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COMPUTER ASSISTED METHODS IN TEACHING BASICS OF MAGNETISM AT HIGH SCHOOL LEVEL

C. KUNCSER[1,2], A. KUNCSER[1], G. MAFTEI[1,3], S. ANTOHE[1]

[1] University Bucharest, Faculty of Physics, 405 Atomistilor Street, P.O. Box MG-11, Măgurele-Ilfov, 077125, Romania,
E-mail: ckuncser@yahoo.com; akuncser@yahoo.com; gelumaftei@yahoo.com; santohe@solid.fizica.unibuc.ro
[2] "C.C. Kiritescu" High School, Pestera Dambovicioara 12, Bucharest, Romania
[3] National Center for Development of Professional and Technical Education, 10-12 Spiru Haret, Bucharest, Romania

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Abstract. Computer assisted methods in teaching physics are discussed. Basics of magnetism, starting from individual magnetic moments and their complex quantum origin, are introduced in a friendly manner by using typical computer based facilities, including diagrams and intuitive graphical representations. The principle of their quantitative estimation *via* the vibrating sample magnetometry technique is also presented, in the frame of high school physics knowledge and abilities. An example for accessing direct experimental measurements *via* remote laboratory techniques is provided, as a step forward, with respect to virtual experiments. The new possibilities offered to the students to participate directly from the classroom to the real experimental activity *via* the remote laboratory techniques are finally discussed.

Key words: teaching *via* computer assisted methods, basics of magnetism, remote laboratory.

1. INTRODUCTION

Once the computer has become widely used and the internet allowed to large pieces of information to be shared between interconnected computers, a major change in the educational process was ready to occur: an evolution from the traditional methods to the computer-assisted teaching and learning. In this way, the computer assisted education (CAE) becomes a didactic method enforced by the informational society; it capitalizes the principles of programmed teaching, in the context of the newly developed communication and informational technologies.

At a first glance, the CAE advantages seem to be obviously, especially in the teaching of physics, considered as one of the toughest curricular disciplines. That is because of the complexity of the involved phenomena, which hardly can be explained by the means of simple traditional methods. So, instead of drawings, the new didactic methods, which rely on the computer possibilities, may offer to the student the opportunity to see a full oriented animation related to a complex physical phenomenon, otherwise very difficult to understand.

By using the computer and the new learning methods, the students benefit of interactive lessons with a good scientific support, much more attractive and instructive as compared to the traditional methods, due to the use of multimedia resources (animations, simulations, virtual experiments, remote laboratory). The necessity of using the new teaching techniques in order to gain the interest of the students for school, given the role and the importance of the computer in their daily life, became obvious.

This paper resumes the main computer assisted methods (CAM) and provides an exemplification of their application in introducing complex notions related to magnetism, in an as much as possible friendly manner. Finally, direct experimental results obtained in a research laboratory are provided via remote laboratory techniques, by using the Team Viewer program. The advantages of the remote laboratory facility with respect to virtual experiments are discussed, by underlying that the remote laboratory represents a step forward *versus* the virtual experiment, because in the first case the children interact with a real device, not with a soft, as in the second case.

2. COMPUTER ASSISTED METHODS FOR TEACHING/LEARNING PHYSICS

Related mainly to the field of physics, the following teaching/learning new methods, assisted by the computer, will be referenced [1–8]: (a) the graphical representation, (b) static and animated diagrams, (c) the live image or video recording of an experiment, (d) the structured text, (e) the presentation.

(a) The graphical representations are efficient ways of passing information. An eloquent graphical representation added to an explanation, can organize the information better and have a bigger impact on the student. The main advantage of the graphical representation resides on the ease of memorizing an image presented in a limited space, visual memory being superior to the lexical one. The current types of graphical representations overcome the traditional orthogonal representations. In order to make diagrams and 3D images for illustrating data or describing the concepts, a computer is able to use clipart, digital photography and powerful programs of graphical processing.

