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A new online database of nuclear electromagnetic moments

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Abstract. Nuclear electromagnetic (EM) moments, i.e., the magnetic dipole and the electric quadrupole moments, provide important information of nuclear structure. As in other types of experimental data available to the community, measurements of nuclear EM moments have been organized systematically in compilations since the dawn of nuclear science. However, the wealth of recent moments measurements with radioactive beams, as well as earlier existing measurements, lack an online, easy-to-access, systematically organized presence to disseminate information to researchers. In addition, available printed compilations suffer a rather long life cycle, being left behind experimental measurements published in journals or elsewhere.

A new, online database (`http://magneticmoments.info`) focusing on nuclear EM moments has been recently developed to disseminate experimental data to the community. The database includes non–evaluated experimental data of nuclear EM moments, giving strong emphasis on frequent updates (life cycle is 3 months) and direct connection to the sources via DOI and NSR hyperlinks. It has been recently integrated in IAEA LiveChart [1], but can also be found as a standalone webapp [2]. A detailed review of the database features, as well as plans for further development and expansion in the near future is discussed.

1. Introduction

The importance of nuclear magnetic dipole and electric quadrupole moments (EM moments) in understanding nuclear structure has been well understood from the early years of nuclear science. Magnetic dipole moments of both ground and excited states provide reliable input on the nuclear wave function in terms of proton and neutron contributions, while the electric quadrupole moment is the most important observable to extract information on the shape of the nucleus. As RIB factories have significantly widened the range of nuclides that can be studied, EM moments can contribute critically to understanding structure far from stability.

As a consequence, the organization of the experimental nuclear EM moments data into an efficient scheme that would facilitate systematic search, access and use is considered a firm necessity. Tabulations of nuclear EM moments data existed already in the ′50 s [3–5] and expanded later on [6–9], while they were sometimes accompanied by theoretical interpretation of moments [10].

The most recent printed compilation existing today is the extensive work by N.J. Stone [11]. That work organizes experimental data of nuclear EM moments horizontally in a systematic tabulated format. It has been the main reference in the field for over a decade [12–15], and includes data and meta-data from earlier compilations, mainly from [7] and [9].

Despite their importance, all print compilations suffer long time intervals between updates (typically 2 to 6 years), if any. In view of the rapidly growing production rate of new data due to radioactive ion beams, it becomes necessary to enrich and update the existing nuclear EM moments compilations with recently published data at a faster rate, while at the same time provide the research community with easy access to these data benefiting from modern technology. This is the main motivation behind creating a new dedicated online database of nuclear EM moments.

2. Database scope and main features

The primary scope of the online database is to provide published experimental data collected during low– and intermediate–energy nuclear experiments, as well as associated meta–data. The database was first published online with a limited data set in 2007, but it made its debut, in fully operational version, in 2012 [16] on a private server, where it still exists. In its recent upgrade and move to the IAEA Nuclear Data Section servers, all database source files, structure and interface have been redesigned to comply with IAEA's IT security requirements and web standards. Integration with IAEA's LiveChart [1] was facilitated by the flexible structure of the database.

The official release of the database on IAEA servers was accompanied by a significant dataset expansion: existing tabulated data until 2014 were transferred directly from print material, such as Stone's compilations existing in both preprint [11,14] and peer–reviewed versions [13,15]. More recent experimental data have been collected by searching literature in more than twenty five (25) international peer–reviewed journals, as well as in Proceedings Volumes of International Conferences. The searching procedure has been greatly assisted by modern technologies offering dynamical content, currently available in most online journals (e.g., RSS/XML feeds), social networks and online archiving tools that provide automation at several stages. Additional

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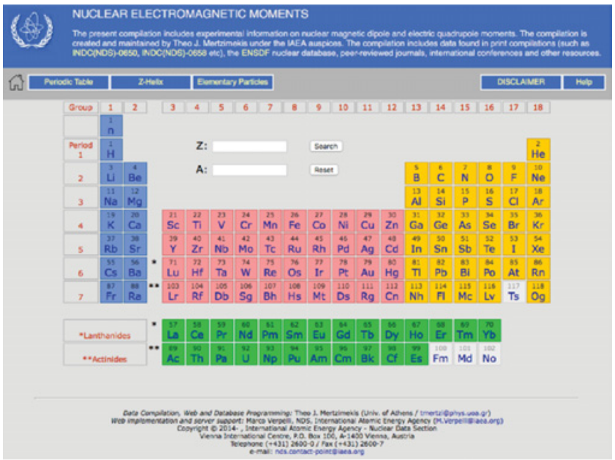

Figure 1. The main user interface of the nuclear EM moments database.

