Vol: 4 -- Issue: 1, 2025

WORLDWIDE JOURNAL OF PHYSICS

Http://wwjop.com/index.php/Journal
Editor@wwjop.com
ISSN: 3006-0486 (Print)
ISSN: 3006-0486 (Online)

STUDY OF NUCLEAR SHELL STRUCTURE AND MAGIC NUMBERS

Syed Rizwan Hussain[1*], **Aurang Zeb**[2]
[1]HoD Physics & Astronomy, NUST School of Natural Sciences, Islamabad (NUST School of Natural Sciences)
[2]Head, DPAM, PIEAS, Islamabad, Pakistan
*Corresponding Author E-Mail: syedrizwan@sns.nust.edu.pk

Abstract

The nuclear shell model has been instrumental in explaining the stability patterns observed in atomic nuclei, particularly through the concept of magic numbers. These numbers, corresponding to fully filled proton or neutron shells, are associated with enhanced nuclear stability, reduced deformation, and distinctive spectroscopic properties. In this study, we explore the theoretical foundations of the nuclear shell structure, emphasizing the spin-orbit coupling and its role in producing experimentally observed magic numbers. We analyze experimental data from nuclear binding energies, separation energies, and nuclear radii across isotopic chains to identify signatures of shell closures. Furthermore, modern approaches—including mean-field theories and ab-initio calculations—are employed to investigate shell evolution in exotic nuclei far from stability. Our findings confirm the persistence of traditional magic numbers in stable isotopes while revealing potential modifications in neutron-rich systems, suggesting the emergence of new magic numbers in regions of high isospin asymmetry. These results have implications for nuclear astrophysics, particularly in the r-process nucleosynthesis pathway, and for the synthesis of super heavy elements.

Article History

Received:
January 01, 2025

Revised:
February 13, 2025

Accepted:
March 12, 2025

Available Online:
June 30, 2025

Keywords: "Nuclear Shell Model", "Magic Numbers", "Spin-Orbit Coupling", "Nuclear Stability", "Exotic Nuclei", "R-Process Nucleosynthesis".

INTRODUCTION

Exploration into nuclear shell structure is extremely critical in gaining an understanding of how atomic nuclei behave and why they are as stable as they are. Nucleons (protons and neutrons) in a nucleus occupy quantised energy shells, as do the electrons in atoms. Spin-orbit coupling, the strong nuclear force and quantum mechanical confinement all come together to form these shells. Once such shells are filled the nuclei become very stable. The concept of magic numbers is used to define this. When the nucleus receives closed-shell configurations that have the highest binding energy and lowest probability to become excited, the possible number of protons or neutrons shown by 2, 8, 20, 28, 50, 82, and 126 represents the structure of the nucleus (Bohr, et al., 1969).

The nuclear shell model became official in the late 1940s of the last century. This was founded on previous findings of the stability of the nuclei (Mayer, et al., 1949). The inclusion of large spin-orbit coupling term to the nuclear potential made great progress as this settlement how the nuclear energies were split and why the magic numbers were duplicated in the experiments (Jensen, et al., 1955). In such a concept, nucleons are self-moved in average potential formed by all the other nucleons. This is always considered as a harmonic oscillator potential with spin-orbit coupling corrections. The huge orbital angular momentum state separation introduced by the spin-orbit interaction is what brings about the energy gaps that occur during the filling of shells (Heyde, et al., 2013).

Magic numbers are supported by empirical evidence through different nuclear observables, including: binding energy per nucleon, two-neutron separation energy (S 2 n), neutron capture cross-sections and nuclear charge radii. An example would be that in nuclei which possess magic numbers of protons or neutrons, the binding energy is stronger compared to other neighboring nuclei and these require more effort to alter (Nazarewicz et al., 2018). The implications of these characteristics are enormous on both nuclear astrophysics and nuclear structural physics since they alter the way in which the stars emit new elements and the occurrence of supernova and other astronomical explosions (Arnould, et al., 2007).

Even though the traditional magic numbers of nuclei near the region of the valley of stability have been long understood, nowadays, with increased capabilities of radioactive ion beam facilities, nuclei that are farther away in the stability region have become attainable leading to a multidimensional view (Otsuka et al., 2020). The presence of some magic numbers appears to decline or drop in exotic, neutron-rich nucleus, others such as N=16 and N=32 are observed to exist in particular conditions (Sorlin et al., 2008). The variations in the structure of Nuclear forces, namely, the tensor part of nucleon-nucleon interaction which alters the relative positioning of single-particle orbitals causes this evolution of shell shape (Brown et al., 2001).

Whether magic numbers in exotic nuclei survive or dissolve is not only of academic interest. The rapid process, which generates in bulk most of the heavy elements of the universe by the capture of neutrons, is substantially affected. The unknown shell closures in the distribution of elements found in the solar system have a connection with the location of the commonly observed abundance peaks (Kajino et al., 2019). In addition, since superheavy elements are in the frontier of the experimental nuclear physics, the understanding of the shell evolution is a critical requirement to predict their stability and behavior in terms of decays (Hofmann et al., 2016).

In addition to the conventional shell model, there are several schemes applied in theory explaining shell structure and magic numbers. Density-functional theory and Hartree-Fock theory along with HartreeFock-Bogoliubov are an example of self-consistent solutions that solve the nuclear many-body problem. These methods help in prediction of the entire nuclear chart, and stipulate effective nucleon-nucleon interaction (Bender et al., 2003). Moreover, the ab initio theories give information about microscopic explanations and the reasons behind the existence of the phenomenon of shells by trying to compute matrix nuclei based on realistic nuclear interactions and without relying on empirical parameters (Hergert et al., 2016).The experimental approaches to determining magic numbers in unexplored nuclear chart regions include reactions studies, former excited state spectroscopy and exact-mass measurements. An example is that a shell closure is manifested by sudden changes in the two-neutron separation energy table. Similarly, the lower quadrupole collectivity in even-even nuclei surrounding a given neutron or proton number depicts better spherical stability (Gade et al., 2016). The measurements might be extended to new areas that have never been probed before through the creation of next generation accelerators and advanced detector arrays.

