IV. Summary of values for the neutron-proton differential cross section. Some of the values have been renormalized as indicated.

| Reference | $\theta_{c.m.}$ | $\sigma(\theta)\pm\epsilon$ (mb) | Energy (Mev)() | $\sigma'(\theta)\pm\epsilon'$ (mb) | Remarks |
|---|---|---|---|---|---|
| S8 | 70 | 52. 4±3 | 14.1 | | No normalization or renormalization needed |
| | 90 | 53 ±2.5 | | | |
| | 120 | 54 ±2 | | | |
| | 140 | 55.5 ±2 | | | |
| | 160 | 55 ±1 | | | |
| | 173 | 56 ±1 | ↓ | | |
| A4 | 48 | 50.7 ±2.3 | 14.1 | | No normalization or renormalization needed |
| | 66.9 | 49.3 ±2.5 | | | |
| | 84.1 | 53.3 ±2.4 | | | |
| | 100.5 | 51.3 ±2.4 | | | |
| | 114.7 | 51.8 ±1.8 | | | |
| | 131.7 | 53.3 ±2.0 | | | |
| | 146.6 | 54.0 ±1.9 | | | |
| | 154.5 | 54.7 ±1.4 | ↓ | | |
| G2 | 180/90 | 1.08 | 17.9 | 45 | Original data relative only. Normalized here to $\sigma_{np}$ tot=535 mb |
| | | | | 41.6 | |
| B2 | 180/90 | 1.06±0.16 | 19.6 | 42.6 | Same as above $\sigma_{np}$ tot=522 mb |
| | | | | 40.2 | |
| R1 | 15.7 | | 13.7 | 33.6 ±8.8 | The relative data given in this paper have been normalized to give absolute cross sections. |
| | 36.1 | | | 55.1 ±1.2 | |
| | 45.0 | | | 54.0 ±1.5 | |
| | 52.8 | | | 50.7 ±1.3 | |
| | 60.2 | | | 55.7 ±1.9 | |
| | 67.0 | | ↓ | 55.1 ±2.0 | For the 13.7-Mev data the value at 36° was used in normalizing $\sigma_{np}(36°)4\pi$ =695 mb, where 695 mb is the $\sigma_{pn}$ total read from Fig. 1. For the 28.4-Mev data the normalization is done here by $\sigma_{np}(87°)4\pi$ =342 mb, where this value of $\sigma_{np}$ total has also been read from Fig. 1. |
| | 73.4 | | 13.7 | 59.0 ±2.2 | |
| | 79.7 | | | 52.9 ±3.0 | |
| | 86.3 | | ↓ | 59.0 ±4.7 | |
| | 11.3 | | 28.4 | 33.3 ±9.5 | |
| | 29.3 | | | 27.7 ±0.5 | |
| | 41.0 | | | 28.4 ±0.6 | |
| | 50.3 | | | 26.9 ±0.8 | |
| | 58.8 | | | 26.1 ±0.8 | |
| | 66.5 | | | 28.4 ±0.8 | |
| | 73.5 | | | 28.4 ±1.0 | |
| | 80.2 | | | 29.2 ±1.5 | |
| | 87.0 | | | 27.2 ±1.8 | |
| | 94.2 | | ↓ | 24.6 ±3.8 | |
| B3 | 180 | | 27.2 | 33.2 ±1.3 | Relative data in paper have been normalized by $(4\pi)\sigma_{np}(120°)$=360 mb |
| | 150 | | | 31.2 ±1.3 | |
| | 120 | | | 28.6 ±1.3 | |
| | 105 | | | 28.0 ±1.8 | |
| | 90 | | | 25.2 ±1.8 | |
| | 76 | | ↓ | 26.0 ±1.8 | |
| H3 | 62 | 11.65±0.38 | 42 | 13.91±0.45 | 42-Mev data were normalized to $\sigma_{np}$ total=170 mb. These data are renormalized here to a better measurement of $\sigma_{np}$ total=203 mb |
| | 70 | 11.40±0.43 | | 13.61±0.51 | |
| | 80 | 11.37±0.55 | | 13.58±0.66 | |
| | 90 | 11.58±0.20 | | 13.81±0.24 | |
| | 100 | 12.40±0.31 | | 14.80±0.37 | |
| | 110 | 12.02±0.23 | | 14.36±0.28 | |
| | 120 | 12.71±0.22 | | 15.19±0.26 | |
| | 130 | 14.50±0.35 | | 17.31±0.42 | |
| | 140 | 14.55±0.23 | | 17.38±0.27 | |
| | 150 | 15.60±0.33 | | 18.62±0.39 | |
| | 160 | 17.02±0.23 | | 20.35±0.27 | |
| | 170 | 17.10±0.55 | | 20.41±0.66 | |
| | 180 | 19.02±0.70 | ↓ | 22.71±0.84 | |
| | 36.0 | 7.66±0.37 | 90 | 7.89±0.38 | 90-Mev data were normalized to $\sigma_{np}$ total=76 mb; renormalized here to $\sigma_{np}$ total=78.3 mb |
| | 49.0 | 5.91±0.34 | | 6.09±0.35 | |
| | 58.9 | 5.19±0.28 | | 5.35±0.29 | |
| | 60.8 | 3.13±0.55 | | 3.22±0.57 | |
| | 68.8 | 3.86±0.16 | | 3.98±0.16 | |
| | 78.7 | 3.87±0.29 | | 3.99±0.30 | |
| | 88.7 | 4.21±0.09 | | 4.34±0.09 | |
| | 98.7 | 4.51±0.17 | | 4.65±0.18 | |
| | 108.8 | 5.34±0.17 | | 5.50±0.18 | |

TABLE IV.—(*Continued*).

| Reference | $\theta_{c.m.}$ | $\sigma(\theta)\pm\epsilon$ (mb) | Energy (Mev) | $\sigma'(\theta)\pm\epsilon'$ (mb) | Remarks |
|---|---|---|---|---|---|
| H3 (contd.) | 118.8 | 6.09±0.17 | 90 | 6.27±0.18 | |
| | 129.0 | 6.53±0.19 | | 6.72±0.20 | |
| | 139.1 | 7.88±0.19 | | 8.11±0.20 | |
| | 149.3 | 8.92±0.23 | | 9.20±0.24 | |
| | 159.5 | 10.90±0.14 | | 11.22±0.14 | |
| | 165.7 | 11.17±0.43 | | 11.50±0.44 | |
| | 169.8 | 12.35±0.32 | | 12.71±0.33 | |
| | 173.9 | 12.85±0.28 | | 13.22±0.29 | |
| | 175.9 | 13.48±1.34 | | 13.88±1.38 | |
| | 180.0 | 15.50±0.70 | | 15.97±0.72 | |
| C6 | 5.1 | 12.9 ±1.2 | 90 | 13.3 ±1.2 | Normalized to data in H3 at 36°. Data renormalized to $\sigma_{np}$ total=78.3 mb. |
| | 10.3 | 12.0 ±0.7 | | 12.4 ±0.7 | |
| | 20.8 | 10.3 ±0.6 | | 10.6 ±0.6 | |
| | 36.0 | 7.6 ±0.4 | | 7.8 ±0.4 | |
| | 10.7 | 5.6 ±1.1 | 290 | | Normalized to data in K1 at 37.8°. No renormalization |
| | 21.7 | 4.3 ±0.9 | | | |
| | 37.8 | 3.6 ±0.7 | | | |
| C7 | 8– 10 | 12.5 ±2.6 | 90 | 12.9 ±2.7 | Data normalized to $\sigma_{np}$ total=76 mb. These data are renormalized to $\sigma_{np}$ total=78.3 mb |
| | 10– 20 | 9.6 ±0.7 | | 9.90±0.7 | |
| | 20– 30 | 9.7 ±0.6 | | 10.0 ±0.6 | |
| | 30– 40 | 7.7 ±0.4 | | 7.92±0.4 | |
| | 40– 50 | 6.6 ±0.5 | | 6.80±0.5 | |
| | 50– 60 | 6.3 ±0.5 | | 6.50±0.5 | |
| | 60– 70 | 4.9 ±0.4 | | 5.05±0.4 | |
| | 70– 80 | 4.4 ±0.3 | | 4.52±0.3 | |
| | 80– 90 | 4.6 ±0.3 | | 4.73±0.3 | |
| | 90–100 | 4.4 ±0.3 | | 4.52±0.3 | |
| | 100–110 | 4.4 ±0.3 | | 4.52±0.3 | |
| | 110–120 | 5.2 ±0.3 | | 5.35±0.3 | |
| | 120–130 | 5.4 ±0.3 | | 5.55±0.3 | |
| | 130–140 | 6.5 ±0.4 | | 6.70±0.4 | |
| | 140–150 | 7.1 ±0.3 | | 7.30±0.3 | |
| | 150–160 | 9.5 ±0.4 | | 9.77±0.4 | |
| | 160–170 | 11.9 ±0.5 | | 12.25±0.5 | |
| | 170–180 | 12.9 ±1.0 | | 13.3 ±1.03 | |
| F2 | 129 | 8.1 ±0.73 | 90 | 8.3 ±0.75 | Data normalized to a smooth curve drawn through the H3 data. Renormalized to $\sigma_{np}$ total =78.3 mb |
| | 159.5 | 9.7 ±0.83 | | 10.0 ±0.86 | |
| | 165.7 | 11.4 ±0.92 | | 11.7 ±0.95 | |
| | 169.8 | 11.8 ±0.50 | | 12.2 ±0.52 | |
| | 171.8 | 11.7 ±0.58 | | 12.1 ±0.60 | |
| | 173.9 | 13.5 ±0.50 | | 13.9 ±0.52 | |
| | 175.9 | 12.0 ±0.61 | | 12.4 ±0.63 | |
| | 178 | 11.6 ±0.64 | | 12.0 ±0.66 | |
| W2 | 74 | 4.28±0.19 | 90 | 4.41±0.20 | Data normalized to data in H3 |
| | 68 | 4.80±0.20 | | 4.95±0.21 | |
| | 62 | 5.42±0.22 | | 5.59±0.23 | |
| | 56 | 5.48±0.22 | | 5.65±0.23 | |
| | 50 | 6.02±0.24 | | 6.20±0.25 | |
| | 44 | 6.11±0.26 | 90 | 6.30±0.27 | |
| | 38 | 6.77±0.29 | | 6.97±0.30 | |
| | 32 | 8.01±0.34 | | 8.26±0.35 | |
| | 26 | 7.60±0.39 | | 7.84±0.40 | |
| S6 | 177.5 | 12.90±0.33 | 93 | 13.30±0.34 | Data normalized to H3 in region of 155°–167°. Renormalized here by 78.3/76 as a result of a new $\sigma_{np}$ total measurement |
| | 175.4 | 12.73±0.31 | | 13.12±0.32 | |
| | 171.5 | 12.50±0.30 | | 12.89±0.31 | |
| | 167.5 | 11.96±0.29 | | 12.32±0.30 | |
| | 161.4 | 10.75±0.27 | | 11.08±0.28 | |
| | 155.4 | 9.53±0.26 | | 9.83±0.27 | |
| S7 | 176.6 | 13.08±0.41 | 91 | | Data normalized to $\sigma_{np}$ total=78.3 mb. No renormalization needed |
| | 175.6 | 13.09±0.38 | | | |
| | 173.7 | 13.30±0.33 | | | |
| | 171.7 | 13.24±0.35 | | | |
| | 169.7 | 12.61±0.32 | | | |
| | 167.3 | 11.84±0.30 | | | |
| | 164.5 | 11.82±0.31 | | | |
| | 162.0 | 10.85±0.33 | | | |
| | 159.4 | 10.42±0.29 | | | |

