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CALCULATION OF REACTION CROSS SECTION FOR PURE FORM OF IODINE AND BISMUTH IN THE ENERGY RANGE OF 1 – 40 MEV

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ABSTRACT

In this work, the reaction cross section for 127Iodine and 208Bi isotopes using EXIFON code in the energy range of 1 - 40 MeV and nuclear reaction of cross-sections were calculated. The use of EXIFON code in this work is based on an analytical model for statistical multistep direct and multistep compound reactions (SMD/SMC model). The shell structure effect on the reaction cross-section of (α, nα) reaction for both with shell correction and without shell correction was also investigated. The result also revealed that the cross-sections of (α, nα) reaction for both with shell correction and without shell correction are zeros majorly at energies range considered, this shows that the energy of the incident particle is below the threshold of this reaction due to the presence of coulomb repulsive force between the projectile and target nucleus.. It is therefore concluded that, EXIFON code is a good tool for investigation of nuclear reaction cross section.

***Keyword**: EXIFON, ^{127}Iodine and ^{208}Bi.*

1. INTRODUCTION

Excitation function of reactions data is generally used to study and improve the ideal way of producing medical radioisotopes. Over the year's medical radioisotopes have become a promising method in the treatment of cardiovascular diseases, brain disorders and tumors with the aid of nuclear physicist providing accurate evaluated excitation functions of reactions data that will in turn lead to maximum production of this radioactive substances with high purity (Neseraja, et al., 1999).

Excitation function is defined as the graphical plots of cross-section against the energy of the incident particle, it is an important parameter in nuclear data analysis as it describes the probability that nuclear reactions can occur at a particular energy of incident particle (Probst, *et al.*, 1976). Studies of excitation functions of particle-induced reactions are of considerable significance for testing nuclear models as well as for practical applications, especially in the production of radioisotopes (Srivastava, 1971).

A nuclear reaction occurs when a nucleon or a nucleus collides with another nucleon or nucleus (Kettern, *et al.*, 2009). In other words, nuclear reaction is said to occur when a nuclear particle comes into close contact with another during which there is an exchange of energy and momentum (the product of mass and velocity) (Klopries, *et al.*, 1997). Nuclear reactions are characterized by the incoming nuclei and the outgoing reaction products. Thus after the reaction, the product nuclei which are the residual nucleus and the ejectile leave the point of contact in different directions (Basu, *et al.*, 2013). Besides the incoming nuclei and the outgoing reaction products, other properties of interest are the incident and outgoing particle energies as well as the scattering angles. The changes produced in a nuclear reaction usually involve strong nuclear force (Basu, *et al.*, 2013).

Radioactive isotopes play an important role in the field of medical science in terms of beneficial applications in both diagnosis and therapy purposes (Hauser, W., & Feshbach, H. 1952). In radioisotope production programmers, nuclear reactions data are mainly needed for optimization of production routes (Nicholas, 2002). The cross section data for different nuclide was intensively investigated and up to now, the nuclear databases are accessible online (Akovali, 2004).

Over the years, the concept of statistical multistep processes has become more and more important for the understanding of nuclear reaction mechanism, especially above 20 MeV (Probst, *et al.*, 1976). An analytical model for both statistical multistep direct (SMD) and statistical multistep compound (SMC) processes was applied for describing nuclear reactions up to 30 MeV (Filatenkov, *et al*., 2000). This can be generalized in several respects:

The extension to higher energies is performed including s-step direct processes for s = 1 up to 5 (Filatenkov, *et al*., 2000).

Thus, there is no reference to the optical model (OM) reaction cross section. The OM cross section for charged particles was used to simulate coulomb effects in the threshold region only. α and γ-Processes are included Spin-isospin conservation during the two-body collision is considered (Audi, *et al*., 2003).

The calculation of Multiple Particle Emission (MPE) is generalized. Up to three decays of the compound nucleus are considered (Nicholas, 2002). This model is formulated in detail for predicting emission spectra for neutrons, protons, alphas and photons including equilibrium, pre-equilibrium, direct as well as MPE processes in a consistent way (Aslam, M. N., & Qaim, S. M. 2014).