(b) The static and animated diagrams can be used mainly for demonstrating and exemplifying the evolution of various processes, otherwise difficult to be presented by text or by simple explanations. Anyway, the animations can be correlated with vocal or written comments and, in principle, it is desired that each animation to permit at any moment to be paused or started again. Rough animations can be obtained in usual presentation programs, like Power Point.

Specialized programs are required for complex animations as well as special programming knowledge, which is generally above the teachers training possibilities. In this respect, it is better to make use of already made animation, the role of the teacher being to introduce it properly in the approached presentation.

(c) Live images or video recording of experiments can be used for educational purposes, both for observing different aspects of the real world and for introducing the students in the environment of a new and complex experiment, impossible to be performed in the classroom. Video recordings may ease the understanding, benefiting of the presence of the intonation or diction (sound being an extremely efficient way to keep attention). Audio-video combination can be used whit the same success. In order to improve the efficiency of such multimedia, mainly by keeping the attention of the students, several aspects have to be taken into account: (i) the recordings to be short, (ii) possibilities of replay, (iii) small pauses incorporated in order to reflect on the message of the sequence just played, (iv) rising of questions or issues in the meantime.

(d) The text holds as a fundamental instrument of teaching (especially in materials given to students as homework), but it must be taken into account that an excessive long text can become a slow and monotonous instrument for passing the information. In addition to these, when using this kind of instrument, are to be considered facts such as: (i) students ability of getting such pieces of information is facilitated by the use of familiar words and clearly expressed phrases; short and easy to assimilate paragraphs and a conversational tone should be used, (ii) as concerning the manner of writing it is recommended to use easy readable font types, keeping the same literature in the entire text. Also it is recommended to associate headlines to each of the paragraphs in order to point the main ideas and to use a proper spacing in order to avoid a disturbing concentration of the text. For editing a text there are used the so called text editors, Microsoft Word, representing a conclusive example. For editing scientific text, the LaTex editor is to be mentioned.

(e) The presentation is a digital successor of the slide frames. It is an efficient tool for transmitting the information, in the case of lessons, speeches, conferences, etc. Such presentations can include text, tables, images, animations and virtual experiments and allows on-line connections to real experiments via remote laboratory techniques. Such presentations are created by specialized programs, the most widely used being Microsoft Power Point.

3. COMPUTER ASSISTED METHODS FOR INTRODUCTION OF FUNDAMENTAL NOTIONS OF MAGNETISM. AN EXAMPLE

The substance is made from atoms having associated, from the point of view of their response to a magnetic field, the so called atomic magnetic moments, μ (not any atom have one). In addition, each of the magnetic moment gives rise to a small magnetic field around it. There are two contributions to the electronic magnetic moment: (i) the orbital magnetic moment and (ii) the spin related magnetic moment. Their origin will be described in the following, by making use of slides of PowerPoint presentations, as examples for applications of computer assisted methods.

(i) The orbital magnetic moment: Many of the atom properties can be explained using the Bohr model for hydrogen atom [9]. According to this model, the electrons are moving around the nucleus on circular orbits. This circular movement is equivalent to an electric current with the intensity:

$$i = \frac{-e}{T} = \frac{-e\omega}{2\pi} = \frac{-ev}{2\pi r}, \tag{1}$$

where e is the elementary electron charge, T is the period of the rotation, v is the electron's speed on the orbit and r is the radius of the orbit. According to the Ampere's relation, to a plane loop of current, it can be associated a vector $\vec{\mu}$ (Fig. 1), called the magnetic moment of the loop [10].

