CALCULATIONS OF NEUTRON AND PROTON INDUCED REACTION FOR ^{238}U IN THE 0.01-200 MEV ENERGY REGION

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Abstract

The calculations of neutron and proton induced reaction Up to 200 MeV for target ^{238}U are performed, the calculated results are generally in rather good accordance with experimental data and reasonable in physics. The theoretical frameworks are the spherical optical model, intranuclear cascade mechanism for nucleon emission based on empirical formula, preequilibrium emission theory based on exciton model, evaporation model and Hauser-Feshbach statistical theory with width fluctuation correction. The fission widths are calculated with Bohr-Wheeler formula.

INTRODUCTION

In recent years, the accelerator-driven system (ADS) has been an interesting focus in nuclear physics[1,2,3]; China has also paid great attention to this field[4]. To satisfy the demands of ADS project of China for intermediate energy nuclear data, two computer programs for calculating nuclear data in medium energy region are being developed: MEND[5] for medium-heavy nucleus ($Z < 70$) and MENDF for fission nuclei ($Z \geqslant 89$) and sub fission nucleus ($70 < Z < 89$). In both programs, the projectile and emitting particles can be neutron, proton, ^{4}He, deuteron, triton and ^{3}He; all reactions in the first, the second, the third, ... up to the 18th particle emission and fission process are considered. All reaction cross sections and energy spectra of six kinds of emitting particles, gamma rays and then all kinds of recoil (residual) nuclei can be calculated, the double-differential cross section of six kinds of emitting particles can also be calculated with Kalbach systematics. Besides, in MENDF, the mass and charge distribution as well as the kinetic energy distribution of fission fragments, υ -values and energy spectra of fission neutrons can also be calculated.

There are many experimental data available in intermediate energy region for ^{238}U, so ^{238}U is a good candidate for testing model calculation methods at intermediate energy region. We intend in a consistent way to calculate all reactions for neutron and proton induced reaction up to 200 MeV.

Basic Theoretical Frames

The theoretical frames of MEND and MENDF are spherical optical model, intranuclear cascade based on empirical formula, pre-equilibrium (PE) statistical theory based on exciton model, evaporation model and Hauser-Feshbach (HF) statistical theory with width fluctuation correction.

Four kinds of spherical optical potential can be employed to calculate the total cross section, shape elastic scattering cross section and its angular distribution, absorption cross section, as well as transmission coefficients used in HF theory and “inverse cross sections” used in PE theory. Usually, the phenomenological optical potential of Becchetti and Greenlees (BG)[6] form or of Koning and Delaroche (KD)[7] form are used. MEND and MENDF can also do the phenomenological optical potential calculation with CH89 parameters[8] and microscopic optical potential calculation based on Skyrme force[9] for n and p channel. The microscopic potential and the later two global phenomenological potential are very useful for those nuclide without experimental data for adjusting optical potential parameters.

The cascade emissions of one to four nucleons with certain fractions before pre-equilibrium and evaporation are considered in MEND and MENDF. The cascade yields of nucleons and the energy spectra of cascade nucleons are calculated with empirical formula[10].

The pre-equilibrium emissions mechanism is included exactly in first, second and third emission processes, it is also exactly (for nucleon emissions) or approximately (for emissions of composite particles) considered in fourth and fifth emission processes. Combining the cascade emissions of nucleons and the pre-equilibrium mechanism, there are some fractions for both pre-equilibrium emission and evaporation in first to sixth emission process, and there is only evaporation (without pre-equilibrium emission) in seventh to eighteenth emission process. For emission of composite particles in pre-equilibrium theory, the improved pick-up reaction mechanism[11] is adopted. In the calculation of state densities for the exciton model, the Pauli principle is accommodated. The angular momentum and parity conservation are not considered in cascade nucleon emissions, PE theory and evaporation model.

The HF theory with width fluctuation correction is only used in low energy region (the incoming energy is less than about 3 to 5 MeV) for first emission process, in which the angular momentum and parity conservation are considered, the cross section and angular distribution of discrete levels can be given.

For the calculation of radiative capture cross section and its gamma spectra, besides the usual evaporation mechanism, the direct and pre-equilibrium emission gamma are also considered in MEND and MENDF. The theory approach and calculation formula are due to J.M.Akkermans and H.Gruppelaar[12]. We get the direct gamma by letting n=1 in their eq.(8).

MEND and MENDF do not calculate the direct reaction contributions, which are calculated with other codes[13,14] and treated as input in MEND and MENDF.