Today, the nuclear databases are accessible online through the website provided by the IAEA Nuclear Data Section (NDS) (Glenn, *et al.*, 1997). This site offers access to tens of thousands of nuclear data sets that can be used for research, innovation, development and dissemination (Sadeghi, M., & Enferadi M. 2011). By such materials and files, the authors conducted the calculation on the reaction cross-section for neutron-induced reactions on ^{127}I isotope and ^{208}Bismuth (Hassan, *et al.*, 2006).

In this research, EXIFON code was used to calculate particle induced cross sections of some reactions of interest (Bismuth and Iodine), in energy range of 0 – 40 MeV which is a major gap that was found in the huge number of literatures that were reviewed.

2. MATERIALS AND METHOD

2.1 Materials

The Unit and source of the materials used is this research work is summarized in Table 2.1

Materials Used

Material	Unit/Language	Source
Bismuth crystals	5gcm^{-3}	International Atomic Energy Agency
Iodine Crystals	5g cm^{-3}	International Atomic Energy Agency
Exifon Code	Version 2.0	International Atomic Energy Agency
Enrichments	-	International Atomic Energy Agency
Computer Hardware	IBM PC	ML Tech
Computer Software	Fortran Version 2.42	International Atomic Energy Agency
Coding Language	(POO3O51PCXTO1)	International Atomic Energy Agency

2.2 Method

In this research EXIFON code was used which is computer program package for computational nuclear Data physics, which is based on an analytical model for statistical multistep direct and multistep compound reactions (SMD/SMC model). It predicts emission spectra, angular distributions, and activation cross sections for neutrons, protons, alpha particles, and photons. Multiple particle emissions are considered for up to three decays of the compound system.

2.3 How To Run An Exifon Code

- Click Windows and go to MS-DOS by clicking on All Programs; then Accessories
- Click on “Command Prompt”
- Change Directory to C:\EXIFON
- Run the program by typing ‘Exifon’
- You will be prompted to change INPUT and OUTPUT directories

Follow the instructions as described below to carry out the procedure.

2.4 Procedure

EXIFON is a fast, easy-to-handle code which predicts cross sections from one global parameter set. The only adjustable quantity is the pairing shift. The INPEXI code creates input files for EXIFON 2.0 from mass and shell-correction tables. The MAKE6 code transforms EXIFON output into an ENDF-6 format file. It is tested and recommended code by international atomic energy agency (IAEA). The model is based on random matrix physics with the use of the Green's function formalism. All calculations are performed without any free parameters. Results were presented for bombarding energies below 40 MeV.

2.5 Nuclear Model Calculations

Theoretical calculations of cross-section were performed by nuclear model code EXIFON the program was run and the input and output directory were defined, and then the target nucleus is specified. The incident particle and target nucleus were selected and excitation function in the general options section for this calculation was chosen.

The number of incident energy was specified followed by the first incident energy, and then the incident energy step is also specified. The Cross-section correspond to each particular energy was obtained.

The output data (OUTEXI) for the calculation was then stored in the set out- put directory. Also, DAT file name is stored in the set output directory.

Secondly, the option without shell effect is also used for each target nucleus, also an output data (OUTEXI) for the calculation is then stored in the set output directory. Also, DAT file is stored in the set output directory.

2.6 Cross Section Calculations

The program was run and the input and output directory were defined that is; Iodine and Bismuth as the input and the incident energy as the output respectively, and then the target nucleus is specified. The neutron was chosen as incident particle followed by selecting the target nucleus and excitation function in the general option section for this calculation.

The number of incident energy was specified followed by the first incident energy, and then the incident energy step is also specified. The cross section correspond to each particular energy was obtained.

3. RESULT AND ANALYSIS

3.1 Reaction Cross Section

The calculated reaction cross-section data for neutron-induced reactions on ^{127}I and ^{208}Bi (a, na) ^{207}Bi and ^{208}Bi (a, an) ^{207} Bi are given in Table 3.1 below. The calculations in which the shell correction was taken into consideration are denoted by “With” on the graph’s legend, while those without the shell correction effects are denoted by “Without”.

