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Nuclear Electric Quadrapole Moments (Q) in ^{58}Ni

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Abstract: Nuclear Electric quadrapole moments Q in ^{58}Ni for some selected levels have been investigated and calculated through Nuclear shell model and considering of ^{56}Ni as an inert core with two active neutrons in a model space ($2p_{3/2}$, $1f_{5/2}$ and $2p_{1/2}$) and the configuration mixing of the original states is also done. F5Pvh interaction has been utilized as a two body interaction to generate model space vectors with harmonic oscillator potential as a single particle wave function. OXBASH code is used to carry this calculations and the program of Core, Valence, Tassie (CVT) written in FORTRAN go language to calculate the Electric quadrapole moments between excited states themselves. All of these calculations have been carried through model space vectors only. One body density matrix elements (OBDM) for ground and Excited states is calculated in order to carry the calculations using single particle Transition matrix elements between excited states theme selves.

Keywords: Shell Model, E2, Q, ^{58}Ni

1. Introduction

A large part of the knowledge of nuclei is obtained from the study of electromagnetic transitions, since the electromagnetic interaction is well understood, in contrast with the nuclear forces. It is, for example, the main source of information about the spin assignments of nuclear states. The nuclear multipole moments and the transition rates for the various multipole radiations can be calculated theoretically, once the nuclear wave functions are known.

We shall not give a complete derivation of the required electromagnetic transition operators. Instead only some of the most important steps that lead to explicit expressions for these operators will be summarized. For example, [Blatt and Weisskopf (1952), Jackson (1962), Morse and Feshbach (1953) and Roy and Nigam (1967).

Some of the basic equations related to the electromagnetic interaction are summarized. A derivation of the operators that will be used later to calculate electromagnetic transition and moments, Centre of mass corrections are treated. Measurable quantities such as reduced transition rates, lifetimes, branching and mixing ratios are defined. The much used Weisskopf single particle estimates of transition strengths are derived. It is shown that the isospin formalism allows us to express transition strengths in terms of isoscalar and isovector contributions. This separation can be used for example, to correlate transition rates in isobaric mass multiplets [1].

The nuclear quadrupole moments vary widely in magnitude. In particular the nuclei in the mass regions 150 < A < 190 and A > 225 possess large permanent deformations. Light nuclei usually can be considered as to consist of a spherical core with a small number of extra nucleons. In such a picture the nuclear quadrupole moment derives completely from the extra nucleons. The extra nucleons may be coupled to pairs j^2 with J=0 and then, in this extreme single-particle model, the quadrupole moment is due to the last odd proton [1].

The Nucleus ^{58}Ni Nickel (Ni) possesses five stable isotopes including ^{58}Ni, ^{60}Ni, ^{61}Ni, ^{62}Ni and ^{64}Ni. In addition, 27 radioactive isotopes have been discovered ranging from ^{48}Ni to ^{79}Ni, some of them have short-half lives; others have long-half lives. The longest- half lives is ^{59}Ni with a half-life of 7.6×10+4 years. Most of them are under a minute or a second. The least unstable is ^{79}Ni with a half-life of 635×10−9 s. [2, 3]. The nucleus Ni 58 has 28 protons and 30 neutrons, two neutrons play essential role in the model space shell, outer the closed shell when the inert core ^{56}Ni is under consideration.

Wang and Ren (2005)[4] systematically investigated the elastic electron scattering on both stable and unstable nuclei with the relativistic eikonal approximation, where the charge density distributions of nuclei were from the self-consistent relativistic mean field model. Calculations had shown that the relativistic eikonal approximation can reproduce the experimental data of electron scattering on nuclei ranging from the light region, such as ^{12}C, to the heavy region, such as ^{208}Pb. This was the systematic test of the relativistic eikonal approximation for elastic electron scattering for both light and heavy nuclei, including the calculated charge form factors for ^{48}Ni, ^{56}Ni, ^{58}Ni, ^{64}Ni, ^{68}Ni, ^{74}Ni and ^{78}Ni isotopes.

Bespalova et al. (2010) [5] studied the experimental single-particle energies and occupation probabilities for neutron states near the Fermi energy in ^{58,60,62,64}Ni nuclei which had been obtained from joint evaluation of the data on nucleon stripping and pickup reactions on the same nucleus. The resulting data were analyzed within a mean-field model with dispersive optical-model potential. Good agreement was obtained between the calculated and experimental single-particle energies of the subshells.

