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Effect of external magnetic field on attenuation coefficient for magnetic substances

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HIGHLIGHTS

- μ_m of Dia, Para and Ferromagnetic substances reported in the presence of magnetic field.
- μ_m gets affected due to external magnetic field and not due to thickness.
- The change in μ is negligible for diamagnetic and paramagnetic than ferromagnetic substances.
- The overall experimental error is of the order of 1-3%.

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ABSTRACT

The measurement of attenuation coefficient of some magnetic substances, to include diamagnetic: Cu, Zn, Ag, Te, Au, Pb, and Perspex; paramagnetic: Al, Ti, Mo, Dy, Ho, and Pt and ferromagnetic substances: Fe, Co, Ni, Gd, FeO, NiO, FeS, and Fe_2O_3, both in the presence and absence of an external magnetic field has been carried out using narrow beam transmission geometry by using gamma ray photons of incident energy 59.54 keV from 100 mCi, ^{241}Am point source. It was observed very keenly that the value of linear attenuation coefficient of various substances mentioned above decreased remarkably. It varied in the range of 1–2%, 2–6% and 6–9% for diamagnetic, paramagnetic and ferromagnetic substances respectively in the presence of an external magnetic field. Measured results elucidated it very clearly that linear attenuation coefficient at $H=0$ T, 0.6 T and 1.2 T continued to decrease with a regular increase of magnetic field. It is also manifested that measurements of linear attenuation coefficient is not affected with the change in thickness of the given substance. Within error limits (1–3%) variations are observed with increases of thickness along with magnetic field. Further to it the obtained results of linear attenuation coefficient without magnetic field ($H=0$ T) were compared with theoretical data tables of FFAST and WinXCOM. It was established that values obtained are well within the experimental errors. To the best of our knowledge no other study in relation to the effect of linear attenuation coefficient in the presence of magnetic field available as precedence.

1. Introduction

It is a well accepted fact that the study of various variegated atomic/nuclear parameters such as photoionization cross-section, X-ray fluorescence, intensity ratio, and attenuation coefficient (linear/mass) play a vital and indispensable role in the much desired progress of diversified fields of Atomic, Molecular, Nuclear, Particle, Radiation and Medical physics which in turn also incorporates environment protection and industrial processing. In the recent past, various parameters such as K shell X-ray fluorescence cross sections (Gurol et al., 2009), fluorescence yields (Demir and Sahin, 2007a), L subshell X-ray fluorescence cross sections, fluorescence yields (Demir and Sahin, 2008), L_3 subshell fluorescence yields, level widths (Demir and Sahin, 2007b, 2007c) and L X-ray intensity ratios (Demir and Sahin, 2007d, 2007e) were measured in the presence of an external magnetic field. There results have also supported the fact that these essential parameters are affected by external magnetic field. According to Chantler et al. (2005), version 2.1 and Hubbell and Seltzer (1995) data tables, total absorption coefficient of a material medium is a combination of cross-sections of various interactions. These interactions get affected if measurement is taken in the presence of an external

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magnetic field. Therefore keeping in view the theoretical and experimental aspects of interaction in the magnetic field lines and incident beam intensity (X-rays/photons), we were in a state of great expectancy that there might be some variations in the linear attenuation coefficient as well. This thought process drove us to measure the linear attenuation coefficient of some of the diamagnetic (Cu, Zn, Ag, Te, Au, Pb, and Perspex), paramagnetic (Al, Ti, Mo, Dy, Ho, and Pt) and ferromagnetic (Fe, Co, Ni, Gd, FeO, NiO, FeS, and Fe_2O_3) substances in the presence of an external magnetic field. To the best of our knowledge no theoretical or experimental result achieved under experimental conditions similar to ours' is available for comparison and collation.

2. Experimental details

For the measurement of linear attenuation coefficient of aforesaid magnetic substances, experiments were performed at the nuclear physics laboratory of SLIET, Longowal, Sangrur, India. The experimental setup equipped with all electronics, magnet position, sample position and collimation positions is shown in Fig. 1. Gamma ray intensity was taken from a radioactive sealed point source of 100 mCi, ^{241}Am which was procured from RITVERC Isotope products St. Petersburg, Russia. The intensity of gamma ray photons at 59.54 keV was detected on NaI (Tl) ORTEC, (2 × 2 in.) detector and the detector was further connected to a Preamplifier 276, Amplifier 572 A, Power supply 4006 and window based Multi-Channel Analyzer (MAESTRO-32MCA). Magnetic substances of high purity i.e. 99.99% in foil form and known uniform thickness were procured from Sigma-Aldrich. The thickness of all substances used in the experiment is tabulated in the corresponding Tables 1–3 for quick reference. In the present measurement some of the substances are in powder form, and the samples in form of pellets were prepared in the laboratory using hydraulic press at pressure 5 t. These substances in powdered form were also procured from Sigma-Aldrich of purity 99.999%. In order to ensure the uniformity of self-prepared samples, the mean of thicknesses was taken from measured values of thickness at five different positions, using a digimatic vernier caliper with accuracy ±0.002 mm, procured from Mitutoyo Corp., Kawasaki, Japan exclusively for the subject experiment. The sample under study was positioned at an angle 45° with respect to axial line, so that the effect of magnetic field can be clearly noticed on the linear attenuation coefficients. The magnetic field (maximum range 1.4 T at 10 mm air gap with flat pole pieces, 'Model EMU-75') unit containing copper coils (12 Ω resistance) having pole pieces of diameter 75 mm with opposite polarity was further connected with a source of constant current and uninterrupted power supply.