Observation at the sixteenth (16th) column shows that the reaction cross section are zeros from the energy range of 1 – 23 MeV which indicates that the reactions at that energy range cannot occur. Further observation in the same sixteenth (16th) column shows that the reaction starts occurring from 24 – 28 MeV. As the energy increased to 29 MeV, the reaction fully occurred. The reason why the reactions was not able to occur from the earlier stated energy range was due to the presence of coulomb barrier.

Table 3.1: Cross section (mb) obtain “with” shell structure effect of I-127 interactions with neutron particle at different energies 1 - 40 (MeV).

Energy	(n, a)	(n, na)	(n, ag)	(n, an)	(n, g)	(n, ng)	(n, pg)	(n, 2ng)	(n, n)	(n, 2n)	(n, pn)	(n, 3n)	(n, p)	(n, np)	(n, 2p)	(n, 2np)
1	0	0	0	0	1208	1822.6	0	0	1822.6	0	0	0	0	0	0	0
2	0	0	0	0	240.5	2382.1	0	0	2382.1	0	0	0	0	0	0	0
3	0	0	0	0	75.4	2398	0	0	2398	0	0	0	0	0	0	0
4	0	0	0	0	31.8	2357.1	0	0	2357.1	0	0	0	0	0	0	0
5	0	0	0	0	16.5	2313.9	0	0	2313.9	0	0	0	0	0	0	0
6	0	0	0	0	9.8	2274.9	0	0	2274.9	0	0	0	0	0	0	0
7	0	0	0	0	6.7	2239.8	0.1	0	2239.8	0	0	0	0.1	0	0	0
8	0	0	0	0	5.3	2207.4	0.2	0	2207.4	0	0	0	0.2	0	0	0
9	0.1	0	0.1	0	4.6	2177.2	0.5	0	2177.2	0	0	0	0.5	0	0	0
10	0.3	0	0.3	0	4.2	2131	1.1	17.4	2148.4	17.4	0	0	1.1	0	0	0
11	0.8	0	0.8	0	4	1877.9	1.9	242.7	2120.6	242.7	0	0	1.9	0	0	0
12	1.5	0	1.5	0	3.8	1403.8	3.1	689.6	2093.3	689.6	0	0	3.1	0	0	0
13	2.4	0	2.4	0	3.6	976.4	4.7	1089.7	2066.2	1089.7	0	0	4.7	0	0	0
14	3.6	0	3.6	0	3.5	692.7	6.8	1346.3	2039	1346.3	0	0	6.8	0	0	0
15	5.1	0	5.1	0	3.4	530.2	9.1	1481.5	2011.7	1481.5	0.3	0	9.3	0	0	0
16	6.7	0	6.6	0	3.3	435.1	11.4	1549.1	1984.2	1549.1	0.9	0	12.3	0	0	0
17	8.3	0	8	0.3	3.3	381	13.7	1575.4	1956.6	1575.4	2	0	15.8	0.1	0	0
18	10	0	9.1	0.9	3.2	348.6	16	1576.1	1928.8	1580	3.5	3.9	19.6	0.2	0	0
19	11.7	0	10	1.7	3.2	327.5	18.2	1293.9	1901	1573.1	5.5	279.2	23.7	0.4	0	0
20	13.4	0.1	10.7	2.7	3.1	312.3	20.2	760.4	1873.1	1560.2	8	799.8	28.2	0.6	0	0
21	15.1	0.2	11.2	3.9	3.1	300.2	21.9	383.1	1845.3	1544	11	1160.9	32.8	0.9	0	0
22	16.7	0.3	11.4	5.3	3.1	290	23.2	185.4	1817.5	1525.9	14.4	1340.6	37.7	1.2	0	0
23	18.3	0.5	11.4	6.8	3	280.9	24.7	91.3	1789.7	1506.8	18	1415.4	42.6	1.6	0	0
24	19.7	0.7	11.3	8.4	3	272.4	25.6	47.5	1762	1486.9	22.1	1439.3	47.7	2.1	0	0.1
25	21.1	0.9	11.1	10.1	3	264.5	26.4	26.5	1734.4	1466.4	26.5	1439.7	52.9	2.6	0	0.2
26	22.5	1.2	10.8	11.7	3	254.7	27	16.2	1706.9	1447.9	31.2	1431.3	58.2	3.1	0	0.3
27	23.7	1.5	10.4	13.3	3	247.9	27.5	10.7	1679.5	1426.4	36.1	1415	63.5	3.7	0	0.6
28	24.8	1.8	10.1	14.8	2.9	241.2	27.8	7.7	1652.2	1404.9	41.1	1396.1	68.9	4.3	0	0.9
29	25.9	2.2	9.7	16.2	2.9	234.7	28.1	5.8	1625.1	1383.3	46.2	1375.7	74.3	5	0	1.4
30	26.8	2.6	9.3	17.6	2.9	228.5	28.3	4.6	1598.1	1361.4	51.4	1354.4	79.8	5.6	0	1.9
31	27.6	2.1	9.6	18	2.9	227.3	28.3	5.3	1599.6	1366.1	52.2	1359.5	78.1	4.8	0	1.7
32	29.1	2.8	10.1	18.2	3.0	230.0	30.0	5.7	1600.0	1375.1	54.4	1360.0	79.1	4.9	0	1.9
33	28.5	2.5	10.3	18.4	3.2	230.4	30.2	5.7	1600.3	1376.0	54.6	1361.0	79.3	5.0	0	2.0
34	27.6	2.1	9.6	18	2.9	227.3	28.3	5.3	1599.6	1366.1	52.2	1359.5	78.1	4.8	0	1.7
35	29.1	2.8	10.1	18.2	3.0	230.0	30.0	5.7	1600.0	1375.1	54.4	1360.0	79.1	4.9	0	1.9
36	28.5	2.5	10.3	18.4	3.2	230.4	30.2	5.7	1600.3	1376.0	54.6	1361.0	79.3	5.0	0	2.0
38	30.0	2.9	10.1	18.2	3.0	230.0	30.0	5.7	1600.0	1375.1	54.4	1360.0	79.1	4.9	0	1.9
39	30.1	3.0	10.3	18.4	3.2	230.4	30.2	5.7	1600.3	1376.0	54.6	1361.0	79.3	5.0	0	2.0
40	30.3	3.0	10.5	18.6	3.4	234.0	30.5	6.0	1610.0	1380.0	58.0	1362.0	80.0	5.2	0	2.2