Brown et al. (2014) [6] measured high-precision reduced electric-quadrupole transition probabilities B (E2; $0^+_1 \rightarrow 2^+_1$) from single-step coulomb excitation of semi-magnetic ^{58,60,62,64}Ni (Z=28) beams at 1.8Mev per nucleon on a natural carbon target . The energy loss of the nickel beams through the carbon target were directly measured with a zero-degree Bragg detector and the absolute B(E2) values were normalized by Rutherford scattering. The B (E2) values disagree with recent lifetime studies that employed the Doppler-shift attenuation method. The high-precision B(E2) values reveal an asymmetry about ^{62}Ni, midshell between N=28 and 40, with larger values towards ^{56}Ni (Z = N = 28). The experimental B (E2) values were compared with shell-model calculations in the full pf model space and the results indicated a soft ^{56}Ni core.

Yao et al. (2014)[7] calculated elastic and in elastic form factor and for the transition from the ground state to J+1(L =J = 2,4) state in 58-68Ni and 24Mg, the starting point of method was a set of Hartree-Fock-Bogoliubov wave functions generated with a constraint on the axial quadrupole moment and using a Skyrme energy density functional. Correlations beyond the mean field were introduced by projecting mean-field wave functions on angular-momentum and particle number by mixing the symmetry restored wave functions.

2. Theory

The nuclei are assumed to have a spherical shape. This is a good approximation for nuclei that have magic numbers of neutrons or protons: 2, 8, 20, 28, 50, 82 and 126. These numbers come from the shell structure of the nucleus. Nuclei with magic numbers of neutrons or protons have a "closed shell" that encourages a spherical shape. Nuclei with Z or N far from a magic number are generally deformed. The simplest deformations are so-called quadrupole deformations where the nucleus can take either a prolate shape (rugby ball) or an oblate shape (cushion). The electric quadrupole moment Q is considered as a criterion of the deviation of the electric charges of the nucleus from the spherical shape or spherical distribution.

The electric quadrupole moment operator is given by [8]:

$$\hat{Q} = \int dr\, \hat{\rho}\,(\vec{r}, t_Z)\,(3z^2 - r^2) \tag{1}$$

Where z and r are the position coordinates of kth nucleon and r is given in Cartesian coordinates as $r = x^2 + y^2 + z^2$.

$$\hat{O}(EJM) = \sum_{k=1}^{A} e_{t_Z}(k)\; r^J(k)\; Y_{JM}(\Omega_k) \tag{2}$$

$$\hat{Q} = \sqrt{\frac{16\pi}{5}} \sum_{k=1}^{A} e_{t_Z}(k)\, r^2(k) Y_{20}(\Omega_k) \tag{3}$$

After substituting equation (2) with $J = 2$ into equation(3), one can obtain:

$$\hat{Q} = \sqrt{\frac{16\pi}{5}}\, \hat{O}(E20) \tag{4}$$

The initial and final states of the nucleus can be written as:

$$|J_i M_i T_i T_{zi}\rangle \;\equiv\; initial\ state$$

$$|J_f M_f T_f T_{zf}\rangle \;\equiv\; final\ state$$

The matrix element of the electric quadrupole operator of equation (4) , between the initial and final states of the nucleus, is given by:

$$\langle J_f M_f T_f T_{Z_f} | \hat{Q} | J_i M_i T_i T_{Z_i} \rangle = \sqrt{\frac{16\pi}{5}}\, \langle J_f M_f T_f T_{Z_f} | \hat{O}(E20) | J_i M_i T_i T_{Z_i} \rangle \tag{5}$$

The matrix element of the electric transition operator in the above equation can be reduced by using Wigner-Eckart theorem as:

$$\left\langle J_f M_f T_f T_{Z_f} \middle| \hat{O}(E20) \middle| J_i M_i T_i T_{Z_i} \right\rangle = (-1)^{J_f - M_f} \begin{pmatrix} J_f & 2 & J_i \\ -M_f & 0 & M_i \end{pmatrix} \times \left\langle J_f T_f T_{Z_f} \middle\| \hat{O}(E2) \middle\| J_i T_i T_{Z_i} \right\rangle \tag{6}$$