$$\vec{\mu} = i\vec{A} = iA\vec{n}, \tag{2}$$

where i is the intensity of the current through the loop and $\vec{A} = \vec{n}A$ is the surface of the area defined by the loop, with $\vec{n}$ the normal at the surface. Considering the expression (1) of the current, the magnitude of the magnetic moment is given by:

$$\mu = iA = -\frac{ev}{2\pi r}\cdot \pi r^2 = -\frac{e}{2} rv. \tag{3}$$

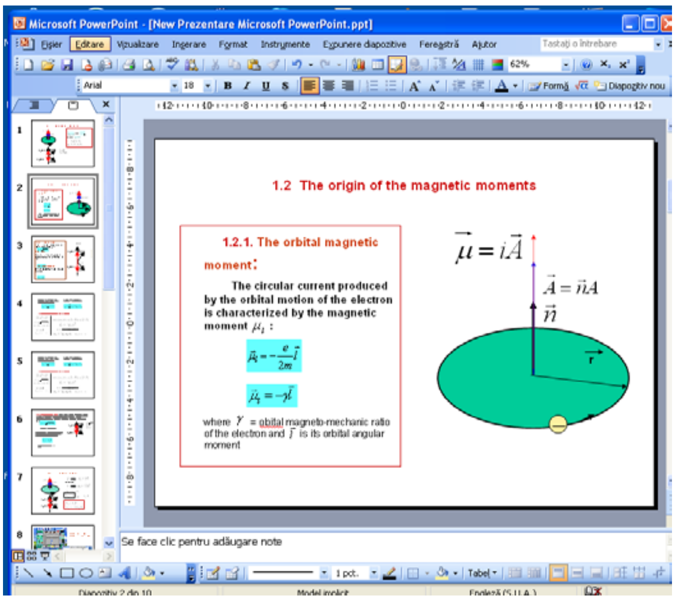

Fig. 1 – PowerPoint presentations for an easy understanding of orbital magnetic moments generated by a current loop, due to the orbital movement of the electron.

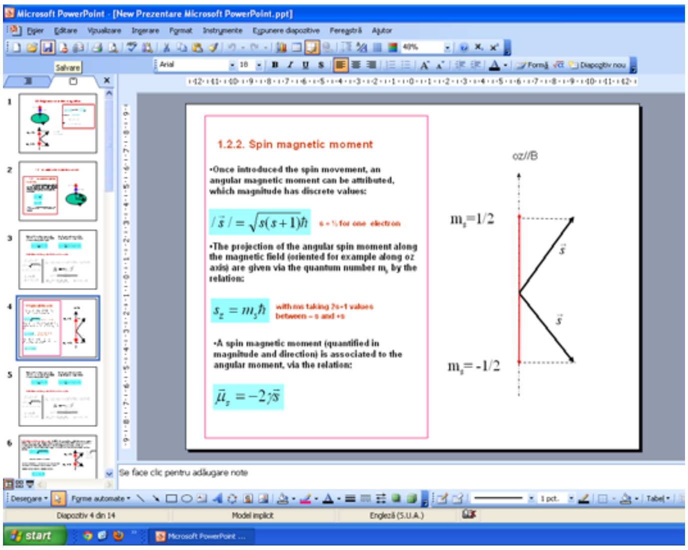

Fig. 2 – PowerPoint presentations for an easy understanding of the quantified directions of the spin orbital (or magnetic) moment.

According to basic notions of classical mechanics, to the electron of mass *m*, moving on the loop, is associated the orbital angular momentum, which is also a vector perpendicular on the loop (and hence, collinear with the magnetic momentum), given by the formula:

$$\vec{l} = \vec{r} \times m\vec{v}, \quad \text{with the magnitude} \quad l = mvr. \tag{4}$$