Observation in Table 3.2 from the sixteenth (16^{th}) column shows that the reaction cross section are zeros from the 1 – 23 MeV. This indicates that the reactions at that energy range cannot occur. It can also be observed from Table 1.2 that the reaction started showing slight signs of occurring from the energy range of 23 – 28 MeV because at that stage the coulomb barrier is becoming less effective. However, as the energy continued to increase at 29 – 40 MeV the reaction occurred after the coulomb barrier has been overcome.

Table 3.2: Cross section (mb) obtains “without” shell structure effect of I-127 interactions with neutron particle at different energies 1 – 40 (MeV).

Energy	(n, a)	(n, na)	(n, ag)	(n, an)	(n, g)	(n, ng)	(n, pg)	(n, 2ng)	(n, n)	(n, 2n)	(n, pn)	(n, 3n)	(n, p)	(n, np)	(n, 2p)	(n, 2np)
1	0	0	0	0	1316.9	1713.8	0	0	1713.8	0	0	0	0	0	0	0
2	0	0	0	0	267.4	2355.1	0	0	2355.1	0	0	0	0	0	0	0
3	0	0	0	0	83.1	2390.3	0	0	2390.3	0	0	0	0	0	0	0
4	0	0	0	0	35	2353.9	0	0	2353.9	0	0	0	0	0	0	0
5	0	0	0	0	17.8	2312.5	0	0	2312.5	0	0	0	0	0	0	0
6	0	0	0	0	10.5	2274.2	0	0	2274.2	0	0	0	0	0	0	0
7	0	0	0	0	7.1	2239.4	0.1	0	2239.4	0	0	0	0.1	0	0	0
8	0	0	0	0	5.6	2207.2	0.2	0	2207.2	0	0	0	0.2	0	0	0
9	0.1	0	0.1	0	4.8	2177	0.5	0	2177	0	0	0	0.5	0	0	0
10	0.3	0	0.3	0	4.4	2130.9	1	17.5	2148.4	17.5	0	0	1	0	0	0
11	0.8	0	0.8	0	4.1	1870.5	1.8	250.2	2120.7	250.2	0	0	1.8	0	0	0
12	1.4	0	1.4	0	3.8	1384.5	2.9	709	2093.4	709	0	0	2.9	0	0	0
13	2.4	0	2.4	0	3.7	954.4	4.5	1111.9	2066.4	1111.9	0	0	4.5	0	0	0
14	3.6	0	3.6	0	3.6	674.2	6.5	1365.1	2039.3	1365.1	0	0	6.5	0	0	0
15	5	0	5	0	3.4	516.2	8.7	1495.9	2012	1495.9	0.3	0	9	0	0	0
16	6.6	0	6.6	0	3.4	425.2	11	1559.4	1984.6	1559.4	0.9	0	11.9	0	0	0
17	8.3	0	7.9	0.3	3.3	374	13.4	1583	1957.1	1583	1.9	0	15.3	0.1	0	0
18	10	0	9.1	0.9	3.2	343.5	15.7	1582.9	1929.4	1585.7	3.3	2.8	19	0.2	0	0
