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A study of gamma attenuation parameters in poly methyl methacrylate and Kapton

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HIGHLIGHTS

- We have measured μ/ρ, Z_{eff}, and N_{el} of PMMA and PMDA-ODA.
- The measured values agree with the theoretical values.
- We have also computed energy absorption and exposure buildup factor.
- These parameters have been found to change with energy and interaction.

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ABSTRACT

Poly methyl methacrylate (PMMA) and Kapton polyimide are polymers used for various aerospace applications. We have measured the gamma attenuation parameters such as mass attenuation coefficient, effective atomic number and electron density of PMMA and Kapton polyimide for various gamma sources of energy ranging from 84 keV to 1330 keV (^{170}Tm, ^{57}Co, ^{141}Ce, ^{203}Hg, ^{51}Cr, ^{113}Sn, ^{22}Na, ^{137}Cs, ^{60}Co, ^{22}Na and ^{60}Co). The measured values agree with the theoretical values. In the present work, we have also computed energy absorption build-up factors and exposure buildup factor of PMMA and Kapton polyimide for wide energy range (0.015–15 MeV) up to the penetration depth of 40 mean free path using Geometrical Progression fitting method. The values of these parameters have been found to change with energy and interaction of gamma with the medium. The present study on gamma attenuation parameters are expected to be helpful in dosimetry, radiation shielding and other radiation physics based applications. The experimental data on the mass attenuation coefficients for Kapton and PMMA is not available in literature. To my knowledge data available e.g. in the NIST data base are based on extrapolations from the measurement of mass attenuation coefficients for the elements. Hence this work is first of its kind and it is useful in the various field of Polymers.

1. Introduction

Poly methyl methacrylate (PMMA) and Kapton polyimide are two examples of polymers that can be utilized for various aerospace applications. The low densities of the polymers pertain to light weight materials that can reduce the mass of a spacecraft for more efficient fuel expenditure (Pawde and Deshmukh, 2009). PMMA has also been used to monitor exposure to ionising radiation by use of spectrophotometry (Berry and Marshal, 1998; Simmons et al., 1970). On the other hand, Kapton is often used as a control coating for exterior spacecraft surfaces due to its thermal stability and chemical resistance. Materials layered the outer surfaces of a spacecraft are subject to harsh environmental conditions, such as exposure to high energy photons (Li et al., 2007). The high-energy photons may cause ionization events in polymeric materials that can create peroxy radicals. In the presence of oxygen these species can initiate degradation. At modest levels, irradiation can lead to a decrease in the molecular weight of the polymer (Ellerin et al., 2001). Gamma radiation is believed to initiate a cascade reaction in many polymers, starting with the formation of radical cations (Ellerin et al., 2001; Woo et al., 1998).

Calculations of the energy absorbed in a medium include not only the contribution of the uncollided photons from the source, but also include the contributions from collided and secondary photons. In practice, this is done by multiplying the contribution of the uncollided photons by the energy absorption buildup factor. The energy absorption buildup factor is the ratio of the total energy absorbed due to uncollided, collided, and secondary photons to the energy absorbed due to only uncollided photons. The energy absorption buildup factor is also defined as the buildup factor in which the quantity of interest is the absorbed or deposited energy

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in the interacting material and the detector response function is that of absorption in the interacting medium. Whereas the exposure build-up factor is defined as that build-up factor in which the quantity of interest is the exposure and the detector response function is that of absorption in air.

Sousa et al. (1998) studied the influence of gamma radiation on PMMA. The gamma irradiation effects on the PMMA was also studied by Silva et al. (2010). Gamma irradiation at room temperature influences physical changes in PMMA (Francetti and Jacques, 1996). The influence of gamma radiation on PMMA at doses lower than 20 kGy was studied and its structural changes were attributed to chain scissions which lowered its average molecular weight (Suarez et al., 2002). The effects of proton radiation on Kapton films were studied by Li et al. (2007). Structure, chemistry and mechanical properties of Kapton was studied after their exposure to fast-neutron and gamma irradiation at a target temperature of 4 K by Megusar (1997). The total absorption coefficients for Kapton and other organic compounds were measured in the X-ray energy range from 13 keV up to about 40 keV using a collimator and high purity germanium detector by Angelone et al. (2001).

Due the importance of PMMA and Kapton in aerospace and other applications, the study of an interaction of gamma radiation in these polymers becomes important. The photon attenuation coefficients (linear and mass attenuation coefficients), effective atomic number and electron density are basic quantities required in determining the attenuation of X-rays and gamma photons in matter. The aim of the present work is to measure the Gamma attenuation parameters such as attenuation coefficient (μ/ρ), effective atomic number (Z_{eff}) and electron density (N_e) of PMMA and Kapton polyimide for various gamma sources of energy ranging from 84 keV to 1330 keV (^{170}Tm, ^{57}Co, ^{141}Ce, ^{203}Hg, ^{51}Cr, ^{113}Sn, ^{22}Na, ^{137}Cs, ^{60}Co, ^{22}Na and ^{60}Co). In the present work, an attempt has been also made to compute energy absorption build-up factors (EABF) and exposure buildup factor (EBF) of PMMA and Kapton polyimide for wide energy range (0.015–15 MeV) up to the penetration depth of 40 mean free path using Geometrical Progression fitting method. These parameters are expected to give vital information on the Gamma attenuation properties of these materials.