TABLE IV.—(*Continued*).

| Reference | $\theta_{c.m.}$ | $\sigma(\theta)\pm\epsilon$ (mb) | Energy (Mev) | $\sigma'(\theta)\pm\epsilon'$ (mb) | Remarks |
|---|---|---|---|---|---|
| S7 | 159.4 | 10.84±0.43 | 91 | | |
| (contd.) | 154.9 | 9.97±0.30 | | | |
| | 149.3 | 9.13±0.24 | | | |
| | 139.1 | 7.74±0.19 | | | |
| | 139.1 | 8.08±0.28 | | | |
| | 129.0 | 6.51±0.17 | | | |
| | 118.8 | 5.99±0.15 | | | |
| | 108.7 | 4.93±0.16 | | | |
| | 98.7 | 4.53±0.14 | | | |
| | 88.7 | 4.19±0.15 | | | |
| | 82.7 | 3.97±0.13 | | | |
| | 78.7 | 4.17±0.15 | | | |
| | 74.7 | 4.08±0.19 | | | |
| | 69.7 | 4.26±0.18 | | | |
| | 64.8 | 4.88±0.29 | | | |
| | 59.8 | 5.61±0.33 | ↓ | | |
| G4 | 29.3 | 8.01±0.84 | 95–100 | | Data normalized to T5 at $\theta=60°$. No renormalization needed |
| | 39.1 | 6.80±0.64 | | | |
| | 48.9 | 5.30±0.67 | | | |
| | 58.7 | 4.58±0.76 | ↓ | | |
| | 19.3 | 6.23±1.14 | 140–145 | | |
| | 29.0 | 5.15±0.48 | | | |
| | 38.8 | 4.10±0.36 | | | |
| | 48.5 | 3.45±0.38 | | | |
| | 58.3 | 2.70±0.44 | ↓ | | |
| T5 | 6.2 | 11.6 ±1.0 | 105 | | Nor normalization or renormalization needed |
| | 10.5 | 11.1 ±1.0 | | | |
| | 20.5 | 10.2 ±0.6 | | | |
| | 30.7 | 8.50±0.4 | | | |
| | 40.9 | 7.10±0.45 | | | |
| | 51.2 | 6.00±0.5 | | | |
| | 61.4 | 4.55±0.5 | ↓ | | |
| | 6.3 | 8.90±1.0 | 137 | | |
| | 10.6 | 8.00±0.6 | | | |
| | 20.7 | 6.90±0.4 | | | |
| | 31.0 | 5.85±0.35 | | | |
| | 41.3 | 4.38±0.4 | | | |
| | 51.6 | 2.86±0.4 | | | |
| | 61.8 | 2.70±0.4 | ↓ | | |
| R3 | 20– 30 | 6.55±0.75 | 130 | | Data normalized to $\sigma_{np}$ total=55.2 mb. No renormalization needed |
| | 30– 40 | 5.59±0.59 | | | |
| | 40– 50 | 3.86±0.44 | | | |
| | 50– 60 | 3.31±0.38 | | | |
| | 60– 70 | 2.45±0.31 | | | |
| | 70– 80 | 2.96±0.33 | | | |
| | 80– 90 | 2.64±0.31 | | | |
| | 90–100 | 2.54±0.30 | | | |
| | 100–110 | 3.13±0.34 | | | |
| | 110–120 | 3.80±0.39 | | | |
| | 120–130 | 5.31±0.48 | | | |
| | 130–140 | 5.23±0.51 | | | |
| | 140–150 | 6.13±0.62 | | | |
| | 150–160 | 8.75±0.87 | ↓ | | |
| R2 | 50 | 2.96±0.43 | 156 | | Data normalized to $\sigma_{np}$ total=46.4 mb. No renormalization needed |
| | 56 | 2.14±0.40 | | | |
| | 65.5 | 2.59±0.40 | | | |
| | 68 | 2.34±0.18 | | | |
| | 76.5 | 1.98±0.22 | | | |
| | 83 | 1.98±0.19 | | | |
| | 89.5 | 2.29±0.18 | | | |
| | 98 | 2.71±0.31 | | | |
| | 99.5 | 2.51±0.19 | | | |
| | 112 | 3.87±0.18 | | | |
| | 124.5 | 4.04±0.28 | | | |
| | 138 | 6.19±0.26 | | | |
| | 149 | 6.88±0.43 | | | |
| | 159 | 7.98±0.13 | | | |
| | 165 | 8.59±0.29 | | | |
| | 171 | 10.04±0.20 | | | |

TABLE IV.—(*Continued*).

| Reference | $\theta_{c.m.}$ | $\sigma(\theta)\pm\epsilon$ (mb) | Energy (Mev) | $\sigma'(\theta)\pm\epsilon'$ (mb) | Remarks |
|---|---|---|---|---|---|
| R2 (contd.) | 174 | 9.68±0.47 | 156 | | |
| | 176 | 10.65±0.46 | | | |
| | 178 | 10.69±0.54 | ↓ | | |
| G1 | 180 | 13.4 ±2.8 | 215 | 13.8 ±2.9 | Data normalized to $\sigma_{np}$ total=41.3 mb. |
| | 164.2 | 8.89±0.66 | | 9.15±0.68 | |
| | 158.8 | 7.58±0.75 | | 7.80±0.77 | |
| | 157.3 | 6.97±1.31 | | 7.18±1.35 | Renormalized because symmetry about 90° (c.m.) was assumed in normalization process and it is now known not to be true. |
| | 148.4 | 5.38±0.47 | | 5.54±0.49 | |
| | 139.9 | 4.18±0.35 | | 4.30±0.36 | |
| | 117.7 | 2.53±0.37 | | 2.61±0.38 | |
| | 117.2 | 2.40±0.32 | | 2.47±0.33 | |
| | 96.9 | 1.31±0.12 | | 1.35±0.12 | |
| | 76.9 | 1.45±0.22 | ↓ | 1.49±0.23 | |
| | 180 | 16.6 ±6.8 | 172 | 17.1 ±7.0 | |
| | 164.5 | 10.9 ±1.4 | | 11.24±1.44 | |
| | 159.3 | 7.6 ±1.5 | | 7.83±1.54 | |
| | 157.8 | 7.0 ±1.2 | | 7.21±1.23 | |
| | 148.8 | 5.3 ±0.8 | | 5.46±0.82 | |
| | 140.5 | 3.5 ±0.9 | | 3.61±0.92 | |
| | 118.2 | 2.1 ±0.9 | | 2.16±0.92 | |
| | 117.7 | 2.5 ±0.4 | | 2.57±0.61 | |
| | 97.4 | 2.4 ±0.4 | | 2.47±0.41 | |
| | 77.5 | 2.3 ±0.7 | ↓ | 2.37±0.71 | |
| K1 | 37.7 | 3.6 ±0.7 | 260 | | Data normalized to $\sigma_{np}$ total=35 mb |
| | 47.2 | 3.3 ±0.6 | | | |
| | 56.8 | 1.1 ±0.6 | | | |
| | 66.6 | 1.7 ±0.4 | | | No renormalization needed |
| | 76.4 | 1.9 ±0.7 | | | |
| | 86.3 | 1.85±0.14 | | | |
| | 96.3 | 1.09±0.26 | | | |
| | 106.5 | 2.02±0.21 | | | |
| | 116.7 | 1.90±0.24 | | | |
| | 127.1 | 2.8 ±0.4 | | | |
| | 137.6 | 4.5 ±0.3 | | | |
| | 148.1 | 4.7 ±0.4 | | | |
| | 158.7 | 6.4 ±0.3 | | | |
| | 169.3 | 7.8 ±0.8 | | | |
| | 180 | 13.7 ±2.1 | ↓ | | |
| D8 | 10– 20 | 3.83±0.63 | 300 | | Data normalized to $\sigma_{np}$ total=35 mb |
| | 20– 30 | 3.48±0.47 | | | |
| | 30– 40 | 3.81±0.41 | | | |
| | 40– 50 | 3.50±0.35 | | | No renormalization needed |
| | 50– 60 | 2.96±0.28 | | | |
| | 60– 70 | 2.31±0.31 | | | |
| | 70– 80 | 2.02±0.20 | | | |
| | 80– 90 | 1.89±0.18 | | | |
| | 90–100 | 1.51±0.14 | | | |
| | 100–110 | 2.07±0.16 | | | |
| | 110–120 | 2.17±0.17 | | | |
| | 120–130 | 2.51±0.19 | | | |
| | 130–140 | 3.06±0.23 | | | |
| | 140–150 | 4.06±0.29 | | | |
| | 150–160 | 4.71±0.37 | | | |
| | 160–170 | 6.48±0.55 | | | |
| | 170–180 | 9.14±1.12 | ↓ | | |
| D9 | 36.6 | 2.9 ±0.5 | 380 | | |
| | 55.5 | 2.3 ±0.3 | | | |
| | 65 | 2.0 ±0.2 | | | |
| | 75 | 2.1 ±0.4 | | | Data normalized to $\sigma_{np}$ total=33 mb |
| | 84.5 | 2.0 ±0.2 | | | |
| | 95 | 1.7 ±0.5 | | | |
| | 105 | 2.0 ±0.2 | | | |
| | 115 | 2.1 ±0.2 | | | |
| | 126 | 2.2 ±0.2 | | | |
| | 136 | 2.8 ±0.2 | | | |
| | 147 | 3.5 ±0.2 | | | No renormalization needed |
| | 158 | 5.3 ±0.5 | | | |
| | 169 | 7.5 ±0.6 | | | |
| | 180 | 11.8 ±1.8 | ↓ | | |

TABLE IV.—(*Continued*).

| Reference | $\theta_{c.m.}$ | $\sigma(\theta\pm\epsilon)$ (mb) | Energy (Mev) | $\sigma'(\theta)\pm\epsilon'$ (mb) | Remarks |
|---|---|---|---|---|---|
| H4 | 12.7 | 3.73±2.10 | 400 | | Data normalized to $\sigma_{np}$ total=33 mb |
| | 15 | 4.43±0.46 | ↓ | | |
| | 20 | 3.07±0.37 | | | No renormalization needed |
| | 30 | 2.84±0.57 | | | |
| | 40 | 3.33±0.20 | | | |
| | 45 | 3.35±0.20 | | | |
| | 50 | 3.38±0.12 | | | |
| | 55 | 2.56±0.23 | | | |
| | 60 | 2.48±0.08 | | | |
| | 70 | 2.22±0.09 | | | |
| | 80 | 1.85±0.06 | | | |
| | 90 | 1.54±0.06 | | | |
| | 100 | 1.42±0.08 | | | |
| | 110 | 1.50±0.08 | | | |
| | 120 | 1.94±0.08 | | | |
| | 130 | 2.50±0.09 | | | |
| | 140 | 3.21±0.09 | | | |
| | 150 | 4.17±0.11 | | | |
| | 160 | 5.25±0.14 | | | |
| | 165 | 5.82±0.22 | | | |
| | 170 | 7.93±0.28 | | | |
| | 175 | 9.57±0.34 | | | |
| | 180 | 13.49±0.91 | | | |
| K3 | 35 | 3.7 ±0.20 | 580 | | Data normalized to $\sigma_{np}$ elastic=26 mb |
| | 45 | 3.0 ±0.30 | ↓ | | |
| | 54 | 2.3 ±0.20 | | | No renormalization needed |
| | 63 | 2.1 ±0.20 | | | |
| | 73 | 1.6 ±0.10 | | | |
| | 83 | 1.1 ±0.10 | | | |
| | 93 | 0.91±0.06 | | | |
| | 103 | 0.78±0.05 | | | |
| | 114 | 0.78±0.05 | | | |
| | 124 | 1.0 ±0.07 | | | |
| | 135 | 1.7 ±0.10 | | | |
| | 147 | 2.1 ±0.20 | | | |
| | 157 | 3.4 ±0.30 | | | |
| | 169 | 5.3 ±0.50 | | | |
| | 180 | 8.5 ±0.80 | | | |

the second scattering. (Sometimes, however, a definition of $e$ is used that gives a value twice that obtained above.) Another notation often used in this definition is $I(\theta,\phi)$, where $\phi=0$ corresponds to left and $\phi=180$ corresponds to right. The sign convention usually used is that spin-up scattering to the left corresponds to positive polarization (Fig. 10).

