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CIRCULAR POLARIZATION OF PHOTONS FOR MAGNETIC MATERIALS STUDIES

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Abstract

Modern scattering theories had suggested in 1970 the possibility of the use of x-ray to study the magnetic density in the magnetic materials such as iron and cobalt. This proposal has encountered many difficulties when using traditional x-ray sources and the reason is that the intensity of photons from these sources is weak and that the magnetic property to be studied is weak as well. But with the progress in building Synchrotrons it was possible to obtain photons with high intensity and circular polarization properties that enabled the study of many magnetic materials.

In this paper the polarization properties of Synchrotron radiation are presented. Also the famous Compton scattering equation is introduced and the magnetic Compton scattering equations are presented along with the introduction of methods for studying magnetic properties of materials using circular polarization of photons.

Index Terms *– **Magnetic Scattering Technique, Photon Circular Polarization., Magnetic Materials Characterization., Photon physics, Synchrotron Radiation.***

I. INTRODUCTION

Compton scattering is a technique for determining the momentum distribution of electrons in condensed matter. When monochromatic photons are Compton scattered (inelastically scattered) in a fixed direction, the observed energy spectrum of the scattered photons is Doppler-broadened due to the motion of the target electrons. However, conventional x-ray and γ-ray sources produce unpolarized photons which limit the use of photon Compton scattering to electron momentum density studies in the target materials. A detailed account of the theoretical and experimental progress in Compton scattering was reviewed in a popular articles by [1,2].On the other hand, the availability of newly developed third source of photons, Synchrotron Radiation (SR), during the past three decades, has been the cornerstone for stimulating the development of the magnetic Compton scattering technique. Synchrotron Radiation is a system in which accelerates inside it electrons to very high speed close to the speed of light in a circular orbit with a synchronous magnetic field [3]. As a result of the movement of electrons in a circular orbit they emit electromagnetic radiation continuously extending from the infrared to the x-ray of the electromagnetic spectrum. Figure 1 shows a diagram of the system (SR). The magnetic fields in the twisted magnets affect the accelerated electrons with large central acceleration. This large central acceleration produces electromagnetic waves up to several hundreds of KeV. The properties of (SR) can be summarized in the following: (i) The intensity produced is ranging from 1kW to several MW. (ii) Also characterized by a high degree of direct rays very fine-collimation. (iii) At the electrons orbit level the radiation produced is 100% linear polarized (see Figure 1). At some point above or below the electrons orbit level the radiation produced is circular polarized.

Since SR has a continuous wavelength distribution, the required incident photon energy can be selected by Bragg reflection from a crystal monochromator. At the current stage of developments, the typical monochromators in use for Compton scattering measurements with SR are either perfect silicon or perfect germanium single crystals. This is because of their high degree of perfection, they have small rocking curves (i.e. of the order of milliradians) which is of the same order as the divergence of the beam. Therefore, the above combined characteristics of these single crystals, allow monochromatisation of the beam with a minimal loss of intensity.

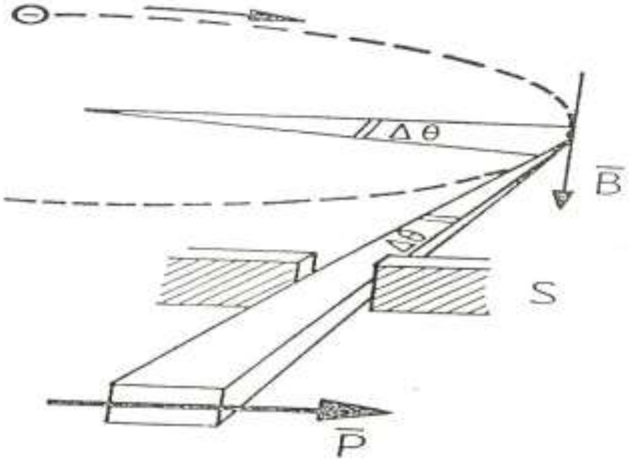

Figure1. Schematic diagram of the SR system. $\bar{B}$ Shows the direction of the magnetic field. $\bar{P}$ Shows the direction of linear polarization of the produced radiation [3].

