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«ǴYLYM JÁNE BILIM - 2023»
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OPTICAL MODEL OF ELASTIC SCATTERING IN THE NUCLEAR REACTION VIDEO (NRV) KNOWLEDGE BASE FOR Li^6 AND Li^6 INTERACTION

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A typical scheme for conducting experiments on the scattering of protons, neutrons and light nuclei (for example, alpha particles) is shown in Figure 1.1. A narrow beam of accelerated particles with energy E_0 (in a laboratory system) falls on a thin plate (or a thin layer of liquid, for example, liquefied gas) of the target. The number of beam particles passing through a unit area every second is called the flux density j_0.

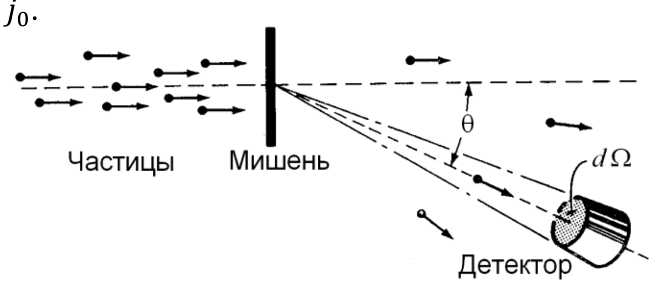


Figure 1.1. Schematic representation of particle scattering [1].

A particle colliding with one of the atomic nuclei of the target is deflected by an angle θ and is detected by a detector located at a distance L from the target and having an area of the detecting surface ΔS. The detector used makes it possible to identify the registered particle and measure its energy. Thus, only elastically scattered particles can be distinguished among the registered products of nuclear reactions. If every second a detector mounted at an angle θ registers ΔN scattered particles, then the ratio [1]

$$\frac{d\sigma}{d\Omega}(\theta) = \frac{\Delta N}{j_0 \Delta\Omega} \qquad (1.1)$$

It is called the differential cross section of elastic scattering (example in Fig. 1.2) and is expressed in units of bn/cp, 1 barn is equal to: 1 b = $10^{-24} cm^2$. For charged particles, the ratio of the elastic scattering cross section to the Rutherford scattering cross section in the Coulomb field is often calculated (excluding nuclear forces)

$$\frac{d\sigma}{d\Omega}(\theta) / \frac{d\sigma_{Ruth}}{d\Omega}(\theta) = \frac{d\sigma}{d\sigma_{Ruth}}(\theta) \qquad (1.2)$$

Rutherford's formula for the elastic scattering cross section of particles with charges Z1e and Z2e (interacting only by Coulomb forces) in the center of mass system is obtained within the framework of classical mechanics, but remains valid in quantum mechanics [2]

$$\frac{d\sigma_{Ruth}}{d\Omega}(\theta_{c.m.}) = (\delta \frac{Z_1 Z_2 e^2}{4E_{c.m.}})^2 sin^{-4}\theta_{c.m.}/2 \qquad (1.3)$$

here, $E_{c.m.}$ is the energy in the system of the center of mass of the particles

$$E_{c.m.} = E_{lab}(1 + m_1/m_2) \qquad (1.4)$$

E_{lab} - is the kinetic energy of a particle of mass m_1 colliding with a stationary particle of mass m_2. The value of the constant δ depends on the choice of the system of units: δ=1 in the system of units of measurement and δ=1/4$\pi\varepsilon_0$ in the SI system, and the value of a dimensionless quantity is the same in any system [3].

$$\delta \frac{e^2}{x_0 E_0} \approx 1.44 \qquad (1.5)$$

here, $E_0 = 1$ MeV, $x_0 = 1$ fm. In calculating the Rutherford cross-section in units of [mb/cp], for energy expressed in units of [MeV] $\tilde{E}_{c.m} = E_{c.m}/E_0$ is convenient to use expressions

$$\left(\delta \frac{Z_1 Z_2 e^2}{4E_{c.m.}}\right)^2 = x_0^2 \left(\delta \frac{e^2}{x_0 E_0} \frac{Z_1 Z_2}{4\tilde{E}_{c.m.}}\right)^2 = 10 S_0 \left(1.44 \frac{Z_1 Z_2}{4\tilde{E}_{c.m.}}\right)^2 \quad (1.6)$$

$$\frac{d\sigma_{Ruth}}{d\Omega}(\theta_{c.m.}) = 10 S_0 \left(1.44 \frac{Z_1 Z_2}{4\tilde{E}_{c.m.}}\right)^2 sin^{-4}\theta_{c.m.}/2\ [mb/avg] \quad (1.7)$$

where $S_0 = 1\,mb = 10^{-27} cm^2$. An example of comparing the experimental differential cross section with the Rutherford cross section is shown in Figure 1.2.