A summary of experiments with polarized nucleon beams is given in Table VIII. Values for the polarization obtained in nucleon-nucleon scattering as a function of angle are listed in Table IX. Figures 11, 12, and 13 show experimental values for the polarization produced in nucleon-nucleon collisions. Double-scattering $p$-$p$ experiments have been performed at energies lower than those listed in Table VIII. Strauch (S12) used 96-Mev protons and found that the polarization from a carbon target is quite small. (For higher energies the polarization from a carbon target is comparable to or larger than from an H target). Using 32-Mev protons, Bradner, Donaldson, and Iloff (B11) and Simmons

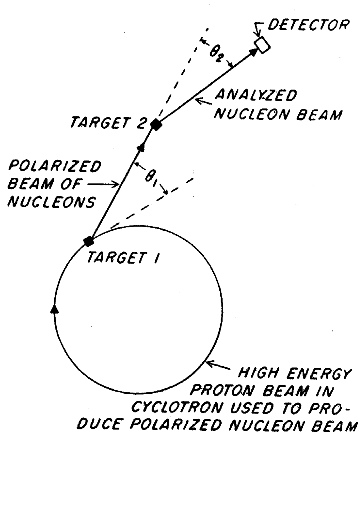


FIG. 9. Typical geometry for nucleon polarization experiment.

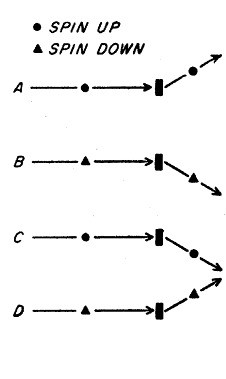


FIG. 10. Sign convention used in nucleon polarization studies. $A$ and $B$ represent positive polarization and $C$ and $D$ negative polarization.

TABLE V. A summary of experiments on the proton-proton differential cross section.

| Reference | Authors | Data normalized | Energy (Mev) | Monitor | Target | Counters | Source of quoted error | Data renormalized here: Yes or No | By how much | Why | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A5 | Allred, Armstrong, Bondelid, Rosen (Los Alamos) | No | 9.7±0.15 | Faraday cup | $H_2$ gas | Nuclear emulsions | Total | No | ··· | ··· | |
| C16 | Cork, Hartsough (Berkeley) | No | 9.73±0.05 | Ion chamber +Faraday cup | $H_2$ gas | Scintillators | Total | No | ··· | ··· | |
| W3 | Wilson (Harvard) | Yes—to 4.9 mb/sterad at 90° for first run and second run tied on to first run at 50° | 10 | Faraday cup | Nylon $(C_{12}H_{22}N_2O)_x$ | Proportional counters | Rms errors from consistency of data | No | ··· | ··· | Data plotted not tabulated. 25°–65° quite flat |
| Y1 | Yntema, White (Princeton) | No | 18.2 | Faraday cup | $CH_2$ | Scintillators in coincidence | Total of 1% at 90° and 0.5% at 30° | No | ··· | ··· | |
| B6 | Burkig, Schrank, Richardson (UCLA) | No | 19.8 | Faraday cup | $H_2$ gas | Scintillator | Total errors =2.0% | No | ··· | ··· | |
| R5 | Royden (UCLA) | No | 19.8 | Faraday cup | $H_2$ gas | Nuclear emulsions | Total errors =2.5% | No | ··· | ··· | |
| C10 | Cork (Berkeley) | No | 18.8–31.8 | Faraday cup | $H_2$ gas | Proportional counters | Counting statistics | No | ··· | ··· | |
| P2 | Panofsky, Fillmore (Berkeley) | No | 29.4 | Faraday cup | $H_2$ gas | Nuclear emulsions | Total | No | ··· | ··· | |
| F3 | Fillmore (Berkeley) | No | 30.1 | Faraday cup | $H_2$ gas | Nuclear emulsions | Counting statistics | No | ··· | ··· | Absolute value good to 2.7% |
| C9 | Cork, Johnston, Richman (Berkeley) | No | 31.8 | Faraday cup | $H_2$ gas | Proportional counters | Total | No | ··· | ··· | |
| K2 | Kruse, Teem Ramsey (Harvard) | No | 40–95 | Faraday cup | $CH_2-C$ | Scintillators | 95 Mev data Counting statistics 90° data total | No | ··· | ··· | |
| B4 | Birge, Kruse, Ramsey (Harvard) | No | 105<br>75 | $C^{12}(p,pn)C^{11}$ | $CH_2$ | Scintillators, in coincidence | Differential 10% absolute 20% | Yes | $\frac{36}{41}$ | Monitor cross section wrong (C14) | C background subtraction from target not made |

TABLE V.—(*Continued*).

| Reference | Authors | Data normalized | Energy (Mev) | Monitor | Target | Counters | Source of quoted error | Data renormalized here: Yes or No | By how much | Why | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C11 | Cassels, Pickavance, Stafford (Harwell) | No | 147 | $C^{12}(p,pn)C^{11}$ also nuclear emulsions | $CH_2-C$ | Proportional counters in 90° coincidence+geometry-defining slit | Total | Yes<br>Data taken using nuclear emulsions should not be renormalized | $\frac{43}{57}$ | Monitor cross section wrong (C14) | (a) Used brass slit in telescope. Calculations made but questionable<br>(b) Reported later lower value (see P3) |
| P3 | Taylor (Harwell) | | 134 | | | | | No | ··· | ··· | (a) $\sigma_{pp}(90°)=3.80\pm0.13$<br>(b) Data obtained by measuring $\sigma_{tot}$ and assuming isotropic scattering, extrapolated to 0°, and Coulomb scattering excluded. |
| P3 | Cassels (Harwell) | | 147 | | | | | No | ··· | ··· | $\sigma_{pp}(90°)=4.05\pm0.28$ new measurement |
| C12 | Garrison (Berkeley) | No | 170<br>260 | Ion chamber +Faraday cup | Liquid H | Scintillators | Counting statistics +others | No | ··· | ··· | Absolute value good to ~8% |
| C8 | Chamberlain, Segrè, Wiegand (Berkeley) | No absolute measurement | 345<br>250<br>164<br>120 | Ion chamber calibrated by Faraday cup | $CH_2-C$ with liquid H at small $\theta$ | Scintillators—coincidence for large $\theta$ not for small $\theta$ | Counting statistics | No | ··· | ··· | other errors ~5%<br>only elastic events counted |
| C13 | Pettengill (Berkeley) | Yes—to 3.75 mb/sterad at 21°<br>No | 300<br>160<br>230<br>330 | Scintillator counting single particles | Liquid H | Scintillators | Total | No | ··· | ··· | (a) At 300 Mev get $\sigma_{pp}(\theta)$ from 6.5 to 21.7° c.m.<br>(b) At 160, 230, and 330 measure $\sigma_{pp}$ total<br>(c) Polarization corrections made |
| O1 | Oxley, Schamberger (Rochester) | No | 240 | $C^{12}(p,pn)C^{11}$ | $CH_2$ | Scintillators in coincidence | Counting statistics | Yes | $\frac{36}{41}$ | Monitor cross section wrong (C14) | (a) C background subtraction from target not made<br>(b) Other errors ~8% |
| T6 | Towler (Rochester) | No | 240 | $C^{12}(p,pn)C^{11}$ | $CH_2-C$ | Nuclear emulsions | Counting statistics | Yes | $\frac{36}{41}$ | Monitor cross section wrong (C14) | Other errors ~9% |
| C12 | Chamberlain, Garrison (Berkeley) | No | 170<br>260 | Ion chamber calibrated by Faraday cup | Liquid H | Scintillators | Counting statistics +others | No | ··· | ··· | Absolute values good to ~8% |

TABLE V.—(*Continued*).

| Reference | Authors | Data normalized | Energy (Mev) | Monitor | Target | Counters | Source of quoted error | Data renormalized here: Yes or No | By how much | Why | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C13 | Chamberlain, Pettengill, Segrè, Wiegand (Berkeley) | Yes—to 3.7 mb/sterad at 20° | 300 | Counter for single protons | Liquid H | Scintillator | Counting statistics | No | ... | ... | |
| F4 | Fischer, Goldhaber (Berkeley) | Yes—to 3.7 mb/sterad | 330 | None | Liquid H | Nuclear emulsions | Counting statistics | No | ... | ... | Small-angle data fits well to relativistic Coulomb $\sigma$ theory |
| M6 | Marshall, Marshall, Nedzel (Chicago) | No | 429<br>271<br>144 | Scintillator counting individual protons | Liquid H | Scintillators in coincidence $\theta>54$ one only $\theta<54$ | Counting statistics | ... | ... | ... | Beam polarized therefore data wrong. Data right in M5. Only elastic events counted |
| C15 | Chamberlain, Wiegand (Berkeley) | No | 340 | Ion chamber +Faraday cup | $CH_2-C$ | Proportional counters | Counting statistics | No | ... | ... | (a) Proportional counter wall cause too high values for $\sigma$ due to scattering—in (b) Data revised and reported later in C8 (c) Other errors ~10% |
| H7 | Harting, Holt, Kluyver, Moore (Liverpool) | No | 380 | Faraday cup | $CH_2-C$ | Scintillators | | No | ... | ... | |
| H5 | Hartzler, Siegel (Carnegie Tech) | None-relative values only | 365–428 | None | $CH_2-C$ | Scintillator | Counting statistics | No | ... | ... | (a) Part of paper on $n$-$p$ cross section. (b) Relative values of $\sigma$ only Only elastic events included in data |
| M5 | Marshall, Marshall, Nedzel (Chicago) | No | 419 | | | | | No | ... | ... | Correction of M6 due to polarization of the beam. Only elastic events counted |
| K4 | Kao, Clark (Carnegie Tech) | No | 432 | Total path length in emulsion | H in emulsion | Nuclear emulsions | Not given | No | ... | ... | Only elastic events |
| S9 | Sutton, Field, Fox, Kane, Mott, Stallwood (Carnegie Tech) | No | 437 | Ion chamber | $CH_2-C$ and Liquid H | Scintillators | Counting statistics | No | ... | ... | Absolute value good to ~5%. Ion chamber $M$ calculated from $\Delta E$/ion pair. Only elastic events counted. |
| M4 | Meshcheryakov, Bogachev, Neganov (Moscow) | No | 460 | Faraday cup +ion chamber | $CH_2-C$ | Scintillators | Counting statistics | No | ... | ... | (a) Events elastic to 5 Mev (per $\theta$) (b) Other error ~10% |
| M7 | Meshcheryakov, Neganov, Soroko, Vzorov (Moscow) | No | 460–660 | Ion chamber | $CH_2-C$ | Scintillators | Counting statistics =3% at 90° | No | ... | ... | Other errors ~5% at 90° and ~8% at 30°. Only elastic events counted |

