Magnetism World

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Abstract

This works aims to systematically, yet in a handy manner, describe the phenomenon of magnetism, in a website format, named http://magworld.physics.auth.gr. In this website, even the less experienced visitor may easily navigate through the history of magnetism, get familiarized with basic concepts and metrology of magnetic quantities. Magnetic materials are classified with respect to their lateral dimensions: Macro-, Micro- and Nano- scale. For each family of materials, corresponding formulations, properties, effects, and applications are described in detail while automatic estimation sheets, useful for researchers working on magnetism related topics, evaluate magnetic quantities in simple steps. Quizzes of variable difficulty also exist, where students of any level may self-evaluate what they have learned by exploring this site. Information appearing on this website is based on the collection, categorization and evaluation of magnetism-related information published in international journals and books. On a year-basis, the website is updated with relevant information to serve as the magnetism's reference database for modern scientific and technological applications. This website's goal is to provide an on-line reference information database, practical and useful for tutors, students, and researchers interested to enter the wonderful world of magnetism.

Keywords: magnetism; magnetic materials; magnetic properties; nanomagnetism; magnetic applications

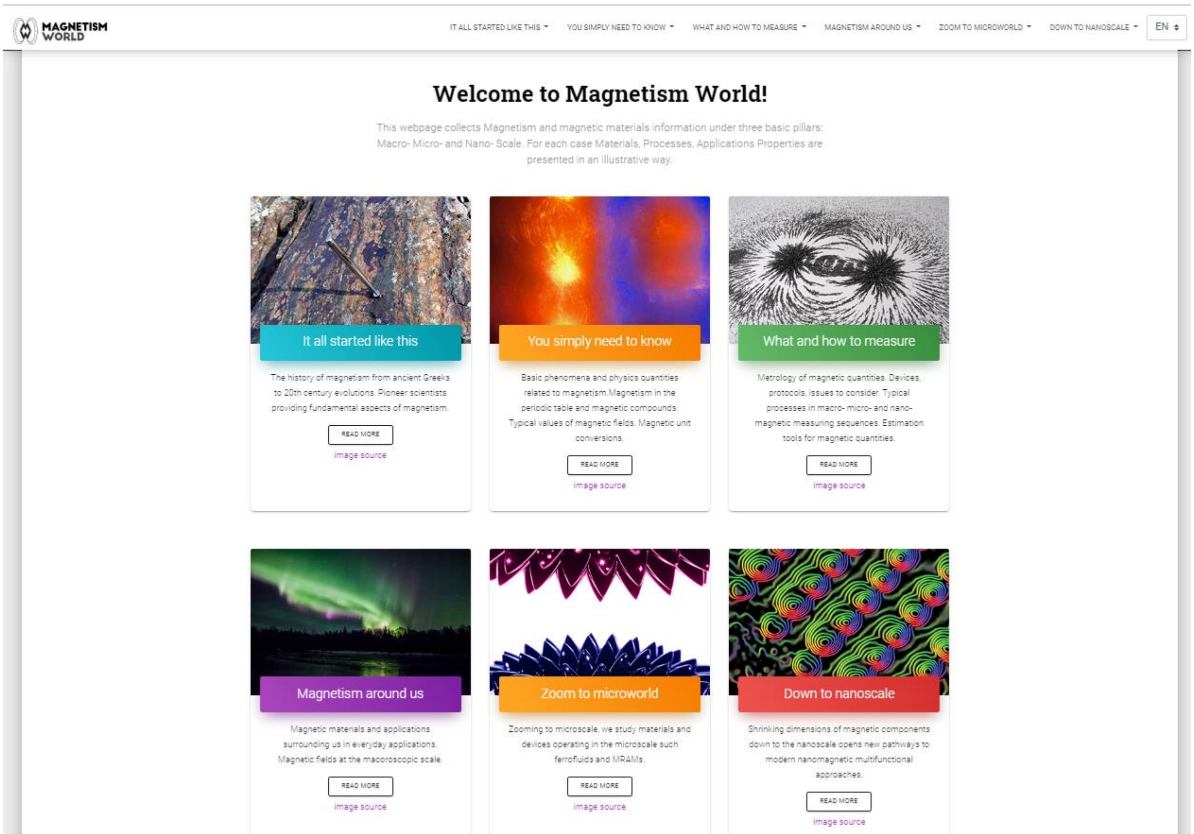
1. Introduction

Today, the phenomenon of magnetism appears in various forms and manifestations on websites and databases. Through these sources, there is typically lack of evaluation and categorization of information, to assist scholars, researchers or even students to search and validate easily reference information regarding materials or effects (Kalogiannakis, Nirgianaki, & Papadakis, 2018; Hirano, & Hirokawa, 2017). The specific research effort aims to systematically record magnetism including historical info, fundamental knowledge, metrology, and a materials' database divided into three categories in terms of dimensions: macroworld, microscale and nanoscale, where each category consists of four interrelated subcategories: Materials, Properties, Effects, Applications. In general, this attempt aims to systematically organize a significant amount of information and offer it as an on-line database useful for students of any level, professors, and researchers interested on magnetic materials. Background knowledge is provided in an illustrative way to introduce and familiarize user with magnetism related materials, effects, and processes. Special care is devoted to the nanotechnology aspect of magnetism associated with certain materials of fundamental and technological interest, pointing out their records and outlining synthetic, compositional and formulation aspects as well as certain experimental prototype measurements (Tsecheri, Salta, & Stavrou, 2019).

2. Methodology

One of the major objectives of this effort is to attract even the least experienced on magnetism visitors in a simple way and to familiarize themselves with basic concepts of magnetism, to overview magnetic materials, properties, effects, and applications surrounding us, to easily collect additional information and enrich their knowledge about the history of magnetism. At the same time, more experienced visitors such as physics students, professors, and researchers are given the opportunity, to overview specialized concepts, and phenomena of magnetism, the metrology of magnetic quantities together with on-line estimation tools as well as magnetic materials categorized on macro- micro- and nano- scale dimensions.

