ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ

Дубна

E1 - 6743

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TOTAL ELASTIC p-p, p-d, p-n CROSS SECTIONS IN THE ENERGY RANGE OF 1-70 GEV

ЛАБОРАТОРИЯ ВЫСОКИХ ЭНЕРГИЙ

1972

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Submitted *to Physics Letters*

I. Total Elastic p-p Cross Sections

The differential cross sections of the elastic $p-p$ scattering were measured in the region of small momentum transfers squared ($|t| \le 0.12$ (GeV/c)^2) in the experiments performed at the Serpukhov accelerator and Dubna synchrophasotron by the method of multiple passages of an internal proton beam through a thin target /1–5/. In the region $0.2 \le |t| \le 0.8$ (GeV/c)^2 the elastic $p-p$ scattering amplitude $f(t)$ can be parametrized in the form:

$$f(t) = (i + a)\frac{\sigma_t}{4hc\sqrt{\pi}}\exp\frac{1}{2}(bt + ct^2) \qquad (1)$$

$$a = \frac{Re\, f(0)}{Im\, f(0)}$$

; b is the slope parameter at small t, a and b were taken from /1,2,4,5/ * ; σ_t is the total cross section.

It is shown in /3,4/ that for $|t| \le 0.12$ (GeV/c)^2 it is possible to take $c = 0$. The analysis of the results of different experiments /6, 7/ shows that in the energy range of 2-30 GeV the value c is very weakly dependent on energy and is equal to 2-3 (GeV/c)$^{-4}$ in the $|t|$ interval 0.2-0.8 (GeV/c)^2. Therefore for the $|t|$ range of 0.2-0.8 (GeV/c)^2 we take $c = 2.5$ for all considered energy region. σ_t for $p-p$, $p-d$ and $p-n$ interactions were taken from refs. /8–10/.

σ_{el} for $p-p$ interactions was determined from the following formula:

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* The b values shown in /1/ and in table I are in agreement with data /3/ (in the limits of the errors), but in analysis /1/ the values a measured in /2/ but not from dispersion relations were used. The values b from /1/ give: $b_0 = 7.32 \pm 0.25$ (GeV/c)$^{-2}$, $b_1 = 0.41 \pm 0.06$ (GeV/c)$^{-2}$ in the following parametrization of the $p-p$ slope parameter $b(s)$:

$$b(s) = b_0 + 2b_1 \ln(S/S_0).$$

$$\sigma_{e\ell} = (1 + a^2)\frac{\sigma_t^2}{16\pi (hc)^2}\left(\int_0^{0.12} \exp bt\, d|t| + \int_{0.12}^{0.8} \exp(bt + ct^2)\, d|t|\right) + \Delta \qquad (2)$$

Δ is the correction connected with the contribution of the region $|t| > 0.8$ (GeV/c)^2. As it is shown in /11/, Δ falls with increasing energy. It is possible to neglect it at energies greater than 25 GeV.

The total elastic $p-p$ cross sections are shown in Table I and in fig.I with the points from ref. /12/. As is seen from the figure, the total elastic $p-p$ cross section decreases with increasing energy from 16 to 5.7 mb in the energy range of 2-1500 GeV. This fact is a consequence of that the slope parameter increases and the value a falls with increasing energy, in the energy range of 10-70 GeV:

$$\sigma_{e\ell} \sim A\frac{1+a^2}{b} = A\frac{1+a^2}{b_0 + 2b_1 \ln S},$$

b_1 is approximately the slope of the Pomeranchuk trajectory, it is equal to 0.4 (GeV/c)$^{-2}$. The empirical curve of the form $\sigma_{e\ell}(p) = \sigma_0 + \sigma_1 p^{-n}$ is shown in fig.I. It was used for all energy range. We have obtained the following values for coefficients using our $p-p$ data and data from ref. /12/:

$\sigma_0 = 5.36 \pm 0.29\, mb$; $\sigma_1 = 16.1 \pm 1.7\, mb$; $n = 0.545 \pm 0/061$ (χ^2/I point $= 1.1$).
Fig.2 shows present data $\sigma_{e\ell}/\sigma_{tot}$ and data from other experiments. It is seen that $\sigma_{e\ell}/\sigma_{tot}$ falls with increasing energy; this is a quite understandable fact, as the total $p-p$ cross section falls very slowly. This is in agreement with the complex momentum theory.

