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ELECTRONIC GUIDE FOR NUCLEAR CROSS-SECTIONS (version 1994)

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Дано краткое описание фортранной программы CROSEC для вычисления интегральных пион-ядерных, нуклон-ядерных и ядро-ядерных сечений взаимодействия (упругих, неупругих и полных). Адрон-ядерные сечения определяются путем интерполяции известных экспериментальных данных для ядер с зарядовым числом $Z > 3$ и области энергий от 14 МэВ до 1 ТэВ. Ядро-ядерные сечения рассчитываются с помощью аппроксимационной формулы (с определенными из сравнения с экспериментом коэффициентами) для энергий, больших нескольких МэВ/нуклон. Программа CROSEC использует 168 кБ памяти и может использоваться интерактивно для выдачи на экран или печать как отдельных значений, так и целых таблиц сечений. Модули CROSEC могут использоваться в качестве подпрограмм в других программах.

Работа выполнена в Лаборатории вычислительной техники и автоматизации ОИЯИ.

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A short description of a fortran CROSEC code providing the integral cross-sections for pion-nucleus, nucleon-nucleus and nucleus-nucleus interactions (total, inelastic, elastic) is given. The hadron-nucleus cross-sections are obtained, by means of interpolation between estimated experimental data at target charge numbers $Z > 3$ and energies from 14 MeV up to 1 TeV. The nucleus-nucleus cross sections are calculated with the help of approximation formula with fitted coefficient at energies above several MeV/nucleons. The CROSEC code uses 168 KB RAM and can be used in interactive way to generate separate values or tables of cross sections on a display screen or file. Fractions of the CROSEC code can be used as subroutines employed by other codes.

The investigation has been performed at the Laboratory of Computing Techniques and Automation, JINR.

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A set of all available experimental integral hadron-nucleus cross-sections at energies exceeding 14 MeV and plots of estimated total,inelastic and elastic cross-sections for pion and nucleon interactions $\sigma_{el}(E), \sigma_{in}(E), \sigma_{tot}(E)$ are presented in paper /1/.

Two methods have been employed to calculate dependence of cross-sections vs energy E. At high energies,where the projectile de Brogle wave length is significantly smaller than the size of the target nucleus,the quasioptical model is used /1/.The parameters of this model have been fitted to obtain best agreement of calculated and experimental data.The high-energy region has been divided into separate intervals with characteristic behavior of cross- sections.(For example,the region near the minimum of nucleon cross-sections at energy about 200 MeV, the resonance region near 180 MeV in case of pion-nucleus cross sections,the interval of smooth cross-section alterations at energies above 1 GeV).A set of parameters has been defined for each interval.Phenomenological approximation of cross-sections , was used at lower energies:

$$\sigma(A, Z, E) = \pi[r_o A^{1/3} + \lambda(A, E)]^2[1 - V(A, Z)/E_c]f(E)\phi(A)^{\alpha(E)},$$

where V is the Coulomb barrier,λ and E are the de Brogle wave langth and the kinetic energy of the projectile in the center of mass system.A and Z are the target nucleus mass and charge numbers.The functions $f(E)$, $\phi(A)$ and $\alpha(E)$ are determined by the sums

$$\Sigma_i \alpha_i E^{\beta_i} \quad \text{and} \quad \Sigma_i a_i A^{b_i}$$

with constant coefficients ($\phi(A) \rightarrow A$, $\alpha(A) \rightarrow$const with the projectile energy increase).

It is quite clear that such approach is only one of many possible approximations.For example, one could as well use also an optical model based on a solution of the Schrödinger equation with a phenomenologocal potential /2 − 4/.In principle,by these means one is capable even to diminish the number of adjustable parameters.Another method of approximation is proposed in paper /5/.At very high energies $E > 10$ GeV it is advantageous to use the Redge pole approximation which allows one to describe simultaneously the cross-sections for several types of particles using the same set of parameters /6/.The concrete choice of approximation slightly influences the shape of the curves $\sigma(E)$.The most important is to perform a selection of experimental data sets used for adjustment when some data are taken with larger weight than the others. Certainly, subjective considerations are present when such a selection is performed. The process of estimation and approximation of measurement results is like to some skill, which helps to provide the value in best agreement with experiment.