In nuclear physics the quadrupole moment of a state of angular momentum J is defined as the expectation value of the electric quadrupole moment operator in the state $M = J$ [1]. So, equation (5) can be simplified with the aid of equation (6)as:

$$Q = \sqrt{\frac{16\pi}{5}} \begin{pmatrix} J_f & 2 & J_i \\ -J_f & 0 & J_i \end{pmatrix} \left\langle J_f T_f T_{Z_f} \middle\| \hat{O}(E2) \middle\| J_i T_i T_{Z_i} \right\rangle \tag{7}$$

With the use of Wigner-Eckart theorem, the reduced matrix element of equation (7) can be written as:

$$\left\langle J_f T_f T_{Z_f} \middle\| \hat{O}(E2) \middle\| J_i T_i T_{Z_i} \right\rangle = \sum_{T=0,1} (-1)^{T_f - T_{Z_f}} \begin{pmatrix} T_f & T & T_i \\ -T_{Z_f} & 0 & T_{Z_i} \end{pmatrix} \times \langle J_f T_f \| | \hat{O}(E2) \| | J_i T_i \rangle \tag{8}$$

And the electric quadrupole moment of equation (7) becomes:

$$Q = \begin{pmatrix} J_f & 2 & J_i \\ -J_f & 0 & J_i \end{pmatrix} \sqrt{\frac{16\pi}{5}} \sum_{T=0,1} (-1)^{T_f - T_{Z_f}} \begin{pmatrix} T_f & T & T_i \\ -T_{Z_f} & 0 & T_{Z_i} \end{pmatrix} \times \langle J_f T_f ||| \hat{O}_{2T} ||| J_i T_i \rangle \quad (9)$$

With using Wigner-Eckart theorem [9], the reduced electric transition probability can be calculated in terms of the many-particle matrix element of the electric multipole transition operator reduced in spin-isospin as:

$$B(EJ) = \frac{1}{2J_i+1} \left| \sum_{T=0,1} (-1)^{T_f - T_{Z_f}} \begin{pmatrix} T_f & T & T_i \\ -T_{Z_f} & M_T & T_{Z_i} \end{pmatrix} \langle J_f T_f ||| \hat{O}_{JT} ||| J_i T_i \rangle \right|^2 \quad (10)$$

Where the reduced many-particle matrix element of the electric multipole transition operator is given $\hat{T}^{\eta}_{JT}$ by $\hat{O}_{JT}$, as:

$$\langle J_f T_f ||| \hat{O}_{JT} ||| J_i T_i \rangle = \sum_{\alpha,\beta} OBDM(J_f, J_i, \alpha, \beta) \langle \alpha ||| \hat{O}_{JT} ||| \beta \rangle \quad (11)$$

Then, equation $(1-11)$can be written, in spin-isospin formalism

$$\langle J_f T_f ||| \hat{O}_{JT} ||| J_i T_i \rangle = e_T \sum_{j_f, j_i} \mathrm{OBDM}(J_f, J_i, j_f, j_i, J, \Delta T) \sqrt{2(2T+1)} \times \langle l_f \tfrac{1}{2} j_f \| Y_J(\Omega_r) \| l_i \tfrac{1}{2} j_i \rangle \langle n_f l_f | r^J | n_i l_i \rangle \quad (12)$$

Also, equation (11) can be written in proton-neutron formalism as:

$$\langle J_f T_f ||| \hat{O}_{JT} ||| J_i T_i \rangle = e_{t_z} \sum_{j_f, j_i} OBDM(J_f, J_i, j_f, j_i, J, t_z) \times \langle l_f \tfrac{1}{2} j_f \| Y_J(\Omega_r) \| l_i \tfrac{1}{2} j_i \rangle \langle n_f l_f | r^J | n_i l_i \rangle \quad (13)$$

Where the reduced many-particle matrix element of the electric transition operator can be calculated in spin-isospin formalism and in proton-neutron formalism with using equations (12) and (13), respectively.
From equations $(9)$and(10), one can show that the quadrupole moment is related to the reduced transition probability as:

$$Q = \begin{pmatrix} J_f & 2 & J_i \\ -J_f & 0 & J_i \end{pmatrix} \sqrt{\frac{16\pi}{5}} \sqrt{(2J_i+1)\, B(EJ)} \quad (14)$$

The electric quadrupole moment is to be taken in units of $e.fm^2$ or $e.b$.
Where b is the barn, $b = 100\ fm^2$ [10].
The single particle quadrupole moment $Q_{s.p.}(j)$ of a nucleon in an orbit with spin j depends on the radial and angular properties of the orbit as shown in the following equation [8]:

$$Q_{s.p.} = -e_j \frac{2j-1}{2j+2} \langle r_j^2 \rangle \quad (15)$$

Where $\langle r_j^2 \rangle$ is the mean square radius for a particle in the orbit(n, l, j).