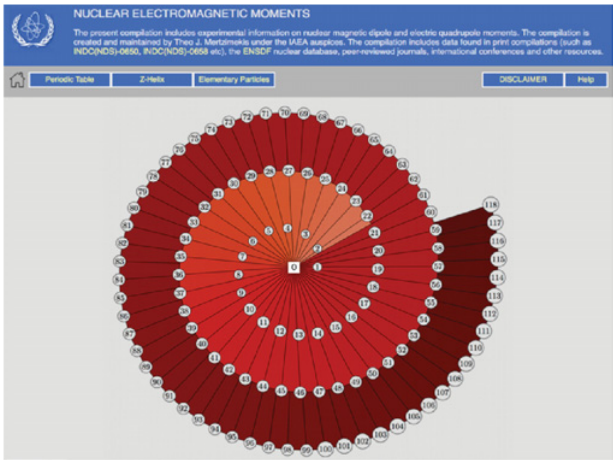

Figure 2. The alternative user interface (Z–helix) of the nuclear EM moments database.

data sets and associated meta–data have been tracked down by researching listings in the Nuclear Science References (NSR) database. It has to be noted that the EM moments database comprises all available experimental data that are in general non-evaluated and are presented "as is".

A large effort has been invested in setting up a routine procedure to perform updates on a frequent, regular basis in a consistent and systematic way, so as to maintain the database's synchronicity with recent literature. The time interval between updates has been set to three months, i.e., four updates are released annually. The particular interval seems to be optimal for the amount of work required to incorporate the data compared to the number of experimental data been made available in various sources.

The frontend of the database

The main user interface (UI) is contained in the frontend of the database. Using the UI, the researcher can submit a query to the database. This query is then processed and through a series of internal procedures the data are retrieved and displayed back to the frontend. The frontend was built in standard HTML, assisted by CSS and JavaScript web technologies. The main design idea was to keep things simple at the frontend, while focusing also on fast query processing. For that reason, advanced web technologies, such as AJAX programming, were not considered during implementation, while functionality and user friendliness have been central requirements.

The user is offered two ways of interaction with the database. The first UI option utilizes a standard periodic table graphical structure (see Fig. 1). The second UI is a helix-type graphical interface, where information can be retrieved by selecting the atomic number, Z, of the element (Fig. 2). Both UI options use the exact same backend. Once an element (i.e., the corresponding Z) is selected, all available isotopes of that element appear in a horizontal list. The user can select the isotope of interest from the output list. For each isotope, all available moments data are presented in a table format (see detailed explanation below). In addition to these two methods of data retrieval from the backend, a webform is provided in the former UI, where the user can type queries for Z, A or both. This selection operates dynamically and can be used in a more powerful way (e.g., the user can retrieve isobar data simultaneously).

For each isotope requested, a table of data is displayed, organized in rows and columns. Abbreviations are adopted from Stone's compilations (who followed Raghavan's work) to maintain users' familiarity with earlier conventions. Columns provided in the output are given below (see example in Fig. 3)

- Column 1: The selected isotope (e.g., ^{26}Mg).
- Column 2: The level energy in keV (e.g., 1809).
- Column 3: The half-life of the level (e.g., 476 fs).
- Column 4: Spin and parity of the level (e.g., 2^{+}).
- Column 5: The magnetic dipole moment value, μ, given in nuclear magneton units μ_N; in case several measurements exist, typically the most recent value appears first (e.g., +1.0(3)).
- Column 6: The electric quadrupole moment value, Q, in units of eb; for multiple values, data are displayed as above. Often the value is followed by the text "Rec": This abbreviation marks a Recommended value as proposed by [14].
- Column 7: If the measurement has been carried out relative to a level of a particular isotope (reference), the latter appears together with its corresponding level energy (e.g., ^{24}Mg 1369 keV).
- Column 8: The experimental method, in an abbreviated format (e.g., TF for "Transient Field"). A short description of the technique is also provided when hovering the mouse over the abbreviation listed in the table.
- Column 9: The NSR keyword, e.g., 1981Sp04. The corresponding URL has been added to hyperlink the NSR to the original citation.
- Column 10: The Digital Object Identifier (DOI) is provided for easy access to the published material containing the original measurement (e.g., 10.1016/0370-2693(81)90200-8). To the best of our knowledge this is the only specialized nuclear database (other than NSR) that provides direct link to the publication via the DOI.