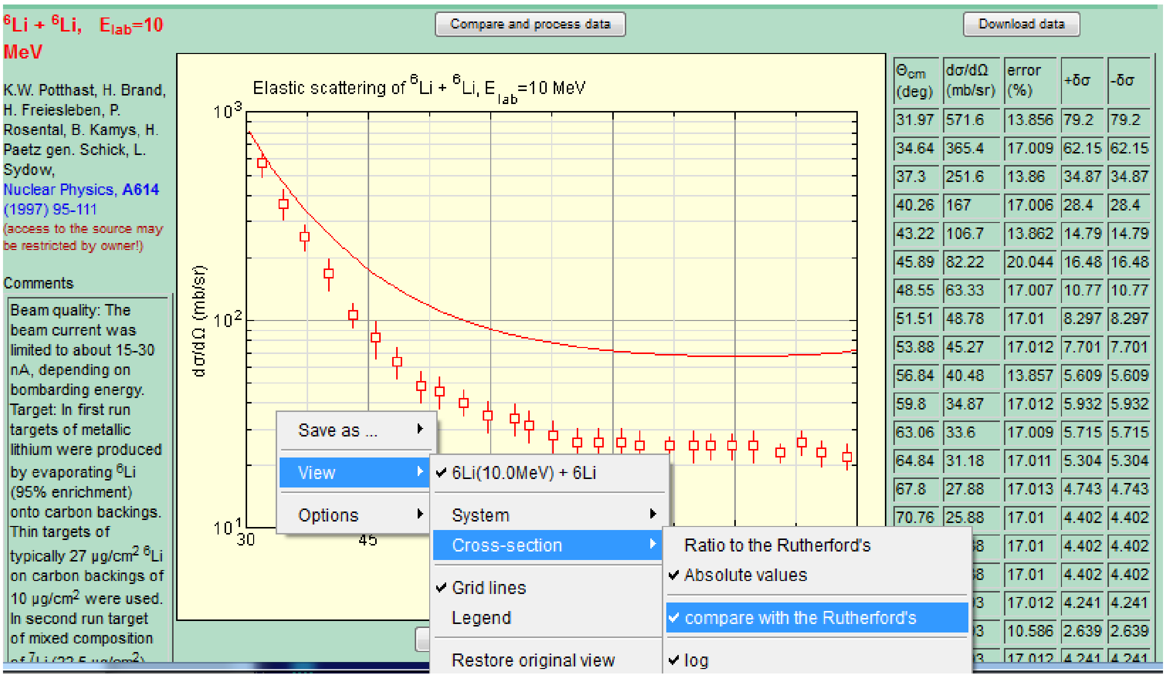


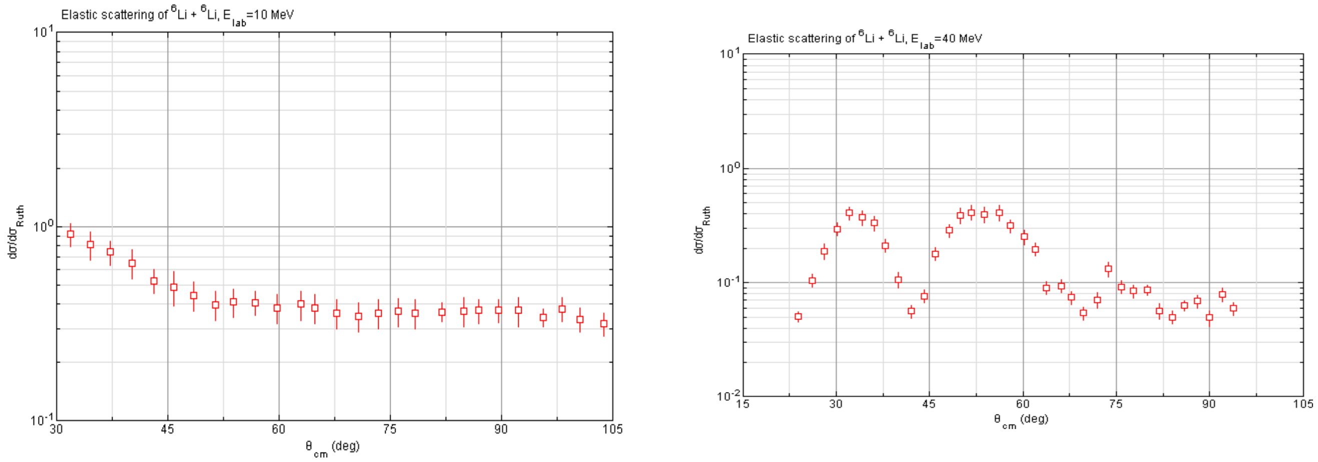
Figure 1.2. Comparison in the NRV knowledge base of the differential cross section of elastic scattering of Li^6 nuclei on Li^6 nuclei with the Rutherford cross section (1.7), (1.8) in the Coulomb field for energy in the laboratory E_{lab}=10 MeV system.

When identical particles collide at an θ angle, either a projectile particle or a target particle can be registered, while their trajectories diverge at right angles. In classical mechanics [2]

$$\frac{d\sigma_{Ruth}^{(2)}}{d\Omega}(\theta) = \frac{d\sigma_{Ruth}}{d\Omega}(\theta) + \frac{d\sigma_{Ruth}}{d\Omega}(\pi - \theta) = \left(\delta \frac{Z_1 Z_2 e^2}{4E_{c.m.}}\right)^2 (sin^{-4}\theta/2 + cos^{-4}\theta/2) \quad (1.8)$$

In the quantum description, identical particles are considered indistinguishable (identical), after the collision it is impossible to answer the question which of the registered particles was falling and which was stationary before the collision, therefore the expression for the section differs from the classical expression (1.8). However, at low speeds, the scattering intensity between any two angles tends to the classical limit due to the mutual compensation of fast quantum oscillations in quantum terms [4].

With large collision target parameters and, as a consequence, small scattering angles, the minimum distance between the projectile particle and the surface of the target core exceeds the radius of action



of nuclear forces, and scattering is mainly determined by Coulomb repulsion (Fig. 1.2). Therefore, at small scattering angles, the ratio (1.2) is close to unity (Fig. 1.3). For large angles, the action of nuclear forces leads to a difference in the ratio (1.2) from unity and the appearance of maxima and minima in the angular distributions (Fig. 1.3b). Maxima in angular distributions are similar to diffraction maxima when light bends around obstacles (for example, a disk). They clearly confirm the wave nature of the movement of nucleons and light nuclei near the target atomic nucleus.

a b

Figure 1.3. Ratio of the elastic scattering cross section of Li^6 nuclei on Li^6 nuclei to the Rutherford cross section for energy in the laboratory system E_{lab}= 10 MeV (a) and 40 MeV (b). Angles in the center of mass system (cm) [5].