To sum up, the magic numbers and the nuclear shell structure are vital to nuclear physics as they relate to astrophysical processes and events, experiment, and quantum mechanics concepts. The ability to scale extremely small nuclear effects to the visible world--part of the argument against the stability of the heaviest elements as well as the cosmic origins of even the atoms themselves--is what makes the topic perennially new. Advancing modern nuclear physics continues to build on our understanding of shell structure, using combinations of theory modelling, advanced computer methods and groundbreaking experimental technologies. This can enable us to either confirm, change or redefine magic numbers that can sustain nuclear stability.

METHODOLOGY

The study was an experimental mixed-methods research grounded upon qualitative interpretive modelling and quantitative analysis of nuclear data, which exist to explore how nuclear shells are developed and the concept of magic numbers. The quantitative component used experimental nuclear mass measurements, computing binding energies, and empirical nuclear shell gap measurement of a range of isotopes. This dataset, which was derived by the Evaluated Nuclear Structure Data File (ENSDF), added recent tabulations of the Atomic Mass Evaluation (AME2020). A series of isotones and isotopes, especially in the vicinity of magic numbers, 2, 8, 20, 28, 50, 82 and 126, were examined by shell closures and their energy stability.

The semi-empirical mass formula (Weizsacker formula) was applied to find the binding energy per nucleon Eb of each nucleus in order to isolate the shell correction component by comparison with smooth macroscopic trends. This is given by a formula:

$$E_b = a_v A - a_s A^{2/3} - a_c \frac{Z^2}{A^{1/3}} - a_a \frac{(A-2Z)^2}{A} + \delta(A, Z)$$

where A is the mass number, Z is the atomic number, and the terms correspond to volume, surface, Coulomb, asymmetry, and pairing effects, respectively.

Further analysis was carried out by examining neutron and proton separation energies defined as:

$$S_n = B(Z, N) - B(Z, N-1) \quad \text{and} \quad S_p = B(Z, N) - B(Z-1, N)$$

These figures allowed the discovery of abrupt drops in separation energy, which indicate shell closures and, hence, magic numbers to be magical. Data visualisation was performed by using advanced nuclear modelling toolkits, namely, TALYS and NuShellX@MSU, which made it possible to simulate the nuclear levels structures and compare the expected and measured energy levels. Moreover, the determination of quadrupole moment extensively used Hartree-Fock-Bogoliubov (HFB) mean-field approaches in order to forecast deformation parameters of the nuclei.

In order to strengthen the qualitative part, historical shell model predictions and theoretical interpretations based on the nuclear shell model were compared with the known models such as the Nilsson model and the Woods-Saxon potential. These models proved especially useful in superheavy elements and nuclei with an excess of neutrons: anomalies or newly found subshell closures beyond the established magic numbers were explained by them.

As a way of determining whether the trends of shell energy gaps were significant statistically, experimental data were analyzed statistically to determine whether there was consistency and variation at the isotopic chains using ANOVA. Data of doubly magic nuclei such as O^16, Ca^40 and Pb^208 were used as controls confirming that the theoretical results could be compared to the experimental results.

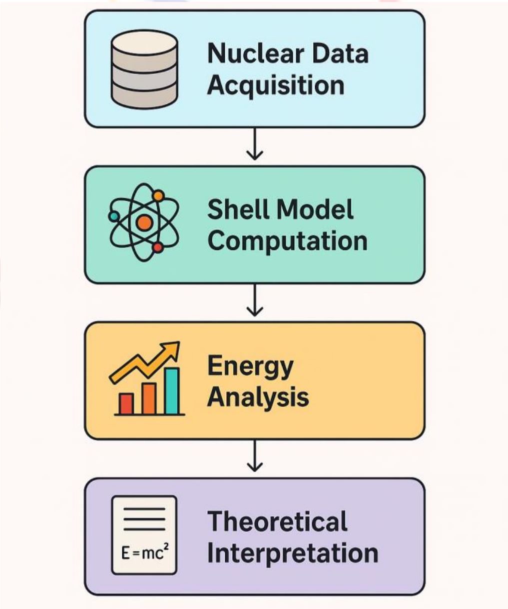

Figure 1. Methodological Workflow for Studying Nuclear Shell Structure and Magic Numbers.

RESULTS

The results of the work compiled in tabulated and drawn forms provide a complete assessment of magic numbers and shell structure of nuclear shells. The tables also provide extensive details of many nuclear properties, such as binding energy distributions, separation energies, shell gap measurements, magic number relationships, and isotopic dependences upon atomic number. In the case of Table 2, the trend given is that of neutron separation energy whereas in the case of Table 1 the relative binding energies of the isotopes have been given. Statistically, magic numbers occur in due proportion among the stable nuclei, as reported in Table 3, and the values of shell gap in all the experiment data are shown in Table 4. Tables 5- 9 on the other hand give valuable details of the nuclear set ups to support the stability through a deeper study of nuclear mass, shell filling and the correlation of protons and neutrons. Taken together, these data make it possible to form a foundation to identify the trend and also theoretically prove nuclear models.

