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PHYSICS EDUCATION

MURPHY – MULTIMEDIA TOOL FOR ADVANCED PHYSICS CONCEPT APPROACH: GIANT MAGNETORESISTANCE (GMR)

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Abstract. Unprecedented development of IT nowadays involves the necessity to explain for enlarged human community (ordinary people) the advanced science concepts. Now, there are needed hard disks with larger and larger capacity of memory and in the same time with smaller and smaller size. A GMR reading head is a perfect device for data reading from hard disks when the magnetic registered information has to be converted into electrical signal. The most up to date reading devices are developed from GMR. This is why in 2007 the discovery of Giant Magnetoresistance by Albert Fert and Peter Grünberg won Nobel Prize in Physics. We present a multimedia tool to explain GMR, made with common resources using MS Movie Maker or Flash. This tool can be used in a constructivist environment, or as a cooperative learning tool integrated in different moments of physics classes.

Key words: giant magnetoresistance, multimedia tool, constructivist environment, cooperative learning.

1. INTRODUCTION

It is hard to imagine our day to day life without computers. More and more information needs to be stocked, so we need new memory devices: faster, smaller and as much as larger is possible. A solution coming up is the winner of Nobel Prize in Physics in 2007: GMR-Giant Magnetoresistance by Albert Fert and Peter Grünberg. Researchers found solutions to adapt the discovery to be technical profitable as to be large-scale developed and to be useful for IT applications widely used. But not all the current and future users have the adequate level of instruction to understand the real meaning of the advanced concept involved. The concept of GMR is not contained in national physics curricula and not available for the young student from primary and high schools. This is a new challenge for today teachers from scientific fields: to approach advanced science concepts as to be understood by those who are real interested in using their technical applications. In this paper we present a solution to this educational challenge: a multimedia tool designed for a better approach of GMR concept.

2. COGNITIVE LOAD THEORY

Theoretical perspective guided our intercession in this paper is Cognitive Load Theory [1], included in general paradigm of constructivism. The necessity of instruction adapting to students' cognitive system constrain is the main concern of this theory. Sweller asseverates that a main aspect of human cognitive architecture is the limited students' working memory capacity; all instructional designs have to be analyzed from the perspective of Cognitive Load Theory. Cognitive Load means students' mental resources allotted to learn an instructional material [2] or to solve a particular task [3].

According to Cognitive Load Theory, the main learning devices are schemes acquisition and automation [3, 4]. As the learning come into being, the main instructional purpose must be the reduction of extrinsic cognitive load, the optimization of intrinsic cognitive load and increasing the cognitive load, relevant for the learning [5, 6].

If the methods of extrinsic cognitive load are well documented [3, 7], the strategies of intrinsic load cognitive optimization and those of increasing of the load relevant for learning are in the attention of researchers in instructional design in last few years [8]. A method of intrinsic cognitive load optimization is the sequential presentation of information (from simple to complex). The presentation of instructional material from simple to complex is more efficient than the presentation from the beginning of the whole material in all its complexity, especially for the case of novices who don't have enough cognitive schemes to manage tasks characterized by a high level of interactivity of the elements [6].

The working memory capacity can be extended by organizing information using schemes and their automation. If information elements are properly grouped, they will be easily retained [9]. Cognitive schemes are then integrated in long time working memory with unlimited capacity. Introduced in long time memory, a cognitive scheme takes only a space unit available as an isolated concept [10].

The schemes theory can explain very well the difference between an expert and a novice. While expert's knowledge is organized in dense conceptual networks reflecting a deep understanding of the subject, the novice's are shared. For problem solving, because of his schemes, the expert can reclaim the solution in long time memory; the scheme will be again restyled in working memory. For a beginner, some of the schemes are missing, the data process are doing step by step and quickly overloaded [11].

In traditional learning the quantity of presented material is much great for one's processing capacity. So, every teacher must consider the Cognitive Load Theory and the implications of this theory to organize the presented material as not overload the working memory. The teacher has to teach the student to create his own schemes and to use the ones contented in long time memory [10]. The teacher will have to organize the material as the beginning student to become expert in this field [12].

Some of effects of this theory were highlighted by the direct relationship with the learning.