TABLE V.—(*Continued*).

| Reference | Authors | Data normalized | Energy (Mev) | Monitor | Target | Counters | Source of quoted error | Data renormalized here: Yes or No | By how much | Why | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| B7 | Bogachev (Moscow) | | 460<br>560<br>660 | | | | | | | | |
| S10 | Selektor, Nikitin, Bogomolov, Zombkovsky (Moscow) | No | 460<br>560<br>660 | Ion chamber +Faraday cup | $CH_2-C$ | Proportional counters | Counting statistics | No | ··· | ··· | (a) Proportional counter walls may cause σ too high same as in C15<br>(b) Errors in abs σ<br>$(E=460)=10\%$<br>$(E=560)=10\%$<br>$(E=660)=\ 5\%$ |
| B13 | Bogomolev, Zombkovski, Nitikin, Selektor (Moscow) | Yes to $\sigma_{pp}(30°)=547$ | 660 | Ion chamber | Liquid H | Scintillators +Čerenkov Counter | Counting statistics | No | ··· | ··· | |
| B5 | Bogachev, Vzorov (Moscow) | No | 660 | Faraday cup +ion chamber | $CH^2-C$ | Scintillators | Counting statistics | No | ··· | ··· | (a) Maximum total error ~10% |
| S2 | Smith, McReynolds, Snow (Brookhaven) | Yes—to Sutton, S9, at 437 Mev at 90° | 440–1000 | Counter telescope+ circulating beam induction electrode | $CH_2-C$ | Scintillators | Counting statistics | No | ··· | ··· | Only elastic events counted |
| D7 | Duke, Lock, March, Gibson, McKeague, Huhges, Muirhead (Birmingham) | No | 950 | None | H in emulsion | Nuclear emulsions | Counting statistics | No | ··· | ··· | (a) Kinematics identifies the elastic events from H<br>(b) Preliminary data only a few events |
| C17 | Cork, Wenzel, Causey (Berkeley) | No | 920<br>2240<br>3490<br>4400<br>6150 | Induction electrode | $CH_2$ | Scintillator telescopes at coincidence angles | ±30% due to calibration of monitor on $E=920$ and 3490 and ±15% on $E=2240$, 4400 and 6150 other errors somewhat less | No | ··· | ··· | (a) Only elastic events counted<br>(b) Secondary monitor ruled out trouble with multiple traversals<br>(c) C target background <10% |

Table VI. Summary of values for the proton-proton differential cross section. Some of the values have been renormalized as indicated.

| Reference | $\theta_{c.m.}$ | $\sigma(\theta)\pm\epsilon$ (mb) | Energy (Mev) | $\sigma'(\theta)\pm\epsilon'$ (mb) | Remarks |
|---|---|---|---|---|---|
| C16 | 29 | 51.7 ±2.3 | 9.7 | | No normalization or renormalization needed |
| | 34 | 52.8 ±2.1 | | | |
| | 41 | 54.3 ±2.1 | | | |
| | 44 | 52.8 ±2.6 | | | |
| | 51 | 54.3 ±2.1 | | | |
| | 54 | 55.4 ±2.3 | | | |
| | 61 | 55.4 ±2.3 | | | |
| | 64 | 56.7 ±2.5 | | | |
| | 71 | 58.8 ±2.4 | | | |
| | 74 | 59.9 ±2.9 | | | |
| | 81 | 58.2 ±2.3 | | | |
| | 84 | 57.8 ±2.3 | | | |
| | 91 | 58.5 ±2.4 | | | |
| | 94 | 58.4 ±2.4 | | | |
| | 101 | 56.7 ±2.2 | | | |
| | 104 | 59.9 ±2.5 | | | |
| | 111 | 58.2 ±2.4 | | | |
| | 114 | 57.8 ±2.7 | | | |
| | 121 | 56.4 ±2.4 | ↓ | | |
| | 24 | 59.2 ±2.6 | 9.85 | | |
| | 26 | 55.5 ±2.6 | | | |
| | 29 | 53.6 ±2.5 | | | |
| | 31 | 50.9 ±2.3 | | | |
| | 34 | 49.6 ±2.3 | | | |
| | 41 | 54.8 ±2.5 | | | |
| | 44 | 56.8 ±2.9 | | | |
| | 61 | 54.1 ±2.5 | ↓ | | |
| C16 | 27°32′ | 55.95±0.50 | 9.7 | | No normalization or renormalization needed |
| | 40°16′ | 52.46±0.43 | | | |
| | 49°48′ | 53.89±0.54 | | | |
| | 59°38′ | 55.06±0.49 | | | |
| | 60°8′ | 55.38±0.60 | | | |
| | 68°20′ | 54.84±0.49 | | | |
| | 79°44′ | 53.91±0.47 | | | |
| | 90°50′ | 56.11±0.51 | | | |
| | 112°35′ | 54.52±0.73 | ↓ | | |
| W3 | 24 | 55 ±3 | 10 | | Data read from graph |
| | 28 | 49 ±1.5 | | | |
| | 32 | 45 ±1.0 | | | |
| | 36 | 47 ±1.0 | | | |
| | 38 | 46 ±1.0 | | | |
| | 40 | 46 ±1.0 | | | |
| | 45 | 47 ±1.0 | | | |
| | 50 | 49 ±1.0 | | | |
| | 52 | 49 ±1.0 | | | |
| | 56 | 49 ±1.0 | ↓ | | |
| Y1 | 90 | 27.32±0.14 | 18.2 | | No normalization or renormalization needed |
| | 80 | 27.29±0.14 | | | |
| | 70 | 27.48±0.14 | | | |
| | 60 | 27.42±0.16 | | | |
| | 50 | 27.27±0.19 | | | |
| | 40 | 26.55±0.21 | | | |
| | 36 | 26.00±0.26 | | | |
| | 30 | 24.94±0.25 | ↓ | | |
| B6 | 14 | 59.7 ±1.5 | 19.8 | | No normalization or renormalization needed |
| | 16 | 38.1 ±0.9 | | | |
| | 18 | 29.8 ±0.7 | | | |
| | 20 | 26.1 ±0.7 | | | |
| | 22 | 24.3 ±0.6 | | | |
| | 24 | 23.4 ±0.6 | | | |
| | 26 | 22.6 ±0.6 | | | |
| | 30 | 23.5 ±0.6 | | | |
| | 36 | 23.6 ±0.6 | | | |
| | 40 | 23.7 ±0.6 | | | |
| | 50 | 24.7 ±0.6 | | | |
| | 60 | 24.0 ±0.6 | | | |
| | 70 | 24.6 ±0.6 | | | |
| | 80 | 24.3 ±0.6 | | | |
| | 90 | 24.5 ±0.6 | ↓ | | |

TABLE VI.—(*Continued*).

| Reference | $\theta_{c.m.}$ | $\sigma(\theta)\pm\epsilon$ (mb) | Energy (Mev) | $\sigma'(\theta)\pm\epsilon'$ (mb) | Remarks |
|---|---|---|---|---|---|
| R5 | 18.04 | 32.2 ±0.8 | 19.8 | | No normalization or renormalization needed |
| | 22.20 | 23.6 ±0.6 | ↓ | | |
| | 24.42 | 23.4 ±0.6 | | | |
| | 26.12 | 23.6 ±0.6 | | | |
| | 29.78 | 22.8 ±0.6 | | | |
| | 32.06 | 22.9 ±0.6 | | | |
| | 35.12 | 23.9 ±0.6 | | | |
| C10 | 90 | 14.4 ±0.15 | 31.8 | | No normalization or renormalization needed |
| | 90 | 18.36±0.18 | 25.45 | | |
| | 90 | 18.7 ±0.32 | 25.2 | | |
| | 90 | 22.8 ±0.51 | 21.9 | | |
| | 90 | 27.2 ±0.68 | 18.8 | | |
| P2 | 87.3 | 16.00±0.31 | 29.4 | | No normalization or renormalization needed |
| | 80 | 16.38±0.27 | ↓ | | |
| | 72 | 16.47±0.27 | | | |
| | 64 | 16.30±0.28 | | | |
| | 56 | 16.70±0.29 | | | |
| | 48 | 15.64±0.31 | | | |
| | 40 | 15.16±0.32 | | | |
| | 32 | 14.02±0.35 | | | |
| | 24 | 13.23±0.38 | | | |
| F3 | 87 | 14.95±0.36 | 30.14 | | No normalization or renormalization needed |
| | 80 | 15.39±0.32 | ↓ | | |
| | 72 | 15.60±0.33 | | | |
| | 64 | 14.52±0.33 | | | |
| | 56 | 14.85±0.35 | | | |
| | 48 | 15.17±0.31 | | | |
| | 40 | 14.64±0.33 | | | |
| | 32 | 13.08±0.34 | | | |
| | 24 | 12.82±0.38 | | | |
| | 16 | 14.54±0.58 | | | |
| | 11 | 25.22±2.19 | | | |
| C9 | 89.7 | 14.30±0.15 | 31.8 | | No normalization or renormalization needed |
| | 77.6 | 14.05±0.15 | ↓ | | |
| | 64.7 | 14.05±0.20 | | | |
| | 52.5 | 14.02±0.17 | | | |
| | 39.8 | 13.27±0.14 | | | |
| | 27.3 | 13.13±0.16 | | | |
| | 90–90 | 14.21±0.25 | | | |
| | 102–78 | 14.15±0.15 | | | |
| K2 | 25 | 4.88 | 95 | | The 25°, 30°, and 35° points were obtained from the liquid H angular distribution fitted to the $CH_2$ data. On the rest of these data no normalization or renormalization is needed. |
| | 30 | 4.88 | ↓ | | |
| | 35 | 4.89 | | | |
| | 40 | 4.93±0.12 | | | |
| | 50 | 4.81±0.10 | | | |
| | 60 | 4.81±0.10 | | | |
| | 70 | 4.68±0.09 | | | |
| | 80 | 4.53±0.10 | | | |
| | 90 | 4.54±0.09 | | | |
| | 90 | 5.40±0.32 | 78.5 | | |
| | 90 | 5.96±0.36 | 69.5 | | |
| | 90 | 8.83±0.62 | 52 | | |
| | 90 | 11.4 ±0.80 | 41 | | |
| | 25 | 6.44 | 70 | | These data were obtained by using the 70-Mev angular distribution and the $\sigma_{pp}(90°)$ value at 69.5 Mev given above |
| | 30 | 6.35 | ↓ | | |
| | 35 | 6.37 | | | |
| | 40 | 6.21 | | | |
| | 80 | 6.29 | | | |
| | 90 | 5.96±0.36 | | | |
| B4 | 40–90 | 5.4 ±1.1 | 105 | 4.75±0.9 | The original data were normalized to the cross section for $C^{12}(9,pn)C^{11}$. New values for this cross section make necessary a renormalization by 36/41 |
| | 40–90 | 6.6 ±1.1 | 75 | 5.8 +1.2 | |
| P3 | 90 | 3.80±0.13 | 134 | | |
| P3 | 90 | 4.05±0.28 | 147 | | |