The first exploratory Compton scattering measurements using monochromatic SR were made by [4] at The Daresbury Laboratory synchrotron, NINA. A detailed information about the SR as regards to magnetic Compton scattering studies, can be found in [5-7]

II. THE IMPORTANCE OF CIRCULAR POLARIZATION OF PHOTONS IN THE STUDY OF MAGNETIC MATERIALS

The importance of this study lies in the presence of Synchrotrons as the sole source for the time being for the production of photons with high intensity and with polarizing properties as introduced above. And for studying magnetic materials using circular polarized photons requires measuring the physical quantity of electrons responsible for a magnetization [8]. This study has been newly developed [9-10] and is based on measuring the dynamic distribution of magnetic electrons in a magnetic material such as Ferro-Ferri. This method is known as Magnetic Compton Profile an extension to what is known as Compton Scattering [11-15].

III. MAGNETIC COMPTON SCATTERING

If the initial photons (before scattering) is circular polarized and this feature is a prerequisite for the study of magnetic materials, the Compton Scattering Cross-Section is given by the following relationship [16]:

$$\left(\frac{d\sigma}{d\Omega dE}\right)=\left(\frac{d\sigma}{d\Omega dE}\right)_0+\left(\frac{d\sigma}{d\Omega dE}\right)_M \text{.....................................(1)}$$

As shown in the relationship (1), the Cross-Section contains two parts: The first part concerns with Charge Scattering are given by the following relationship:

$$\left(\frac{d\sigma}{d\Omega dE}\right)_0=Z\frac{r_0^2}{2}[\ 2-\sin^2\theta\ (1+P_L)]\ J(P_Z)\text{....................................(2)}$$

Where Z number is the number of electrons in the atom, r_0 the classical electron radius, θ angle scattering, P_L degree of linear polarization of incident photons and J (P_z) is the Compton Profile.

$$J(P_Z)=\iint n(P)dp_x dp_y\text{.................................(3)}$$

J(P_z) is defined as the projection of the electron momentum density n(p) along the scattering vector parallel to (z-axis). n(p) does not depend on spin and are summed on all the electrons participating in the scattering. It can be seen from relationship (2) that the charge scattering depends only on the degree of linear polarization of the incident photons.

The second part of the equation (1) is originally based on magnetic electron spin and is given by the following relationship:

$$\left(\frac{d\sigma}{d\Omega dE}\right)_M=P_C\frac{r_0^2}{2}(1-\cos\ \theta)\times S\left(\hat{k}_1\frac{E_1}{m_e c^2}\cos\ \theta+\ \hat{k}_2\frac{E_2}{m_e c^2}\right)J_{mag}(P_Z)\text{........(4)}$$

Where P_c is the degree of circular polarization of photons, $\hat{k}_1$, $\hat{k}_2$ are unit vectors along the direction of incident and scattered photons . E_1 is the energy of the incident photon, and E_2 is the energy of the scattered photons. S is the Spin magnetic moment per atom and J_{mag} (P_z) is the magnetic Compton profile

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$$J_{mag}(P_Z)=\iint n_{up}(P)-n_{down}(P)dp_x dp_y\text{...................................(5)}$$

The total scattering shown in the relationship (1) means that when the interaction between the incident photons and the electrons responsible for magnetization in the material, the incident wave (photons) as an electromagnetic wave (containing an electric field component E and magnetic field component B), these components produce electron acceleration by the electric field in the wave E and are also accelerated by the magnetic field (as a result of the interaction of the magnetic field B and μ magnetic moment of the atom). This implies that the total scattering is produced from the interaction of polarized photons with charge and polarized magnetic moment of electrons and this shows an overlap between charge scattering and Spin.

To study the magnetic material as shown in the relationship (4), the Magnetic Cross-Section requires that the photon to have circular polarization and the reason is that the amount of magnetic scattering must be imaginary. With this condition the process of overlap between the charge and spin magnetic moment disappears. This implies that the incident photons must have complex polarization (i.e. circular polarization). It can be seen from the relationship (4) as well that the Magnetic Cross-Section reference changes its sign when the spin direction of the magnetic moment of the atom is reversed.

