Optical Model Analysis of Elastic Scattering within Low Energy Nuclear Knowledge Base NRV

http://nrv.jinr.ru/nr/

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Introduction

- In 1911, Rutherford was the first who apply the nuclear scattering by bombarding the gold foil with $\alpha$ particles to study the structure of atoms.
- Then this idea expanded and forced the invention of accelerators to get higher energy colliding particles to study the structure of the atomic nuclei.
- It resulted in vast amount of the experimental data and number of theoretical approaches to the data description.
Everybody time to time does the following:

- Search for available experimental data in the databases
- Processing and drawing these data
  - Use some graphics packages
- Analysis of the experimental data
  - Finding appropriate theoretical model
  - Preparation of input data and run the code
  - Processing of the obtained results

It requires time, resources and experience.
These databases provide detailed information on their subject only.

In order to obtain complete data user needs to visit all databases.
Nuclear Data Resources in the Internet

- The Isotopes Project (LBNL) [http://ie.lbl.gov/](http://ie.lbl.gov/)
- TUNL [http://www.tunl.duke.edu/~datacomp/](http://www.tunl.duke.edu/~datacomp/)
- NN-Online [http://nn-online.org/](http://nn-online.org/)
- NDC JAEA [http://wwwndc.jaea.go.jp/](http://wwwndc.jaea.go.jp/)
Computer Codes for Nuclear Data

- **TALYS** – software for the simulation of nuclear reactions
  [http://www.talys.eu/](http://www.talys.eu/)
- **EMPIRE** – modular system of nuclear reaction codes for advanced modeling of nuclear reactions using various theoretical models
- **SAMMY** – an R-matrix tool for analysis of cross section data in the resolved and unresolved resonance regions
- **FRESCO, CCFULL, GRAZING, ABAREX, DWUCK, CHUCK, and many others**
Extracting data directly by using the nuclear data resources or computer codes is not easy as it looks.
Difficulties

- The databases provide detailed information on their subject only. In order to obtain complete data user needs to visit all databases.

- User needs an additional software on his PC in order to process data.

- Computer codes need to be downloaded and installed, they have complicated interface, non-advanced user needs significant time in order to run programs.

- Most of the codes are not integrated with databases.
Solution

- Combination of the databases on nuclear properties and experimental cross sections of nuclear reactions along with computer codes of theoretical models in a unique system.

- This system is named the Knowledge Base on low energy nuclear physics.

- **We named this specific software the**

  “Nuclear Reactions Video” (NRV)
Features of the NRV knowledge base

- Databases (nuclear properties and cross sections)
- Computing Codes (OM, CC, DWBA, ...)
- Free access for remote user (web-server based)
- Multi-user architecture
- User-friendly interface
- Hypertext and Graphical representation of results
- Processing of the data and obtained results
- Everything is downloadable (text & graphics)
1. Processing of exp. data
- Visualization of all the data
- Adaptation of the data

2. Nuclear Models
- Shell models
- α, β – decays
- Fission, SF

3. Nuclear Dynamics
- Elastic scattering (Optical and Classical models)
- Inelastic scattering (DWBA, CC, DIC)
- Transfer reactions (DWBA, GRAZING,...)
- Break-Up (DWBA, CC, Classical model)
- Fusion (CC, Langevin equation, Empirical model)
- Driving potential
- Nuclear models (Shell model, LDM, TCShM)
- Decay of excited nuclei (Statistical model)
- Evaporation residues
- Kinematics (2-body, 3-body, Q-calculator)

NRV-server

1. Available databases
2. Publications

Databases
MySQL, Java-Script, PHP

Computing Codes
C++, Java, Fortran

1. Properties of nuclides
- Spin, Parity, Half-life, Decay modes
- Mass, Q-values, Excited states
- Radius, Deformation, B(Eλ)

2. Cross sections of nuclear reactions
- Elastic Scattering
- Heavy-Ion Fusion
- Evaporation Residues
Example: Optical Model for Elastic scattering in NRV

For a given set of the OM parameters the Optical Model code of the NRV allows one to calculate and present in graphical and tabular forms all the quantities mentioned above: the partial waves $\psi_l(r)$, the partial matrix element $S_1$, the total wave function in the 3-dimentional space $\Psi_{k}^{(+)}(r, \theta)$, and the differential cross section $d\sigma / d\Omega$.

An automatic search of the OMP parameters can be fulfilled with a fit of the calculated elastic scattering angular distribution to the available experimental data. Many addition possibilities are also included to the Optical model code which allows one to analyze an investigated process in detail.
Nuclear Dynamics: Elastic Scattering

Optical model of the elastic scattering of nuclear particles in NRV

The Schrödinger equation

\[
\left[-\frac{\hbar^2}{2\mu} \nabla^2 + V_{OM}\right] \Psi^{(+)}(\vec{r}, \vec{k}) = E_k \Psi^{(+)}(\vec{r}, \vec{k})
\]

with phenomenological Optical Potential

\[
V_N = \frac{V_o}{1 + \exp\left(\frac{r - R_v}{a_v}\right)} \quad W = \frac{W_o}{1 + \exp\left(\frac{r - R_w}{a_w}\right)}
\]

\[
\Psi^{(+)}(\vec{r}, \vec{k}) \rightarrow e^{ikr \cos \vartheta} + f(\vartheta) \frac{e^{ikr}}{r}
\]

Elastic scattering cross section in general case is

\[
\frac{d\sigma}{d\Omega}(\vartheta) = |f_c(\vartheta) + f'(\vartheta)|^2
\]

\[
f'(\vartheta) = \frac{1}{2ik} \sum_l (2l + 1) e^{2i\sigma_l} (S_l - 1) P_l(\cos \vartheta)
\]
Elastic Scattering of Deuteron on $^{12}$C in The Energy Range From 60 to 90 MeV

- At 60.6 MeV
Elastic Scattering of Deuteron on 12C in The Energy Range From 60 to 90 MeV

- At 77.3 MeV
Elastic Scattering of Deuteron on $^{12}$C in The Energy Range From 60 to 90 MeV

- At 90 MeV
Concluding remarks:

- Study the Optical model of elastic scattering of nuclear particles and get an experience in work with NRV Optical model:
  - Preparation of experimental data (\(^{12}\)C(d,d) \(E_d = \) up to 90 MeV)
  - Choice of parameters of Optical model potential.
  - Calculation and visualization of the following quantities:
    - Differential Cross Section,
    - S-Matrix,
    - OM Interaction
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Thank you for your attention