TABLE VI.—(*Contineud*).

| Reference | $\theta_{c.m.}$ | $\sigma(\theta)\pm\epsilon$ (mb) | Energy (Mev) | $\sigma'(\theta)\pm\epsilon'$ (mb) | Remarks |
|---|---|---|---|---|---|
| C11 | 25 | 5.57±0.53 | 147 | 4.20±0.40 | The original data were normalized to the cross section for $C^{12}(p,pn)C^{11}$. New values for this cross section make necessary a renormalization by 43/57 |
| | 35 | 5.03±0.23 | | 3.80±0.17 | |
| | 45 | 5.16±0.23 | | 3.90±0.17 | |
| | 60 | 5.09±0.23 | | 3.84±0.17 | |
| | 75 | 5.04±0.23 | | 3.80±0.17 | |
| | 90 | 4.94±0.22 | ↓ | 3.74±0.17 | |
| C12 | 10.1 | 5.10±0.26 | 170 | | No normalization or renormalization needed |
| | 16.7 | 3.69±0.15 | | | |
| | 23.0 | 3.52±0.09 | | | |
| | 31.3 | 3.61±0.09 | | | |
| | 41.7 | 3.55±0.08 | | | |
| | 62.2 | 3.27±0.10 | ↓ | | |
| | 9.6 | 5.27±0.24 | 174 | | |
| | 12.4 | 4.37±0.17 | | | |
| | 16.8 | 3.92±0.14 | | | |
| | 23.0 | 3.96±0.10 | | | |
| | 31.3 | 3.99±0.10 | | | |
| | 41.6 | 3.90±0.09 | | | |
| | 62.3 | 3.60±0.10 | ↓ | | |
| | 10.6 | 4.38±0.21 | 259 | | |
| | 17.0 | 3.84±0.11 | | | |
| | 23.4 | 3.90±0.09 | | | |
| | 31.9 | 3.56±0.06 | | | |
| | 42.5 | 3.58±0.04 | | | |
| | 63.5 | 3.50±0.06 | ↓ | | |
| | 9.3 | 5.75±0.34 | 260 | | |
| | 17.0 | 3.85±0.11 | | | |
| | 23.4 | 3.90±0.06 | | | |
| | 31.9 | 3.84±0.06 | | | |
| | 42.5 | 3.74±0.07 | | | |
| | 63.3 | 3.64±0.07 | ↓ | | |
| C8 | 35.6 | 4.31±0.21 | 345 | | $CH_2$ target |
| | 36.4 | 3.93±0.15 | | | |
| | 43.4 | 3.79±0.15 | | | No normalization or renormalization needed |
| | 44.0 | 4.17±0.13 | | | |
| | 45.8 | 3.64±0.07 | | | |
| | 46.1 | 3.99±0.11 | | | |
| | 52.4 | 3.77±0.10 | | | |
| | 60.8 | 3.83±0.13 | | | |
| | 64.0 | 3.55±0.11 | | | |
| | 64.0 | 3.74±0.14 | | | |
| | 70.6 | 3.67±0.16 | | | |
| | 72.2 | 3.67±0.11 | | | |
| | 80.2 | 3.95±0.12 | | | |
| | 87.6 | 3.86+0.10 | | | |
| | 88.2 | 3.91±0.08 | | | |
| | 88.2 | 3.70±0.08 | | | |
| | 88.6 | 3.85±0.06 | | | |
| | 88.6 | 3.54±0.09 | | | |
| | 89.2 | 4.15±0.36 | ↓ | | |
| | 11.3 | 5.1 ±0.36 | 345 | | Liquid H target |
| | 11.3 | 5.38±0.49 | | | |
| | 15.2 | 3.71±0.22 | | | |
| | 15.2 | 3.21±0.17 | | | |
| | 21.1 | 3.51±0.10 | | | |
| | 21.7 | 3.06±0.15 | | | |
| | 32.5 | 3.52±0.09 | | | |
| | 33.1 | 3.51±0.11 | | | |
| | 42.8 | 3.48±0.10 | | | |
| | 42.8 | 3.40±0.08 | | | |
| | 53.2 | 3.40±0.08 | | | |
| | 53.2 | 3.28±0.10 | ↓ | | |
| | 47.4 | 3.97±0.51 | 250 | | |
| | 47.4 | 3.23±0.29 | 250 | | |
| | 62.0 | 4.38±0.27 | 247 | | |
| | 64.6 | 3.84±0.20 | 250 | | |
| | 78.4 | 3.69±0.15 | 250 | | |
| | 78.4 | 3.53±0.18 | 250 | | |
| | 87.2 | 3.67±0.21 | 250 | | |
| | 87.4 | 3.69±0.10 | 249 | | |
| | 87.6 | 3.95±0.22 | 250 | | |

TABLE VI.—(*Continued*).

| Reference | $\theta_{c.m.}$ | $\sigma(\theta)\pm\epsilon$ (mb) | Energy (Mev) | $\sigma'(\theta)\pm\epsilon'$ (mb) | Remarks |
|---|---|---|---|---|---|
| C8 (contd.) | 87.6 | 3.59±0.21 | 250 | | |
| | 89.6 | 3.56±0.27 | 247 | | |
| | 89.6 | 3.28±0.16 | 247 | | |
| | 59.9 | 3.38±0.23 | 164 | | |
| | 60.8 | 4.08±0.45 | 163 | | |
| | 88.6 | 3.88±0.26 | 163 | | |
| | 88.6 | 3.54±0.35 | 164 | | |
| | 90.0 | 3.60±0.17 | 164 | | |
| | 63.0 | 3.67±0.56 | 120 | | |
| | 63.0 | 4.40±0.50 | 120 | | |
| | 77.8 | 4.25±0.33 | 120 | | |
| | 85.2 | 3.85±0.25 | 120 | | |
| | 89.2 | 3.95±0.12 | 118 | | |
| C13 | 6.5 | 10.71±0.74 | 300 | | These data are normalized to $\sigma_{pp}(21°)$ =3.75 mg/sterad |
| | 7.6 | 7.46±0.58 | ↓ | | |
| | 8.7 | 4.85±0.37 | | | |
| | 11.0 | 4.42±0.27 | | | No normalization needed |
| | 13.0 | 4.13±0.20 | | | |
| | 17.3 | 3.88±0.17 | | | |
| | 21.7 | 3.75±0.18 | | | |
| | 20–90 | $3.81^{+0.15}_{-0.07}$ | 330 | | Average $\sigma_{pp}(\theta)$ over angular interval indicated is given |
| | 20–90 | $3.58^{+0.19}_{-0.12}$ | 230 | | |
| | 20–90 | $4.16^{+0.19}_{-0.10}$ | 160 | | |
| O1 | 90 | 4.81±0.06 | 240 | 3.54±0.04 | Combined data are given here. The original data in both these papers were normalized to the cross section for $C^{12}(p,pn)C^{11}$. New values for this cross section make necessary a renormalization by 36/49 |
| | 79 | 5.05±0.08 | ↓ | 3.71±0.06 | |
| | 70 | 5.25±0.11 | | 3.86±0.08 | |
| | 69.1 | 5.04±0.05 | | 3.71±0.04 | |
| | 49.2 | 4.82±0.08 | | 3.54±0.06 | |
| | 48.6 | 4.93±0.12 | | 3.62±0.09 | |
| | 39.4 | 5.03±0.10 | | 3.70±0.07 | |
| | 27.5 | 4.83±0.11 | | 3.55±0.08 | |
| | 26.8 | 4.85±0.11 | | 3.56±0.08 | |
| T6 | 71.9 | 4.33±0.22 | 240 | 3.18±0.16 | |
| | 45.2 | 4.81±0.25 | ↓ | 3.54±0.18 | |
| | 36.6 | 4.90±0.28 | | 3.60±0.21 | |
| | 28.3 | 4.43±0.21 | | 3.24±0.15 | |
| | 27.2 | 4.38±0.38 | | 3.22±0.28 | |
| | 18.6 | 4.59±0.31 | | 3.38±0.23 | |
| | 13.0 | 5.16±0.39 | | 3.80±0.29 | |
| | 8.7 | 15.8 ±1.6 | | 11.60±1.18 | |
| F4 | 4.67 | 35.7 ±2.3 | 330 | | Data were normalized to 3.7 mb/sterad at 10° to 13° |
| | 5.26 | 18.1 ±1.02 | ↓ | | |
| | 5.88 | 14.62±1.02 | | | |
| | 6.52 | 8.59±0.82 | | | |
| | 7.28 | 6.34±0.61 | | | |
| | 8.57 | 4.15±0.33 | | | No renormalization needed |
| | 9.20 | 3.62±0.31 | | | |
| | 10.16 | 3.29±0.33 | | | |
| | 11.12 | 4.56±0.25 | | | |
| | 11.43 | 3.14±0.36 | | | |
| | 12.93 | 3.45±0.31 | | | |
| | 14.80 | 3.49±0.29 | | | |
| | 16.77 | 3.58±0.23 | | | |
| | 18.63 | 3.44±0.27 | | | |
| | 20.87 | 4.02±0.24 | | | |
| | 22.80 | 3.62±0.29 | | | |
| | 24.27 | 3.75±0.31 | | | |
| | 26.03 | 3.66±0.31 | | | |
| | 27.57 | 3.63±0.35 | | | |
| | 29.70 | 3.81±0.35 | | | |
| H7 | 4.14 | 26.40±1.19 | 380 | | No normalization or renormalization needed |
| | 4.69 | 15.90±0.68 | | | |
| | 5.28 | 11.47±0.48 | | | |
| | 6.42 | 6.63±0.23 | | | |
| | 7.56 | 5.31±0.17 | | | |
| | 8.73 | 4.57±0.12 | | | |
| | 9.9 | 4.35±0.10 | | | |