2. Present work

2.1. Theoretical calculation of effective atomic number and electron density

In the present work, the mass attenuation coefficients and photon interaction cross sections in the energy range from 1 keV to 100 GeV are generated using its composition (NIST data, 1998) and WinXCom program (Gerward et al., 2004). The total molecular cross section [σ_m] is computed from the following equation using the values of mass attenuation coefficients [$(\mu/\rho)_c$]

$$\sigma_m(E) = \left(\frac{1}{N}\right)\left(\frac{\mu(E)}{\rho}\right)_c \sum_i n_i A_i \ \text{mb} \tag{1}$$

where n_i is the number of atoms of ith element in a given molecule, $(\mu/\rho)_c$ is the mass attenuation coefficient of biomolecule, N is the Avogadro's number, and A_i is the atomic weight of element i. The effective (average) atomic cross section for a particular atom in the compound (σ_a) is estimated using the equation

$$\sigma_a = \frac{\sigma_m}{\sum_i n_i} \text{mb} \tag{2}$$

The effective electronic cross section (σ_e) is computed from mass attenuation coefficient $(\mu/\rho)_i$ of ith element in the given molecule.

$$\sigma_e = \left(\frac{1}{N}\right)\sum_i \left\{\left(\frac{f_i A_i}{Z_i}\right)\left(\frac{\mu}{\rho}\right)_i\right\} = \frac{\sigma_a}{Z_{eff}} \text{mb} \tag{3}$$

where, f_i is the fractional abundance (a mass fraction of the ith element in the molecule) and Z_i is the atomic number of the ith element in a molecule. Finally the Z_{eff} is estimated as

$$Z_{eff} = \frac{\sigma_a}{\sigma_e} \tag{4}$$

The effective electron density, N_e, expressed in the number of electrons per unit mass is closely related to the effective atomic number. For an element, the electron density is given by $N_e = NZ/A$. This expression can be generalized for a compound,

$$N_e = \frac{N}{\sum_i n_i A_i} Z_{eff} \sum_i n_i \ \text{electrons/g} \tag{5}$$

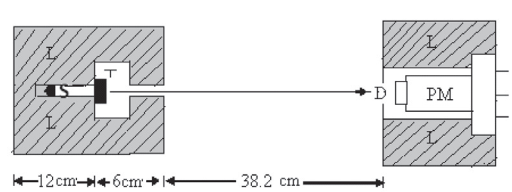
In the present work, N_e and Z_{eff} of PMMA and Kapton polyimide are computed from Eqs. (4) and (5).

2.2. Measurement of effective atomic number and electron density

Some of the earlier workers measured the mass attenuation coefficient of photons using alternate to transmission experiments (Tran et al., 2003; Chantler et al., 2001). Some of the earlier workers also measured the mass attenuation coefficient of photons using transmission experiments. We have measured mass attenuation coefficients using transmission experiment. Transmission experiments with the narrow beam (good-geometry) setup were used for measuring the incident and transmitted intensities, and hence calculating the attenuation coefficient. The narrow geometry experimental setup used in the present measurement is as shown in Fig. 1. We have used a NaI(Tl) crystal detector mounted on a photomultiplier tube housed in a lead chamber and a sophisticated PC based MCA for a detection purpose, gamma sources such as ^{170}Tm (84), ^{57}Co(122), ^{141}Ce(141), ^{203}Hg(279), ^{51}Cr(320), ^{113}Sn(392), ^{137}Cs(661.6), ^{22}Na(511, 1274) and ^{60}Co (1173, 1332 keV) and PMMA and Kapton polyimide as target samples. The spectrum of ^{60}Co measured by detector using MCA shows two peaks corresponds to 1.17 and 1.33 MeV. The counts corresponds to this peaks at that channel is proportional to intensity. The sample was directly attached to the opening of the lead shield where source is placed. The integral intensities, I_0 and I of the beam before and after passing through the sample are measured for sufficient time. $(\mu/\rho)_c$ of the sample is then estimated using the relation.

$$\left(\frac{\mu}{\rho}\right)_c = \left(\frac{1}{t\rho}\right)\ln\left(\frac{I_o}{I}\right) \tag{6}$$

Where, t and ρ are the thickness and density of the sample respectively. Experimental values of N_e and Z_{eff} of PMMA and Kapton polyimide are obtained by substituting the measured values of $(\mu/\rho)_c$ in Eqs. (1)–(5).



S-Source Position, T-Target sample, L-Lead Shielding, D-Detector, PM-Photomultiplier

Fig. 1. Schematic diagram of the experimental setup.

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