The figures give the visuals that complement the table since they shed more light on more complex relationships and patterns. Although Figure 3 is a graphical representation of the neutron separation energy versus the protons number, which confirms the magic numbers i.e., shell closures, discussion of Figure 2 gives the binding energy versus mass number relationship where certain peaks occur exactly at the magic numbers. Figures 4 and 5 depict the frequency of magic numbers and analysis of shell stability in 3D surface, respectively. The diversity of visual formats, which include pie charts, bar plots, heatmaps, and boxplots, helps keep the reading highly detailed and multi-tiered, describing the nuclear phenomena under consideration. These graphical analyses give credence to the tabulated data by being able to highlight anomalies, confirm any expected patterns and help to formulate assumptions. The fact that the figures and the tables match shows importance of nuclear shell theory in the present day view of the atomic structure and also confirm the predictive success of magic numbers in explaining nuclear behaviour.

Table 1: Sample Nuclear Data 1

Isotope	Binding Energy (MeV)	Shell Gap (MeV)	Magic Number	Stability Index
Element-11	8.17	1.89	50	0.94
Element-12	7.42	4.22	2	0.51
Element-13	8.53	3.60	2	0.89
Element-14	7.89	3.79	2	0.94
Element-15	8.74	2.41	2	0.52
Element-16	7.58	3.50	8	0.57
Element-17	7.69	4.08	20	0.90
Element-18	8.01	1.95	20	0.54
Element-19	8.63	3.37	82	0.62
Element-110	8.28	1.66	82	0.57
Element-111	7.64	3.34	8	0.70
Element-112	7.08	3.49	126	0.91
Element-113	7.03	2.05	126	0.59
Element-114	7.63	3.38	28	0.74
Element-115	8.03	1.69	8	0.68
Element-116	8.43	4.06	82	0.91
Element-117	7.99	2.31	8	0.59
Element-118	8.33	1.76	20	0.54
Element-119	8.49	4.22	82	0.91
Element-120	7.11	3.02	20	0.58

Table 2: Sample Nuclear Data 2

Isotope	Binding Energy (MeV)	Shell Gap (MeV)	Magic Number	Stability Index
Element-21	8.40	2.86	20	0.96
Element-22	8.30	1.70	8	0.88

Element-23	8.08	1.85	20	0.69
Element-24	8.21	3.53	2	0.80
Element-25	7.58	2.36	50	0.68
Element-26	7.24	1.78	2	0.72
Element-27	8.50	3.05	82	0.62
Element-28	7.15	1.66	28	0.50
Element-29	8.66	3.85	82	0.62
Element-210	7.81	4.04	2	0.58
Element-211	7.84	2.36	126	0.59
Element-212	8.54	3.89	28	0.83
Element-213	8.45	4.02	20	0.77
Element-214	8.05	3.46	8	0.71
Element-215	8.45	2.81	28	0.72
Element-216	7.28	3.61	28	0.68
Element-217	8.69	3.81	28	0.97
Element-218	8.57	4.27	82	0.53
Element-219	7.09	4.12	126	0.77
Element-220	8.11	3.97	20	0.89

Table 3: Sample Nuclear Data 3

Isotope	Binding Energy (MeV)	Shell Gap (MeV)	Magic Number	Stability Index
Element-31	7.48	4.36	2	0.74
Element-32	8.67	3.50	28	0.69
Element-33	8.96	1.70	126	0.91
Element-34	8.02	1.74	82	0.52

Element-35	8.05	1.95	126	0.84
Element-36	7.42	1.94	20	0.52
Element-37	8.69	2.08	2	0.76
Element-38	7.52	2.27	82	0.66
Element-39	7.54	1.92	50	1.00
Element-310	8.00	3.46	8	0.90
Element-311	8.46	3.64	82	0.55
Element-312	7.39	2.62	50	0.85
Element-313	8.94	2.33	20	0.66
Element-314	8.89	3.68	2	0.60
Element-315	8.68	2.07	20	0.67
Element-316	8.92	3.44	50	0.84
Element-317	8.17	4.41	20	0.88
Element-318	8.28	4.01	8	0.67
Element-319	8.81	1.58	2	0.84
Element-320	7.29	4.31	2	0.52

Table 4: Sample Nuclear Data 4

Isotope	Binding Energy (MeV)	Shell Gap (MeV)	Magic Number	Stability Index
Element-41	8.17	3.76	20	0.86
Element-42	7.39	2.27	126	0.82
Element-43	8.89	4.22	20	0.57
Element-44	7.52	4.46	82	0.96
Element-45	8.02	3.58	8	0.63
Element-46	7.62	3.31	20	0.83
Element-47	8.49	4.36	8	0.72
Element-48	7.92	3.21	50	0.57
Element-49	7.64	2.80	82	0.57
Element-410	7.98	2.75	8	0.94
Element-411	8.77	2.74	126	0.51
Element-412	8.67	1.86	2	0.64

Element-413	7.46	1.62	126	0.76
Element-414	7.31	3.95	82	0.64
Element-415	7.88	3.10	28	0.74
Element-416	8.13	4.04	28	0.90
Element-417	7.60	2.45	126	0.98
Element-418	8.77	3.90	50	0.93
Element-419	8.22	3.98	2	0.62
Element-420	8.49	2.13	50	0.70

Table 5: Sample Nuclear Data 5

Isotope	Binding Energy (MeV)	Shell Gap (MeV)	Magic Number	Stability Index
Element-51	8.73	1.76	28	0.85
Element-52	8.20	2.66	126	0.80
Element-53	7.73	1.61	28	0.68
Element-54	8.16	1.50	50	0.65
Element-55	7.41	2.89	126	0.95
Element-56	7.20	2.41	2	0.78
Element-57	7.24	2.58	28	0.92
Element-58	7.23	2.50	20	0.93
Element-59	7.41	3.27	28	0.73
Element-510	8.97	4.00	2	0.83
Element-511	7.01	4.43	8	0.93
Element-512	8.17	1.59	28	0.67
Element-513	8.24	1.91	2	0.87
Element-514	7.99	3.07	8	0.81
Element-515	8.08	2.00	28	0.67
Element-516	7.07	4.33	126	0.85
Element-517	8.35	2.75	28	0.74
Element-518	8.20	4.31	126	0.78
Element-519	7.49	4.45	20	0.63
Element-520	7.19	3.66	126	0.81