TABLE VI.—(*Continued*)

| Reference | $\theta_{c.m.}$ | $\sigma(\theta)\pm\epsilon$ (mb) | Energy (Mev) | $\sigma'(\theta)\pm\epsilon'$ (mb) | Remarks |
|---|---|---|---|---|---|
| H7 | 11.0 | 4.35±0.09 | 380 | | |
| (contd.) | 12.1 | 4.34±0.10 | | | |
| | 13.2 | 4.31±0.08 | | | |
| | 14.3 | 4.35±0.09 | | | |
| | 15.4 | 4.26±0.08 | | | |
| | 16.5 | 4.27±0.08 | | | |
| | 17.6 | 4.27±0.08 | | | |
| | 19.8 | 4.20±0.08 | | | |
| | 21.8 | 4.22±0.08 | | | |
| | 24.0 | 4.12±0.08 | | | |
| | 26.2 | 4.18±0.08 | | | |
| | 28.4 | 4.08±0.08 | | | |
| | 30.0 | 4.04±0.08 | | | |
| | 30.6 | 4.01±0.08 | | | |
| | 36.0 | 4.04±0.08 | | | |
| | 43.0 | 4.01±0.08 | | | |
| | 50.0 | 3.86±0.07 | | | |
| | 65.0 | 3.76±0.07 | | | |
| | 90.0 | 3.70±0.06 | ↓ | | |
| M5 | 90 | 3.42±0.13 | 419 | | The original data given in M6 were taken with a polarized beam. This paper corrects that trouble. No renormalization needed |
| | 80 | 3.56±0.23 | | | |
| | 65 | 3.34±0.19 | | | |
| | 54 | 3.23±0.12 | | | |
| | 54 | 3.18±0.21 | | | |
| | 43 | 3.74±0.21 | | | |
| | 28 | 3.41±0.20 | ↓ | | |
| K4 | 16.2–36.9 | 4.5 ±1.1 | 432 | | No normalization or renormalization needed |
| | 36.9–53.1 | 3.6 ±0.8 | | | |
| | 53.1–66.4 | 3.9 ±0.9 | | | |
| | 16.2–25.8 | 4.6 ±1.0 | | | |
| | 25.8–36.9 | 5.4 ±1.0 | | | |
| | 36.9–44.4 | 3.2 ±0.9 | ↓ | | |
| S9 | 17 | 4.13±0.20 | 437 | | No normalization or renormalization needed |
| | 25 | 4.27±0.21 | | | |
| | 28 | 4.04±0.20 | | | |
| | 30 | 4.03±0.20 | | | |
| | 36 | 4.05±0.20 | | | |
| | 50 | 3.82±0.19 | | | |
| | 65 | 3.62±0.18 | | | |
| | 90 | 3.49±0.17 | ↓ | | |
| M4 | 20 | 3.98±0.56 | 460 | | One telescope used to obtain data |
| | 27 | 3.73±0.34 | | | |
| | 33 | 3.97±0.16 | | | |
| | 40 | 4.06±0.16 | | | No normalization or renormalization needed |
| | 46 | 3.99±0.12 | | | |
| | 53 | 3.84±0.14 | | | |
| | 55 | 3.36±0.25 | | | |
| | 66 | 3.82±0.14 | | | |
| | 78 | 3.52±0.14 | | | |
| | 90 | 3.50±0.10 | ↓ | | |
| | 55 | 3.59±0.21 | 460 | | Two telescopes in coincidence used to obtain data |
| | 66 | 3.81±0.18 | | | |
| | 78 | 3.56±0.20 | ↓ | | |
| M7 | 90 | 3.31±0.15 | 460 | | |
| | 90 | 3.20±0.18 | 510 | | |
| | 90 | 2.95±0.12 | 562 | | No normalization or renormalization needed |
| | 90 | 2.92±0.11 | 586 | | |
| | 90 | 2.63±0.10 | 610 | | |
| | 90 | 2.58±0.12 | 622 | | |
| | 90 | 2.30±0.10 | 634 | | |
| | 90 | 2.20±0.10 | 645 | | |
| | 90 | 2.05±0.07 | 657 | | |
| | 30 | 4.18±0.44 | 460 | | |
| | 30 | 4.93±0.29 | 562 | | |
| | 30 | 5.67±0.26 | 610 | | |
| | 30 | 6.37±0.36 | 634 | | |
| | 30 | 6.53±0.37 | 645 | | |
| | 30 | 6.55±0.28 | 657 | | |

TABLE VI.—(*Continued*)

| Reference | $\theta_{c.m.}$ | $\sigma(\theta)\pm\epsilon$ (mb) | Energy (Mev) | $\sigma'(\theta)\pm\epsilon'$ (mb) | Remarks |
|---|---|---|---|---|---|
| S10 | 30 | 3.58±0.31 | 460 | | |
| | 45 | 3.89±0.09 | | | |
| | 60 | 3.82±0.09 | | | |
| | 75 | 3.60±0.12 | | | No normalization or renormalization performed. Proportional-counter wall scattering might give too high results |
| | 90 | 3.68±0.09 | | | |
| | 40 | 4.32±0.14 | 560 | | |
| | 60 | 3.66±0.19 | | | |
| | 75 | 3.28±0.14 | | | |
| | 90 | 3.22±0.13 | | | |
| | 30 | 5.47±0.12 | 660 | | |
| | 40 | 4.97±0.10 | | | |
| | 50 | 4.03±0.12 | | | |
| | 60 | 3.21±0.12 | | | |
| | 70 | 2.59±0.10 | | | |
| | 80 | 2.19±0.11 | | | |
| | 90 | 2.06±0.08 | | | |
| B7 | 5 | 33 ±6 | 460 | | |
| | 10 | 5.91±0.46 | | | No normalization or renormalization needed |
| | 15 | 4.69±0.38 | | | |
| | 5 | 26 ±5 | 560 | | |
| | 10 | 8.04±0.78 | | | |
| | 15 | 6.78±0.63 | | | |
| | 20 | 6.29±0.58 | | | |
| | 25 | 5.70±0.53 | | | |
| | 5 | 18.9 ±1.1 | 660 | | |
| | 10 | 11.0 ±0.7 | | | |
| | 15 | 8.67±0.53 | | | |
| | 20 | 7.75±0.48 | | | |
| | 25 | 6.56±0.40 | | | |
| B5 | 30 | 5.58±0.15 | 657 | | |
| | 40 | 4.78±0.26 | | | |
| | 50 | 3.99±0.20 | | | |
| | 60 | 3.41±0.13 | | | No normalization or renormalization needed |
| | 70 | 2.94±0.12 | | | |
| | 80 | 2.20±0.05 | | | |
| | 90 | 2.07±0.03 | | | |
| B13 | 7.5 | 17.32±1.85 | 660 | | Normalized to $\sigma_{pp}(30°)=5.47$ |
| | 10 | 14.98±0.60 | | | |
| | 16 | 7.80±0.49 | | | |
| | 20 | 6.75±0.29 | | | No renormalization needed |
| | 25 | 5.79±0 41 | | | |
| | 30 | 5.47±0.29 | | | |
| S2 | 33.2 | 3.86 | 440 | | The data are normalized to $\sigma_{pp}(90°)=3.49$ mb/sterad at 437 Mev from S9 |
| | 44.0 | 3.80 | | | |
| | 65.4 | 3.62 | | | |
| | 79.9 | 3.52 | | | |
| | 90.0 | 3.49 | | | |
| | 27.5 | 6.12±0.15 | 590 | | |
| | 34.7 | 5.42±0.10 | | | No renormalization needed. Errors have been read from graph |
| | 50.0 | 4.18±0.7 | | | |
| | 65.1 | 3.28±0.10 | | | |
| | 90.0 | 2.43±0.05 | | | |
| | 28.5 | 7.60±0.20 | 800 | | |
| | 49.8 | 3.44±0.10 | | | |
| | 90.0 | 0.89±0.05 | | | |
| | 36.5 | 5.66±0.10 | 1000 | | |
| | 41.3 | 4.54±0.10 | | | |
| | 53.7 | 2.44±0.07 | | | |
| | 64.0 | 1.33±0.05 | | | |
| | 77.0 | 0.79±0.05 | | | |
| | 90.0 | 0.62±0.05 | | | |
| D7 | 0–41 | 5.3 ±1.0 | 950 | | No normalization or renormalization needed |
| | 41–60 | 3.1 ±1.0 | | | |
| | 60–75 | 1.3 ±0.5 | | | |
| | 75–90 | 0.4 ±0.3 | | | |

TABLE VI.—(*Continued*)

| Reference | $\theta_{c.m.}$ | $\sigma(\theta)\pm\epsilon$ (mb) | Energy (Mev) | $\sigma'(\theta)\pm\epsilon'$ (mb) | Remarks |
|---|---|---|---|---|---|
| C17 | 49.4 | 3.3 | 920 | | Data are normalized to readings on an induction electrode which reads the intensity of the circulating beam. Trouble with multiple traversals has been eliminated from the system. The absolute value is good to ±30% for $E=920$ and 3490, and is good to ±15% for $E=2240$, 4400, and 6150. The errors listed include counting statistics, uncertainty in angles, etc., but not the ±15% due to the monitor uncertainty. |
| | 72.1 | 0.76 | ↓ | | |
| | 91.7 | 0.45 | ↓ | | |
| | 14.7 | 20.8 ±1.2 | 2240 | | |
| | 23.6 | 11.0 ±0.6 | ↓ | | |
| | 29.2 | 6.64±0.61 | ↓ | | |
| | 44.0 | 1.12±0.098 | ↓ | | |
| | 57.6 | 0.428±0.060 | ↓ | | |
| | 70.3 | 0.255±0.034 | ↓ | | |
| | 93.5 | 0.1445±0.0280 | ↓ | | |
| | 34.2 | 1.7 | 3490 | | |
| | 49.2 | 0.26 | ↓ | | |
| | 64.4 | 0.07 | ↓ | | |
| | 78.5 | 0.06 | ↓ | | |
| | 10.6 | 20.5 ±1.1 | 4400 | | |
| | 14.2 | 18.3 ±1.4 | ↓ | | |
| | 17.5 | 12.73±0.90 | ↓ | | |
| | 21.3 | 6.01±0.52 | ↓ | | |
| | 24.5 | 2.96±0.33 | ↓ | | |
| | 28.5 | 1.99±0.23 | ↓ | | |
| | 37.4 | 0.473±0.063 | ↓ | | |
| | 53.2 | 0.100±0.029 | ↓ | | |
| | 69.0 | 0.0382±0.0156 | ↓ | | |
| | 7.6 | 27.7 ±2.8 | 6150 | | |
| | 11.6 | 24.6 ±2.2 | ↓ | | |
| | 15.2 | 10.1 ±1.3 | ↓ | | |
| | 20.0 | 5.51±1.10 | ↓ | | |
| | 20.8 | 3.06±0.70 | ↓ | | |
| | 23.6 | 1.31±0.31 | ↓ | | |
| | 27.6 | 0.651±0.293 | ↓ | | |

(S13) looked for polarization from carbon targets, and found essentially no polarization. Rose (R6) has reported, "A study has been made of the variation with energy of the asymmetries at 12° and at 16° in C, Al, and Fe. All data show steady decrease as the energy is lowered. The C and Al curves fall to very low values at 60 Mev, while the Fe asymmetry is zero or perhaps negative at 75 Mev." From all these data it appears that the polarization falls quite suddenly below 130 Mev, but that between 130 Mev and 430 Mev the polarization is fairly constant.