The known experimental information on nucleus-nucleus cross-sections is insufficient to compile a detailed plot curves, especially if one considers approximation relations can be used with coefficients fitted by means of comparison with the known experimental data/1/. Of course, the accuracy of the results is lower than that for hadron-nucleus interactions.

A convenient for practical use code is described in papers /7, 8/ which provides σ_{el}, σ_{in}, σ_{tot} calculated by means of linear and in some cases by quadratic interpolation of cross- sections at intermediate energies, charge and mass numbers of target nucleus.

We propose an improved version of this code supplemented by a subroutine which uses approximation relations for calculation of integral nucleus-nucleus cross-sections. The new version appears more covenient for practical applications.

The CROSEC code includes following modules:

- MAIN MODULE for reading, input and printing separate values or tables of hadron-nucleus and nucleus-nucleus cross-sections (mbarns);
- function SIGHAD for calculation of pion-nucleus and nucleon-nucleus-cross-sections;
- functions SIGION, FHS and FC for calculation of nucleus-nucleus cross-sections;
- several BLOCK DATA with evaluated cross-sections at fixed values E,A,Z

After starting the program one must insert the eight numbers in free format:

ITYPE PA PZ TA TZ E1 E2 E

representing respectively:

$ITYPE = 1$ or $ITYPE = 2$ — calculation of total or inelastic cross-sections;

$ITYPE = 3$ — calculation at once of total, inelastic and elastic cross-sections;

PA, PZ—projectile mass and charge numbers (for pions $PA = 0.14$);

TA, TZ—the same for target nucleus;

E1, E2—the lowest and the highest energies in the considered interval;

ES —energy step.

To break the procedure one must insert 0 (zero) or BYE

For example, if one needs to obtain cross-sections of negative pion (pi-) with nucleus Cu-63.5 in the energy range from 20 MeV up to 100 MeV with a step 10 Mev one must enter (in free format):

3 0.14 -1 63.5 29 20 100 10

The computer replies:

```
*********************************************
CODE FOR CALCULATION OF NUCLEON-NUCLEUS,
PION-NUCLEUS
AND NUCLEUS-NUCLEUS TOTAL,INELASTIC AND ELASTIC
++++++++++ CROSS-SECTIONS (MBARNS) ++++++++
************************************************
WRITTEN BY V.S.BARASHENKOV AND A.POLANSKI
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*************************************************
ENTER:
ITYPE  AP  PZ  TA  TZ  E1  E2  ES
PION-NUCLEUS CROSS-SECTIONS (MBARNS)
 ENERGY(MEV)  TOTAL  INELASTIC  ELASTIC
     20.0     1400.0    725.0     675.0
     30.0     1500.0    782.5     717.5
     40.0     1600.0    840.0     760.0
     50.0     1737.0    930.0     807.0
     60.0     1875.0   1020.0     855.0
     70.0     1981.0   1110.0     871.0
     80.0     2088.0   1200.0     888.0
     90.0     2144.0   1247.0     897.0
    100.0     2200.0   1295.0     905.0
ENTER:
```

ITYPE PA PZ TA TZ E1 E2 ES

At this stage one must type a new set of input parameters or to break the procedure typing 0 (zero) or BAY.

The SIGHAD and SIGION functions can be used separately with other codes to calculate a current value of hadron-nucleus or nucleus-nucleus cross -section:

$CS = SIGHAD(IS, PA, PZ, TA, TZ, E)$

$CS = SIGION(IS, PA, PZ, TA, TZ, E)$

where E is a projectile energy (MeV for hadrons and MeV/nucleon (for nucleus);

$IS = 1$ or $IS = 2$ for calculation of total or inelastic cross-sections;

PA,PZ,TA,TZ are explained above parameters.

The CROSEC code is written in FORTRAN.It uses 168 RB real memory.

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