The momentum dependence of the value $\sigma_{e\ell}/\sigma_{tot}$ in this energy region was approximated by the curve of the following form:

$$\sigma_{e\ell}/\sigma_{tot}(p) = a_0 + a_1 p^{-n}.$$

We have obtained the following results for our data and data from ref. /12/:

$$a_0 = 0.157 \pm 0.007$$

$$a_1 = 0.360 \pm 0.047 \qquad \frac{\chi^2}{1\ \text{point}} = 0.56$$

$$n = 0.602 \pm 0.080 .$$

There is some difference between our σ_{el} and σ_{el} from /6/ . For obtaining the absolute values of $d\sigma/dt$ we have used the latest data on total cross sections. But the extrapolated data $d\sigma/dt\ (t=0)$ from ref. /6/ are higher, than optical points.

2. *Total Elastic p−d Cross Sections*

The differential cross sections of the elastic $p-d$ scattering were measured using the same method /5,13,14/ . It is shown that the amplitude of the elastic $p-d$ cross section may be also parametrized by (I). To determine $\sigma_{el}(p-d)$, we have

integrated the $p-d$ differential cross section in the t-region of 0.-0.2 $(GeV/c)^2$. The parameters a , b , c were taken from /5,13/ , the correction Δ was de-termined from experiments at large t . $\Delta <$ 0.1 mb at energies greater than 6 GeV. As b in the $p-d$ scattering is equal to $\sim 40\ (GeV/c)^{-2}$, approximately 90% of $\sigma_{el}(p-d)$ is contained in the t-interval of $0 \leq |t| \leq 0.05\ (GeV/c)^{-2}$. As is seen from fig.3 and Table II the total elastic $p-d$ cross section also decreases with increasing energy. The physical reasons of this fact are the same as in the case of the $p-p$ scattering.

3. *Total Elastic p−n Cross Sections*

The parameters of the elastic $p-n$ scattering amplitude were determined from $p-d$ and $p-p$ elastic scattering data in the framework of the Glauber model /15/ . Formula (I) was also used for parametrization of the $p-n$ elastic scattering amplitude and (2) for $\sigma_{el}(p-n)$. Δ and c were the same as for $p-p$ scattering. The results are shown in fig.I. As is seen, $\sigma_{el}(p-n)$ coincide with $\sigma_{el}(p-p)$ within the limits of errors and also decrease with increasing energy as $\sigma_{el}(p-p)$.

4. *Asymptotic Relations and Energy Dependence of the Elastic and Total Cross Sections*

In ref. /16/ on the basis of general principles of the quantum field theory a limitation on the behaviour of the imaginary part of the elastic scattering amplitude $f(s,t)$ has been obtained for high energies:

$$\frac{1}{f(s,0)}\left[\frac{d^n f(s,t)}{dt^n}\right]_{t=0} > \frac{1}{(2n+1)n!}\left[\left(1+\frac{1}{2n+1}\right)\frac{\sigma_{tot}^2}{16\pi\sigma_{el}}\right]^n. \qquad (3)$$

Having determined the $p-p$, $p-d$, $p-n$ slope parameters at small t, the cross sections of the elastic scattering and the total cross sections from ref. /8/, we tried to check the performance of the inequalities (3). As the calculations shows, inequalities (3) for the first and second derivatives of the $p-p$ and $p-d$ scattering amplitudes are performed in the energy range of 10-60 GeV. Table III presents, as an example, the values of these inequalities for $p-p$ and $p-d$ interactions at $n=1$ and $n=2$ at three energy values. At large n the performance of the relations becomes to be more evident.

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Received by Publishing Department
on September 28, 1972

TABLE I

Total Elastic p-p Cross Sections and the p-p Slope parameter in the ragion $0.08 \leq |t| \leq 0.12 (GeV/c)^2$