2.1. MODALITY EFFECT

When a material is presented to the students visually and auditory, the results are better than in the case the same material is presented only written [13].

This effect can be explained based on the hypothesis of a dual channel assuming that auditory and visual materials are analyzed in two different subsystems of working memory [14]. Using such presentations the student can use both channels (visual and auditory), in order to extend the working memory capacity [15].

For example is better to visually present a scheme or a diagram and the explanations to be verbally offered, than the explanations are offered using a text associated to the scheme [16].

2.2. SPLIT-ATTENTION EFFECT

This effect concurs when more visual information sources spatially separated have to be mentally integrated. For example, if the enunciation of a task is on one page and the figure on another page, the student has to distribute his attention between the two sources for mentally integrating. Mentally integration calls for resources in working memory [15]. A physically integrated format such as a graphic organizer with the associated assessments placed in a suitable place on the organizer, can significantly contribute to learning, reducing the working memory overload [17].

Instructional materials based on Cognitive Load Theory can increase learning. Cognitive Load Theory suggests that learning is better when instructional material is aligned with human cognitive architecture [11].

For visualization of information processing of abstract notions in physics is recommended to use Graphic Organizers (GO). They are dignifying the layout of different relationships between terms, ideas, problems, factors, causes-effects in a problem rationally needed to approach, how in formations processing is visualized. Graphical representation is the problem's global image, as an artifact of building and understanding related to the task [18].

Most of the high school physics teachers are asked to answer some questions over curriculum because the students are very curious to know everything about up to date science discoveries. They don't have the time to wait until that concept would be taught at the class, so the teacher has to use the most uncommon methods to be understood. A good results solution may be using constructivist environments and cognitive-constructivist methods [18].

Physics conceptual map making is for students' mental effort in linking words-concepts. Laying emphasis on linking word-concepts, conceptual maps open perspectives to an active and conscious physics learning process [19].

3. MULTIMEDIA TOOL FOR ADVANCED SCIENCE CONCEPTS

To design a multimedia tool for educational purpose is to consider constructivist perspectives on advanced science concept approach. Cognitive load theory is the base of Mayer's principles of multimedia learning: modality principle, split attention principle, redundancy principle, and multimedia principle [20, 21]. Even the curriculum not includes advanced science concepts; teachers can use adequate strategies and informatics tools to introduce them to their science interested students, as is related in many physics education papers [22–30].

3.1. DATA STORAGE AND GMR

"Hunger" for storage and processing of data is a characteristic of the epoch. The device meeting these requirements is the hard disk drive (HDD). Appeared in 1956, hard disk drives started as a rare and expensive additional feature on computers. In a couple of decades, capacity per HDD has increased from few megabytes to greater than terabyte, physical volume has decreased by tens of thousands of times, and access time has decreased from hundreds to a few milliseconds. This impressive evolution has lead to dramatically price decreasing. By the late '80s hard disk were standard on even cheapest PC. Currently, HD applications expand to most computing applications (including consumer applications).

Like many other data storage devices, HDDs record data by magnetizing ferromagnetic material directionally. Positioning the direction of magnetization in one of two possible states is writing patterns of binary data bits. The data is read by detecting the state of magnetization and decoding the originally written data.

The stocking surface of each HDD's platter is conceptually divided into small sub-micrometer-sized magnetic regions (magnetic domains) that forms a magnetic dipole which generates a magnetic field. A write head moves above the platter and magnetizes every magnetic domain by generating a strong local magnetic field. Reading data means convert the direction of magnetization in electrical signal. This requirement is fulfilled by the magnetoresistance (MR) – variation of electrical resistance due to the application of a magnetic field. When the hard disk becomes smaller and smaller, each elementary magnetized area shrinks. This means that for every bit each magnetized region becomes narrower and can be read increasingly more difficult. New forms of MR namely anisotropic magnetoresistance (AMR) and giant magnetoresistance (GMR) were used to read heads. The aim of MURPHY's educational instrument is to present in simple words the way from electrical resistance to giant magneto resistance and stocking data devices.