Neutron Induced Reaction for Target ^{238}U

Firstly, the code APMN[15] is used to search for the optimal sets of optical potential parameters in neutron channel of both the BG[6] and the KD[7] form. For n + ^{238}U, there are many experimental data of total, nonelastic cross sections, and elastic scattering angular distributions. All experimental data of nonelastic cross sections are measured with low accuracy in 50’s and 60’s years of last century, so the optimal sets of optical potential parameters in neutron channel are searched mainly based on the experimental data of total cross sections and elastic scattering angular distributions.

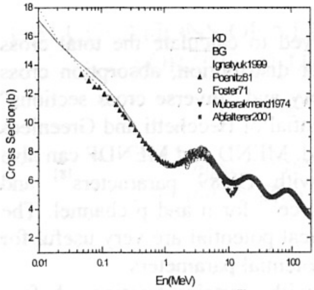

Fig.1. Total cross section for $n+^{238}U$

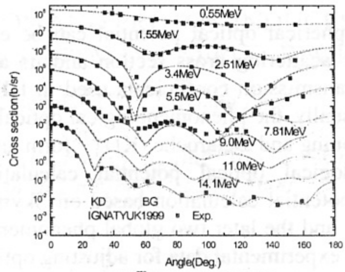

Fig.2. $^{238}U(n,el)$ angular distributions, the result s are offset by factors of 10

The total cross section and elastic scattering angular distributions. In Fig.1 and Fig.2, the Calculated results with optical potential parameters of both the BG and the KD form are compared with the available experimental data and Ignatyuk's[16] evaluation, respectively. Then we decide that the optimal set of KD (rather than BG) OMP in neutron channel are used in our HF and PE statistical calculations. With the form and symbols of KD global neutron OMP in ref. [8], our optimal neutron OMP parameters are:

V_1=59.29657-21.0(N-Z)/A-0.024A, V_2=0.0073063-1.48*10^{-6}A

V_3= 2.200366*10^{-5}- 2.0*10^{-8}A,

V_4= 11.52676*10^{-9}

W_1= 10.97903+0.0167A,

W_2= 56.87801+0.0795A

d_1=17.83719-16.0(N-Z)/A,

d_2=0.06033069+0.003802/(1+exp[(A-156.0)/8.0]), d_3= 6.269081

V_{so1}=3.468516+0.0030A, V_{so2}=0.00094084

W_{so1}= -6.07807, W_{so2}= 141.2979

E_f=-11.2814+0.02646A

r_v=1.263206-0.4054$A^{-1/3}$,

a_v= 0.6981602-1.487*10^{-4}A

r_w= 1.373458-0.4054$A^{-1/3}$,

a_w= 0.9084001-1.487*10^{-4}A

r_d= 1.215957-0.01585 $A^{1/3}$,

a_d=0.9367781-1.656*10^{-4}A

r_{so}=0.8204769-0.647 $A^{-1/3}$, a_{so}= 0.1897177

The direct inelastic cross sections, calculated with the code ECIS95[14] and P.G.Young's deformed nuclear OMP[17] ,are treated as input for our main program MENDF.

In MENDF for the first emitting and fission process, HF statistical theory is used in lower energy

region, PE statistical theory is used in higher energy region, and the transitional energy region is 2.5—5.5 MeV for n + ^{238}U.

The fission cross sections are given in Fig.3, from which we can see that the result of our calculation of fission cross sections are in pretty good agreement with experimental data.

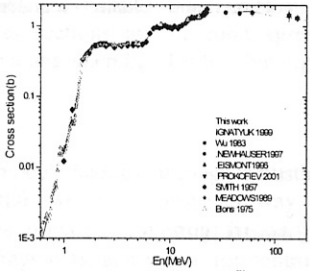

Fig.3. Fission cross section for n+^{238}U

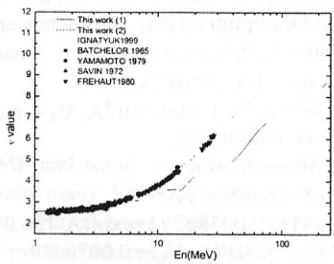

Fig.4. Numbers of neutrons per fission for n+^{238}U

The neutron numbers per fission (ν values) are given in Fig.4, The ν values in this work (2) include both the emitting neutrons before fission and the evaporation neutrons from the fission fragments, but those in this work (1) only include the evaporation neutrons from the fission fragments and not including the emitting neutrons before fission because they are already included in neutron production cross sections for our calculations with MENDF. Below 6 MeV, there is only first chance fission, so the ν values in this work (1) and (2) are with same values. From Fig.4 we can see that the ν values in this work (2) are in very good accordance with experimental data.

The normalized spectra of fission neutrons at 14.7MeV are given in Fig.5, from which we can see that our calculated normalized fission neutrons spectra are in good accordance with experimental data except for emitting neutron energy below 0.8 MeV, our calculated values are lower than experimental data. That is to say our calculated normalized spectra of fission neutrons is some harder than experimental values.