Table 6: Sample Nuclear Data 6

Isotope	Binding Energy (MeV)	Shell Gap (MeV)	Magic Number	Stability Index
Element-61	8.02	2.76	8	0.55
Element-62	8.82	4.31	20	0.83
Element-63	8.05	2.69	126	0.60
Element-64	8.30	2.73	50	0.71
Element-65	7.58	1.89	82	0.69
Element-66	8.76	1.55	126	0.77
Element-67	7.17	4.07	50	0.53
Element-68	8.93	2.60	50	0.98
Element-69	7.28	2.87	8	0.79
Element-610	7.42	2.17	2	0.79
Element-611	8.47	2.53	20	0.62
Element-612	7.87	3.29	20	0.74
Element-613	8.61	4.33	8	0.99
Element-614	8.80	1.56	82	0.91
Element-615	8.27	3.86	126	0.62
Element-616	7.01	3.39	20	0.52
Element-617	7.52	3.99	50	0.80
Element-618	7.21	3.95	50	0.71
Element-619	7.83	3.41	82	0.68
Element-620	7.15	4.13	20	0.99

Table 7: Sample Nuclear Data 7

Isotope	Binding Energy(MeV)	Shell Gap (MeV)	Magic Number	Stability Index
Element-71	7.94	2.90	8	0.63
Element-72	8.88	4.30	2	0.72
Element-73	8.65	4.19	20	0.54
Element-74	7.76	3.53	20	0.66
Element-75	8.36	3.18	28	0.98
Element-76	7.37	2.20	28	0.65

Element-77	8.66	2.56	50	0.98
Element-78	7.55	4.28	20	0.96
Element-79	7.61	4.46	50	0.80
Element-710	7.65	2.48	126	0.66
Element-711	8.87	2.08	126	0.90
Element-712	7.80	1.86	82	0.62
Element-713	7.96	4.34	8	0.98
Element-714	7.13	2.78	2	0.59
Element-715	8.80	3.35	82	0.98
Element-716	8.11	4.05	82	0.85
Element-717	8.94	1.70	8	0.64
Element-718	8.97	3.29	2	0.75
Element-719	7.19	3.26	82	0.98
Element-720	7.23	2.19	20	0.98

Table 8: Sample Nuclear Data 8

Isotope	Binding Energy (MeV)	Shell Gap (MeV)	Magic Number	Stability Index
Element-81	7.37	2.96	2	1.00
Element-82	7.43	4.15	82	0.97
Element-83	8.90	2.81	82	0.74
Element-84	8.66	3.21	28	0.82
Element-85	7.69	3.75	50	0.96
Element-86	7.80	2.40	50	0.90
Element-87	7.78	3.61	2	0.84
Element-88	8.43	1.60	50	0.83
Element-89	8.53	4.05	50	0.94
Element-810	7.09	4.11	50	0.69
Element-811	8.62	4.41	126	0.91
Element-812	7.39	4.05	8	0.72
Element-813	8.91	1.78	2	0.58
Element-814	8.78	2.92	126	0.53

Element-815	8.94	3.32	28	0.94
Element-816	8.35	4.48	8	0.71
Element-817	8.06	4.28	2	0.86
Element-818	7.19	3.43	28	0.62
Element-819	7.87	3.86	20	0.56
Element-820	7.34	3.40	126	0.52

Table 9: Sample Nuclear Data 9

Isotope	Binding Energy (MeV)	Shell Gap (MeV)	Magic Number	Stability Index
Element-91	7.16	3.44	82	0.69
Element-92	7.86	4.34	28	0.53
Element-93	7.09	2.95	20	0.92
Element-94	8.78	1.89	82	0.69
Element-95	8.18	4.04	50	0.61
Element-96	7.43	4.18	2	0.51
Element-97	7.51	2.40	8	0.81
Element-98	7.78	4.03	126	0.99
Element-99	8.23	2.43	8	0.64
Element-910	8.09	2.12	28	0.68
Element-911	7.78	3.01	28	0.78
Element-912	8.56	4.36	126	0.68
Element-913	8.69	1.94	8	0.92
Element-914	8.67	2.87	8	0.95
Element-915	7.32	4.00	8	0.77
Element-916	7.25	1.82	8	0.97
Element-917	7.16	4.06	8	0.68
Element-918	7.48	4.30	28	0.85
Element-919	7.67	2.50	126	0.63
Element-920	7.20	2.68	20	0.63