Due to the co-linearity between the orbital angular momentum and the magnetic momentum, a straightforward connection results between their magnitudes, *via* relations (3) and (4):

$$\mu_l = -\frac{e}{2m} rmv = -\frac{e}{2m} l. \tag{5}$$

Evidently, this relation holds true also written with vectors:

$$\vec{\mu}_l = -\frac{e}{2m}\vec{l} = -\gamma\,\vec{l}. \tag{6}$$

It is worth to mention that relation (6), written for an atom with one electron, can be extended to the case of an atom with many electrons, within the Russell-Saunders approximation (neglecting the spin-orbit interaction in light atoms with atomic number $Z < 30$), just by switching to the angular momentum of the atom $\vec{L}$ (expressed as the vector sum of the individual electron angular moments):

$$\vec{\mu}_L = -\frac{e}{2m}\vec{L} = -\gamma\,\vec{L}\,. \tag{6*}$$

While the angular momentum of the orbital motion of an electron can have according to the quantum mechanics only discrete values given by the relationship:

$$/\,\vec{l}\,/ = \sqrt{l(l+1)}\hbar\,,\ \text{with the quantum number } l = 0,1,2,\ldots,n\text{–}1, \tag{7}$$

it results *via* relations (5) and (7) that the magnitude of the orbital magnetic moment can have also only discrete values, the quantification relation being expressed as follows:

$$\mu_l = \sqrt{l(l+1)}\,\frac{e\hbar}{2m},\quad \text{with } l = 0,1,2,\ldots,\ n\text{–}1. \tag{8}$$

The constant $\frac{e\hbar}{2m} = \mu_B = 9.29 \cdot 10^{-24}\,\mathrm{A \cdot m^2}$ is the so called Bohr magneton with the meaning of an elementary magnetic moment. Projections of the orbital magnetic moments along the field directions can be defined, as exemplified in the following paragraph.

(ii) The spin magnetic moment. In 1926, Uhlenbeck and Goudsmit have hypothesized the existence of the spin movement of the electron, to which, by strict analogy with the orbital angular moment, can be associated a spin angular momentum, $\vec{s}$.

Extending this analogy to quantum mechanics, similar to relation (7), the magnitude of the spin angular moment for one electron has also discrete values, according to the relation:

$$/\,\vec{s}\,/ = \sqrt{s(s+1)}\hbar\,,\ \text{with the quantum number } s = 1/2. \tag{9}$$

It is to notice that in case of atoms with many electrons, within the Russell-Saunders approximation, a spin angular momentum $\vec{S}$ can be defined (as the vector sum of individual spin angular moments of electrons) and the overall quantum number S can be specifically evaluated from combinations of individual quantum numbers s, with a resulting integer/half integer number. Except of the magnitude of the angular spin moment, also the direction of the angular spin (or orbital) momentum is quantified, resulting discrete values for its projection on an arbitrary axis (usually such quantification axis is chosen along the field direction). Hence, the projections of the angular spin moment along the magnetic field (oriented for example along the *Oz* axis) are given *via* the quantum number m_s by the relation:

$$s_z = m_s\hbar\,,\ \text{with } m_s \text{ taking } 2s{+}1 \text{ values between } -s \text{ and } +s$$

$$(e.g.\ m_s = +, -\tfrac{1}{2} \text{ for one electron}) \tag{10}$$

The orientations of the spin angular momentum of an electron and its projections on the field axis are illustrated in Fig. 2 (a similar representation is valid also for the angular moment of the orbital motion).

To the spin angular moment is attached, similar to the case of the orbital moment, a spin magnetic moment. Initially, by analogy with the orbital magnetic moment, was assumed that the two quantities are linked *via* a relationship similar to (6). Surprisingly, the experimental evaluation of the magneto-mechanic ratio for the spin movement (*i.e.* the ratio between the value of the spin magnetic moment and the spin angular moment) has shown that it is two times higher than for orbital motion (result known as spin magnetic anomaly). Therefore, the correct relationship between the two spin moments (magnetic and angular) is:

$$\vec{\mu}_s = -2\frac{e}{2m}\vec{s} = -2\gamma\vec{s}\ . \qquad (11)$$

In case of an atom with many electrons, characterized by a spin $\vec{S}$, relation (11) becomes:

$$\vec{\mu}_S = -2\frac{e}{2m}\vec{S} = -2\gamma\vec{S}\ . \qquad (11^*)$$

Similarly, the magnetic moment projection on z axes can be written:

$$\mu_{Sz} = -2\frac{e\hbar}{2m}M_S = -2\mu_B M_S \ \ (= \pm\mu_B \text{, for an electron}). \qquad (12)$$