Calculations of elastic scattering cross sections

^{6}Li + ^{6}Li, E_{lab}=40 MeV

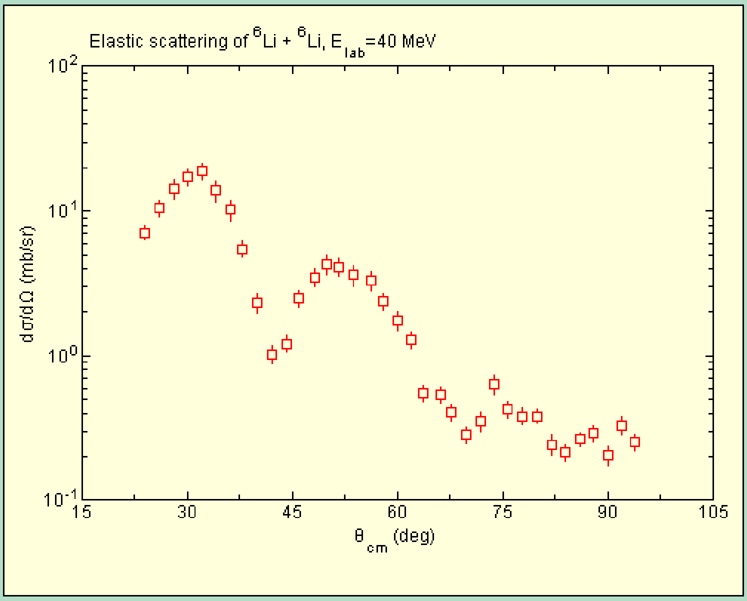
Compare and process data

Download data

K.W. Potthast, H. Brand, H. Freiesleben, P. Rosental, B. Kamys, H. Paetz gen. Schick, L. Sydow,
Nuclear Physics, A614 (1997) 95-111
(access to the source may be restricted by owner!)

Comments

Beam quality: The beam current was limited to about 15-30 nA, depending on bombarding energy.
Target: In first run targets of metallic lithium were produced by evaporating ^{6}Li (95% enrichment) onto carbon backings. Thin targets of typically 27 μg/cm^2 ^{6}Li on carbon backings of 10 μg/cm^2 were used. In second run target of mixed composition of ^{7}Li (22.5 μg/cm^2) and ^{6}Li (40 μg/cm^2) on carbon backings of 20 μg/cm^2.
Data obtained: author graph (digitized with GSYS 2.4)



Theoretical analysis of the data

Java blocked?

Θ_{cm} (deg)	dσ/dΩ (mb/sr)	error (%)	+δσ	-δσ
23.92	7.101	10.582	0.7514	0.7514
26.16	10.49	13.032	1.367	1.367
28.17	14.25	15.425	2.198	2.198
30.18	17.31	13.033	2.256	2.256
32.18	18.81	13.031	2.451	2.451
34.18	13.83	15.423	2.133	2.133
36.18	10.17	15.418	1.568	1.568
37.95	5.499	13.032	0.7166	0.7166
39.94	2.314	15.424	0.3569	0.3569
42.15	1.029	13.023	0.134	0.134
44.16	1.216	13.019	0.1583	0.1583
45.96	2.511	13.027	0.3271	0.3271
48.19	3.508	13.025	0.4569	0.4569
49.98	4.262	15.43	0.6576	0.6576
51.76	4.142	14.976	0.6203	0.6203
53.76	3.601	15.424	0.5554	0.5554
56.21	3.309	15.425	0.5104	0.5104
57.98	2.366	13.031	0.3083	0.3083
60.21	1.739	15.423	0.2682	0.2682
61.98	1.279	13.026	0.1666	0.1666

Figure 1.3. Experimental data for elastic scattering of Li^6 nuclei on Li^6 nuclei with energy E_{lab}= 40 MeV