PGeV/c	σ_{el}(mb)	b*
2,8	I6,3 ± I,0	7,60 ± 0,43
4,8	I4,4 ± I,2	7,80 ± 0,44
6,9	I0,6 ± 0,6	9,I4 ± 0,35
8,9	I0,I ± 0,5	9,40 ± 0,30
I0,9	9,9 ± 0,5	9,I6 ± 0,37
I3,2	8,87± 0,29	I0,32 ± 0,I7
I5,5	8.75± 0,29	I0,3I ± 0,I5
I8,9	8,59± 0,I7	I0,24 ± 0,II
2I,7	8,I5± 0,I6	I0,47 ± 0,I4
24,6	8,02± 0,I6	I0,48 ± 0,I3
27,5	7,96± 0,I5	I0,52 ± 0,I2
30,5	7,87± 0,I4	I0,49 ± 0,I2
33,3	7,66±0,I4	I0,69 ± 0,I2
36,2	7,70± 0,II	I0,57 ± 0,II
38,0	7,60± 0,I0	I0,68 ± 0,09
40,6	7,52± 0,II	I0,82 ± 0,II
45,2	7,40± 0,II	I0,90 ± 0,09
50,6	7,48± 0,I2	I0,84 ± 0,II
52,I	7,33± 0,I2	II,00 ± 0,I2
54,4	7,23± 0,II	II,I2 ± 0,I3
57,0	7,2I± 0,I0	II,II ± 0,I0
60,2	7,25± 0,I0	II,05 ± 0,08
63,5	6,89± 0,09	II,50 ± 0,II
66,I	7,07± 0,09	II,24 ± 0,II
69,2	6,86± 0,09	II,46 ± 0,09
69,8	6.86± 0,I0	II,48 ± 0,I5

A systematic error in σ_{el} is 3.5% at $13 < p < 70$ GeV/c, at $2.8 \leq p \leq 10.9$ GeV/c it is essentially smaller than a statistical one.

* The tables of differencial cross-sections with α and b values are published in /1/.

T A B L E   II

Total Elastic p-d Cross Sections

P GeV/c	σ_{el}(mb)	P GeV/c	σ_{el}(mb)	P GeV/c	σ_{el}(mb)	P GeV/c	σ_{el}(mb)
I,7	I2,I8±0,44	II,2	9,5I±0,34	57,2	8,05±0,24	I4,4	8,96±0,3I
2,8	I2,84±0,9I	I5,9	9,3I±0,35	60,8	7,88±0,2I	20,8	8,87±0,23
4,8	II,59±0,76	20,5	8,80±0,29	64,8	7,8I±0,2I	47,2	8,07±0,I7
6,9	I0,39±0,57	26,5	8,62±0,29	70,2	7,70±0,2I	60,8	7,58±0,I7
8,9	9,68±0,50	34,8	8,27±0,23			69,8	7,88±0,I6
I0,9	I0,82±0,65	48,9	8,05±0,26				

For p > 11 GeV/c a systematic error in σ_{el} is 3–4%, in the interval $1.7 \leq p \leq 10.9$ GeV/c a systematic error is essentially smaller than a statistical one.

T A B L E   III

Values of Inequalities from Ref. 16 for p-p and p-d Scattering

P GeV/c	n = 1 values of inequal. in $(GeV/c)^{-2}$	n = 2 values of inequal. in $(GeV/c)^{-4}$
	p-p	
I5,5	5,00 ± 0,20 > 4,I5 ± 0,I7	24,9±2,0 > I2,7±I,0
30,5	5,34 ± 0,20 > 4,38 ± 0,I9	28,5±2,I > I4,I±I,2
60,2	5,70 ± 0,20 > 4,82 ± 0,2I	32,5±2,3 > I7,2±I,4
	p-d	
I5,9	I9,I ± 0,8 > I3,7 ± 0,7	427 ± 34 > I38 ± I8
34,8	I9,4 ± 0,8 > I4,8 ± 0,8	434 ± 34 > I6I ± I9
60,8	20,8 ± 0,8 > I6,3 ± 0,9	504 ± 37 > I97 ± 2I