Practically it is possible to separate the magnetic scattering from the total scattering. This can be done by reversing the direction of the magnetic field of the electromagnet. Figure 2 shows the idea of preparing experiments for studying magnetic materials where the magnetic material is placed between the poles of a magnet and the direction of the of the incident wave is set as close as possible to the direction of magnetization in the material. This leads to an increase in the magnetic Cross Section to the limit, (see the relationship (4)).

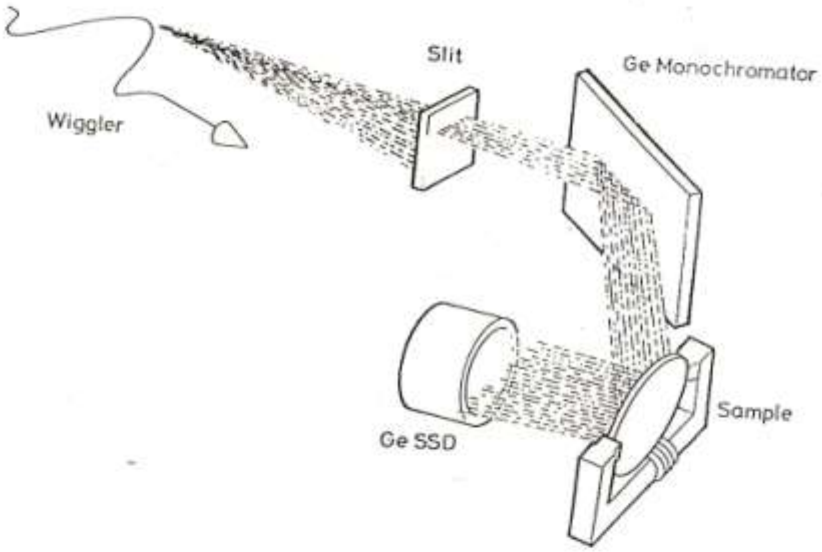

Figure2. Shows the geometric position of the magnetic material to be studied.

The intensity of the scattered photons is recorded then reverse magnetization of the sample and record the intensity of scattered photons for the same time. The difference between the two magnetisation directions in the sample gives the resultant magnetic Compton profile. Figure 3 shows J_{mag} (P_z) of ferromagnetic nickel metal [17]. This result was compared with theoretical models, where the curve intermittent represents APW model and curve points represents KKR model. Both theoretical models have been convoluted with Gaussian of FWHM = 0.7 au(1 au of electron momentum= 1.99×10^{-24} m.kgs^{-1})

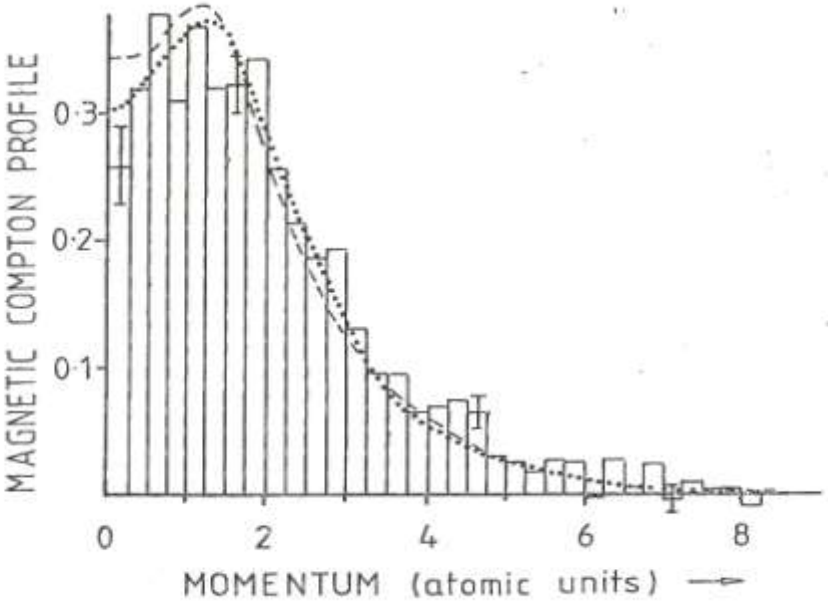

Figure3. The magnetic Compton profile of ferromagnetic nickel metal [17].