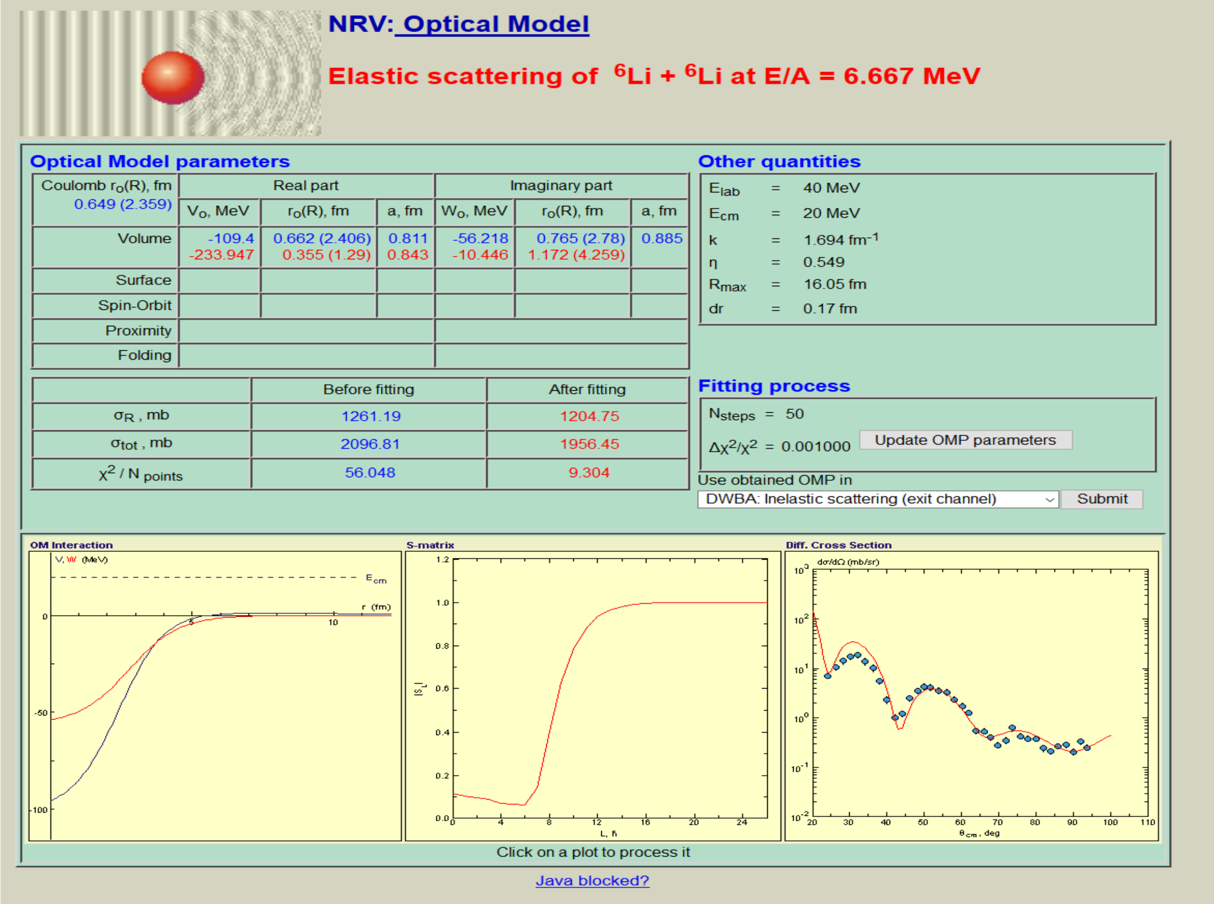


Figure 1.4.