3.2. RESISTANCE AND MAGNETORESISTANCE

Metals and semiconductors are chemical elements whose atoms can easily lose electrons. A crystal of metal or semiconductor can be imagined as a network of positive ions immersed in a cloud of delocalized electrons. The electrons move freely through the network, randomly, in all directions - in the absence of an applied external electric field. The electric current passing through conductor, when an electric field was applied to it, is generated by the oriented movement of quasi-free electrons in opposite direction of the applied electric field. The electrical resistance is due according with Classical Theory of the Electronic Conduction of the Metals (Drude Lorentz's Theory), to the frequently collisions of the accelerated electrons with the nodes of crystalline network of metals (more precisely the electron-phonon interactions) or with different defects levels, because during these processes the electrons loses their kinetic energy gained in the acceleration processes between two successive collisions. As the electrons movement direction is straighter, the conductance of the material is higher.

The motion of an electron occurs with high mean speed $\left(\approx 10^3\,\mathrm{m}\cdot\mathrm{s}^{-1}\right)$ on trajectories that are straight lines – between successive collisions with the network ions (or other obstacles – abnormalities in the network). The mean time between two collisions, relaxation time $\left(\approx 10^{-14}\,\mathrm{s}\right)$, is a measure of how easy the electron moves in the network.

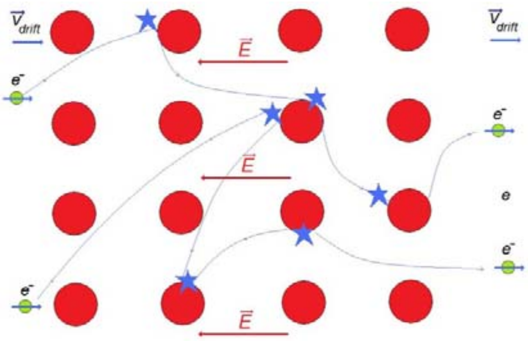

Fig. 1 – The motion of electrons in a fixed network of ions in the presence of the electric field. In the figure, the big red disks represent ions and the stars represent electron-ion collisions. The small green disks represent electrons; the arrows over these disks represent drift speed. The colored versions could be accessed at http://www.infim.ro/rrp/.

When applying an external electric field, conduction electrons' trajectories are arcs of parabola (Fig. 1); the motion of electrons acquires an ordered component having the same direction with the electric field. This component, characterized by a small "drift speed" $\left(\approx 10^{-3}\,\mathrm{m}\cdot\mathrm{s}^{-1}\right)$ is the same for all the electrons in the cloud. Because of electrons cloud drift, there is a net flow of electric charge in crystal [11, 12]. The average distance traveled by the electron during relaxation time is the mean free path of charge carriers.

The electric resistivity of a conducting material is hindering the free movement of electric charge. It suffered due to electron collisions with ions of the network. As the mean free path increases, the electrical resistivity of material decreases.

Figure 2 presents a very simplified modeling of electron motion in electric field when a magnetic field is applied, too.

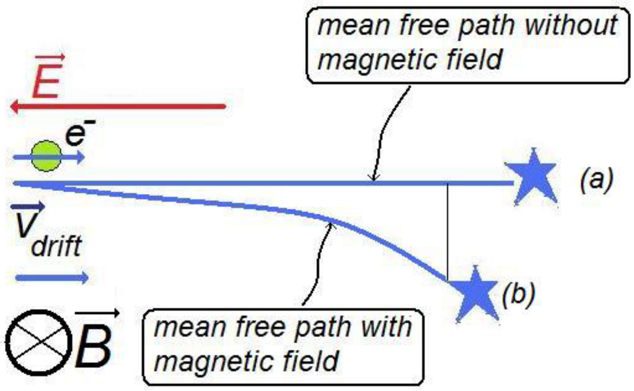

Fig. 2 – Apparent shortening of the electron mean free path when applying a magnetic field: a) image of electron path from beginning to the collision (represented by star) under electric field; b) image of electron path from beginning to the collision (represented by star) under electric field and a perpendicular applied magnetic field. The trajectory is curved and consequently its projection on the electric field direction shortens. The colored versions could be accessed at http://www.infim.ro/rrp/.