TABLE VII. Values for neutron-neutron differential cross sections. The data on $I(\theta)$ are Golovin's values for the magnitude of the interference term in scattering of neutrons from deuterium at 300 Mev.

| Reference | $\theta$ | Energy | $\sigma_{nn}(\theta)$ | $I(\theta)$ |
|---|---|---|---|---|
| D10 | 12 | 300 | 7.9 ±1.5 | |
| | 16 | ↓ | 6.0 ±1.0 | |
| | 20 | ↓ | 4.8 ±0.7 | |
| | 30 | ↓ | 3.2 ±0.6 | |
| | 40 | ↓ | 3.2 ±0.6 | 0.60 |
| | 50 | ↓ | 3.5 ±0.8 | 0.36 |
| | 60 | ↓ | 3.8 ±0.6 | 0.20 |
| | 70 | ↓ | 3.75±0.6 | 0.10 |
| | 80 | ↓ | 3.75±0.6 | 0.09 |
| | 90 | ↓ | 3.6 ±0.8 | 0.04 |
| D13 | 30 | 590 | 5.8 ±0.8 | |
| | 49 | ↓ | 4.7 ±0.5 | |
| | 55 | ↓ | 3.8 ±0.4 | |
| | 67 | ↓ | 2.9 ±0.35 | |
| | 78 | ↓ | 2.3 ±0.30 | |
| | 89 | ↓ | 2.5 ±0.25 | |

Most experiments done on polarization determine the magnitude of $P$ but not the sign of $P$. Two experiments have been performed to determine the absolute sign of the polarization of a nucleon beam. One has been performed by Brinkworth and Rose (B12). "The first scattered beam is reduced to a few Mev (a band from 4.5 to 9 Mev) and scattered left and right into photographic plates in 5 atmospheres of helium. From known phase shifts for this scattering one anticipates a left-right ratio of 3.6 or 0.28, depending on the sign of the polarization. The data are consistent with 3.6. The polarization is thus known to be positive, meaning that

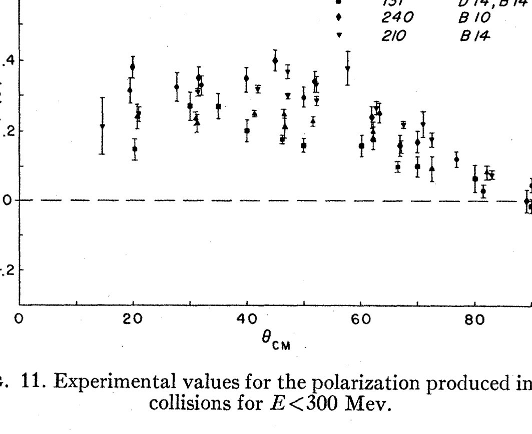


FIG. 11. Experimental values for the polarization produced in $p$-$p$ collisions for $E<300$ Mev.

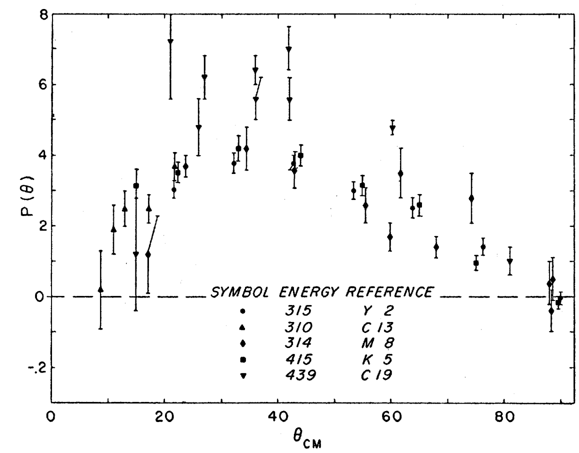


FIG. 12. Experimental values for the polarization produced in $p$-$p$ collisions for $E>300$ Mev.

the direction of predominant spin is parallel to the direction of rotation in the scattering of an originally unpolarized beam."

The experiment by Marshall and Marshall (M9) gave the same answer with a somewhat different geometry.

Some triple-scattering experiments have been performed (Y2) to measure the depolarization or rotation of the plane of polarization of a polarized beam of protons.

## X. EXPLANATION OF TABLES

Tables I–III, and V are summaries of experiments performed on nucleon-nucleon cross sections.

*Data normalized.*—In most of the $\sigma_{np}(\theta)$ and some of the $\sigma_{pp}(\theta)$ experiments the data obtained are angular distributions of a counting rate that must be normalized by the use of other data to get absolute values of the cross section. Whether or not this is done and how it is done are indicated in this column.

*Energy.*—This column lists the energies of the incident particles. For protons only one value is listed, because proton beams are usually nearly monoenergetic. But for high-energy neutrons the beam usually has a spread in energy. Because of this, three values are given to indicate the energy spectrum. $E_{\text{peak}}$ corresponds to the energy of the peak of the spectrum; $E_{\text{upper}}$ and $E_{\text{lower}}$ correspond to the energies of the half-height points above and below the peak energy (Fig. 14).

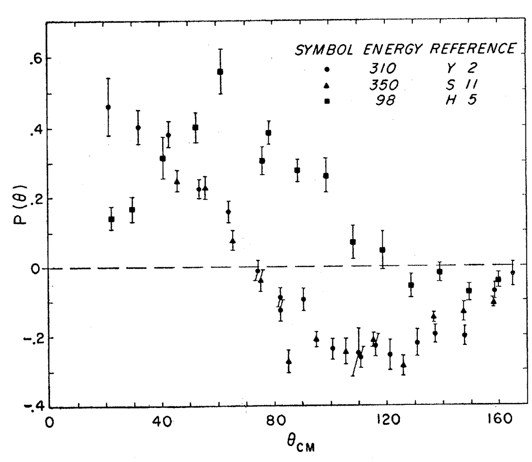


FIG. 13. Experimental values for the polarization produced in $n$-$p$ collisions.

The values indicated for $E_{\text{cutoff}}$ are experimental limits placed on the lowest-energy neutron that will be counted. This is frequently done by placing an absorber in a proton-recoil telescope. This process makes the neutron beam effectively more monoenergetic.

*Monitor.*—This column indicates what device was used to count particles in the incident beam. In some cases—for example, cloud chamber work—no monitor is used because only an angular distribution is desired. In this case the angular distribution is taken all at once and therefore no normalization to unit incident beam is needed.

*Target.*—Proton targets are obtained normally by $CH_2-C$ subtraction or use of H gas, or—more recently—liquid hydrogen. In a few cases no subtraction was made for the carbon in a $CH_2$ target. This normally

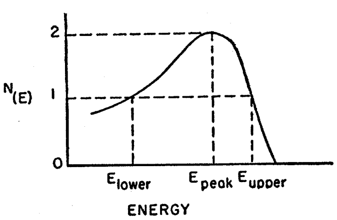


FIG. 14. Sample neutron energy spectrum showing meaning of $E$ peak, $E$ upper, and $E$ lower.

should be done if the incident beam is energetic enough to produce protons from carbon.

Neutron targets are usually obtained by a deuterium-hydrogen subtraction. This is subject to limitations discussed in Sec. III.

*Counters.*—This column indicates the type of detector used to study the particles emerging.

*Errors.*—Different authors treat errors differently. Fairly frequently only counting statistics (almost always expressed in standard deviations) are considered. In the cases in the table where the error is called total, various other contributing factors—such as geometry, target, beam, detection efficiency, etc.—have been included. This so-called "total error" is not actually the total error; it is merely one in which several factors other than counting statistics have been taken into account. Some authors may not have treated other possible errors adequately. It would be nice if all the data could be considered on an equal basis with respect to errors; but as they cannot, the differences should be kept in mind. For example, when only counting statistics are considered in $\sigma_{np}(\theta)$ there usually is an error in the normalization process associated with the value of $\sigma_{np}$ total used that should be combined with the counting statistics errors.

TABLE. VIII. Summary of Experiments on Nucleon Polarization.

| Reference | Authors | Energy | Type of interaction | Target 1 | $\theta_1$ | $P_1$ | Target 2 | Detectors | Errors | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| H5 | Hillman, Stafford (Harwell) | 98±3 Mev neutrons | $n$-$p$ | Be | 26° L<br>26° R | 0.085±0.006 | $CH_2-C$ | Scintillation proton recoil telescope counting neutrons | Counting statistics +geometry +stray fields +background | Checked with unpolarized beam |
| D14 | Dickson, Salter (Harwell) | 133 Mev protons | $p$-$p$ | C | 20° | 0.7 ±0.1 | $CH_2$ | 2 scintillation telescopes in coincidence | Not given | |
| F5 | Fischer, Baldwin (Berkeley) | 174±10 Mev protons | $p$-$p$ | Be | 13° L | 0.76 ±0.05 | Liquid H | Scintillation telescopes | Counting statistics | $P_1$ is known for 315 Mev beam. It is assumed to remain constant for the beam degraded in energy to 170 Mev |
| B10 | Baskir, Chesnut (Rochester) | 240 protons | $p$-$p$ | Be<br>C | 20°<br>20° | 0.82 ±0.01<br>0.91 ±0.01 | $CH_2-C$ and liquid H | Counter telescope | Not given | Data read from graph |
| Y2 | Ypsilantis (Berkeley) | 315 Mev protons | $p$-$p$ | Be | 13° L | 0.76 ±0.03 | Liquid H<br>Liquid D | Scintillation telescope | Counting statistics | (1) Errors due to geometry and stray field give $\Delta P_2=\pm 0.003$ (2) Elastic scattering from the proton in the deuteron agreed with the free $p$-$p$ data well |
| | | 310 Mev protons | $p$-$n$ | Be | 13° L | 0.69 ±0.05 | Liquid D | Scintillation proton recoil telescope counting neutrons | Counting statistics | |
| | | 276 Mev protons | $p$-$p$ | Be | 17° | 0.67 ±0.05 | Liquid H | Scintillation telescope | Counting statistics +error in $P_1$ | |
| C13 | Chamberlain, Pettengill, Segrè, Wiegand (Berkeley) | 310 Mev protons | $p$-$p$ | Be | 13° L | 0.74 ±0.01 | Liquid H | Split ring scintillators | | |
| M8 | Marshall, Marshall, Nagle, Skolnik (Chicago) | 314 Mev protons | $p$-$p$ | Be | 14° R | 0.60 | Liquid D | Scintillation telescope counting protons also in coincidence counting protons and neutrons | Not given | |
| S11 | Siegel, Hartzler, Love (Carnegie Tech) | 350 Mev neutrons | $n$-$p$ | C | 20° R | 0.163±0.007 | Liquid H | Scintillation telescope | Counting statistics | Checked with unpolarized beam |
| K5 | Kane, Stallwood, Sutton, Fields, Fox (Carnegie Tech) | 415 Mev protons | $p$-$p$ | C | 13° | 0.53 ±0.03 | Liquid H | Scintillator telescopes | Counting statistics +error in $P_1$ | |
| C19 | de Carvalho, Heiberg, Marshall, Marshall (Chicago) | 439 Mev protons | $p$-$p$ | Be | 14° R | 0.50 | Liquid H | Counters | Counting statistics | Data read from graph |

TABLE IX. Summary of values of $P(\theta)$.