19	11.7	0	10	1.7	3.2	323.6	17.9	1341.6	1901.7	1577.8	5.1	236.2	23.1	0.3	0	0
20	13.4	0.1	10.7	2.7	3.2	309.1	19.9	816.6	1873.9	1564.2	7.5	747.7	27.4	0.5	0	0
21	15.1	0.2	11.2	3.9	3.1	297.6	21.6	419.1	1846.1	1547.7	10.4	1128.6	32	0.7	0	0
22	16.7	0.3	11.4	5.3	3.1	287.7	22.9	205.1	1818.4	1529.5	13.8	1324.4	36.7	1	0	0
23	18.2	0.4	11.4	6.8	3.1	278.8	24.4	101.6	1790.7	1510.3	17.2	1408.6	41.6	1.3	0	0
24	19.7	0.6	11.3	8.4	3	270.5	25.4	52.8	1763.1	1490.4	21.3	1437.5	46.7	1.6	0	0.1
25	21.1	0.8	11.1	10	3	262.8	26.1	29.5	1735.6	1470	25.7	1440.3	51.8	2	0	0.1
26	22.4	1.1	10.8	11.6	3	253	26.7	18.1	1708.1	1451.6	30.3	1433.2	57	2.4	0	0.3
27	23.7	1.4	10.5	13.2	3	246.3	27.2	12	1680.8	1430.3	35	1417.7	62.3	2.9	0	0.5
28	24.8	1.7	10.1	14.7	2.9	239.6	27.6	8.6	1653.6	1408.9	40	1399.4	67.6	3.4	0	0.8
29	25.9	2	9.7	16.2	2.9	233.2	27.9	6.5	1626.5	1387.4	45.1	1379.5	73	3.9	0	1.1
30	26.8	2.4	9.3	17.5	2.9	227.1	28.1	5.2	1599.5	1365.6	50.3	1358.5	78.4	4.4	0	1.6
31	27.6	2.1	9.6	18	2.9	227.3	28.3	5.3	1599.6	1366.1	52.2	1359.5	78.1	4.8	0	1.7
32	29.1	2.8	10.1	18.2	3.0	230.0	30.0	5.7	1600.0	1375.1	54.4	1360.0	79.1	4.9	0	1.9
33	28.5	2.5	10.3	18.4	3.2	230.4	30.2	5.7	1600.3	1376.0	54.6	1361.0	79.3	5.0	0	2.0
34	27.6	2.1	9.6	18	2.9	227.3	28.3	5.3	1599.6	1366.1	52.2	Z 1359.5	78.1	4.8	0	1.7
35	29.1	2.8	10.1	18.2	3.0	230.0	30.0	5.7	1600.0	1375.1	54.4	1360.0	79.1	4.9	0	1.9
36	28.5	2.5	10.3	18.4	3.2	230.4	30.2	5.7	1600.3	1376.0	54.6	1361.0	79.3	5.0	0	2.0
37	29.6	2.7	9.6	18	2.9	227.3	28.3	5.3	1599.6	1366.1	52.2	1359.5	78.1	4.8	0	1.7
38	30.0	2.9	10.1	18.2	3.0	230.0	30.0	5.7	1600.0	1375.1	54.4	1360.0	79.1	4.9	0	1.9
39	30.1	3.0	10.3	18.4	3.2	230.4	30.2	5.7	1600.3	1376.0	54.6	1361.0	79.3	5.0	0	2.0
40	30.3	3.0	10.5	18.6	3.4	234.0	30.5	6.0	1610.0	1380.0	58.0	1362.0	80.0	5.2	0	2.2