When a magnetic field is applied, the free path of electron is curved due to Lorentz force. As a result, the length of this path on the direction of electric field is shorter. Consequently the resistivity of material increases. The change in the electric resistivity of a metal or a semiconductor due to magnetic fields, caused by the screwing action exercised on trajectories by these fields is called magnetoresistance effect. First discovered by William Thompson (Lord Kelvin) in 1856, magnetoresistance is the property of a conducting material to increases the value of its electrical resistivity – depending on the angle between the direction of electric current and orientation of magnetic field.

3.3. MAGNETORESISTANCE OF MAGNETIC MATERIALS

A material is ferromagnetic if contains ions having magnetic moments that must add a positive contribution to the net magnetization of sample. In such a material the cloud of bounded electrons located around each ion of the crystal deforms slightly as direction of magnetic field and magnetization rotates. The electronic cloud extends in the plane perpendicular on magnetization. Therefore the scattering undergone by the conduction electrons depends on direction of magnetization. If the exterior magnetic field and the magnetization of material lies transverse to the electric current passing through material, the bounded electrons orbits lies in the plane of the current so that scattering of conduction electrons is small – giving a low resistivity to the material (Fig. 3b). Conversely, if the exterior magnetic field and the magnetization of material lies in the same direction with the electric current, the bounded electrons orbits lie in the plane perpendicular to the current so that scattering of conduction electrons is great (collisions occurs often) – giving a high resistivity to the material (Fig. 3a).

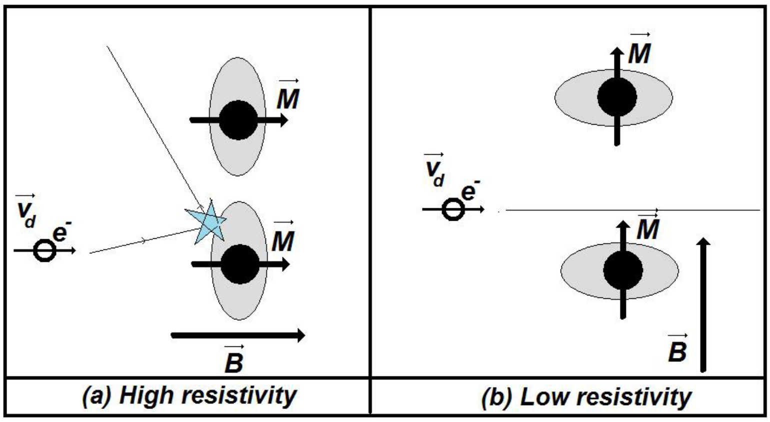

Fig. 3 – Scattering of conduction electrons in a magnetic material. The ions (black disks) surrounded by cloud of bounded electrons (gray spot) shows different "effective surface" for collision (represented by blue star) with conduction electrons. $\vec{B}$ represents the magnetic field induction, $\vec{M}$ represents the magnetization of ion and $\vec{v}_d$ is the speed of conduction electrons. The colored versions could be accessed at http://www.infim.ro/rrp

Because of this behavior, the resistivity of magnetic material is different if measured on a direction parallel or perpendicular with the external magnetic field – as shown in Fig. 4. When the direction of electric current and the direction of magnetic field are parallel, the resistivity increases up to a saturation value. The saturation appears when the deformation of cloud of electrons around ions is greatest.

When the direction of electric current and the direction of magnetic field are perpendicular, the resistivity decreases down to a saturation value. The saturation appears again when the deformation of cloud of electrons around ions is greatest. In both situations, only the direction of magnetic fields is important and not the sign of the induction.

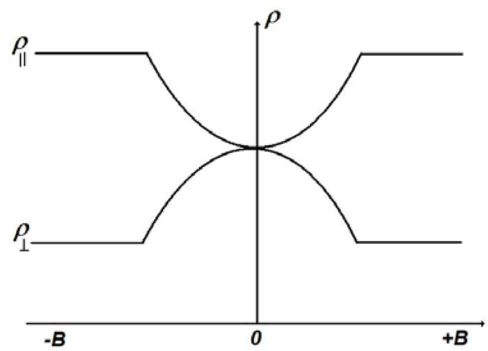

Fig. 4 – Dependence of electrical resistivity on magnetic flux density *B* when the magnetic field is parallel with the direction of electric current $\rho_{||}$, and when the magnetic field is perpendicular to the direction of electric current, $\rho_{\perp}$, respectively.