| Reference | Types of interaction | Energy | $\theta_{c.m.}$ | $P(\theta)$ | Remarks |
|---|---|---|---|---|---|
| H5 | *n-p* | 95 | 22.5 | +0.143±0.032 | |
| | | | 29.8 | +0.170±0.037 | |
| | | | 41.0 | +0.318±0.060 | |
| | | | 52.5 | +0.403±0.042 | |
| | | | 61.5 | +0.561±0.064 | |
| | | | 76.0 | +0.307±0.040 | |
| | | | 78.5 | +0.387±0.033 | |
| | | | 88.5 | +0.280±0.032 | |
| | | | 98.5 | +0.265±0.049 | |
| | | | 108.0 | +0.071±0.048 | |
| | | | 118.5 | +0.048±0.054 | |
| | | | 128.5 | −0.054±0.035 | |
| | | | 138.5 | −0.016±0.028 | |
| | | | 149.0 | −0.073±0.025 | |
| | | | 159.5 | −0.038±0.022 | |
| D14 | *p-p* | 133 | 30 | +0.27 ±0.04 | |
| | | | 35 | +0.27 ±0.035 | |
| | | | 40 | +0.20 ±0.03 | |
| | | | 50 | +0.16 ±0.02 | |
| | | | 60 | +0.16 ±0.03 | |
| | | | 70 | +0.10 ±0.03 | |
| | | | 80 | +0.065±0.04 | |
| | | | 90 | −0.014±0.02 | |
| B14 | *p-p* | 130 | 20°38′ | +0.149±0.03 | |
| | | | 46°24′ | +0.178±0.012 | |
| | | | 66°46′ | +0.100±0.015 | |
| | | | 81°54′ | +0.029±0.019 | |
| | | 170 | 31°16′ | +0.238±0.018 | |
| | | | 41°38′ | +0.251±0.009 | |
| | | | 41°38′ | +0.257±0.010 | |
| | | | 46°48′ | +0.251±0.012 | |
| | | | 51°57′ | +0.229±0.013 | |
| | | | 62°11′ | +0.200±0.028 | |
| | | | 67°16′ | +0.158±0.017 | |
| | | | 82°28′ | +0.084±0.021 | |
| | | 210 | 13°42′ | +0.217±0.08 | |
| | | | 21°04′ | +0.250±0.021 | |
| | | | 21°04′ | +0.286±0.10 | |
| | | | 31°32′ | +0.311±0.010 | |
| | | | 31°32′ | +0.326±0.027 | |
| | | | 31°32′ | +0.323±0.027 | |
| | | | 42°00′ | +0.321±0.010 | |
| | | | 42°00′ | +0.338±0.028 | |
| | | | 47°12′ | +0.302±0.007 | |
| | | | 47°12′ | +0.370±0.021 | |
| | | | 52°22′ | +0.289±0.011 | |
| | | | 52°22′ | +0.357±0.053 | |
| | | | 52°22′ | +0.335±0.022 | |
| | | | 57°31′ | +0.381±0.047 | |
| | | | 62°40′ | +0.268±0.018 | |
| | | | 62°40′ | +0.275±0.027 | |
| | | | 67°48′ | +0.219±0.010 | |
| | | | 71°00′ | +0.222±0.037 | |
| | | | 72°53′ | +0.178±0.020 | |
| | | | 83°02′ | +0.077±0.012 | |
| | | | 92°58′ | −0.006±0.027 | |
| | | | 112°36′ | −0.175±0.032 | |
| F5 | *p-p* | 174 | 20.8 | +0.241±0.036 | |
| | | | 31.3 | +0.222±0.024 | |
| | | | 46.8 | +0.213±0.032 | |
| | | | 62.2 | +0.180±0.034 | |
| | | | 72.4 | +0.093±0.037 | |
| B10 | *p-p* | 240 | 20 | +0.38 ±0.03 | Data read from graph |
| | | | 32 | +0.35 ±0.03 | |
| | | | 40 | +0.35 ±0.03 | |
| | | | 45 | +0.40 ±0.03 | |
| B10 (contd.) | *p-p* | 240 | 52 | +0.34 ±0.03 | |
| | | | 62 | +0.24 ±0.03 | |
| | | | 67 | +0.16 ±0.03 | |
| | | | 70 | +0.17 ±0.03 | |
| | | | 90 | 0 ±0.03 | |
| | | | 120 | −0.25 ±0.03 | |
| Y2 | *p-p* | 315 | 21.6 | +0.305±0.023 | |
| | | | 32.3 | +0.378±0.027 | |
| | | | 42.9 | +0.379±0.020 | |
| | | | 53.4 | +0.303±0.025 | |
| | | | 63.9 | +0.251±0.027 | |
| | | | 76.2 | +0.142±0.025 | |
| | | | 89.4 | −0.005±0.016 | |
| | *p-p* | 276 | 19.3 | +0.314±0.036 | |
| | | | 27.8 | +0.324±0.041 | |
| | | | 32.0 | +0.329±0.028 | |
| | | | 49.9 | +0.295±0.027 | |
| | | | 63.4 | +0.251±0.027 | |
| | | | 76.8 | +0.122±0.021 | |
| | | | 90.0 | +0.044±0.019 | |
| | *p-n* | 310 | 21.6 | +0.462±0.081 | Data obtained from proton scattering on deuterium |
| | | | 32.3 | +0.403±0.048 | |
| | | | 42.9 | +0.382±0.036 | |
| | | | 53.4 | +0.225±0.028 | |
| | | | 63.9 | +0.158±0.030 | |
| | | | 74.2 | −0.012±0.030 | |
| | | | 82.3 | −0.090±0.028 | |
| | | | 82.3 | −0.126±0.033 | |
| | | | 90.6 | −0.097±0.032 | |
| | | | 100.7 | −0.238±0.030 | |
| | | | 109.9 | −0.249±0.072 | |
| | | | 110.2 | −0.261±0.030 | |
| | | | 116.1 | −0.228±0.032 | |
| | | | 121.3 | −0.255±0.043 | |
| | | | 130.8 | −0.222±0.039 | |
| | | | 137.3 | −0.197±0.026 | |
| | | | 147.7 | −0.202±0.029 | |
| | | | 158.4 | −0.074±0.023 | |
| | | | 164.9 | −0.023±0.035 | |
| C13 | *p-p* | 310 | 6.5 | −0.21 ±0.27 | |
| | | | 7.6 | +0.11 ±0.28 | |
| | | | 8.7 | +0.02 ±0.13 | |
| | | | 11.0 | +0.19 ±0.07 | |
| | | | 13.0 | +0.25 ±0.05 | |
| | | | 17.3 | +0.25 ±0.04 | |
| | | | 21.7 | +0.37 ±0.04 | |
| M8 | *p-p* | 314 | 17 | +0.125±0.11 | |
| | | | 24 | +0.375±0.03 | |
| | | | 35 | +0.425±0.06 | |
| | | | 43 | +0.36 ±0.05 | |
| | | | 56 | +0.26 ±0.05 | |
| | | | 60 | +0.17 ±0.04 | |
| | | | 62 | +0.35 ±0.07 | |
| | | | 68 | +0.14 ±0.03 | |
| | | | 74 | +0.28 ±0.07 | |
| | | | 88 | +0.05 ±0.06 | |
| | | | 93 | −0.18 ±0.10 | |
| | | | 102 | −0.07 ±0.05 | |
| S11 | *n-p* | 350 | 46°21′ | +0.248±0.031 | |
| | | | 55°51′ | +0.227±0.034 | |
| | | | 65°29′ | +0.075±0.027 | |
| | | | 75°13′ | −0.039±0.032 | |
| | | | 85° 7′ | −0.273±0.032 | |
| | | | 95° 9′ | −0.210±0.022 | |
| | | | 105°20′ | −0.246±0.038 | |
| | | | 115°41′ | −0.213±0.019 | |
| | | | 126° 8′ | −0.289±0.030 | |

TABLE IX.—(*Continued*).

| Reference | Types of interaction | Energy | $\theta_{c.m.}$ | $P(\theta)$ | Remarks |
|---|---|---|---|---|---|
| S11 (contd.) | *n-p* | 350 | 136°45′ | $-0.147\pm0.014$ | |
| | | | 147°28′ | $-0.132\pm0.028$ | |
| | | | 158°15′ | $-0.106\pm0.014$ | |
| K5 | *p-p* | 415 | 15.5 | $+0.317\pm0.041$ | |
| | | | 22 | $+0.353\pm0.027$ | |
| | | | 33 | $+0.421\pm0.036$ | |
| | | | 43.5 | $+0.402\pm0.029$ | |
| | | | 55.5 | $+0.317\pm0.028$ | |
| | | | 65 | $+0.260\pm0.030$ | |
| | | | 75 | $+0.117\pm0.021$ | |
| | | | 90 | $-0.017\pm0.023$ | |
| C19 | *p-p* | 439 | 15 | $+0.12\pm0.16$ | Data read from graph |
| | | | 21 | $+0.72\pm0.16$ | |
| | | | 26 | $+0.48\pm0.08$ | |
| | | | 27 | $+0.62\pm0.06$ | |
| | | | 36 | $+0.56\pm0.06$ | |
| | | | 36 | $+0.64\pm0.04$ | |
| | | | 42 | $+0.56\pm0.06$ | |
| | | | 42 | $+0.70\pm0.06$ | |
| | | | 59 | $+0.48\pm0.02$ | |
| | | | 81 | $+0.10\pm0.04$ | |
| | | | 99 | $-0.12\pm0.04$ | |
| | | | 99 | $-0.28\pm0.04$ | |
| | | | 119 | $-0.48\pm0.02$ | |
| | | | 119 | $-0.56\pm0.02$ | |

For a more comprehensive discussion of errors, the reader should consult the original papers. Errors are discussed in some of the papers where the source of the errors in the cross-section values is not indicated.

*Data renormalized here.*—There are several reasons why some of the original cross-section data should be modified because of more recent measurements. These columns tell which experiments have been modified in this paper, how much the data have been changed, and why the data needed changing. This information is repeated in Tables IV and VI.

Table VIII summarizes experiments on nucleon polarization. Several entries also need explaining.

*Type.*—This describes the type of nucleon interaction in which the polarization is studied:

*n-p* = high-energy polarized neutrons incident on a hydrogen target,
*p-p* = high-energy polarized protons incident on a hydrogen target, and
*p-n* = high-energy polarized protons incident on a neutron target.

*Target 1 and Target 2.*—The target material used to produce the polarized nucleon beam is given here as Target 1 and the target material of the second (analyzing) target is given as Target 2 (see Fig. 14).

$P_1$.—The value of the fraction of polarization of the polarized beam is listed here.

## XI. CONCLUSIONS

By considering the combined data the following information can be obtained.

(1) The interference term $R$ in the total cross section for proton scattering from deuterium is about 6 mb for energies above 100 Mev.

(2) The values for $\sigma_{nn}$ total and $\sigma_{pp}$ total agree with each other within experimental error. This is in agreement with the charge-independence hypothesis.

(3) The values for $\sigma_{np}(\theta)$ are essentially symmetrical about 90° c.m. up to 90 Mev. In the energy range 300 to 400 Mev the curves are definitely peaked backwards.

(4) From about 170 Mev up to 430 Mev for angles from about 20° c.m. to 90° c.m. the value of $\sigma_{pp}(\theta)$ is roughly constant at 3.7 mb/sterad. Above 430 Mev the curves for $\sigma_{pp}(\theta)$ become peaked forwards.

(5) The values of $\sigma_{nn}(\theta)$ agree statistically with $\sigma_{pp}(\theta)$. This is in agreement with the charge-independence hypothesis.

(6) All the cross-section data form a consistent pattern. There are no statistically real differences in the cross-section values from different experimenters whose work can be directly compared.

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