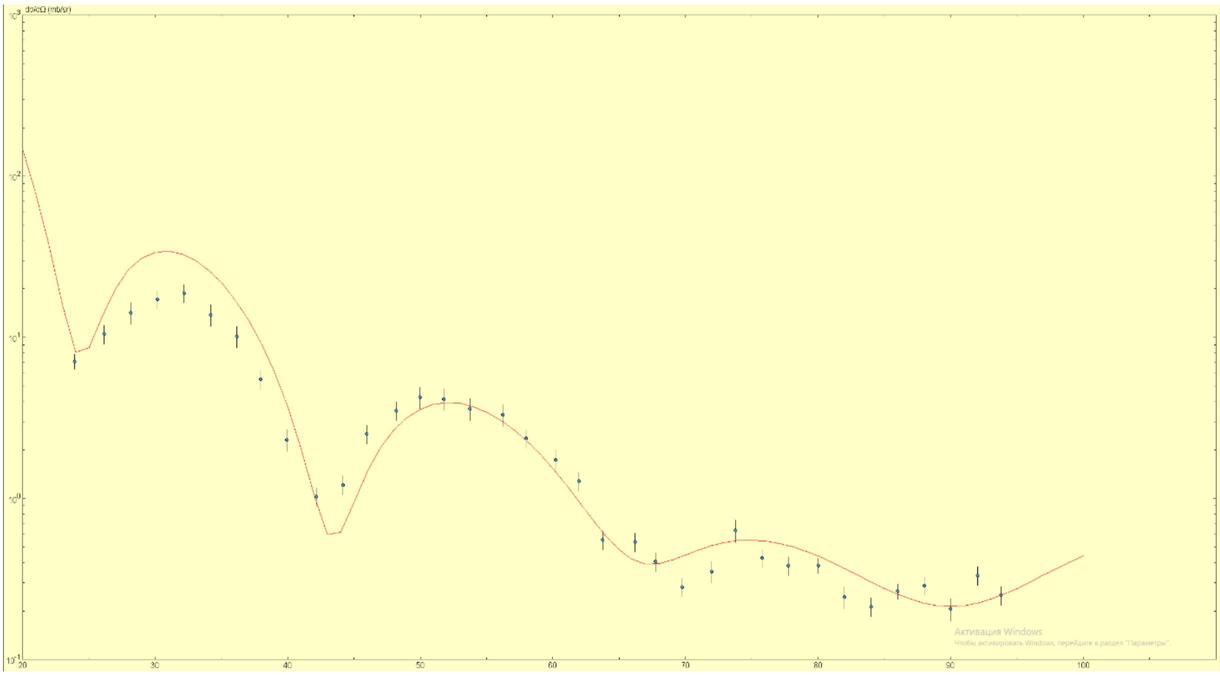
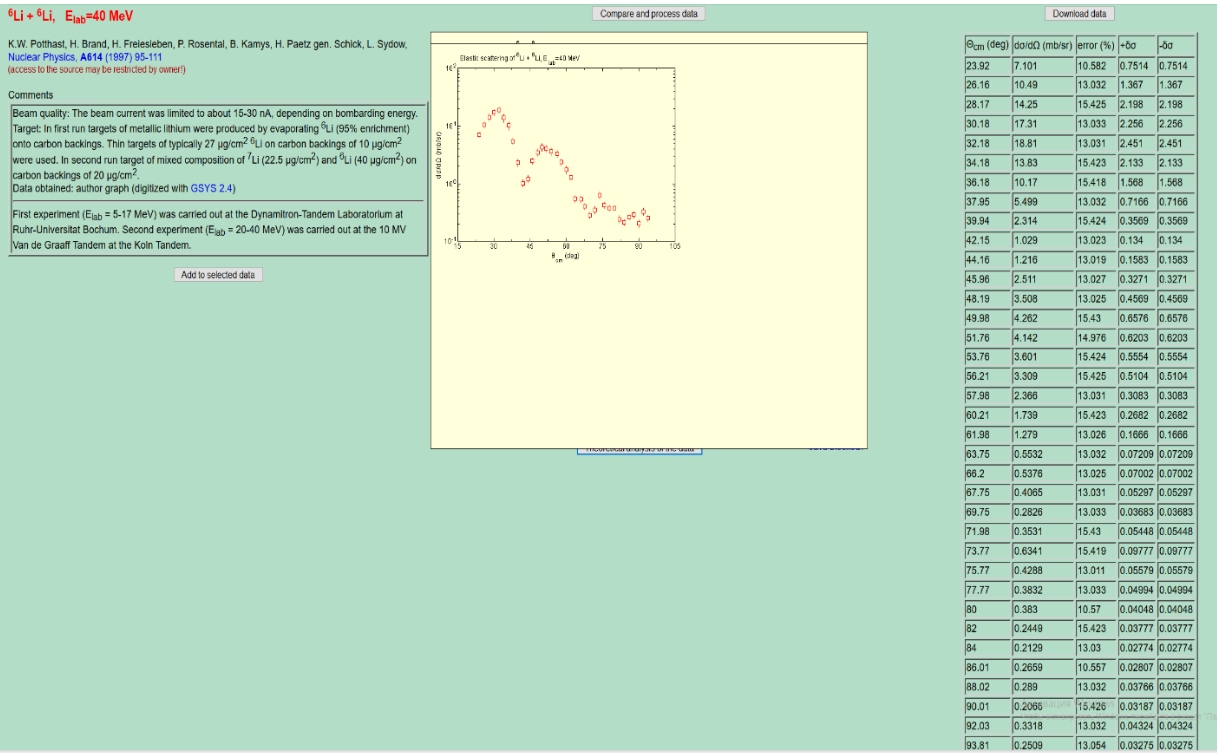


Figure 1.5.


$^{6}Li + ^{6}Li$, E_{lab}=40 MeV

Compare and process data

Download data

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Comments

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Target: In first run targets of metallic lithium were produced by evaporating ^{6}Li (95% enrichment) onto carbon backings. Thin targets of typically 27 μg/cm^2 ^{6}Li on carbon backings of 10 μg/cm^2 were used. In second run target of mixed composition of ^{7}Li (22.5 μg/cm^2) and ^{6}Li (40 μg/cm^2) on carbon backings of 20 μg/cm^2.
Data obtained: author graph (digitized with GSYS 2.4)

First experiment (E_{lab} = 5-17 MeV) was carried out at the Dynamitron-Tandem Laboratorium at Ruhr-Universitat Bochum. Second experiment (E_{lab} = 20-40 MeV) was carried out at the 10 MV Van de Graaff Tandem at the Koln Tandem.