This kind of magnetoresistance observed for conducting magnetic material is called anisotropic magnetoresistance (AMR).

3.4. MAGNETORESISTANCE OF THIN MAGNETIC LAYERS

Giant magnetoresistance appears in structures of thin layers of magnetic metals separated by layers of non-magnetic conducting materials. As is already stated the electric resistance of a material is determined by the scattering processes to which electric charge carriers are subject. In a simplified model about the electrical resistivity of magnetic thin layers, electrons having the spin parallel to magnetization of layer are not colliding while electrons having spin antiparallel to magnetization collide. If the scattering process is strong, the mean free path of carriers is short and the resistance is large; conversely, if the scattering process is weak, the mean free path of carriers is long and the resistance is lower as illustrated in Fig. 5.

Depending on the thickness of non-magnetic layer, the configuration of two successive magnetic layers will be ferromagnetic as in Fig. 6A or anti-ferromagnetic as in Fig. 6B. Such a structure presents magnetoresistance effect of up to 50%. The effect also occurs in a system of multilayer magnetic films.

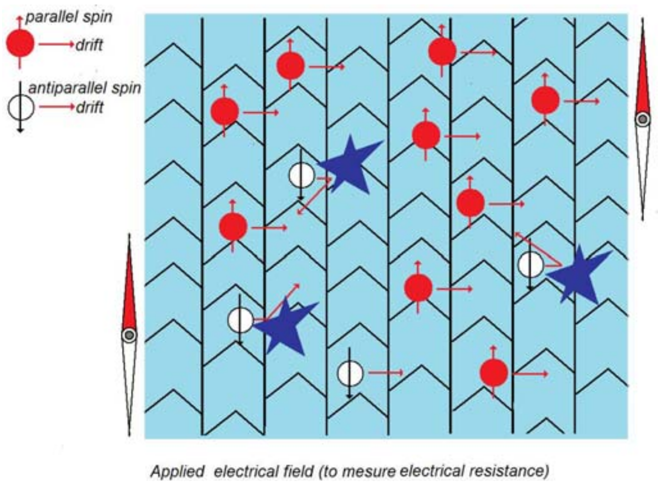

Fig. 5 – Simplified model of the electrical resistance as a function of mutual orientation of local magnetization and spin. Electrons having spin parallel to magnetization are not colliding while electrons having spin antiparallel to magnetization collide. The colored versions could be accessed at http://www.infim.ro/rrp/.

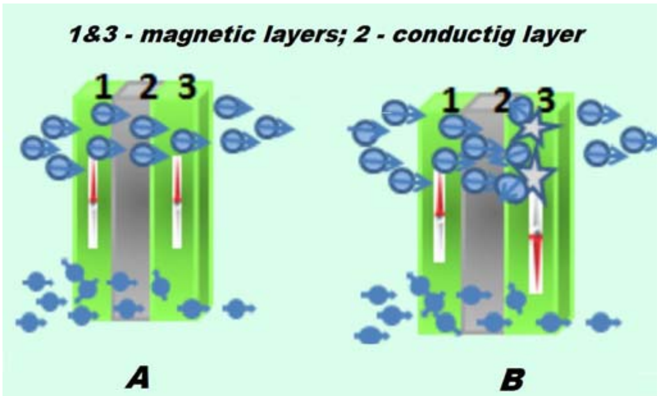

Fig. 6 – Structures of two thin magnetic layers separated by a conducting one. Depending on mutual orientation of magnetization in the two magnetic layers, electrical resistance of the structure is: A) low; B) high. The colored versions could be accessed at http://www.infim.ro/rrp/.