Nevertheless, a clarification with respect to the information transmitted to the students during the above presentation is required. In spite of the simplified argumentation based mainly on classical or semi-classical models as well as on extended analogies between orbital and spin moments, the above mentioned relations can be fully understood in frame of successive models and theories, progressively developed along the last century and which can not be introduced just at the high school level. If the orbital motion can be easy explained *via* the semi-classical model, the spin related moments and the quantification relations can be explained only in the frame of the non-relativistic quantum theory. Finally, an even more complex (relativistic) quantum theory is required for the explanation of the atypical correlation between the spin and the angular magnetic moments.

Due to the two contributions at the magnetic moment, the total magnetic moment of an atom with many electrons, within the Russell-Saunders approximation, can be defined as the sum of orbital and spin magnetic moments:

$$\vec{\mu}_{at} = \vec{\mu}_L + \vec{\mu}_S\,. \qquad (13)$$

Very often, in case of the solid state, the orbital angular moment is quenched [11] and the solely contribution to the total magnetic moment comes from the spin magnetic moment. Hence, the magnitude of the magnetic moment is μ_S.

If the substance is not in the presence of an applied magnetic field, atomic magnetic moments are usually randomly oriented, and the field generated by them in a point in space is null. Placing the substance in an external magnetic field, magnetic moments will orient more and more along the applied field (depending on the applied field magnitude), and the field generated by the substance in a point in space becomes non-zero. Considering the magnetic moments as vectors, it results that in the presence of an applied magnetic field, the sum vector of the magnetic moments of the sample gives a non-zero resultant. Vector sum of the magnetic moments per unit volume (or equivalent, the net magnetic moment per unit volume) is defined as a vector quantity, called magnetization $\vec{M}$ [12]. Alternatively, a net magnetic moment per mass unit, called specific magnetization, $\vec{\sigma}$, can be defined. Because in an applied magnetic field the magnetization is non zero, one says that the substance becomes magnetized under the influence of an applied magnetic field. A magnetized substance generates a magnetic field outside of its own, through which can be measured the magnetic properties of the substance, via the determination of the magnetization $\vec{M}$. In an enough high applied magnetic field, all the atomic magnetic moments are oriented along the field direction (they are co-linear) and, taking into account that in 1 g of substance with atomic number A, there are N_A (Avogadro's number) atoms, the magnitude of the specific magnetization can be written as:

$$\sigma = (N_A / A)\mu_{at}. \qquad (14)$$

Hence, the above relation, connects macroscopic parameters (specific magnetization), which can be experimentally measured, to microscopic parameters (magnetic moments or spin numbers) on each students ask often on possibilities of quantitative estimation. In the following, the principle of a magnetic measurement providing the magnetization will be described, as well as the possibility to follow in real time, at the classroom, such an experiment, *via* remote laboratory techniques.

4. MAGNETIC MEASUREMENTS

The magnetic proprieties of the substance can be analyzed by using multiple magnetometry techniques. An advanced technique, which can be fully explained on the basis of the notions learned in high school, is the vibrating sample magnetometry (VSM). In a vibrating sample magnetometer (Fig. 3), the sample is connected to a rod which vibrates harmonically in an uniform magnetic field generated by a superconducting magnet, along the *z* axis (vertical direction in Fig. 3).