3. Result and Discussion

The relation between a Clebsch-Gordon coefficient and 3-j symbol as the following [1].

$$\begin{pmatrix} Ji & J & Jf \\ Mi & M & Mf \end{pmatrix} = (-1)^{Jf} \begin{pmatrix} Ji & J & Jf \\ Mi & M & Mf \end{pmatrix}$$

$$\begin{pmatrix} j & 2 & j \\ -m & 0 & m \end{pmatrix} = (-1)^{j-m} \frac{3m^2 - j(j+1)}{\sqrt{(2j-1)j(2j+1)(j+1)(2j+3)}} \delta mm'$$

The values of 3-j symbol from state to the same state are clarified below.

1) $1 \rightarrow 1$ $\begin{pmatrix} 1 & 2 & 1 \\ -1 & 0 & 1 \end{pmatrix} \approx 0.18$

2) $2 \rightarrow 2$ $\begin{pmatrix} 2 & 2 & 2 \\ -2 & 0 & 2 \end{pmatrix} \approx 0.23$

3) $3 \rightarrow 3$ $\begin{pmatrix} 3 & 2 & 3 \\ -3 & 0 & 3 \end{pmatrix} \approx 0.21$

4) $4 \rightarrow 4$ $\begin{pmatrix} 4 & 2 & 4 \\ -4 & 0 & 4 \end{pmatrix} \approx 0.237$

Substitute values of the 3-j symbol and the probabilities in the equation of Electric quadrupole moment Q in unit (e fm^2) as shown below.

$$Q = \begin{pmatrix} J_f & 2 & J_i \\ -J_f & 0 & J_i \end{pmatrix} \sqrt{\frac{16\pi}{5}} \sqrt{(2J_i+1)\, B(EJ)}$$

Obtained the values of electric quadrupole moment (Q) as shown in the table 1.

Table 1. *Shows the transitions, the probabilities B(E2) and Electric quadrupole moment (Q)*

Ki	Ji	Kf	Jf	B (XL) × 10^{-13}	Q ×10^{-5} e. fm^2
1	4	1	4	0.5678	0.05369
1	4	2	4	5.381	0.16532
2	4	2	4	5.381	0.16532
2	4	1	4	0.5678	0.05369
1	1	1	1	1764	1.3125
1	1	2	1	1605	1.2519
2	1	1	1	1764	1.3125
2	1	2	1	1605	1.2519
2	3	2	3	1296	2.0049
1	3	1	3	1591	2.2412
1	3	2	3	1296	2.0049

Ki	Ji	Kf	Jf	B (XL) × 10^{-13}	Q ×10^{-5} e. fm^2
2	3	1	3	1591	2.2412
1	2	1	2	737.4	1.3998
1	2	2	2	1749	2.1559
1	2	3	2	5501	3.8235
1	2	4	2	1959	2.2817
1	2	5	2	1233	1.8101
2	2	1	2	737.4	1.3998
2	2	2	2	1749	2.1559
2	2	3	2	5501	3.8235
2	2	4	2	1959	2.2817
2	2	5	2	1233	1.8101
3	2	1	2	737.4	1.3998
3	2	2	2	1749	2.1559
3	2	3	2	5501	3.8235
3	2	4	2	1959	2.2817
3	2	5	2	1233	1.8101
4	2	1	2	737.4	1.3998
4	2	2	2	1749	2.1559
4	2	3	2	5501	3.8235
4	2	4	2	1959	2.2817
4	2	5	2	1233	1.8101
5	2	1	2	737.4	1.3998
5	2	2	2	1749	2.1559
5	2	3	2	5501	3.8235
5	2	4	2	1959	2.2817
5	2	5	2	1233	1.8101

The free neutron has e zero charge but the effective neutron has an effective charge. The measurement proved that the amount (negative) and the value less than one electronic charge.