In the structure of ferromagnetic thin layers, one may consider that conduction electrons are divided into two groups having respectively the spin parallel and antiparallel with the local magnetization of the first magnetic layer. GMR appears when the scattering processes for one spin orientation of conduction electrons is stronger than for other spin orientation (spin depended scattering). Let us admit that electrons with spin parallel to magnetization suffer less collision than those whose spin is oriented antiparallel with local magnetization. When magnetic layers are ferromagnetic coupled, as in Fig. 6A, only half of electrons experience strong scattering while the other half suffer only weak scattering processes. Consequently, the overall electric resistance of material will be reduced. When magnetic layers are anti-ferromagnetic coupled as in Fig. 6B, all electrons experience strong scattering at the interface where the magnetization of material is opposite to the spin orientation. Consequently, the electric resistance of material will be large. In contrast to the AMR, GMR do not depend on direction of current. GMR depends only on the relative orientation of magnetization in the parallel ferromagnetic layers.

In a read-head based on GMR is included a structure of two magnetic films. The lower film has its magnetization pinned in one orientation, while the other magnetic layer (sense layer) is free to switch back and forth in the presence of magnetic field generated by disk's domains. Spin dependent scattering gives a low resistance state when the magnetic layers are ferromagnetic aligned while a high resistance state is obtained in the anti-ferromagnetic configuration. These states will be read as zero and one.

3.5. DESCRIPTION OF MURPHY

It is very important that the students' attention not to be split by interrogating multiple sources of information avoiding such formats. In the same time the information has not to be presented in multiple forms or unnecessarily elaborated [21].

In the study of Giant Magneto resistance (GMR) we presented a friendly interface containing a synthesis of the whole material as shown in Fig. 7.

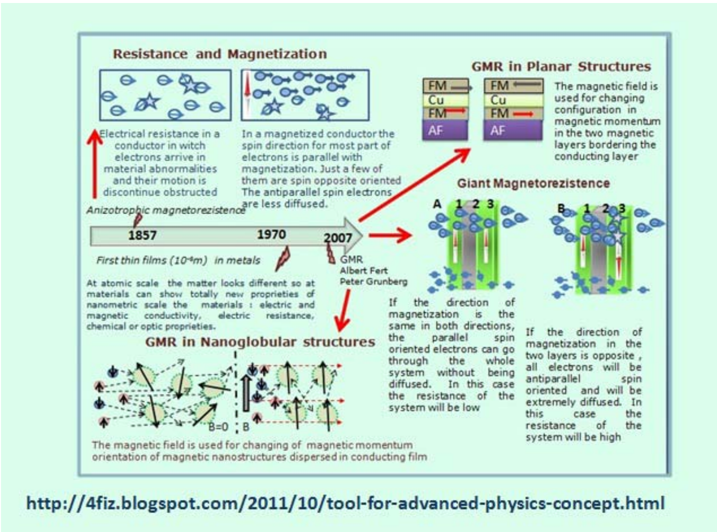

Fig. 7 – Friendly interface of MURPHY. The colored versions could be accessed at http://www.infim.ro/rrp.

In the purpose of a brief presentation of the problem, we used pictures, schemes, arrows and we reduced at minimum the number of words.

The preferred colors are light nuance for background to make a good connection with advanced physics concepts students are trying to approach.

The highlighted arrows make the connection with the next pictures explaining the concepts mentioned. By clicking the icon a hyperlink connection is available to go to the next step.

4. CONCLUSIONS

This tool is designed for interested physics students from excellence centers or for those who attend optional courses in high schools but it can be adapted by an experimented teacher to be used in common classes along with adequate constructivist teaching elements: cooperative learning or constructivist environments.

MURPHY involves using collaborative virtual environment together with constructivist strategies. For a better result in designing this informatics tool, every detail is important: to have a friendly user interface, to use significant colors, to simplify graphics as cognitive schemes. It is important not to overload students' working memory according to Seller's Cognitive Load Theory by using less text and more graphics in display. As most of our students learn visually, MURPHY can favor a better understanding of advances science concepts.

This tool can be used by the teacher for different classes, according to students' interest in the study of physics. For novices, the teacher has to give more explanations so the information will be received in the working memory using dual channels: visual and auditory.

Today science teachers have a great responsibility to keep students' interested in explaining the way all the gadgets they use, work, albeit the science curriculum is approach historically. There is not enough time in middle and high school to learn about all the concepts needed to explain advanced ones, as GMR. Giant Magnetoresistance has a lot of applications in electronics and IT, so this is why students are interested in it.

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