A digital Gauss meter was used to measure the strength of magnetic field between two poles of opposite polarity. The intensity of gamma rays from source to detector was taken through three collimations having apertures 3, 2 and 2 mm as shown in Fig. 1. These collimations were used to ensure the acceptance less than 3° (Midgley, 2006; Gupta et al., 2013) as shown in Fig. 1. The entire experimental assembly was shielded and safeguarded properly to avoid Bremsstrahlung radiation and Pb X-rays with lead bricks and aluminum foil of uniform thickness (1.15 mm). To add on the detector was also shielded with a mu metal with open face (diameter 2 × 2 in.) to avoid the direct interaction of magnetic field lines with detector hose. The detector was placed at a distance of 15 cm from the axial line of the magnetic field to ensure the minimum effect of magnetic field on the detector. This was ascertained by measuring the strength of applied magnetic field at different positions. A typical X-ray spectrum for Dy with and without magnetic field is shown in Fig. 2. From the observed spectrum it is clear that there is no distortion in the spectrum at $H = 1.2$ T and no peak shift due to external magnetic field. This indicates that the detector was not influenced by an external magnetic field.

3. Methodology

In the subject experimental setup, to achieve the desired objectives, a linear transmission geometry was used to study attenuation coefficient of magnetic substances (diamagnetic: Cu, Zn, Ag, Te, Au, Pb, and Perspex; paramagnetic: Al, Ti, Mo, Dy, Ho, and Pt; ferromagnetic: Fe, Co, Ni, Gd, FeO, NiO, FeS, and Fe_2O_3). In the first phase of the experiment, the intensity of gamma ray I and I_0 (with and without sample of particular known thickness) for the diamagnetic substance Cu ($Z = 29$) in the absence of magnetic field i.e. $H = 0$ T was measured, whereas the attenuation coefficient was measured using standard Beer–Lambert law, the relation of said law is given as under:

$$I = I_0 e^{-\mu t_i} \quad (1)$$

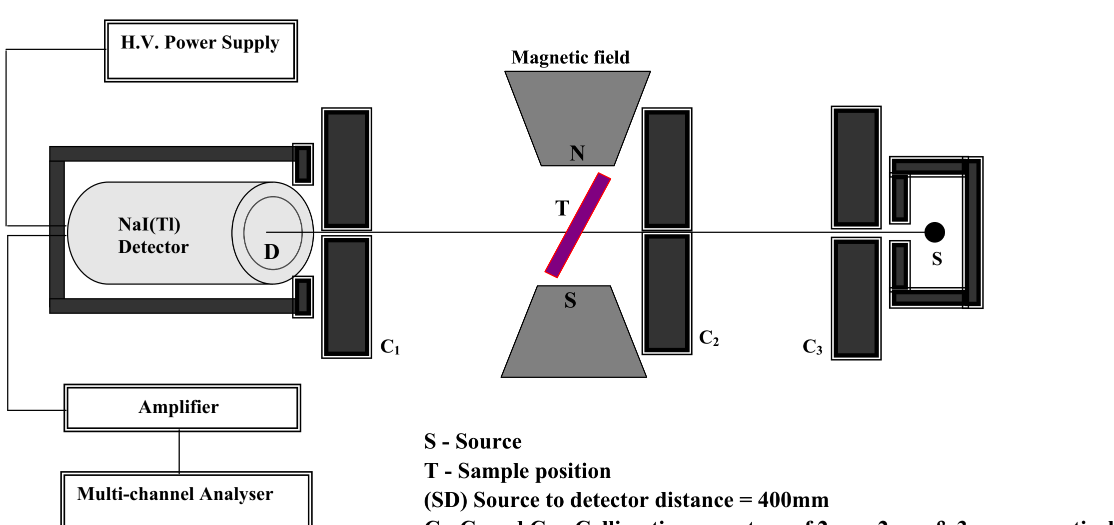

Fig. 1. Experimental arrangement for measurement of linear attenuation coefficient with/without magnetic field.