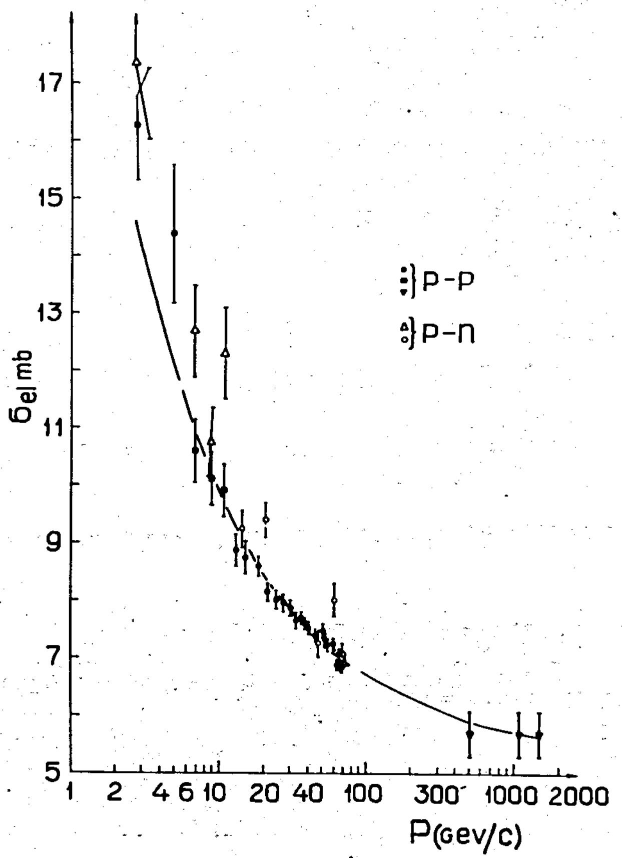

Fig.1. The total elastic $p-p$ and $p-n$ cross sections. ● , ■ - our $p-p$ data. ▼ - ISR $p-p$ data /12/ , Δ , ○ - our $p-n$ data. The systematic errors are: ● - 3.5%, Δ - 15%, ○ - 6%. The empirical curve is shown.

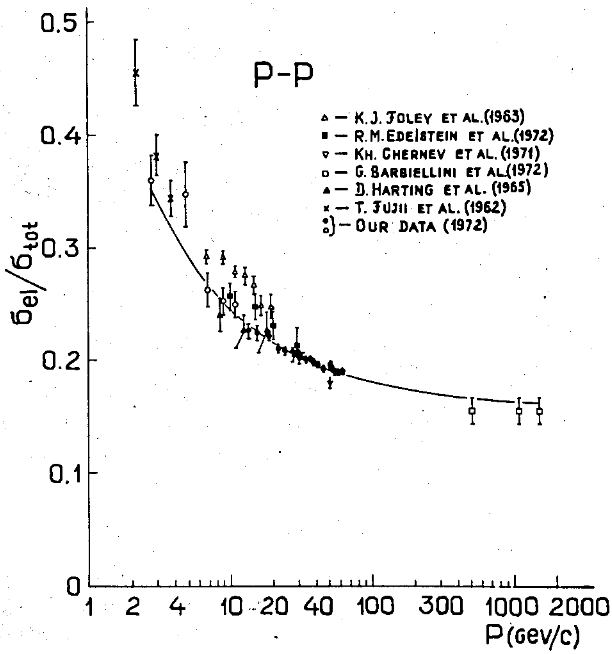

Fig.2. The dependence $\sigma_{e\ell} / \sigma_t$ (P) for $p-p$ interactions. The empirical curve for our data and ISR data /12/ is shown.

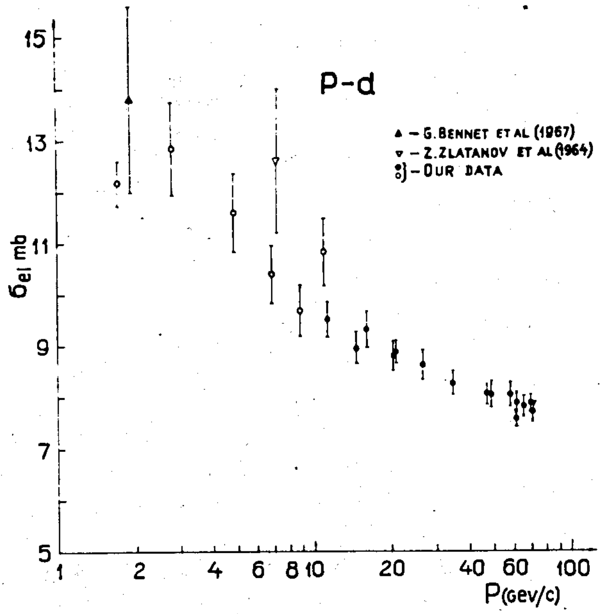

Fig.3. The total elastic $p-d$ cross sections, the systematic error in ● is 3-4%.