The backend

The backend is the actual database. It comprises all components that stay invisible to the user during the

Magnesium (Z=12)

^{21}Mg	^{23}Mg	^{24}Mg	^{25}Mg	^{26}Mg	^{27}Mg	^{29}Mg	^{31}Mg	^{33}Mg

Isotope	Energy [keV]	$t_{1/2}$	Spin/Parity	μ [nm]	Q [b]	Ref. Std	Method	NSR keyword	doi
^{26}Mg	1809.	476 fs	2^+	+1.0(3)		[^{24}Mg 1369]	TF	1981Sp04	10.1016/0370-2693(81)90200-8
					-0.21(2) Rec		CER	1991He09	10.1103/PhysRevC.43.2546
					-0.14(3)		CER, R	1981Sp07	10.1016/0370-1573(81)90177-0
					-0.14(3) or -0.10(3)		CER	1982Sp05	10.1016/0375-9474(82)90466-3
					-0.11(6)		CER	1977Sc36	10.1016/0375-9474(77)90108-7

Figure 3. A representative output screen following a database query.

Sodium (Z=11)

^{20}Na	^{21}Na	^{22}Na	^{23}Na	^{24}Na	^{25}Na	^{26}Na	^{27}Na	^{28}Na	^{29}Na	^{30}Na	^{31}Na

Isotope	Energy [keV]	$t_{1/2}$	Spin/Parity	μ [nm]	Q [b]	Ref. Std	Method	NSR keyword	doi
^{26}Na	0.	1.07 s	3^+	+2.851(2)		[^{23}Na]	ABLS	1978Hu12	10.1103/PhysRevC.18.2342
					-0.0053(2) Rec	[^{23}Na]	CFBLS, b-NMR	2000Ke09	10.1007/s100500070117
					-0.08(5)		ABLS	1982To05	10.1103/PhysRevC.25.2756

Magnesium (Z=12)

^{21}Mg	^{23}Mg	^{24}Mg	^{25}Mg	^{26}Mg	^{27}Mg	^{29}Mg	^{31}Mg	^{33}Mg

Isotope	Energy [keV]	$t_{1/2}$	Spin/Parity	μ [nm]	Q [b]	Ref. Std	Method	NSR keyword	doi
^{26}Mg	1809.	476 fs	2^+	+1.0(3)		[^{24}Mg 1369]	TF	1981Sp04	10.1016/0370-2693(81)90200-8
					-0.21(2) Rec		CER	1991He09	10.1103/PhysRevC.43.2546
					-0.14(3)		CER, R	1981Sp07	10.1016/0370-1573(81)90177-0
					-0.14(3) or -0.10(3)		CER	1982Sp05	10.1016/0375-9474(82)90466-3
					-0.11(6)		CER	1977Sc36	10.1016/0375-9474(77)90108-7

Aluminium (Z=13)

^{23}Al	^{24}Al	^{25}Al	^{26}Al	^{27}Al	^{28}Al	^{30}Al	^{31}Al	^{32}Al	^{33}Al	^{34}Al

Isotope	Energy [keV]	$t_{1/2}$	Spin/Parity	μ [nm]	Q [b]	Ref. Std	Method	NSR keyword	doi
^{26}Al	0.	7 x 10^5 y	5^+	+2.804(4)		[^{27}Al]	ABLS	1996Co04	10.1088/0954-3899/22/1/008
					+0.26(3) Rec	[^{27}Al]	ABLS	1997Le19	0.1088/0954-3899/23/9/015
					+0.27(3)	[^{27}Al]	ABLS	1997Le19	10.1088/0954-3899/23/9/015

Figure 4. A representative screen displaying $A = 26$ isobar data and meta–data.

search, retrieval, and display operations. There are two main parts in the backend: the database tables and the database script handlers.

The data tables

The database tables are stored in MariaDB format containing all information mentioned earlier. The current version of the database has more than 5300 rows in the table of nuclear EM moment values, corresponding to over 1100 levels. The entries have been checked thoroughly to ensure reliability and data integrity with respect to original sources. For entries adopted from earlier printed compilations a few typographical errors were located and corrected including citations, NSR keywords and EM moments values.