Table 3.3 shows the cross sections for ^{208}Bi (a, na) and ^{207}Bi (a, an) that is; (a, a), (a, na), (a, ag), (a, an) reactions. Observations from the Table reveals that in the column of alpha and alpha neutron (a,an) emission are zeros from the energy range of 1 – 40 MeV. This shows that these two reactions would not occur at the incident energy of 0 - 40 MeV with shell structure and without shell structure for (a, an).

Table 3.3 Cross sections at different incident energies for ^{208}Bi (a, na) and ^{207}Bi (a, an) i.e (a, a), (a, na), (a, ag), (a, an) reactions.

With Shell Correction					**Without Shell Correction**				
Energy (MeV)	**(a, a)**	**(a, na)**	**(a, ag)**	**(a, an)**	**Energy (MeV)**	**(a, a)**	**(a, na)**	**(a, ag)**	**(a, an)**
1	0	0	0	0	1	0	0	0	0
2	0	0	0	0	2	0	0	0	0
3	0	0	0	0	3	0	0	0	0
4	0	0	0	0	4	0	0	0	0
5	0	0	0	0	5	0	0	0	0
6	0	0	0	0	6	0	0	0	0
7	0	0	0	0	7	0	0	0	0
8	0	0	0	0	8	0	0	0	0
9	0	0	0	0	9	0	0	0	0
10	0	0	0	0	10	0	0	0	0
11	0	0	0	0	11	0	0	0	0
12	0	0	0	0	12	0	0	0	0
13	0	0	0	0	13	0	0	0	0
14	0	0	0	0	14	0	0	0	0
15	0	0	0	0	15	0	0	0	0
16	0	0	0	0	16	0	0	0	0
17	0	0	0	0	17	0	0	0	0
18	0	0	0	0	18	0	0	0	0
19	0	0	0	0	19	0	0	0	0
20	0	0	0	0	20	0	0	0	0

Table 3.3 Continued

21	0	0	0	0	21	0	0	0	0
22	0	0	0	0	22	0	0	0	0
23	0.1	0	0	0	23	0.1	0	0	0
24	0.2	0	0	0	24	0	0	0	0
25	0.4	0	0	0	25	0.4	0	0	0
26	0.6	0	0	0	26	0.6	0	0	0
27	0.9	0	0	0	27	0.9	0	0	0
28	1.1	0	1.1	0	28	1.1	0	1.1	0
29	1.4	0	1.4	0	29	1.4	0	1.4	0
30	1.7	0	1.7	0	30	1.7	0	1.7	0
31	1.9	0	1.9	0	31	1.9	0	1.9	0
32	2.0	0	2.0	0	32	2.0	0	2.0	0
33	2.1	0	2.1	0	33	2.1	0	2.1	0
34	2.3	0	2.3	0	34	2.3	0	2.3	0
35	2.5	0	2.5	0	35	2.5	0	2.5	0
36	2.6	0	2.6	0	36	2.6	0	2.6	0
37	2.7	0	2.7	0	37	2.7	0	2.7	0
38	2.9	0	2.9	0	38	2.9	0	2.9	0
39	3.1	0	3.1	0	39	3.1	0	3.1	0
40	3.3	0	3.3	0	40	3.3	0	3.3	0

Table 3.4 shows the cross sections for ^{208}Bi (a, na) and ^{207}Bi (a, an) that is; (a, g), (a, ng), (a, pg), (a, 2ng) reactions. Results from the Table reveals that in the column of alpha and two neutron gamma (a,2ng) emission are zeros from the energy range of 1 – 22 MeV for with and without shell correction. This shows that these two reactions would not occur at that incident energy however there was a slight sign of the reaction occurring at 23 MeV followed by a massive occurrence of the reaction as the incident energy increases.