Figure 1: The homepage of the website http://magworld.physics.auth.gr which includes the 6 main information areas starting in 1st row with general attributes: It all started like this, You simply need to know-Basic concepts, What and how to measure and continuing in 2nd row with specific categories of materials with respect to their lateral dimensions: Magnetism around us (macroscale), Zoom to microworld (microscale), Down to nanoscale (nanoscale) where respective properties, effects and applications are discussed and specific on-line estimation routines are included accordingly.



Source: The homepage of website http://magworld.physics.auth.gr

Therefore, the website is split in six major information areas as depicted in Figure 1, each one consisting of six sub-categories. From left to right and from top to bottom, the website tabs are gradually getting more specialized. The proposed categorization is proposed as a handy tool, starting with general information (first row: *It all started like this*, *You simply need to know*, *What and how to measure*) and getting deeper in magnetic materials (second row) split in three categories with respect to their lateral dimensions: *Magnetism around us* (Macroscale Materials:), *Zoom to microworld* (Microscale materials), *Down to nanoscale* (Nanoscale materials). Each materials' category consists of six subcategories with more specific information packages. According to the degree of familiarity, (students, professors, researchers) visitors may navigate and readily collect updated information about certain aspects of magnetism and related materials.

This website's content is based on the collection, categorization and evaluation of magnetism-related information published in prestigious international journals and books, providing in all cases the corresponding references. The information will be regurarly updated and enriched with scientific goals and acheivements on the field to serve as the magnetism's reference database for modern magnetic scientific and technological applications.

3. Results

The six major information areas appearing on home page of the website are described as follows:

The first information area (first row-leftmost tab) is named *It all started like this* and provides general knowledge, easily comprehendible to general knowledge visitors since it addresses the *history* roadmap *of magnetism*, the *pioneer* scientists, the *magnetic materials*, either in element or in compound form, in a handy table format, including physical and chemical properties (Andrä, & Nowak, 2007). A historical framework is necessary to explore the basic concepts, problems and any difficulties identified as well, and the questions raised. In this way, the potential user according to the degree of familiarity (students at different education level) will be able to collect information about the history and evolution of magnetism over the centuries. Therefore, the historical flashback is divided into periods-stations, starting from the first stage of the discovery of magnets and reaching up to the modern era. Reference is made to basic concepts in the discovery of the magnet and to the first magnetic observations and related phenomena together with scientific evolutions up to date. Emphasis is given to all pioneer scientists who paved the magnetism roadmap over the centuries as well as to the experiments carried out by them and their contribution to the evolution of magnetism. A typical example is *Gilbert* who carried out several experiments and through his book *De magnete*, which is considered by many researchers one of the first and most important works in science, documented the knowledge of his era about magnetism and electricity (Coey, 2010). Information on elements and compounds with magnetic features is collected and assists as handy glossary for students and researchers. The user may also explore an overview of magnetism *everyday applications* usually overlooked at first glance. This information area concludes with two educational tabs: a). *Let's get magnetized* including an educational activity on magnetism with 10 stops suitable for elementary and high-school students and b). *Magnetic games* where one may find useful links for on-line magnetic games and companies providing educational material concerning magnetism.