IV. DISCUSSION AND CONCLUSION

Although attempts have been conducted on the use of radioactive traditional sources for the study of magnetic materials, these attempts did not succeed and the reason is due to several factors, including photons generated from these sources are weak and unpolarized. Attempts for production of circular polarized photons from these traditional sources leads to a decrease in the intensity of incident photons, which is originally weak from the source. This does not allow the study of magnetic materials because the magnetic phenomenon to be studied is weak. According to the principle of "statistical precision" it requires that the intensity of incident photons must be high and this in turn allows conducting experiments in a short time. It can also be added that magnetic materials have the ability to absorb photons according to the photoelectric absorption phenomenon and this in turn also leads to a reduction in the scattering photons. These problems have forced scientists to look for an alternative source of photons than conventional radioactive sources, in terms of the intensity of photons and their polarization properties. It can be concluded that at the present time and the future SR remains the only source for the production of high energy photons, high intensity and polarity properties characteristic. This allows the study of magnetic materials and provides a novel experimental method that is complementary to neutron diffraction and contributing to test modern Band-Theories that are related to solid-state physics

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REFERENCES

[1] Cooper, M. J., Comtemp. Phys., 1977, 18, 489
[2] Cooper, M. J., Rep. Prog. Phys., 1985, 48, 415
[1] Buras, B., and Tazzari, S., 1984, Report of the European Synchrotron Radiation Project.
[4] Cooper, M. J., Communications on Physics., 1976, 1, 159
[5] Katawa, H., Sato, M., Iwazumi, T., Ando, M., Shiotani, N., Itoh, F., Sakutai, H., Sakurai, Y., Watanabe, Y., & Nanao, S., Rev. Sci. Instrum., 1991, 62, 2109
[6] Loupias, G., Chomilier, J. & Guerard, J., Solid State Commun., 1985, 55, 299
[7] Shiotani, N., Tanaka, Y., Sakurai, Y., Sakai, N., Ito, M., Itoh, F., Iwazumi, T., and Kawata, H., J. Phys. Soc. Jap., 1993, 62, 23
[8] Platzman, P. M. and Tzoar, N., (1970)., "Magnetic Scattering of X Rays from Electrons in Molecules and Solids"., Phys. Rev. B2, 3356
[9] Sakai, N. and Ono, K., (1976)., "Compton Profile Due to Magnetic Electrons in Ferromagnetic Iron Measured with Circularly Polarized γ Rays"., Phys. Rev. Letts. 37, 351
[10] Cooper, M. J., Lauandy, D., Cardwell, D. A., Timms, D. N., Holt, R. S., and Clark, G., (1986) "Spin dependent momentum distribution in iron studied with circularly polarized synchrotron radiation"., Phys. Rev. B34, 5984
[11] Hamouda, S. A., (1990)., "Directional Magnetic Compton Profile Studies" Proceedings of the Daresbury Study 23 November, U.K.
[12] Hamouda, S. A., (1989)., "Compton Scattering Studies Of magnetization Density"., Solid State Physics Conference., The institute of Physics 19-21 Dec.
[13] Doon GIBBS, D. E. MONCTON et K. L. D'AMICO (1985)., "Magnetic x-ray scattering studies of the rare-earth metal holmium."., J. Appl. Phys., 57:3619
[14] R. S. HOLT, D. LAUNDRY, D. A. CARDWELL, M. COOPER, T. NAYLOR, S. MANNINEN, P. HATTON (1986)., "Polarized x-ray study of the spin-dependent Compton profile of ferromagnetic iron". Nucl. Instrum. Methods Phys. Res. Sect. A, 243:608–610

[15] M. BLUME (1985)., “Magnetic scattering of x rays”., J. Appl. Phys., 57:3615
[16] Lovesy, S. W., (1987)., “Magnetic Compton scattering”., J. Phys. C., 20, 5625
[17] Timms, D. N., Brahmiaa, A., Cooper, M. J., Collins, S. P., Hamouda, S. A., Laundy, D., Kilbourne, C., and St-Lager, M. J., (1990) “Spin dependent anisotropy in the momentum density of ferromagnetic nickel metal”., Phys Cond. Mat. , 2, 3427