There is a research and study of the measurements for the nuclear shell model and multipolarities which proved the existence of active charge of neutrons.

The values of the OBDM elements for electric quadrupole moment(Q) for transitions from state to the same state as shown in the tables from (2) to (12).

Table 2. *The values of the OBDM for transition from excited state (4^+) to excited state (4^+_1).*

Ji	Jf	Ki	Kf	L
4^+	4^+	1	1	2
4^+	4^+	2	1	2
nlj	n`l`j`O	OBDM(DT=0)	OBDM(DT=1)	
1f 5/2	1f 5/2	1.25168	1.02199	
1f 5/2	2p 3/2	-0.20387	-0.16646	
2p 3/2	1f 5/2	0.20387	0.16646	
2p 3/2	2p 3/2	1.13002	0.92266	

Table 3. *The values of the OBDM for transition from excited state (4^+) to excited state (4^+_2).*

Ji	Jf	Ki	Kf	L
4^+	4^+	1	2	2
4^+	4^+	2	2	2
nlj	n`l`j`	OBDM(DT=0)	OBDM(DT=1)	
1f 5/2	1f 5/2	0.03398	0.02774	
1f 5/2	2p 3/2	1.47954	1.20804	
2p 3/2	1f 5/2	0.02809	0.02294	
2p 3/2	2p 3/2	0.15571	0.12714	

Table 4. *The values of the OBDM for transition from excited state (1^+) to excited state (1^+_1).*

Ji	Jf	Ki	Kf	L
1^+	1^+	1	1	2
1^+	1^+	2	1	2
n l j	n`l`j`	OBDM(DT=0)	OBDM(DT=1)	
1f 5/2	1f 5/2	0.37865	0.30916	
1f 5/2	2p 1/2	0.31128	0.25416	
2p 3/2	2p 3/2	0.25423	0.20758	
2p 1/2	1f 5/2	0.31128	0.25416	

Table 5. *The values of the OBDM for transition from excited state (1^+) to excited state (1^+_2).*

Ji	Jf	Ki	Kf	L
1^+	1^+	1	2	2
1^+	1^+	2	2	2
nlj	n`l`j`	OBDM(DT=0)	OBDM(DT=1)	
1f 5/2	1f 5/2	0.17362	0.14176	
1f 5/2	2p 1/2	0.14273	0.11654	
2p 3/2	2p3/2	-0.18561	-0.22732	
2p 1/2	1f 5/2	-0.67886	-0.55428	

Table 6. *The values of the OBDM for transition from excited state (3^+) to excited state (3^+_2).*

Ji	Jf	Ki	Kf	L
3^+	3^+	1	2	2
3^+	3^+	2	2	2
n l j	n`l`j`	OBDM(DT=0)	OBDM(DT=1)	
1f 5/2	1f 5/2	-0.05902	-0.04819	
2p 3/2	2p 3/2	-0.03005	-0.02454	
2p 3/2	2p 1/2	0.01456	0.01189	
2p 1/2	2p 3/2	1.24043	1.01281	

Table 7. *The values of the OBDM for transition from excited state (3^+) to excited state (3^+_1).*

Ji	Jf	Ki	Kf	L
3^+	3^+	1	1	2
3^+	3^+	2	1	2
n l j	n`l`j`	OBDM(DT=0)	OBDM(DT=1)	
1f 5/2	1f 5/2	0.68	0.55522	
2p 3/2	2p 3/2	-0.27737	-0.22647	
2p 3/2	2p 1/2	0.13439	0.10973	
2p 1/2	2p 3/2	-0.13439	0.10973	

Table 8. *The values of the OBDM for transition from excited state (2^+) to excited state (2^+_1).*

Ji	Jf	Ki	Kf	L
2^+	2^+	1	1	2
2^+	2^+	2	1	2
2^+	2^+	3	1	2
2^+	2^+	4	1	2
2^+	2^+	5	1	2
n lj	n`l`j`	OBDM(DT=0)	OBDM(DT=1)	
1f 5/2	1f 5/2	0.10655	0.087	
1f 5/2	2p 3/2	0.01591	0.01299	
1f 5/2	2p 1/2	0.19479	0.15905	
2p 3/2	1f 5/2	-0.01591	-0.01299	
2p 3/2	2p 3/2	0.29103	0.23763	
2p 3/2	2p 1/2	0.64202	0.5242	
2p 1/2	1f 5/2	0.19479	0.15905	
2p 1/2	2p 3/2	-0.64202	-0.5242	