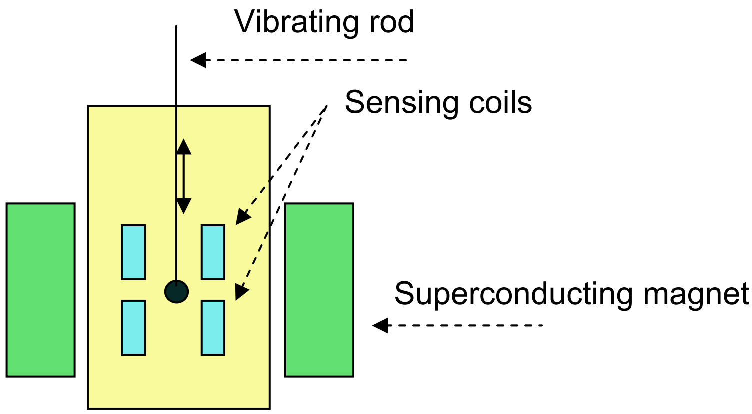

Fig. 3 – Easy understanding diagram for illustrating the working principle of a vibrating sample magnetometer. The sample is represented by the small black sphere, connected to the vibrating rod.

The frequency of the movement, generated *via* an electro-mechanical vibrator, is of tens of Hz and the amplitude is of the order of mm. Since in the presence of an applied magnetic field, the sample is characterized by its overall magnetic moment (proportional to the magnetization), the vibration of this moment induces in the exterior an alternating magnetic field. Two collecting coils are placed around the sample. The alternate magnetic field induces in the coils an alternate magnetic flux, which according to Faraday's law, induces a current proportional with the flux variation and hence with the time variation of the magnetization. The electric signal is collected and then integrated, resulting a signal proportional with the overall magnetic moment/magnetization/specific magnetization of the sample. It is to notice that the two coils are specifically connected in order to add the electrical signals generated by the vibration of the sample and to compensate parasitic signals connected to the thermal shifts. The proportionality constant between the magnetic moment of the sample and the voltage collected at the coil output is determined by a calibration with a sample of standardized magnetic moment. It is to notice that, these measurements allows the determination of the evolution of the magnetic moment as a function of the applied magnetic field (magnetization measurements and hysteresis loops) or its evolution with temperature. The mentioned dependences offer important information on the magnetic properties of the studied substances and on the microscopic mechanisms responsible for these properties. An important way to transmit such complex information to the students during the classes is to use the remote laboratory technique.

A remote laboratory corresponds to the situation where the control and the observation of a real physical instrument are mediated through a computer. An adequate remote access to that computer is provided through a specific communication network.

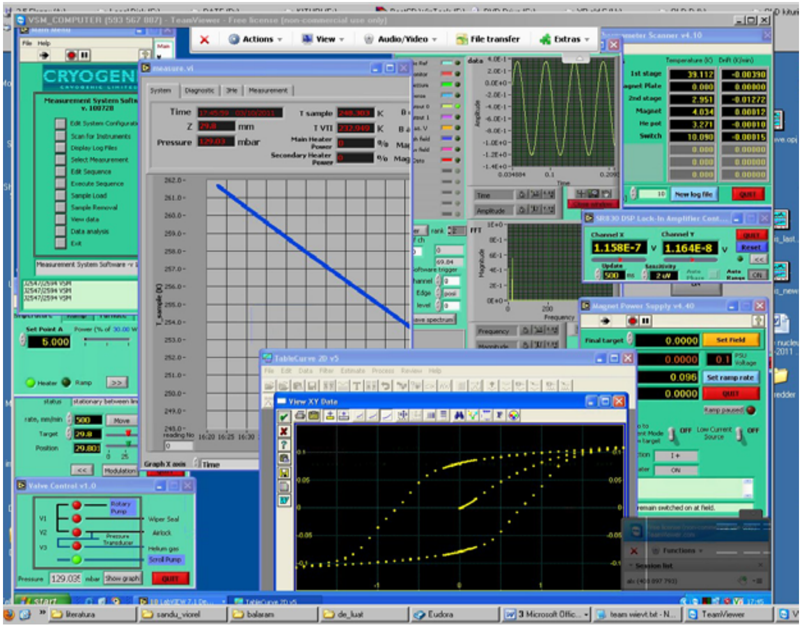

Fig. 4 – A print screen image of the desk command of the VSM magnetometer, accessed *via* the TeamViewer program, which allows the observation and the control of a real measurement.