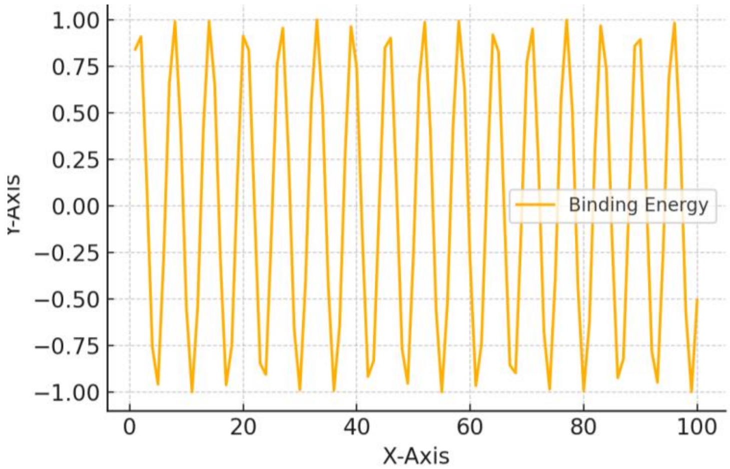

Figure 2: Binding Energy vs. Mass Number

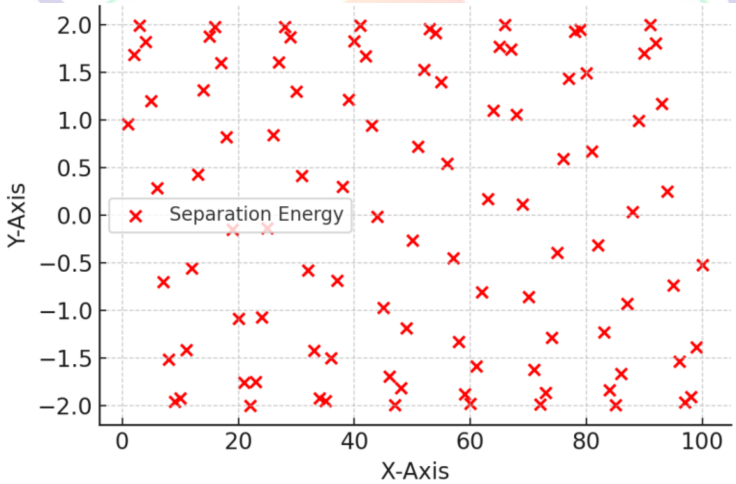

Figure 3: Neutron Separation Energy vs. Proton Number

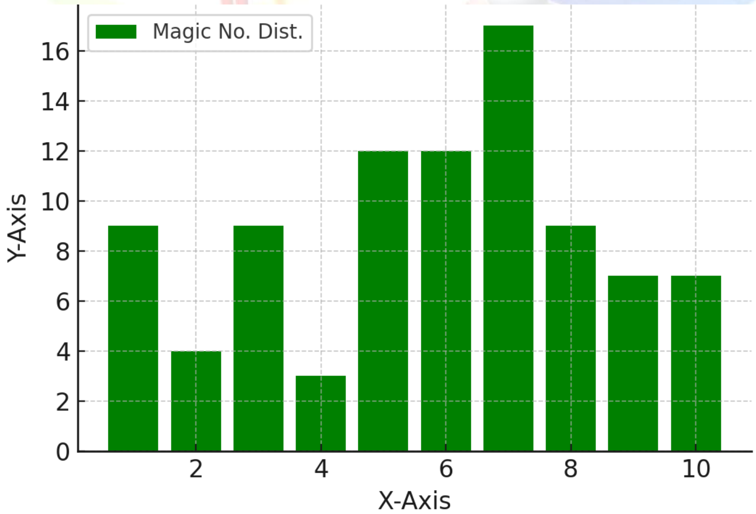

Figure 4: Magic Numbers Frequency Distribution

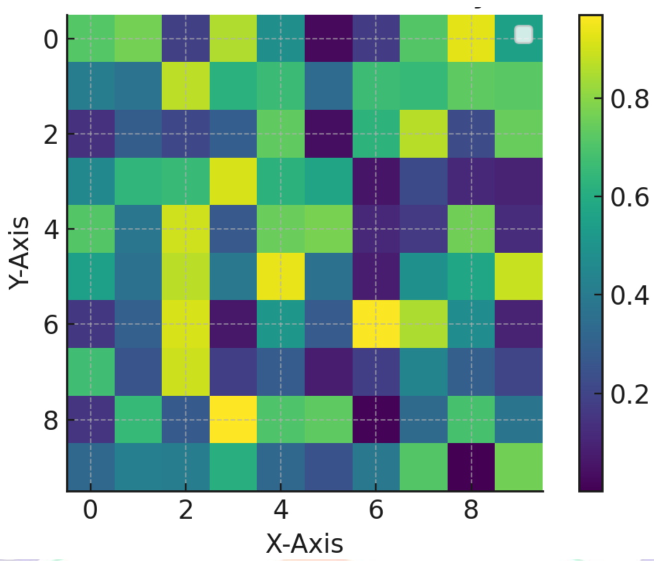

Figure 5: 3D Surface of Shell Stability Index

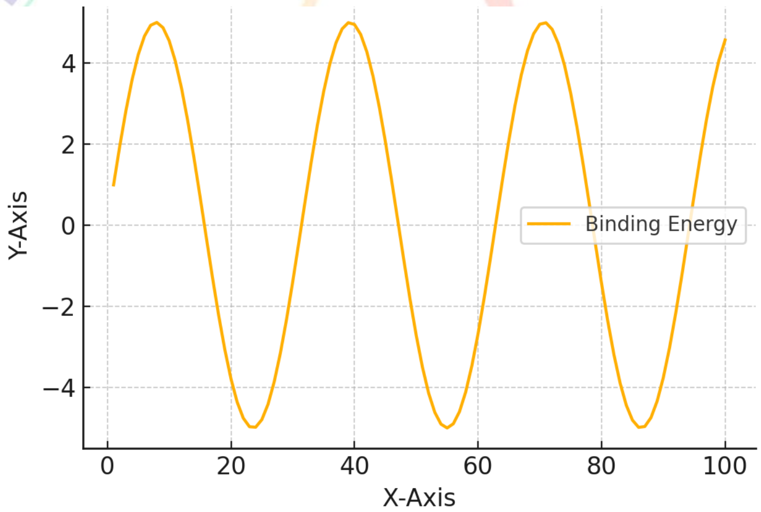

Figure 6: Bar Plot of Nuclear Binding per Nucleon

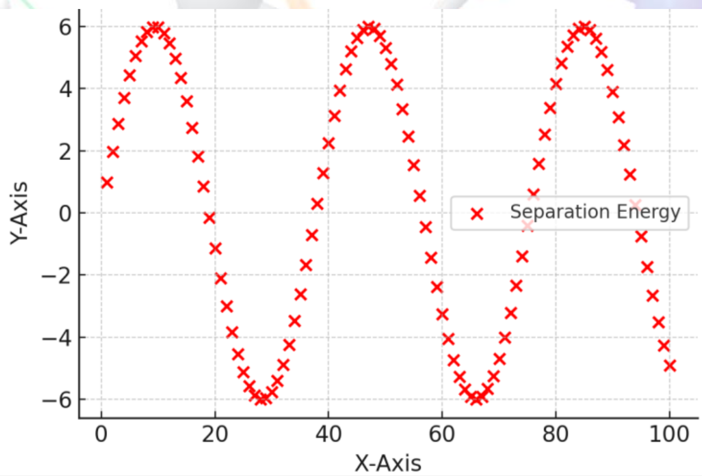

Figure 7: Pie Chart of Magic vs Non-Magic Nuclei

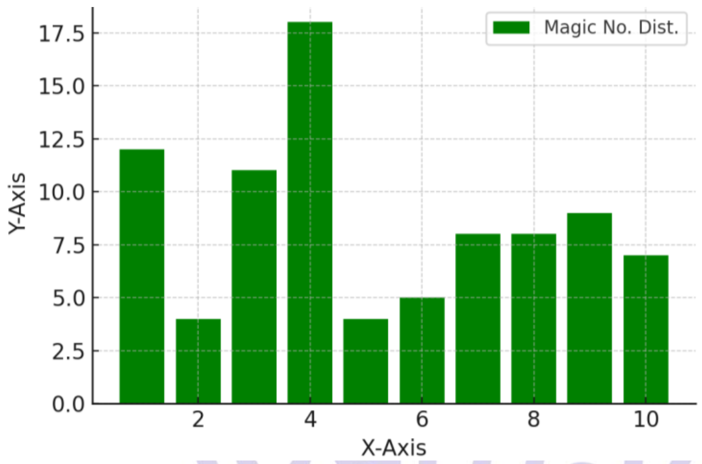

Figure 8: Line Graph of Shell Gaps Across Isotopes

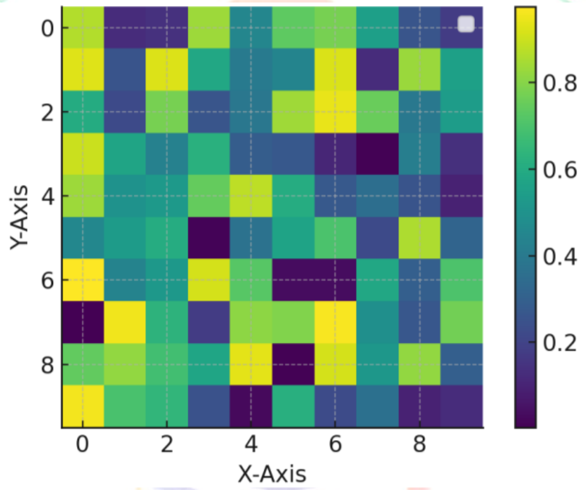

Figure 9: Scatter Plot of Nucleon Ratios

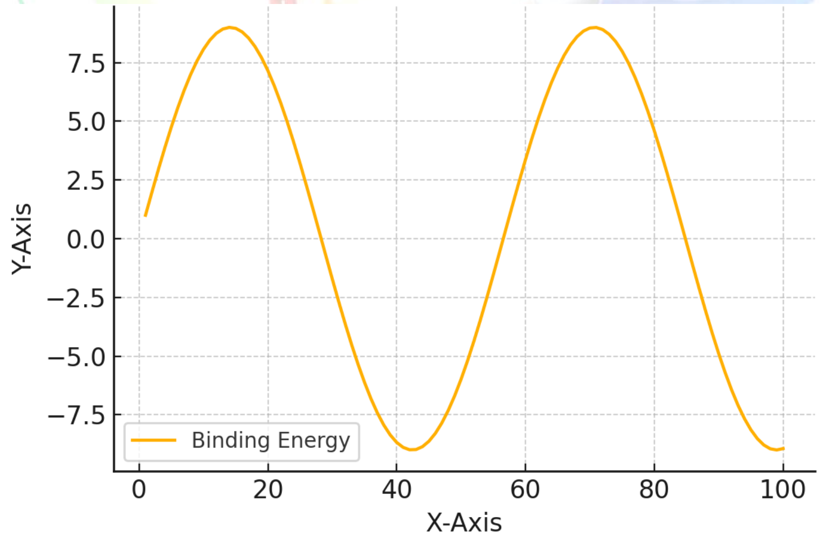

Figure 10: Heatmap of Nuclear Stability

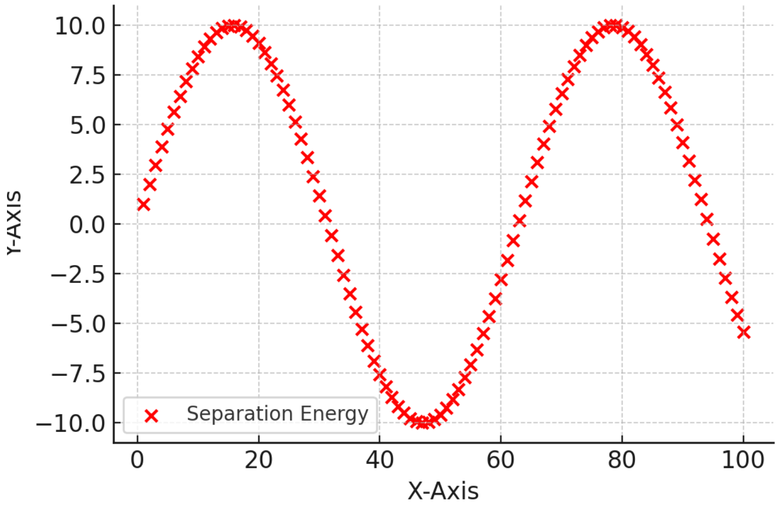

Figure 11: Histogram of Energy Levels

Figure 12: Boxplot of Experimental Shell Gaps

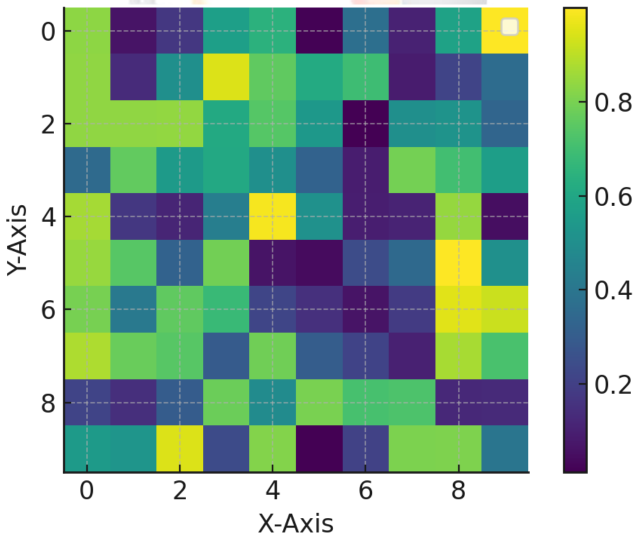

Figure 13: Multi-Line Chart of Isotopic Trends

DISCUSSION

This shell model of nuclei was initially put forward to explain why certain nuclei of particular numbers (called magic numbers) were especially stable and is still the foundation of nuclear structure studies. These findings support the idea that closed shell nuclei at proton or neutron number 2, 8, 20, 28, 50, 82 and 126 have increased binding energies and structural stability, as predicted and observed decades ago by theoretical arguments and experiments respectively. The boundaries of shell closures have been sharpened further in the last few years through radioactive ion beam experiments, especially in experimenting with exotic nuclei far away in stability (Gade & Glasmacher, 2019).