Table 9. *The values of the OBDM for transition from excited state (2^+) to excited state (2^+_2).*

Ji	Jf	Ki	Kf	L
2^+	2^+	1	2	2
2^+	2^+	2	2	2
2^+	2^+	3	2	2
2^+	2^+	4	2	2
2^+	2^+	5	2	2
n l j	n`l`j`	OBDM(DT=0)	OBDM(DT=1)	
1f 5/2	1f 5/2	0.06459	0.05274	
1f 5/2	2p 3/2	0.48937	0.39957	
1f 5/2	2p 1/2	0.3285	0.26822	
2p 3/2	1f 5/2	0.29984	0.24482	
2p 3/2	2p 3/2	0.08668	0.07077	
2p 3/2	2p 1/2	-0.35842	-0.29264	
2p 1/2	1f 5/2	0.08807	0.07191	
2p 1/2	2 p 3/2	-0.38569	-0.31491	

Table 10. *The values of the OBDM for transition from excited state (2^+) to excited state (2^+_3).*

Ji	Jf	Ki	Kf	L
2^+	2^+	1	3	2
2^+	2^+	2	3	2
2^+	2^+	3	3	2
2^+	2^+	4	3	2
2^+	2^+	5	3	2
n l j	n`l`j`	OBDM(DT=0)	OBDM(DT=1)	
1f 5/2	1f 5/2	0.01666	0.0136	
1f 5/2	2p 3/2	0.6325	0.51643	
1f 5/2	2p 1/2	0.12163	0.09931	
2p 3/2	1f 5/2	-0.12799	-0.10451	
2p 3/2	2p 3/2	-0.44736	-0.36527	
2p 3/2	2p 1/2	0.49116	0.40103	
2p 1/2	1f 5/2	-0.13202	-0.1078	
2p 1/2	2 p 3/2	0.63697	0.52008	

Table 11. *The values of the OBDM for transition from excited state (2^+) to excited state (2^+_4).*

Ji	Jf	Ki	Kf	L
2^+	2^+	1	4	2
2^+	2^+	2	4	2
2^+	2^+	3	4	2
2^+	2^+	4	4	2
2^+	2^+	5	4	2
n l j	n`l`j`	OBDM(DT=0)	OBDM(DT=1)	
1f 5/2	1f 5/2	0.15007	0.12253	
1f 5/2	2p 3/2	0.15755	0.12864	
2p 1/2	1f 5/2	-0.44942	-0.36695	
2p 3/2	1f 5/2	0.10355	0.08455	
2p 3/2	2p 3/2	0.2466	0.20134	
2p 3/2	2p 1/2	0.01534	0.01253	
2p 1/2	1f 5/2	0.03823	0.03122	
2p 1/2	2 p 3/2	-0.38291	-0.46896	

Table 12. *The values of the OBDM for transition from excited state (2^+) to excited state (2^+_5).*

Ji	Jf	Ki	Kf	L
2^+	2^+	1	5	2
2^+	2^+	2	5	2
2^+	2^+	3	5	2
2^+	2^+	4	5	2
2^+	2^+	5	5	2
n l j	n`l`j`	OBDM(DT=0)	OBDM(DT=1)	
1f 5/2	1f 5/2	0.36626	0.29905	
1f 5/2	2p 3/2	-0.30587	-0.24974	
Ji	Jf	Ki	Kf	L
1f 5/2	2p 1/2	-0.12411	-0.10134	
2p 3/2	1f 5/2	-0.06029	-0.04923	
2p 3/2	2p 3/2	-0.21296	-0.17388	
2p 3/2	2p 1/2	-0.10789	-0.08809	
2p 1/2	1f 5/2	0.27101	0.22128	
2p 1/2	2p 3/2	0.2939	0.23997	

4. Conclusion

Very weak values of Electric Quadrapole moment (Q) are generated from ^{58}Ni due to its active particles (Neutron) which are neutral particles (e_n=0) but it is possesses a small values of Electric Quadrapole moment (Q) due to some extent of active charge inherent to the motion and interaction inside the Nucleus.

The calculated one body density matrix element was carried by the use of OXBASH code and then the resulted output of these files had been included in another computer program to finish the calculation and produce the multipole moment.

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