The knowledge background on magnetism is collected in the second tab entitled *You simply need to know* split in six sub-categories named *Elements*, *Basics*, *Facts & Figures*, *Macroscale*, *Microscale* and *Nanoscale*. A practical table with magnetic features of periodic table appears in *Elements*, together with an overview of physical and chemical properties. In *Basics*, fundamental knowledge on magnetism including basic definitions and effects to assist deeper understanding on the underlying physics. *Facts & Figures* provides values of magnetic fields, starting from the universe and ending inside biological entities. This area also includes three additional tabs named *Macroscale*, *Microscale* and *Nanoscale* respectively. Here, preliminary information is collected, concerning magnetic properties, effects related materials and applications at the corresponding length scale.

The 3rd tab is named *What and how to measure* where the visitor may find useful and practical information concerning magnetic quantities (*Quantities and units*) and their metrology (*Metrology*). Typical questions like *What physical quantity describes the intensity of a magnetic field? Are there other relevant physical quantities? What are the units used? Are there any typical values? a*re answered in this area together with hints and tips to perform reliable magnetic experiments and ways to safely extract relevant quantities. *Devices* outlines a brief overview of typical experimental setups used worldwide to characterize magnetic materials, including principles of operation, advantages, and drawbacks. What follows are the two tabs corresponding to the two major categories of measurements *Static* and *Dynamic* magnetic *measurements* where examples of protocols and relevant experimental data sets are given Typical examples are VSM (Vibrating Sample Magnetometry) and FMR (FerroMagnetic Resonance), respectively. Thus, the user may get acquaintance with the role of a specific measuring sequence and observe, for example, illustrative datasets outlining the performance of typical magnetic materials (Balasubramanian, Sakurai, Wang, Xu, Ho, Chelikowsky, & Sellmyer, 2020; Nouailhat, 2008). The final tab of this category is named *Calculations* and provides an on-line automatic sheet to directly estimate or simulate magnetic features from adequate magnetic experiments or simulations.

A more rigorous description of materials residing at the three length scales appears on the 2nd row individual tabs as follows: *Magnetism around us* (Macroscale materials), Zoom to microworld (Microscale materials) and *Down to Nanoscale* (Nanoscale materials). In each category information is classified in the following subcategories *Materials*, *Properties*, *Effects*, *Applications*, *Estimations* and *Quizzes*. As clearly outlined by their names the first four subcategories collect information, at each specific size regime, about the magnetic materials and their features suitable for technological exploitation. On the other hand, the tab *Estimations* is a practical on-line sheet with multiple routines, again focusing on the specific size regime, to readily estimate quantities usually encountered in magnetic studies, and necessary for data evaluation and interpretation by students, young researchers, and scientists. Typical examples include hysteresis loop area, energy product, anisotropy constant, blocking temperature, single-domain size, Néel and Brownian relaxation times. Quizzes is the last tab in each materials' category and provides a 10 questions' multiple-choice quiz with classified difficulty (easy, medium, hard) selected randomly from q question bank with more than 300 questions.

It should be emphasized here that special care is given to collect and evaluate up to date information concerning microscale and nanoscale magnetic materials. For example, the focus in the *Zoom to the microworld* (Microscale materials) is on the properties of the materials and the metrology of magnetic materials with one or more dimensions in the μm regime. Here, starting from the description of the specific magnetic characteristics occurring at these dimensions, their micrometric evaluation is attempted, and procedures are proposed to extract sound conclusions of collective magnetic features qualitatively and quantitatively. For example, the smaller the size of a material, the more unstable its magnetization resulting to certain constraints: *Which are the limitations of magnetic recording media? How is temperature affecting an unstable magnetic moment?*

Going on to nanoscale materials (*Down to nanoscale*) where one or more dimensions are limited in the *nm* regime (approaching the atomic level) has substantial effects on magnetic features: At this point, peculiar and novel phenomena arise due to quantum confinement a distinctly different theoretical background is often required (Czichos, Saito & Smith, 2006). Terms like magnetic anisotropy and superparamagnetism may be fine-tuned at the atomistic level according to modern applicability aspects and can give information about magnetism based on atomic theory. Magnetic nanostructures with one, two and three nano-dimensions, which constitute an interesting category of materials for both scientific and technological exploration due to advances in both magnetism and magnetic materials (Martin, Nogues, Kai Liu, Vicent, & Schuller, 2003; Vajtai, 2013), are discussed and correlation of their features at the nano/micro/macro is described.