Hence, the remote lab represents a step forward versus a virtual experiment, because in this case the students interact with a real device, they can participate at a real experimental activity, in a real laboratory, even from distance. The psychologist Jean Piaget pointed long time ago that the cognitive development is generally rooted in the tactile interaction with the objects in their environment [13]. Remote labs can be a useful complementary educational resource to hands-on labs [14] as they allow monitoring or supervising a running experiment remotely. An exemplification of such an experiment providing the recording of the magnetization reversal *via* a High Magnetic Field Measurement System working in VSM mode (Cryogenics Ltd) is presented in Fig. 4.

The on-line connection to the command desk of the real device is performed via the TeamViewer software (freeware) which allows both the visualization of the real measurement (*e.g.* see the down black window providing the magnetization reversal *versus* the applied magnetic field) as well as the full control on the device parameters, such as applied field, sample position, temperature of different components including the sample, vibration movement parameters and quality, writing measurement sequences, etc. The magnetization reversal can be subsequently discussed and interpreted by using also animation programs (*e.g.* [15]), as illustrated in Fig. 5.

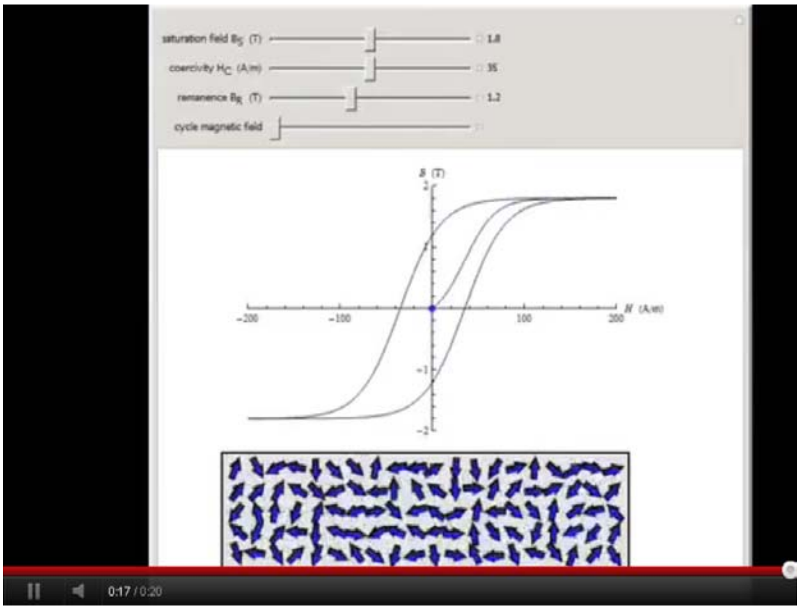

Fig. 5 – An animation illustrating the observed magnetic reversal [15].

5. CONCLUSIONS

The use of the computer in the educational process develops a new pedagogy based on the interactive logic student-computer, as complementary from that based on the traditional relationship student-teacher. The teacher must be careful to the maintenance of the balance between these two relationships for the complete formation of the student. On the other hand, the integration of computer in teaching process does not involve replacement of the teacher by machine, but only taking over by the machine of some functions and tasks of the teacher, leading to the optimization of the transmitting information process. Different methods can be used for the efficient computer assisted teaching and learning, most of them being exemplified in this work, in case of introduction of complex notions of magnetism. Finally, a remote laboratory technique is presented, which allows a direct correlation between the acquired knowledge on microscopic information and macroscopic parameters provided by a complex experimental facility, located in a real research laboratory.

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