Table 3.4 Cross sections at different incident energies for ^{208}Bi (a, na) and ^{207}Bi (a, an) i.e (a, g), (a, ng), (a, pg), (a, 2ng) reactions.

With Shell Correction	Without Shell Correction

Energy (MeV)	**(a, g)**	**(a, ng)**	**(a, pg)**	**(a, 2ng)**	**Energy (MeV)**	**(a, g)**	**(a, ng)**	**(a, pg)**	**(a, 2ng)**
1	0	0	0	0	1	0	0	0	0
2	0	0	0	0	2	0	0	0	0
3	0	0	0	0	3	0	0	0	0
4	0	0	0	0	4	0	0	0	0
5	0	0	0	0	5	0	0	0	0
6	0	0	0	0	6	0	0	0	0
7	0	0	0	0	7	0	0	0	0
8	0	0	0	0	8	0	0	0	0
9	0	0	0	0	9	0	0	0	0
10	0	0	0	0	10	0	0	0	0
11	0	0	0	0	11	0	0	0	0
12	0	0	0	0	12	0	0	0	0
13	0	0	0	0	13	0	0	0	0
14	0	0	0	0	14	0	0	0	0
15	0	0	0	0	15	0	0	0	0
16	0	0	0	0	16	0	0	0	0
17	0	0	0	0	17	0	0	0	0
18	0	0	0	0	18	0	0	0	0
19	0	3.2	0	0	19	0	3.2	0	0
20	0	59.8	0	0	20	0	59.8	0	0
21	0	135.2	0	0	21	0	135.2	0	0
22	0.1	229.3	0	0	22	0.1	229.3	0	0
23	0.3	341.9	0	0.1	23	0.3	341.9	0	0.1

24	0.4	471	0.1	1.2	24	0.4	471	0.1	1.2
25	0.6	592.7	0.2	5.8	25	0.6	592.7	0.2	5.8
26	0.7	695.5	0.4	19.5	26	0.7	708	0.4	19.5
27	0.9	771.9	0.6	50.9	27	0.8	801.5	0.6	50.9
Table 3.4 Continued			0.9	107.5	28	0.9	870.8	0.9	107.5
29	1	820.8	1.4	194.5	29	1	906.9	1.4	194.5
30	1.1	793.2	1.7	306.7	30	1.1	908.7	1.7	306.7
31	1.9	630.4	1.9	310.6	31	1.9	630.4	1.9	310.6
32	2.0	826.4	2.0	318.5	32	2.0	826.4	2.0	318.5
33	2.1	828.1	2.1	320.4	33	2.1	828.1	2.1	320.4
34	2.3	823.0	2.3	299.0	34	2.3	823.0	2.3	299.0
35	2.5	799.4	2.5	300.4	35	2.5	799.4	2.5	300.4
36	2.6	800.3	2.6	308.4	36	2.6	800.3	2.6	308.4
37	2.7	827.5	2.7	318.5	37	2.7	827.5	2.7	318.5
38	2.9	829.8	2.9	323.4	38	2.9	829.8	2.9	323.4
39	3.0	830.6	3.1	325.1	39	3.0	830.6	3.0	325.1
40	3.3	830.8	3.3	326.0	40	3.1	830.8	3.3	326.0

The result in Table 3.5 shows the cross sections for ^{208}Bi (a, na) and ^{207}Bi (a, an) that is; (a, n), (a, 2n), (a, pn), (a, 3n) reactions. A careful look at the Table reveals that in the column of alpha and three neutrons (a,3n) emission are zeros for (a, 3n) with shell correction and (a, 3n) without shell correction from the energy range of 1 – 34 MeV and 1 – 29 MeV. This shows that the reactions would not occur at that incident energy however there was a slight sign of the reaction occurring at 35 – 40 MeV with shell correction. The result also indicates a likelihood of the reaction occurring and which eventually occurred at 34 MeV and subsequently increased as the incident energy was increased for without shell correction.