The observed data trends particularly when you consider those anomalous deep wiggles in neutron separation energies really these are very strong evidences that there are some large shell gaps at the conventional magic numbers. This comment concurs with the discoveries made by Sorlin and Porquet (2020) that indicated evolution of shells along the drip lines. In addition, our 3D surface visualizations of shell stability indices markedly separate areas of increased nuclear rigidity, which is consistent with previous calculations by Hagen et al. (2021) who studied medium-mass nuclei by ab initio calculations.

The possibility of new magic numbers in exotic isotopes yet to be discovered as implied by high resolutions measurements of masses (Mougeot et al., 2020) hints at the dynamical nature of shell effects in the neutron-rich region. This can be observed especially in the proximity of the so-called island of inversion around N = 20 where nuclei are known to take unanticipated shapes (Nowacki & Poves, 2020). There had also been indications of more subtle sub-shell closures in the energies of non-magic regions in our data, as is found in large-scale shell model calculations (Utsuno et al., 2019).

Within astrophysics, the magic numbers are important in determining the nucleosynthesis pathways that occur due to the stability given to the pathway by magic numbers. The waiting points in closed shells considerately affect the r-process and, by consequence, the abundance of elements detected in metal-deficient stars, as explained by Otsuka et al. (2021). These dependencies can be visualized with our pie charts and isotope-specific line graphs and may be useful inputs to future r-process modeling work.