The novel feature of the database is that a dedicated column holding the Digital Object Identifiers (DOI) for each single entry –wherever available– has been incorporated into the tables. In the vast majority of cases, all NSR keywords have a one-to-one correspondence with a DOI. However, in a rather limited number of cases, the NSR server is missing the corresponding DOI, most often because the source is not available online or the journal has still not entered the NSR database (the majority of such cases correspond to terminated journal series or articles prior to 1990). All available DOI have been inserted in the database and hyperlinked to the original source using the official DOI name-resolving server, `http://dx.doi.org`.

The data handlers

The connection between the front– and back–end is handled by a set of PHP scripts. Hard–coded operations responsible for decoding the query, accessing the database tables, retrieving and processing the data, and formatting output are included in the PHP scripts. Depending on the initial query by the user, the data handlers can provide information on specific isotopes or a group of isobars (depending on the initial Z–A or A–alone query). The script handlers are written so that they could be easily modified to serve future expansions of the database.

The accompanying blog

The database is accompanied by a blog, where an informal archiving of information related to EM moments, experimental data and theoretical studies takes place. The blog is useful for the updates due to easy archiving of journal, conference or preprint papers that can be accessed at a later stage, before an official release takes place. The blog uses the popular open-source Wordpress engine, and is currently hosted at `http://magneticmoments.info/wp`. It is open, but moderated, to all subscribers from the scientific community.

Examples of use

Two typical examples of the database usage are described below. When the user queries the database for a particular isotope a typical output is similar to Fig. 3. Here, the example considered is the ^{26}Mg nucleus.

In the dynamically produced webpage, the data handlers display a table containing basic spectroscopic information (e.g., lifetime, spin/parity etc.), available μ and Q moments values, and supplementary bibliographical and informational data (e.g., experimental method, DOI numbers etc.).

For the case of ^{26}Mg displayed, only one measurement of the magnetic moment is known $\mu = +1.0(3)$ (the number in the parenthesis being the uncertainty of the last significant digits), measured by the Transient Field technique (abbreviated as "TF") relative to the known magnetic moment of the 1369 keV level in ^{26}Mg. There are additionally four known electric quadrupole moment measurements, listed in the following rows, all measured by Coulomb Excitation Reorientation ("CER"). The NSR keywords and DOI numbers for each entry are hyperlinked to the corresponding entries on the NNDC NSR server and the electronic version of the original sources, respectively.

A second example deals with a query regarding isobars with $A = 26$. Besides ^{26}Mg, two more isobars exist for the moment in the database for $A = 26$, namely ^{26}Na and ^{26}Al. The corresponding tables for these nuclides are listed in ascending Z, as illustrated in Fig. 4.

3. Conclusions and future work

A new web-based database (`http://magneticmoment.info`) for nuclear electromagnetic moments data has been created. The project supersedes all existing printed compilations, supported by frequent updates of published experimental data provided openly to the scientific community.

The provision of reliable data has been a central motivation from the beginning. A rather exhaustive check of the incorporated data has been carried out during development. The feature of linking information to the original published source, mainly by the newly provided meta-information (DOI), is a key feature enhancing the credibility of the database.

Future plans focus on keeping the frequency of updates constant, expanding the database with additional nuclear observables, and adding plotting capabilities to facilitate the search for systematic trends in the EM moments data across a range of nuclei.

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References

[1] IAEA LiveChart, `https://www-nds.iaea.org/livechart`
[2] `http://magneticmoments.info/data`
[3] J.E. Mack, Rev. Mod. Phys. **22**, 64 (1950)
[4] B.T. Feld, Ann. Rev. Nucl. Sci. **2**, 239 (1953)
[5] H. Kopfermann, Akad. Verl.-Ges. (1956)
[6] G.H. Fuller, J. Phys. Chem. Ref. Data **5**, 835 (1976)
[7] P. Raghavan, At. Data Nucl. Data Tables **42**, 189 (1989)
[8] P. Pyykkö, Mol. Phys. **99**, 1617 (2001)
[9] P. Pyykkö, Mol. Phys. **106**, 1965 (2008)
[10] R.J. Blin-Stoyle, Rev. Mod. Phys. **28**, 75 (1956)
[11] N.J. Stone, INDC(NDS)-0658 (2014)
[12] N.J. Stone, INDC(NDS)-0594 (2001)
[13] N.J. Stone, At. Data Nucl. Data Tables **90**, 75 (2005)
[14] N.J. Stone, INDC(NDS)-0650 (2013)
[15] N.J. Stone, At. Data Nucl. Data Tables **111–112**, 1 (2016)
[16] T.J. Mertzimekis, HNPS2013 Proceedings (2013)
[17] T.J. Mertzimekis et al., NIM A **807**, 56 (2016)