Add to selected data

Θ_{cm} (deg)	dσ/dΩ (mb/sr)	error (%)	+δσ	-δσ
23.92	7.101	10.582	0.7514	0.7514
26.16	10.49	13.032	1.367	1.367
28.17	14.25	15.425	2.198	2.198
30.18	17.31	13.033	2.256	2.256
32.18	18.81	13.031	2.451	2.451
34.18	13.83	15.423	2.133	2.133
36.18	10.17	15.418	1.568	1.568
37.95	5.499	13.032	0.7166	0.7166
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56.21	3.309	15.425	0.5104	0.5104
57.98	2.366	13.031	0.3083	0.3083
60.21	1.739	15.423	0.2682	0.2682
61.98	1.279	13.026	0.1666	0.1666
63.75	0.5532	13.032	0.07209	0.07209
66.2	0.5376	13.025	0.07002	0.07002
67.75	0.4065	13.031	0.05297	0.05297
69.75	0.2826	13.033	0.03683	0.03683
71.98	0.3531	15.43	0.05448	0.05448
73.77	0.6341	15.419	0.09777	0.09777
75.77	0.4288	13.011	0.05579	0.05579
77.77	0.3832	13.033	0.04994	0.04994
80	0.383	10.57	0.04048	0.04048
82	0.2449	15.423	0.03777	0.03777
84	0.2129	13.03	0.02774	0.02774
86.01	0.2659	10.557	0.02807	0.02807
88.02	0.289	13.032	0.03766	0.03766
90.01	0.2066	15.426	0.03187	0.03187
92.03	0.3318	13.032	0.04324	0.04324
93.81	0.2509	13.054	0.03275	0.03275

Figure 1.4; 1.5; 1.6; Data entry form for calculations of elastic scattering of Li^6 nuclei on Li^6 nuclei.

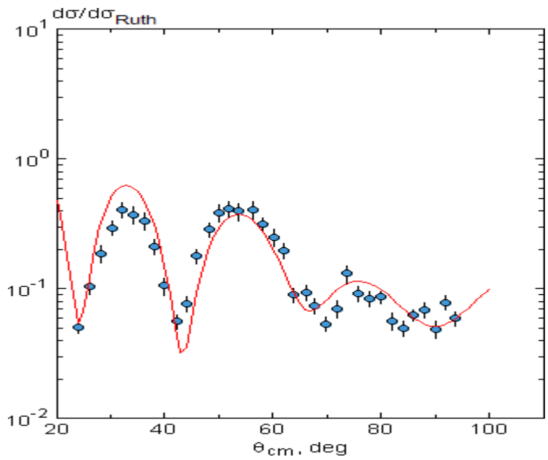

Figure 1.7. The ratio of the differential cross-section of elastic scattering to the Rutherford cross-section of 6Li nuclei on Li^6 nuclei at an energy of 40 MeV. The curve corresponds to the calculation within the optical model, the points are experimental data (see Fig. 1.7).