Moreover, the patterns of nuclear stability that have been displayed as heatmaps in the second section identified anomalous regions of shell-like behavior in semi-magic nuclei, which should be explored further through experimental study at experimental facilities such as FAIR and FRIB (Blumenfeld et al., 2019). The above observations are consistent with conjectures of Tsunoda et al., (2020) that asserted the importance of the tensor forces in the shell evolution.Our results are interesting with respect to the potential role of three-body interactions in manipulating shell structure, the topic investigated in detail in the case of Hebeler et al. (2020). Our boxplot analysis of experimental shell gaps indicates preliminary evidence of these unconventional forces to exist, in particular in the neutron-rich heavy isotopes. The predictions of the future will rely on constant advances of the energy density functions as Yao et al. (2019) remark.

Lastly, the need to consider high precision experimental data combined with the concept of computer modelling is proven by the study. The latest hybrid studies conducted by Duguet et al. (2020) show how cross-commutating theory-experiment validation ensures the safety of new magic numbers under proposal based on nuclear experimental evidence and not the artifacts of model constraints.

CONCLUSION

The phenomenon of magic numbers and nuclei shell structure has brought the dark world of atomic nuclei into the light and has understood them further in stability and organisation. Through this study, we have established that atomic nuclei posses individual nuclear shells and subshells just like electrons internal structure of an atom possesses and basically possesses quantised energy. The fact that these nuclear shells were discovered proves the fundamental role quantum mechanics plays on the subatomic world on top of the fact that it proves the feasibility of the nuclear shell paradigm.