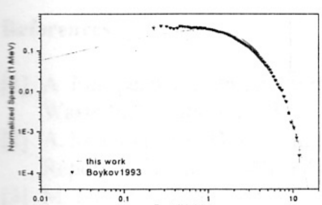

Fig.5 Normalized Spectra of Fission Neutrons at 14.7 MeV for n+^{238}U

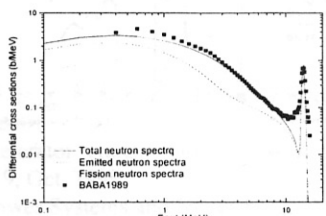

Fig.6. Secondary neutron spectra at En=14.05 MeV for n+238

The total outgoing neutron differential cross sections at 14.05MeV are given in Fig.6. Our calculated total outgoing neutron spectra are in good accordance with experimental data given by Baba in 1989 when 3.0 < E_{out} <9.0 MeV, lower than experimental data when E_{out} <3.0 MeV, and thinner than experimental value near the 14 MeV elastic peak.

Proton Induced Reaction for Target ^{238}U

The code APMN[5] is used to search for the optimal sets of optical potential parameters of the KD form. For p + ^{238}U, the optimal sets of optical potential parameters are searched based on the experimental data of absorption cross sections and elastic scattering angular distributions. Our optimal OMP parameters are:

$V_1=56.450+21.0(N-Z)/A-0.024A$,

$V_2=0.0084901+4.23*10^{-6}A$

$V_3= 5.33865*10^{-5}+ 1.1360*10^{-8}A$, $V_4= -8.0*10^{-9}$

$W_1= 8.3004+0.009629A$,

$W_2= 109.399+0.0795A$

$d_1=25.4565+16.0(N-Z)/A$,

$d_2=0.0184418+0.003802/(1+\exp[(A-156.0)/8.0])$, $d_3= 10.3895$

$V_{so1}=9.7556+0.0030A$, $V_{so2}=0.0070639$

$W_{so1}= -0.0000002$, $W_{so2}= 280.0000$

$E_f=-8.4075+0.01378A$

$r_c=0.70+0.697A^{-2/3}+12.994A^{-5/3}$

$r_v=1.2550577-0.4054A^{-1/3}$,

$a_v= 0.7926494-1.487*10^{-4}A$

$r_w= 1.4368911 -0.4054A^{-1/3}$,

$a_w= 0.7440530-1.487*10^{-4}A$

$r_d= 1.2388047 -0.01585 A^{1/3}$,

$a_d= 0.4804756+5.2049999*10^{-4}A$

$r_{so}= 1.2692896-0.647 A^{-1/3}$, $a_{so}= 0.6680794$

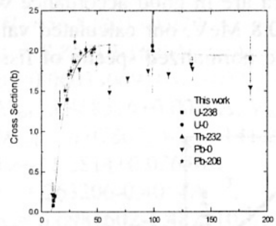

Fig.7. The absorption cross sections for p+238U

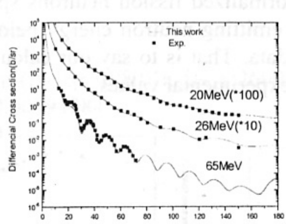

Fig.8. ^{238}U(p,el) angular distribution

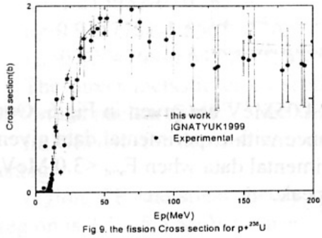

Fig 9. the fission Cross section for p+^{238}U

The absorption cross sections and elastic scattering angular distributions. In Fig.7 and Fig.8, the calculated results with optical potential parameters are compared with the available experimental data, respectively. Our calculation values are in reasonable agreement with experimental data

The fission cross sections are given in Fig.9, from which we can see that our calculated fission cross sections are in good agreement with experimental data and Ignatyuk's[16] evaluation values when Ep<45Mev, but higher than

Summary

Using model theories, through adjusting OMP and some "fission parameters", with the code MENDF we in a consistent way calculate many kinds of cross sections, angular distributions of elastic scattering, fission ν values, neutron energy spectra, independent yields of fission fragments, and so on, for neutron and proton induced reaction Up to 200 MeV for target ^{238}U. Through the comparison of the calculation results with experimental data, we can see our calculated values are in rather good accordance with experimental data.

At present in MENDF, for the first chance fission and the first emitting process, HF theory is used in lower energies and PE theory is used in higher energies, and the fission parameters are different in HF and PE. This is not satisfactory, we should unify or combine HF and PE theory and use a common set of fission parameters in first emitting and fission process for the future work.

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