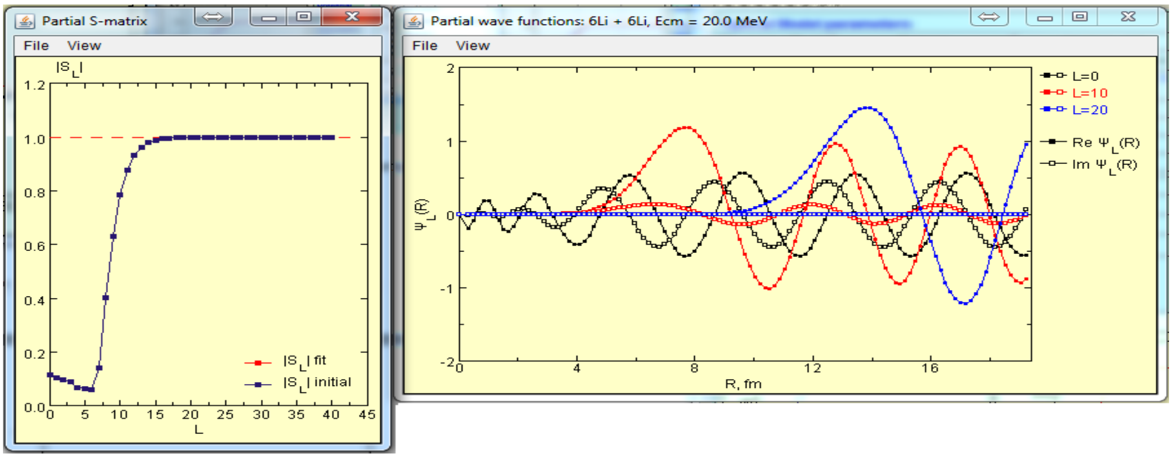

Figure 1.8. Partial waves with orbital quantum numbers L = 0, 10, 20 (right) and the dependence of the partial S-matrix on L for elastic scattering of Li^6 nuclei on Li^6 nuclei with energy E_{lab}= 40 MeV.

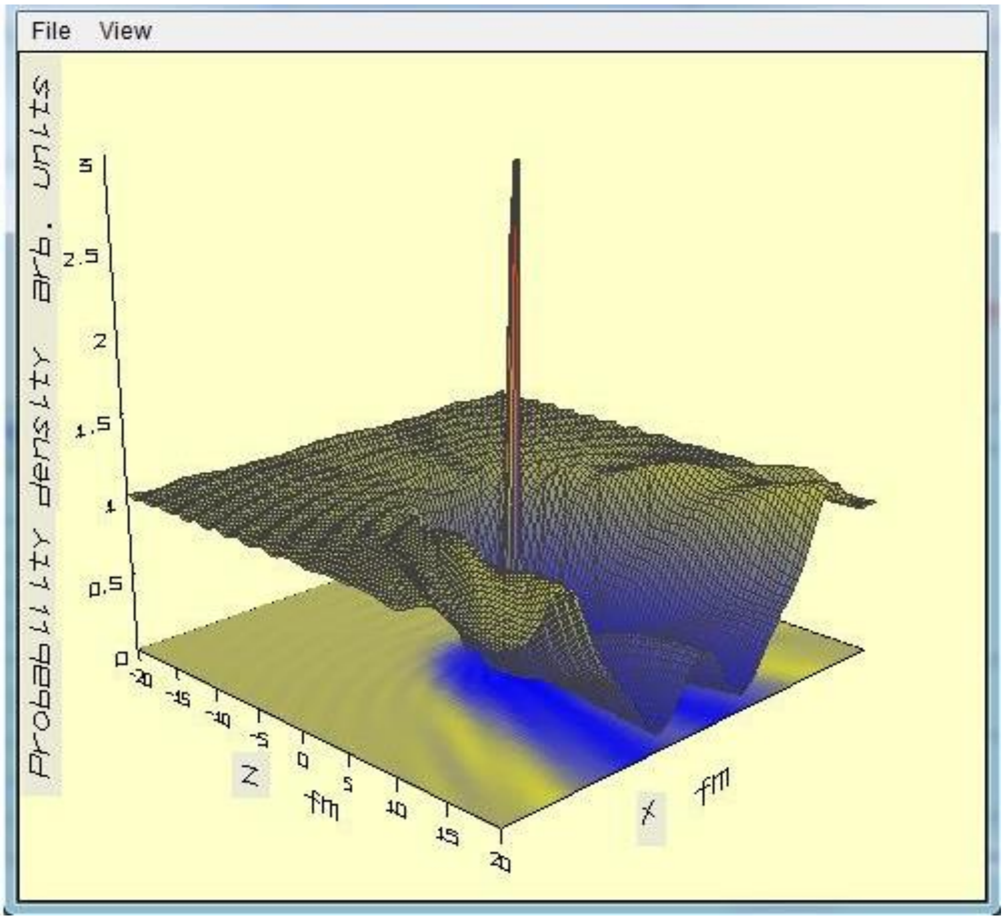

Figure 1.9. Probability density $|\psi_k(r)|^2$ for elastic scattering of Li^6 nuclei on Li^6 nuclei with energy E_{lab}= 40 MeV, the Oz axis coincides with the direction of the initial velocity of the projectile particle.

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