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Theoretical Calculation of Energies of Projectile like Fragments in ^{76}Ge (635 MeV) + ^{198}Pt Deep-Inelastic Collisions

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Abstract

The theoretical calculation of the energies of projectile like fragments (PLFs) using the heavy-ion reactions between ^{76}Ge and ^{198}Pt are reported in this article. The incident beam energy was 635 MeV. The calculated values of PLFs are compared with the previous experimental results and it is shown that the theoretical calculations of PLFs are consistent with the experimental values. The elastic peak of the projectile is compared theoretically and experimentally. Moreover, the Q-value and binding energy of PLFs were also calculated.

Keywords: Projectile-like fragments; deep-inelastic collisions; incident beam 635 MeV

1. Introduction

Heavy-ions deep-inelastic collisions (DICs) are currently one of the most rapidly developing trends to find the nuclear structure of neutron-rich and proton-rich nuclei. DICs have properties of two quite opposite nuclear processes: compound nucleus decay and direct reactions. Like direct reaction, DICs have strong coupling between the input channel and the output reaction channels. DICs products do not exist in the direction of the motion of initial nuclei or their atomic and mass numbers in compound nucleus decay [1]. The peculiar properties of DICs are very important to the study of both proton rich as well as neutron rich nuclei. Usually proton rich nuclei could be produced in a fusion reaction and neutron rich nuclei are produced in fission reactions [2].

The structures of neutron-rich nuclei produced in the DICs were studied by in-beam γ-ray spectroscopy with a crystal ball, which was a large array of Ge detectors with anti-Compton shields. Several DICs studies of the neutron-rich nuclei were also conducted by the German national laboratory for mass separator heavy ion research (GSI) group [3-6]. However, only a few number of nuclei have been studied by means of in-beam γ-ray technique. Broda and his collaborators observed γ rays of $^{64\text{-}68}$Ni using the DICs with the projectile energies not so high from the Coulomb barrier [7]. Besides those methods, an experiment was carried out at the Japan Atomic Energy Agency (JAEA), Tokai-Mura, Ibaraki to investigate the isomers around ^{68}Ni by deep-inelastic collisions ^{76}Ge (635 MeV) + ^{198}Pt. This effort led to identifying 13 isomers and was reported to the journals [2, 4, 5, 8]. The experimental fragments energies were measured by known ΔE-E counter telescope [5]. Recently, we have calculated Compton scattering of 662 keV gamma rays proposed by Klein-Nishina formula and isomers around ^{68}Ni [9, 10]. The theoretical energies of projectile-like fragments in DICs have not been calculated yet. At present, we have calculated projectile-like fragments in ^{76}Ge (635 MeV)+^{198}Pt DICs and compared them with previous experimental values [2].

1. Theoretical calculations

Binding Energy (B.E)

The binding energy [10] can be calculated using:

$$B.E = \Delta m.\, c^2 \qquad (1)$$

where Δm (mass defect) = $[Z\,(m_p+m_e) + (A\text{-}Z)m_n] - m_{atom}$
Z is the atomic number, A is the mass number, m_p is the mass of proton, m_n is the mass of neutron and c is the velocity of light.

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Coulomb Barrier

In reaction, projectile and target nuclei easily overcome the electric repulsion to get close for attractive nuclear strong force between them to fuse them apart in the reaction. This is what Coulomb barrier is all about.

From equation: $E_c = \frac{Z_1 Z_2}{A_1^{\frac{1}{3}} + A_2^{\frac{1}{3}}} MeV$ (2)

Z_1= Proton number of projectile nucleus
Z_2= Proton number of target nucleus
A_1= Atomic number of projectile nucleus
A_2= Atomic number of target nucleus

Q-value

The Q-value of the reaction ^{76}Ge (635 MeV) + ^{198}Pt is calculated by equation (4):

$$Q = [(M_x + m_x) - (M_Y + m_y)]\, c^2 \quad (3)$$

where, m_x = Rest mass of x (Projectile), M_x = Rest mass of X (Target)
m_y = Rest mass of y (PLFs), M_Y = Rest mass of Y (TLFs)
c = velocity of light

Projectile-like fragments energies

The analytical relationship between the kinetic energy of the projectile and outgoing particle of two body nuclear reaction [11] is shown in Fig. 1.