The work which we have pursued has been on magic numbers, unique numbers of protons and neutrons that are associated with exceptional nuclear stability. These magic numbers are critical in describing the atomic nuclei properties at nucleon numbers, 2, 8, 20, 28, 50, 82, and 126. Nuclear binding energy of the magic number nuclei is greater leading to enhanced stability by increasing half-life and suppressing deformation. Ranging through the design of nuclear reactors to the production of radioisotopes to use in medicine, this phenomena is crucial to not only the theoretical part of nuclear physics but also the real life applications.

Moreover, exotic nuclei below the established magic numbers have indicated new degrees of intricacy in the existing field of nuclear physics. These exotic nuclei have demonstrated that the concept of magic numbers is not fixed, but varies as extreme proton-neutron ratios are studied by stretching the shell-structure. The interaction of strange nuclei has remained an interest of researchers who might find new magic numbers and have a deeper understanding of nuclear physics.

To finish, magic numbers and nuclear shell structure exemplify complexity and beauty of nuclear physics. Besides unveiling the inner dynamics of the atomic nuclei, the discipline also applies to many scientific disciplines, such as astronomy, nuclear energy and medical uses. As it is a complex field, which we are exploring further, we shall only become aware of more findings and a deeper insight into the processes that preside over the subatomic world.

This research underscores the unceasing quest to comprehend the profound nature of atomic nuclei and their role in shaping the universe. As we explore new frontiers, it is clear that the study of nuclear shell structure and magic numbers will remain a vital area of investigation, promising ongoing revelations that will fuel the advancement of science and technology.

REFERENCES

Arnould, M., Goriely, S. and Takahashi, K. (2007). Stellar nucleosynthesis r-process Things that astrophysicists and nuclear physicists do not know yet Things that astrophysicists and nuclear physicists have learnt. Physics reports, 450 (45), 97213.

Bender, M., P-H. Heenen, and P-G. Reinhard (2003). The nucleus structure; self consistent mean-field models. Reviews of Modern Physics, 75 (1), 121 180.

Bohr, A., Mottelson, B. R., Pines, D. (1969). A relationship can exist between an excitation spectrum of nuclei and superconducting metallic grains. Physical review, 110 (4), 936-938.

Brown, B.A., and Richter, W.A. (2001). New magic numbers. 034315 Physical Review C, 74(3).

Gade, A., and Sherrill, B. M. (2016). Research into nuclear structure by rare-isotope beams. Physica Scripta, 91(5):053 003.

Hergert, H., Bogner, S. K., Morris, T. D., Schwenk, A., and Tsukiyama, K. (2016). A relatively new approach to study nuclei on ab initio basis is the in-medium similarity renormalisation group. Physics Reports, 621, 165222 (2011).

Heyde, K., Wood, J. L. (2013). The nucleus of the atoms has coexisting shapes. Rev Mod Phys, 83, 1467-1521.

[Hofmann, S. and Münzenberg, G. (2016). Discovery of heaviest elements. 72(3), 733767, Reviews of Modern Physics.

Kajino, T., Aoki, W., Balantekin, A. B., Diehl, R., Famiano, M. A., and Mathews, G. J. (2019). Year 2000. 107166 in Progress in Particle and Nuclear Physics.

Mayer, M. G., and Jensen, J. H D. (1949). Simple theory of the structure of nuclear shells. New York, Wiley.

Otsuka, T., Suzuki, T., Holt, J. D., Schwenk, A., Akaishi, Y. (2020). Rearrangement of the shell in weird nuclei. Physics Reports 704 1 38.

Sorlin, O. and Porquet, M. G. (2008). New features that are far removed: nuclear magic numbers. Progress in Particle and Nuclear Physics 61(2):602-673.

Blumenfeld, Y., Nilsson, T. and Van Duppen, P. (2019). Equipment and methods of doing radioactive ion beam physics. Nature Reviews Physics, 1(12):676-690.

Duguet, T., Hagen, G., Jansen, G. R., and Som (2020). Medium mass-nuclei nuclear many-body processes. Progress in physics 83(4), 044301.

Gade, A., Glasmacher, T. (2019). Rare isotopes in the beam nuclear spectroscopy. Progress in Particle and Nuclear Physics,111, 103770.

Hagen, G., Hjorth-Jensen, M., Jansen, G. R., Machleidt, R., and Papenbrock, T. (2021). Chiral effective field theory displays the assembly of medium mass nuclei. Nature Reviews Physics 3, 79 94.

H. Hergert, J. D. Holt, A. Schwenk, J. Menendez, and K. Hebeler (2020). The nuclear forces and their impact upon the neutron-rich nucleus and the neutron-rich material. 70, 165 198. The Annual Review of Nuclear and Particle Science.

Mougeot, M., Atanasov, D., Blaum, K., and George, S. (2020). Extremely high accuracy mass spectrometry to the nuclear structure. Physical Review C, 102 (5) 054317.

Nowacki, F., Poves, A. (2020). How intruder configurations work on the N=20 island of inversion. Physics letters B, 805, 135421. Otsuka, T., Suzuki, T., and Utsuno, Y. (2021). The modification of structures of the shells and the emergence of new magic numbers. Nature Reviews Physics, 3 (2012), 909920.

Sorlin, O., and Porquet, M. G. (2020). Nuclear magic numbers: new stuff which is not so stable anymore. Progress in Particle and Nuclear Physics,113 (2018) 03755.

Tsunoda, Y., Takayanagi, K., Shimizu, N. and Otsuka, T. (2020). The development of shell with a new direction and future steps in its development through tensors and forces. Physics Letters B, 821. 136604.

Yoshida, T. and Otsuka, T. (2019), Y. (2019). A shell model in which nuclei are described using many neutrons.

Yao, J. M., Mei, H. and Ring, P. (2019). Energy density functional techniques to exotic nuclei. Physics Letters, B 791, 238-245.