Such a systematic study with respect to materials and dimensions aims to highlight the interconnection not only between the properties of materials and applications in each category but to outline the role of dimensionality, as well. For example, *How are parameters such as dimensions, temperature affect the magnetic response of a material?* Eventually, the visitor gets an overview of how various properties and applications of magnetic materials are may be modified, such as the energy product and magnetic anisotropy and can examine, compare, and evaluate reference data of the the corresponding measurements.

Key points of this work are (a) the systematic recording of the evolution of magnetic materials and their properties, their characteristics while deepening in the field of nanotechnology and (b) the use of experimental data for technological applications as well as the processing of the values of experimental data in low-dimensional materials.

This website addresses the following educational goals for the phenomenon of magnetism:

I. **Realizing the magnetism's phenomenon as something unified**, without separating it into phenomena related to either the macroworld or the nanoscale. At the same time, there is a logical flow in the provision of information to make it easier for the user to access the survey for magnetism related data.

II. **In-depth understanding of concepts and clarification of the magnetism related phenomena** (Rodríguez Calderón, & García Ruíz, 2019), while referring to the properties of materials as well as their applications, in a simple and accessible way (Borghes, & Gilbert, 1998) for someone with a basic physics background i.e., the elementary concepts related to magnetism.

III. **Collecting valid information and classifying it**, to make it easier to search for materials, properties, and applications. Thus, a critical human mass will have access to valid information related to phenomena and modern devices related to magnetic properties (Bozzo, Daffara, Michelini, Monti, & Vercellati, 2019).

IV. **Linking the magnetism's phenomenon and the properties of magnetic materials to real world** in a wider scale of material dimensions. At the same time, classification is distinguished with respect to way we observe *from outer to inner*, starting for example, from the universe and ending to the human body's interior.

The final product is a web-interfaced database containing updated information and potential users are able to perform easy searches both based on a material, property or application or combinations of them. This attempt is bilingual (Greek and English) to assist its evaluation both at regional and international level. The evaluation of the website will be attempted through invitations-test visits to different age groups (Elementary, High School, University both students and tutors) (Mueanploy, 2016). In fact, there are on-line cognitive difficulty familiarization tests and on-line magnetic feature calculations. These include questions covering a wide range of concepts and phenomena related to magnetism, randomly selected from a continuously updated question bank. Thus, is given user the opportunity to delve into concepts in an interactive way provided by the plethora of closed-type questions but also achieves its immediate feedback through online answers (Finkelstein, 2005; Kalkanis, & Tobras, 2019). This interaction will significantly improve the functionality of the website in terms of both its technical part and its content. (Gunawan, Jufri, Nisrina, Al-Idrus, Ramdani, & Harjono, 2021; Jing, L. & Chandralekha 2016). In this way, the potential user according to the degree of familiarity (students, tutors, researchers) will be able to collect information about magnetism (Gunawan et al, 2021; Pryotz, 2020).

4. Conclusion

This work presents an interactive tool for the study and exploration of magnetism in all manifestations and forms as well as in all dimensions from the macroscale to the nanoscale. The site design framework is in such a way that information and knowledge are provided in a variety of ways and at the same time focuses on user interaction through certain activities. For example, online quizzes with a difficulty rating of the questions, calculators built for different magnetic dimensions and the conversion of magnetization units, as well as interactive games are innovative tools and a special way to approach and explore the wonderful world of magnetism. This enables, on the one hand to inexperienced, in relation to the concepts of magnetism, a student to be able to understand the phenomenon of magnetism and, on the other hand, to the researcher or student to be able to deepen the concepts of magnetism. The acquisition of knowledge in this way can be considered as highly effective, substantial, interesting, stimulating, fun and modern, because it follows the dictates of the twenty-first century and tries to adapt to the conditions of modern technology. Eventually, this website provides an updated on-line reference information database, practical and useful for anyone interested to enter the wonderful world of magnetism.

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