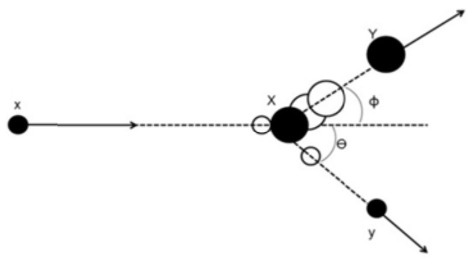

Fig. 1. Schematic diagram of two body nuclear reaction [11]

The PLFs are calculated by equation (4) and (5),

$$Q = E_y\left(1 + \frac{m_y}{M_Y}\right) - E_x\left(1 - \frac{m_x}{M_Y}\right) - \frac{2\sqrt{m_x m_y E_x E_y}}{M_Y}\cos\theta \quad (4)$$

$$E_Y = Q - E_y + E_x \quad (5)$$

where:
E_y: Projectile like fragments (PLFs) energies, E_x: projectile energies
E_Y: Target like fragments (TLFs) energies
m_x: Mass of projectile, m_y: Mass of PLFs, M_Y: Mass of TLFs
θ: Scattering angle

2. Results and discussion

Table 1 shows the list of thirteen isomers populated in deep inelastic collisions ^{76}Ge (635 MeV) + ^{198}Pt, which were detected using an isomer-scope [2]. The binding energy, Coulomb barrier and Q-value in the reactions are given in Table 1 and were calculated by equation 1, 2 and 3 respectively. The experimental elastic peaks of ^{76}Ge are taken from ref. [8]. The elastic and projectile like fragments (PLFs) energies were measured by standard time of flight (TOF) ΔE-E technique. The individual projectile-like fragments energies (Ey) were calculated using equation 4 and 5. The energies of target-like fragments (E_Y) were calculated by considering the experimental elastic energy 520 MeV of ^{76}Ge [12]. The detailed calculations were done by using an open excess software for the theoretical value of nuclear reaction process. This is called kinematics and it is useful to calculate the binding energy, fragments energy, Q-values in a nuclear reaction [12].

Table 1. Coulomb barrier, Binding energy, Q-value, Elastic peak and Energies of projectile like fragments

Nuclei	Coulomb barrier energy (MeV)	Binding energy (MeV)	Q-value (MeV)	Elastic peak Expt.[2] (MeV)	Elastic peak Cal. (MeV)	PLF energy Expt. [2] (MeV)	PLF energy Cal. (MeV)
^{63}Ni		552.09	-27.140			340(8)	350.5
^{64}Cu		559.29	-28.473			345(8)	346.7
^{65}Ni		567.85	-20.381			360(8)	355.1
^{66}Ni		576.83	-15.344			380(8)	358.8
^{66}Cu		576.27	-20.139			370(8)	354.9
^{67}Zn		585.19	-19.046			370(8)	355.2
^{68}Ga	248	591.68	-21.433	520(4)	558.7	380(8)	352.7
^{69}Cu		599.97	-13.586			420(8)	358.7
^{70}Ga		609.64	-13.462			390(8)	358.2
^{74}As		642.32	-10.387			470(8)	358.4
^{83}Br		721.55	10.216			370(8)	368.9
^{84}Kr		732.26	13.584			370(8)	370.8
^{86}Sr		748.93	13.675			300(8)	369.4

The experimental elastic peak of ^{76}Ge was 520(4) MeV and calculated elastic peak was 558.7 MeV. It is shown that calculated elastic fragments deviated 6 % compared to experimental values. The binding energies are much larger than the fragments energies which are reasonable, because if fragments energies are comparable to binding energy, protons or neutrons knock out from the nuclei. Moreover, the calculated PLFs are also consistent with experimental PLFs.

Figure 2 shows the comparison between calculated and experimental energies of projectile-like fragments. It is shown that calculated data are in good agreement with experimental values. The calculated PLFs energy of ^{74}As nucleus is largely deviated from experimental values. This might be due to experimental error such as doublet of gamma rays, background estimation and population of weak signal and side feeding gamma decays etc.

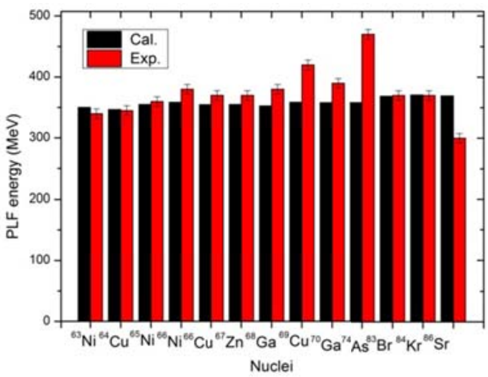

Fig. 2. Energy of projectile-like fragments (PLFs) for 13 isomers (calculation and experimental)

3. Conclusion

Energies of thirteen projectile-like fragments populated in ^{76}Ge + ^{198}Pt reactions are calculated and compared with the previous experimental values [2]. The present theoretically calculated values of energies of PLFs are in good agreement with the experimental. Binding energies and Q-values and Coulomb barrier in the reactions are also calculated precisely.

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