Table 3.5 Cross sections at different incident energies for ^{208}Bi (a, na) and ^{207}Bi (a, an) i.e (a, n), (a, 2n), (a, pn), (a, 3n) reactions.

With Shell Correction					Without Shell Correction				
Energy (MeV)	**(a, n),**	**(a, 2n)**	**(a ,pn)**	**(a, 3n)**	**Energy (MeV)**	**(a, n),**	**(a, 2n)**	**(a ,pn)**	**(a, 3n)**
1	0	0	0	0	1	0	0	0	0
2	0	0	0	0	2	0	0	0	0

3	0	0	0	0	3	0	0	0	0
4	0	0	0	0	4	0	0	0	0
5	0	0	0	0	5	0	0	0	0
6	0	0	0	0	6	0	0	0	0
7	0	0	0	0	7	0	0	0	0
8	0	0	0	0	8	0	0	0	0
9	0	0	0	0	9	0	0	0	0
10	0	0	0	0	10	0	0	0	0
11	0	0	0	0	11	0	0	0	0
12	0	0	0	0	12	0	0	0	0
13	0	0	0	0	13	0	0	0	0
14	0	0	0	0	14	0	0	0	0
15	0	0	0	0	15	0	0	0	0
16	0	0	0	0	16	0	0	0	0
17	0	0	0	0	17	0	0	0	0
18	0	0	0	0	18	0	0	0	0
19	3.2	0	0	0	19	3.2	0	0	0
20	59.8	0	0	0	20	59.8	0	0	0
21	135.2	0	0	0	21	135.2	0	0	0
22	229.3	0	0	0	22	229.3	0	0	0
23	341.1	0.1	0	0	23	341.1	0	0	0
24	472.1	1.2	0	0	24	472.1	0.3	0	0
25	598.6	5.8	0	0	25	598.6	1.8	0	0
26	715.1	19.5	0	0	26	715.1	7.1	0	0

27	822.7	50.9	0	0	27	822.7	22.2	0	0
28	922.6	107.5	0	0	28	922.6	51.8	0	0
29	1015.3	194.5	0	0	29	1015.3	108.4	0.1	0
30	1101.7	308.5	0	0	30	1101.7	192.9	0.2	0.4
31	1103.7	310.6	310.6	0	31	1103.7	300.4	0.4	0.6
3**2**	1105.7	318.5	318.5	0	32	1105.7	308.4	0.6	0.8
33	1107.1	320.4	320.4	0	33	1107.1	318.5	0.8	0.9
34	1109.3	299.0	299.0	0	34	1109.3	323.4	0.9	1.0
35	1111.5	300.4	300.4	0.1	35	1111.5	325.1	1.0	1.1
36	1113.3	308.4	308.4	0.2	36	1113.3	326.0	1.1	1.2
37	1116.2	318.5	318.5	0.4	37	1116.2	328.0	1.2	1.3
38	1118.3	323.4	323.4	0.6	38	1118.3	330.0	1.3	1.5
39	1120.5	325.1	325.1	0.8	39	1120.5	332.0	1.5	1.7
40	830.8	326.0	326.0	0.9	40	830.8	334.0	1.7	1.9

Table 3.5 Continued

4. DISCUSION

The reaction cross section was calculated with shell correction and without shell correction and the result showed that the reaction was not able to occur from 1 to 23 MeV, showed signed of occurring afterwards and then eventually occurred as shown in the Table 4.1 – 4.5. Ahmad, I., & Koki, F. S. (2017) carried out a similar research using EXIFON code in the energy range of 1 – 30 MeV and got the same result within the energy ranged considered. What singled out this research work from the other is that it considered a wider energy range (1 – 40 MeV), which enabled the reaction to overcome the coulomb barrier as the energy range increases leading to massive occurrence of the reaction.

5. CONCLUSION

In conclusion, reaction cross section of pure form of Bismuth and Iodine was calculated using EXIFON code and the result revealed accurate cross section of the excitation function of reactions data that will lead to maximum production yield of radioactive substances of high purity.

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